Aquatic invertebrate diversity and distribution at Aammiq Marsh, Lebanon

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Summary
A survey of aquatic invertebrates was conducted at Aammiq Marsh, Bekaa Valley, Lebanon from April to June 2002, with some additional sampling during December 2003. The aim of the survey was to compile as complete a list as possible of the aquatic invertebrates present at Aammiq, and to compare the invertebrate communities occurring in different habitat types within the marsh area.

Overall, 78 invertebrate taxa were recorded, with species-level identifications possible for most of the Coleoptera (beetles) and Odonata (dragonflies and damselflies). The Coleoptera comprised 18 genera and 22 identified species, of which 9 were new records for Lebanon. None of the Odonata were new records.

The different marsh habitats surveyed included aquatic plant (macrophyte) beds, submerged grasses around the marsh shoreline, the edges of *Phragmites* reed beds, the inner reed bed (10-20 m from the edges of reed beds), small isolated pools near the main marsh, and meadows that were flooded for only 2-4 weeks after winter rains. Also surveyed were macrophyte, reed edge and inner reed habitats in a nearby permanent pool.

High variability and the small number of samples taken from some habitats reduced the power of statistical tests to show differences among the invertebrate communities of the different habitat types. However, aquatic invertebrates reached higher densities in the Macrophyte, Submerged Grass, Reed Edge and Isolated Pools habitats than in the Wet Meadows, Inner Reeds and Permanent Pool habitats. Invertebrate diversity (taxonomic richness) showed a very similar pattern to invertebrate density among the habitat types, except that richness in the Isolated pools was lower than in the Submerged Grass and Macrophyte habitats.

The composition of the invertebrate community was very different in the Permanent Pool to Aammiq Marsh, with near-total absence of some invertebrate groups that were abundant in Aammiq, and a dominance of chironomid midges. The composition of the Isolated Pools was very variable, probably reflecting their diversity in terms of physical size (width and depth), vegetation, dissolved oxygen and temperature regimes and the presence/abundance of fish predators.

Overall, it is clear that a diversity of habitat types in the marsh leads to a diversity in the invertebrates fauna. Thus Aammiq Marsh can be considered as a "habitat mosaic", and maximum invertebrate diversity will be maintained when the marsh is managed to preserve a range of different aquatic vegetation types and hydrological characteristics. However, some habitat types, e.g. macrophytes and submerged grass, support a greater diversity and density of invertebrates than others. Therefore, if maximum invertebrate productivity for the benefit of birds or other vertebrates is a management goal, then efforts may be directed to maximising the abundance of these habitat types.

Invertebrates are fundamental to the ecology of Aammiq Marsh, as they provide a critical link between the primary producers and the higher consumers, and they are

essential in recycling dead plant material. They are also sensitive indicators of the health of the marsh. This study has provided baseline data, and future monitoring of aquatic invertebrates using the techniques described here is strongly recommended.

Introduction

Invertebrates are often overlooked in conservation projects as they are usually smaller and considered less attractive than vertebrates. However, their importance should not be underestimated. Their diversity far exceeds that of vertebrates (for example, 75% of all animal species are insects), and they include some fascinating and beautiful creatures such as the butterflies and dragonflies, making them worthy of conservation for their own sake. IUCN recognises the conservation value of many types of insect by including them in its Red List of Threatened Species.

In wetlands, invertebrates are extremely important ecologically. They provide a crucial link between the primary producers (aquatic plants and algae) and the higher consumers (fish, birds, amphibians). As a food for higher consumers, they are particularly important as a source of protein. Birds require high protein levels during breeding and moulting, and duckling survival has been shown to increase with invertebrate abundance (Scheffer, 1998). Thus invertebrate densities in a wetland may be a major factor determining its suitability as a reproduction habitat for waterfowl (Scheffer, 1998). As well as their use as food, invertebrates also play a vital role as recyclers of dead plant material, shredding and breaking down plant material to a size and structure where bacteria and aquatic fungi can further process it (Weller, 1981). In addition to their ecological functions, freshwater invertebrates are also sensitive indicators of ecosystem health, thus they can provide important data for ecological monitoring.

In Lebanon, one of the main barriers to conservation of freshwater organisms and habitats is the lack of current and complete data sets. In introducing its publication "Etude de la diversite biologique du Liban", the Lebanese Ministry of Agriculture states that "the lists included in this work are no longer up to date; it is urgent to undertake new studies to have complete information on the current state of the Lebanese freshwater fauna." (translated from Ministry of Agriculture, Volume 6: "L'Etat actuel de nos connaissances sur le peuplement dulciaquicole au Liban"). Lebanon's National Biodiversity Strategy and Action Plan states that "research….. and studies on freshwater biodiversity should be expanded and supported", and aims to "establish a database system for freshwater richness and endangered species." The Aammiq Marsh in the Bekaa Valley, the focus of A Rocha Lebanon's work, has been thoroughly surveyed in terms of its vertebrate fauna over a period of 10 years. However regarding aquatic invertebrates, only one study has been published (El Hage, 1979). This study provides good coverage of molluscs, but records only 4 species of arthropod, therefore it is seriously incomplete. Another unpublished survey was conducted by Jaradi (1996) but identifications are of doubtful accuracy. "Etude de la diversite biologique du Liban" (Ministry of Agriculture) mentions that Aammiq contains 4 endemic species of aquatic invertebrate, but does not name them. Because of this lack of data, certain spectacular groups such as the dragonflies remain under-appreciated, and the importance of Aammiq Marsh for aquatic invertebrate biodiversity across the Middle East remains unknown.

Furthermore, the management plan for Aammiq, recently been prepared by A Rocha Lebanon, is presently limited by lack of aquatic invertebrate data. The marsh, rather than being a uniform habitat, is better regarded as a mosaic of many kinds of habitats, including reed beds, flooded meadows, open water, flowing springs, small isolated pools, permanent and temporary waters (cf. Dimentman *et al*., 1992). Management of the marsh involves management of these different habitat types, possibly increasing the extent of some at the expense of others. Management therefore involves some important questions, for example, should we dig pools to create permanent water in an area that presently dries out for several months of the year? Should we attempt to isolate certain pools or parts of the marsh from fish predators such as the introduced *Gambusia*?

It is known from the wetland literature that different habitat types support very different communities of invertebrates, and some are much more diverse and productive than others (Williams and Feltmate, 1992). For example, habitats with aquatic plant growth have more diverse and abundant invertebrate communities than those without, and invertebrate diversity is correlated with the density and structural complexity of the aquatic plants (Scheffer, 1998). At Aammiq, because we presently know little about the diversity and abundance of the fauna that exist in the different habitat types, we don't yet have a good basis for making management decisions. Invertebrates are an important component of the fauna, and since they represent the base of the food chain, they also affect other components. Thus they can tell us a great deal about the value of the different habitats in supporting wildlife, and inform our management practices.

Therefore, the current survey was conducted to:
1) Compile a list of aquatic invertebrate taxa occurring in Aammiq Marsh for the recognition of endangered, rare or endemic invertebrates and to provide data for assessments of aquatic biodiversity in Lebanon.
2) Provide baseline data for future comparisons that might indicate decline or improvement in wetland health
3) Determine which habitat types within the marsh area support the greatest diversity and abundance of aquatic invertebrates. Especially:

a) To determine whether aquatic invertebrates are more abundant and diverse in pools isolated from fish predators, e.g. introduced mosquito fish (*Gambusia affinis*).

b) To determine whether aquatic invertebrates are more abundant and diverse in permanently flooded pools than in areas that dry out seasonally.

Site

Aammiq Marsh (33° 44' N, 35° 47' E) is situated in the Bekaa Plain, a fertile plain 10-30 km wide that stretches between the Lebanon and Anti-Lebanon mountain ranges at an altitude of 850-1100 m a.s.l. (Fig. 1). The two mountain ranges run parallel to each other in a NNE-SSW direction, rising steeply from the eastern shores of the Mediterranean Sea. The marsh (863-865 m a.s.l.) lies on the western side of the plain, at the foot of the Lebanon Range (here called the Barouk Ridge) (Fig. 1).

Aammiq Marsh, as it currently exists, is a small remnant of extensive wetlands that once covered a large proportion of the Bekaa Plain. According to local people, these wetlands once stretched as far north as Zahle, 30 km north of Aammiq (Fig. 1).

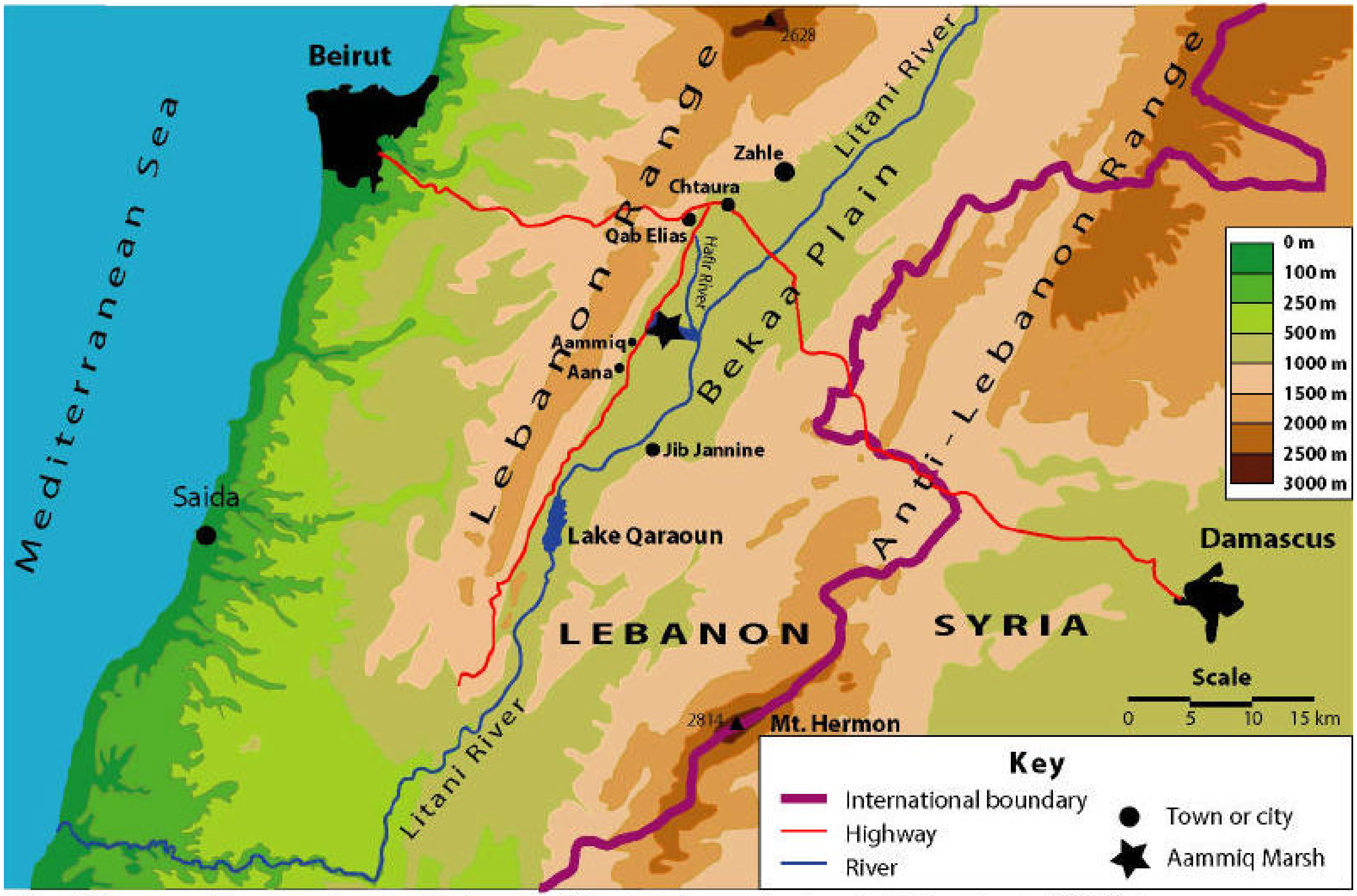


Fig. 1 Topographic map of central Lebanon. (Used with permission of GEOprojects (U.K.) Ltd.

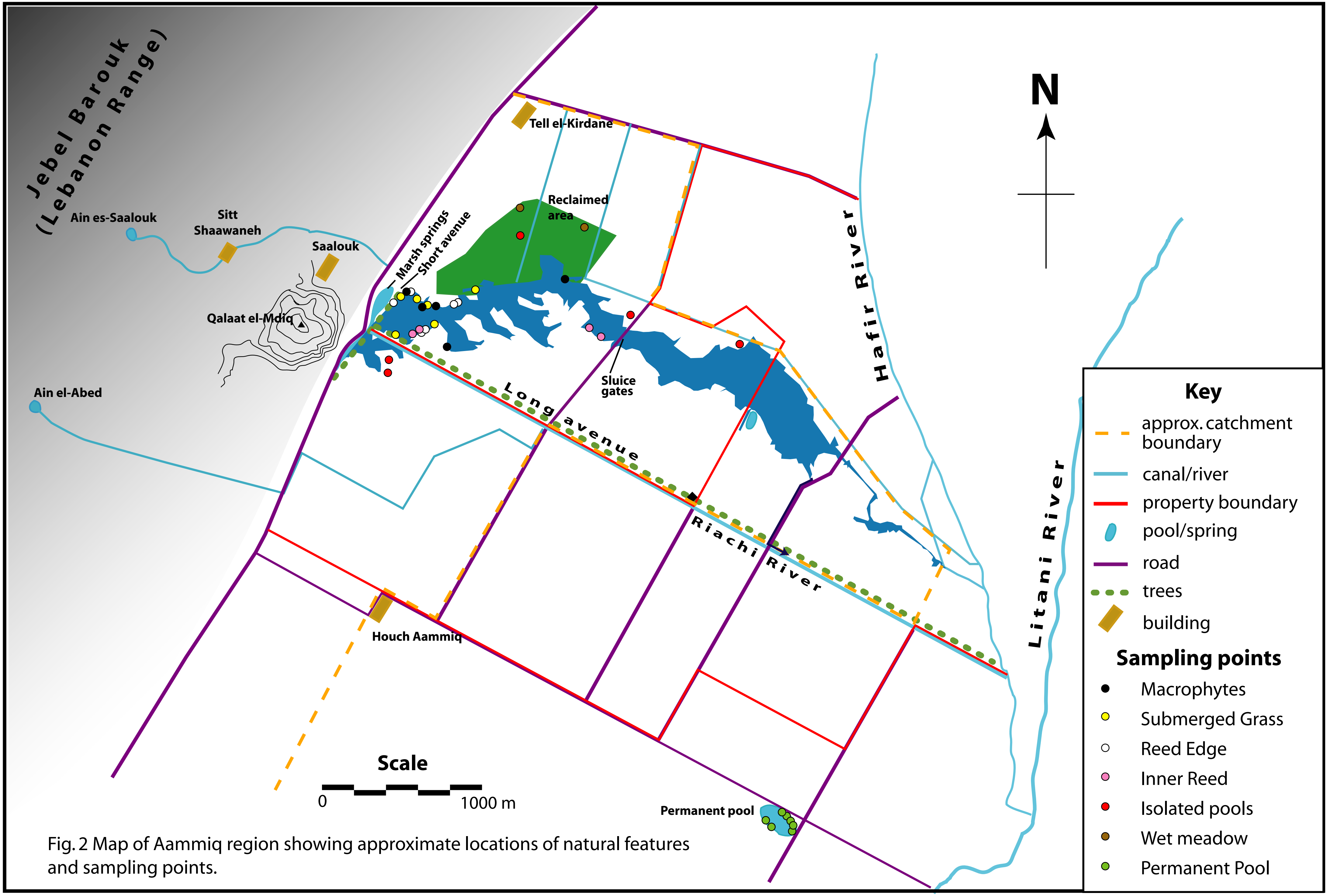


Fig. 2 Map of Aammiq region showing approximate locations of natural features and sampling points.

As has commonly occurred throughout the world, the wetlands have been progressively drained and converted to agricultural production since ancient times. These changes have affected Aammiq Marsh. Maps dating back to 1939 show the extent of the marsh as significantly greater than it is today (Walley, 1997), though maps from the 1950s show the marsh boundaries very close to their present position. The major change to Aammiq Marsh in the last 30 years is that the once perennial surface waters now disappear almost completely for 5-6 months each year. Probably this is mostly the result of ground water abstraction through deep boreholes in the region.

Water levels in Aammiq Marsh are highly seasonal not only due to seasonal human water use but also due to the Mediterranean climate of Lebanon. In a typical year, 90% of the rain falls between November and April (Lebanese Ministry of Environment, 2001) and no rainfall occurs from June to August. Therefore, during the months of January to March, the marsh is typically full of water and the agricultural fields around the marsh are frequently flooded. The marsh water levels usually begin to drop from May to July, and in a normal to dry year, the marsh may be completely dry from late July to December.

Precipitation varies not only seasonally but also from year to year; annual precipitation can vary from less than 30% of the average to more than 200%. Since the mid-1970s there has been a steady decline in annual rainfall, which may be due to human-induced climate change or may be part of a natural cycle (Sene *et al.*, 1999). Because of the highly variable water levels, the flooded area of the marsh changes greatly from season to season and year to year. Heavy rains can temporarily flood an area of up to 300 ha, but the area that remains continuously flooded for up to four months during the wet season is about 70 ha (Fig. 2). The water covering this area mostly originates from a line of springs at the base of the Lebanon Range, the western edge of the marsh. This water travels east to southeast for about 3 km, spreading over an area up to 500 m wide, then gradually narrows to a canal that flows another 1 km to join the Hafir River.

Within the marsh area are a variety of different aquatic habitat types, formed by different hydrology and vegetation types. Wet meadows are areas of grassland outside the main marsh boundary that are flooded for only a short period of days or weeks following heavy rain. Also outside the main marsh boundary are small pools a few metres to tens of metres in diameter and a few centimetres to 2 metres deep. These are connected by surface water to the main marsh during the floods that follow heavy rain, but are isolated from the main marsh thereafter. Shallow pools dry out early in the dry season, but a few deeper ones may persist almost as long as water remains in the main marsh. Among them, isolated pools contain the full range of vegetation types found in the main marsh.

Man-made ditches crossing the fields around the marsh form another habitat for aquatic plants and animals. These also contain the full range of vegetation types, and differ not only in depth but also in terms of flow; they are connected and disconnected from sources of flowing water several times per year as required for irrigation or drainage of the nearby fields.

Within the main marsh, the margins contain a mosaic of different vegetation types – submerged grass, aquatic broad-leaved plants (called macrophytes from here) and reeds (mostly *Phragmites*, but in some areas *Typha*) – each type providing different habitat conditions. Grasses occur in shallower areas that dry early in the dry season, whereas macrophytes and reeds can grow in deeper water that persists for longer. The deepest areas of the marsh, those covered by 2-3 m of water during the wet season, contain little or no rooted vegetation, though some areas support floating mats of *Ranunculus* (water crowfoot).

About 2 km south of the main marsh is a man-made pool, excavated in the early 1980s. In contrast to the main marsh, where the water level falls by several metres in the dry season, this pool experiences water level changes of only a few centimetres. Therefore, whereas most or all aquatic habitats in the main marsh are temporary, aquatic habitats in the excavated pool remain permanently flooded. Reedbeds in the excavated pool tend to be more mature than those found in the main marsh, and contain significant build-up of dead reed material, much of which falls into the water or forms a thick mat over the water. Such build-up of decomposing organic matter occurs only in certain places of the main marsh, probably because at times when the marsh is dry, the reedbeds are often burned by local shepherds.

Temperatures in the Bekaa reflect the Mediterranean climate and high altitude. Average daytime temperatures in winter are 10-13°C, and in summer are 32-34°C.

Methods

Invertebrates

Aquatic invertebrates were sampled from several contrasting habitat types in the marsh and its surroundings during spring (4 May to 5 July) 2002 (see Fig. 2 and Appendix 1 for sampling locations and dates). Habitats at the margins of the main marsh included aquatic macrophytes, submerged grasses, reed bed edges (up to 1 m from the edge of the reed bed) and the inner reed environment (10-20 m from the edge of the reed bed). Habitats around the marsh included wet meadows (sampled while surface water remained after heavy rains) and isolated pools. In the excavated (permanent water) pool, macrophytes, reed edge and inner reed environments were sampled.

Sampling involved placing a round open-bottomed barrel, 38 cm diameter (=0.454 m^2 area), in 20-30 cm deep water. Within the barrel, vegetation above water level was cut with a knife and discarded. Vegetation below water level was cut at ground level and placed in a sealed plastic bag. The water remaining in the barrel was then stirred and a small pail was used to pour all of this water through a 250μm mesh hand net. In the lab, within 4 hours of collection, the vegetation samples were washed through the same hand net and dislodged invertebrates were combined with those in the corresponding water sample. This combined sample was then sieved into 2 size fractions, one larger than 1mm and one 250 μm - 1 mm. Both fractions were retained, but due to time constraints, only the larger fraction was included in this study. Invertebrates were either live-sorted or preserved in 70% ethanol. Identifications were made using the keys of Macan (1959) and Girod *et al.* (1980) for molluscs, Argano (1979) for isopods, van Niewenhuijzen (2003) for Coleoptera: Dytiscidae, Hansen (1997) for Coleoptera: Hydrophilidae, Dumont (1991) for Odonata, Engblom (1997) for mayflies, Hungerford (1933) for Hemiptera:Notonectidae, Smith (1997) for Diptera. Identifications were assisted by Andre van Niewenhuijzen (Netherlands) and by reference to species checklists from Lake H. (Dimentman *et al.*, 1992) and a past survey of Aammiq Marsh (Jaradi, 1996).

The number of replicate samples taken from each habitat type reflected the degree of variability expected in each type, and loss of one or two samples (Table 1).

Over the two-month sampling period, seasonal shifts in the species composition may have occurred. To avoid confounding this seasonal effect with the effect of habitat, the different habitat types were sampled in parallel rather than in sequence.

In December 2003, a further survey of aquatic invertebrates was conducted with Andre van Niewenhuijzen. This survey focussed on aquatic beetles and Hemiptera (true bugs), and was done qualitatively using hand nets. The sampling are was similar to that of the 2002 survey, but also included ditches within the marsh area, and Ain el Abed, a fast-flowing spring on the Barouk Mountain south and west of Aammiq Marsh.

Table 1. Number of replicate samples taken from each habitat type.

Habitat type	Number of replicate samples
Macrophyte	6
Submerged Grass	6
Reed Edge	6
Inner Reed	5
Isolated Pools	5 pools x 3 replicates each
Wet meadow	2
Permanent pool Macrophyte	3
Permanent pool Reed Edge	3
Permanent pool Inner Reed	2

Data analyses

Diversity of the invertebrate communities were measured both by “taxonomic richness” (the total number of taxa occurring in each habitat) and by the Shannon Wiener Diversity Index (which takes into account the relative abundances of the different taxa as well as their presence). Habitats that have several taxa occurring in high abundance score higher on this index than those that have an equal number of taxa but only a few abundant ones.

Differences in invertebrate density and richness between the different aquatic habitats were detected using Analysis of Variance (ANOVA) on the log(x+1)-transformed data. Transforming the data reduces the influence of extremely high values which may affect the analyses out of proportion to their biological significance. It also brings the data set more closely into line with the necessary conditions (assumptions) of the analyses. Results of all statistical tests are reported in brackets, giving first the value of the test statistic, then the “degrees of freedom”, which relates to the number of replicate samples used in the analysis, then the “p value”, which is the probability that a significant result may have occurred by chance alone. A p value less than 0.05 indicates that the test has shown a significant difference between the samples (only a 1 in 20 chance that the difference found was due to random chance alone). The lower the p value the more certain one can be that the difference found between the samples is real. All the ANOVA analyses were conducted using SPSS 11.0 software.

Differences in the invertebrate community composition between the different habitats were analysed and displayed graphically with multi-dimensional scaling (MDS) using Primer 5 software. These differences were tested statistically using the ANOSIM (analysis of similarity) procedure, and the taxa that contributed most to the differences between sites were identified using the SIMPER procedure.

Physicochemical characteristics

At the time of invertebrate sampling, physical characteristics of the sites were recorded: location (by GPS), water depth at sampling point, dimensions of pools, degree of shading, vegetation type and density, amount of dead plant material. Between 28 May and 10 June, dissolved oxygen, temperature and conductivity were measured at one or more of the replicates of each habitat type using hand-held electronic probes. Measurements were made at sunrise (about 5am) and again at 4pm to coincide with expected daily maxima and minim of oxygen and temperature. Extra measurements were made in some isolated pools not sampled for invertebrates, to better characterise the physical conditions of this habitat type.

Chemical parameters of the water were measured in July 2002 and then monthly from January to June 2003 at four sites not directly related to the invertebrate sampling sites. These included the marsh springs, two other points at intervals along the length of the marsh (Fig. 2), and from a ditch that drains the fields south of the marsh. The excavated pool was sampled once in June 2003. Water samples were sent to the Lebanese Ministry of Public Health for analysis, and on two occasions to Lebanese Agricultural Research Institute (LARI) at Tel Amara. Analysis was limited to major nutrients and basic chemical properties such as pH and total dissolved solids. Pesticides and herbicides could not be measured within the project budget, but it is hoped that they can be included at least once in future tests. Data from water testing are presented in Appendix 2.

Results

Physicochemical conditions

Physical dimensions of the Isolated Pools measured are shown in Table 2.

Table 2. Physical dimensions and vegetation types in Isolated Pools A-D sampled for temperature and oxygen.

	Length (m)	Width (m)	Depth (m)	Vegetation type
Pool A	8	15	0.8	Grass and some *Ranunculus*
Pool B	2	3	0.35	Sparse emergent sedges, moderately dense grass, some filamentous algae on surface, some *Ranunculus*.
Pool C	50	30	0.9	Mostly open water, with grassy edge. Thick reed bed in middle.
Pool D	5	5	0.5	Emergent sedges, dense macrophytes, grassy edge

Dissolved oxygen and temperature changes in various marsh habitats between mid-afternoon and early morning on 28-30 May are shown in Figs. 3-8. Water emerging from the springs at the western end of the marsh had mild temperatures and high dissolved oxygen with negligible daily changes in either parameter. In open water areas of the marsh, temperatures were significantly warmer but probably not stressful for animal life, oxygen levels were high, and only modest daily changes occurred in either parameter.

In contrast, the shallow vegetated habitats where most invertebrates live showed extreme daily fluctuations in dissolved oxygen. Near the water surface (5 cm and 20 cm depths), oxygen levels reached saturation or super-saturation during most of the daylight hours, and fell to between 0.2 and 6.5 mg/L overnight. These fluctuations are due to the activity of aquatic plants, which produce oxygen by photosynthesis during the day and consume it through respiration at night.

It was expected, therefore, that sites with dense growth of aquatic plants would show greater fluctuations than those with fewer or no plants. The effect should be more noticeable in constricted habitats (e.g. Isolated Pools) than in habitats that have a through-flow of water. These trends are shown to some extent by Figs. 3-8, where the highest maximum oxygen levels are found in macrophyte habitats (e.g. Perm Macro) and in isolated pools (e.g. Iso B) that have a mixture of macrophytes, filamentous green algae and grasses. However, Reed Edge habitats in the main marsh and Permanent Pool also showed high dissolved oxygen changes. This may be due to "periphyton", algae growing on the stems of the reeds that photosynthesises like other aquatic plants. The Inner Reed habitat had consistently lower oxygen than other habitat types, probably because shading by the tall reeds restricted photosynthesis by aquatic plants and algae, and because decaying reed material consumed oxygen. The importance of decaying reed material on oxygen levels was shown in the Permanent Pool by the lower oxygen concentrations among old reeds (more decaying material) than among new reeds (less decaying material). The oxygen levels in the Inner Reeds may be too low for fish and some aquatic invertebrates.

The two smallest and shallowest Isolated Pools (B and D) showed slightly lower oxygen minima, but not consistently greater oxygen fluctuations than the larger pools

(A and C) or the main marsh habitats (Submerged Grass and Reed Edge). Possibly this is because through-flow of water in the vegetated near-shore habitats of the main marsh and larger pools was not as great as expected. In contrast, in the open water habitat through-flow reduced daily oxygen fluctuations in the main marsh (high through-flow) compared to those in the Permanent Pool (low through-flow).

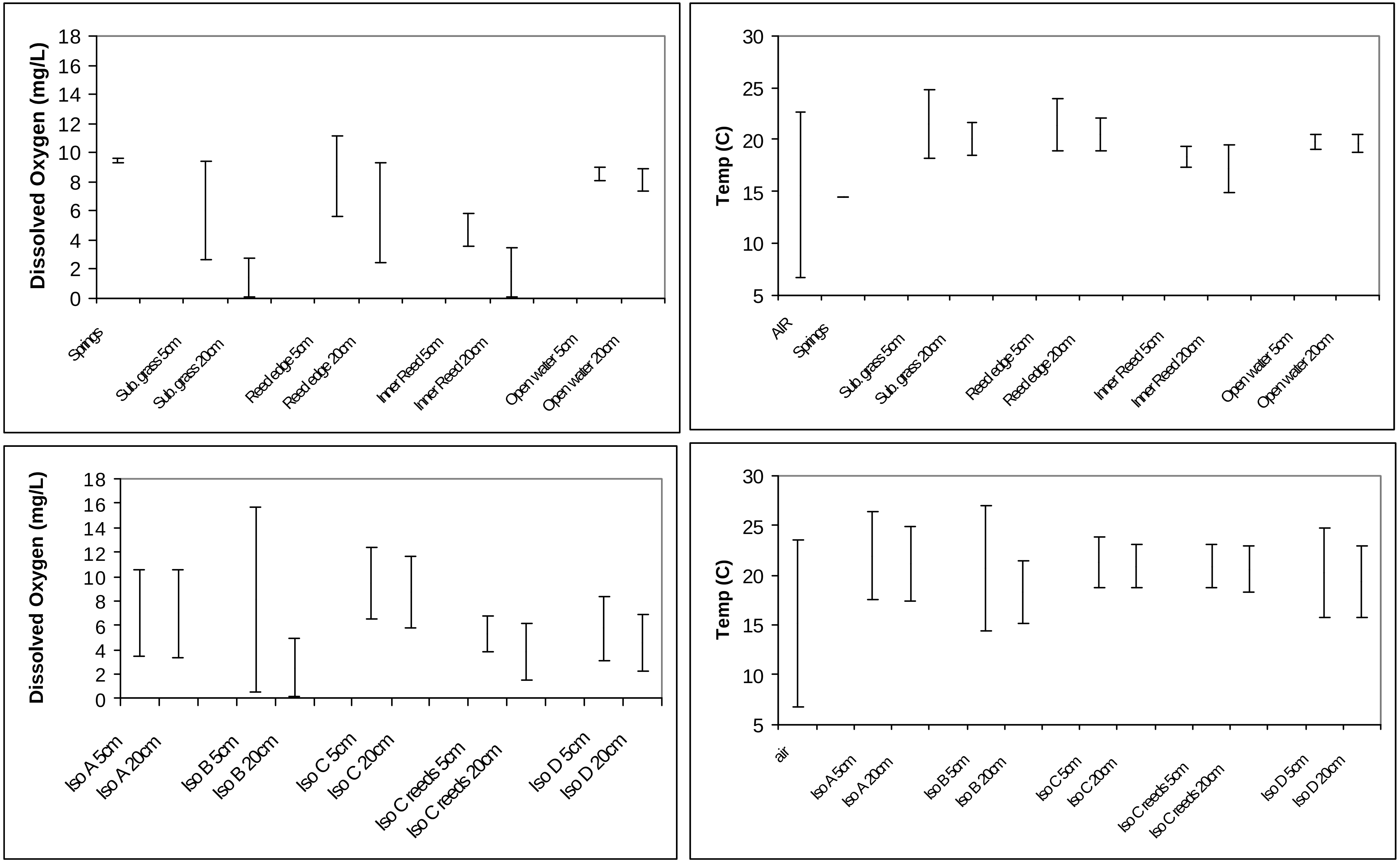
The differences in oxygen production between different plant types was investigated further by sampling around individual plants at 4pm, the mid-afternoon peak of oxygen (Table 3). These results show that *Ranunculus* and filamentous green algae produced much higher peak oxygen levels than grasses and reeds.

Table 3 Dissolved oxygen (mg/L) at 4pm in water surrounding different types of submerged plant.

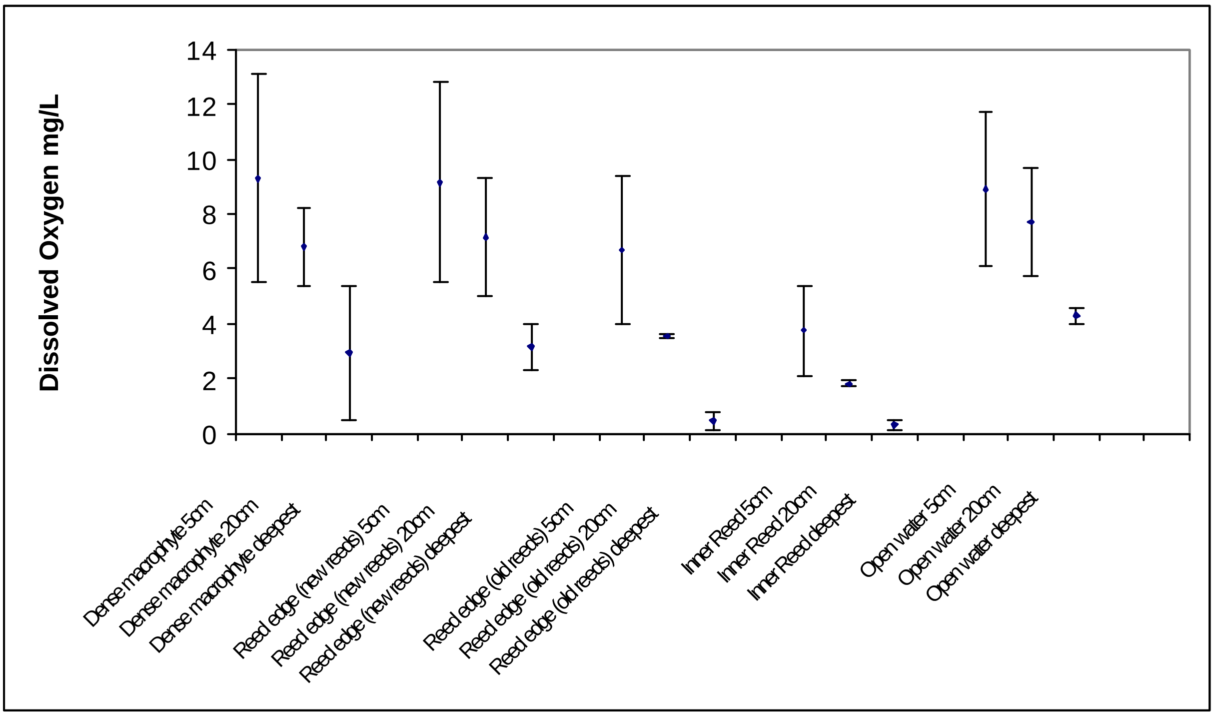
Plant species	Isolated pool A	Isolated pool B	Isolated pool C
Ranunculus	15.0	16.0	
Filamentous green algae		14.6	
Grasses	9.0	9.5	12.4
reeds			6.8

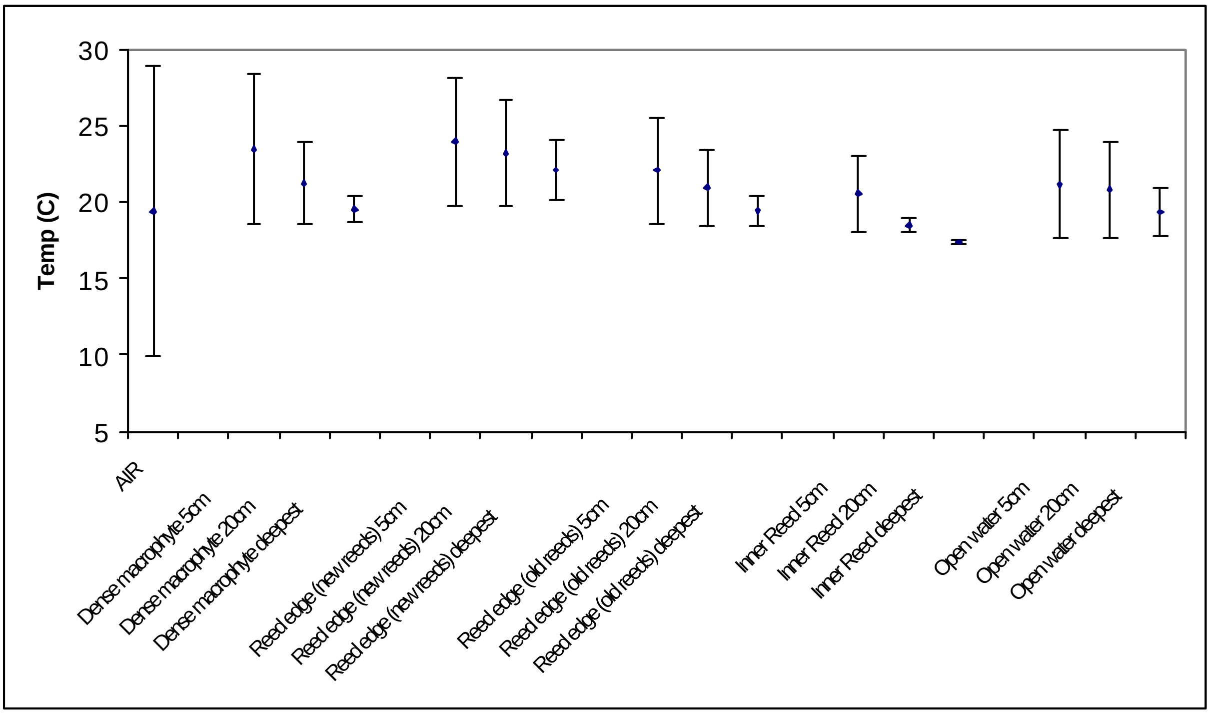
In all habitat types, oxygen peaks and troughs were lower at 20 cm depth than at 5 cm. Oxygen peaks during the day may be lower because of less light available for photosynthesis. Oxygen troughs at night may be lower because water at 20 cm deep is closer to the sediments where decaying organic matter is consuming oxygen and is further from the water surface where oxygen exchange with the air is possible. Some habitat types (e.g. Submerged Grass, Inner Reed and Isolate Pool B) had almost no detectable oxygen over night at 20 cm deep.

Daily temperature fluctuations in shallow aquatic habitats were expected to be very high due to high air temperatures (up to 40 ºC) experienced in the Bekaa Valley. During this survey, however, air temperatures remained moderate (peak of 23 ºC), and water temperatures also remained moderate (up to 27 ºC in some of the Isolated Pools). These temperatures are far from the thermal limits for invertebrates, but may cause some thermal stress for fish. As expected, daily temperature peaks were higher in the small Isolated Pools than in the main marsh habitats, though the difference was only 2-3 ºC. The smaller Isolated Pools experienced slightly greater temperature fluctuations than the larger ones, fluctuations at 5 cm deep were slightly greater than at 20 cm deep, and the shaded Inner Reed habitats had much more moderate temperatures than those exposed to direct sunlight.



Figs. 3-6 Top graphs (Figs. 3-4) Dissolved oxygen and temperature changes between 2pm (28 May 02) and 5.40am (29 May 02) in some of the marsh habitat types, at 2 depths (5 cm and 20 cm) below the water surface. Bottom graphs (Figs. 5-6) Dissolved oxygen and temperature changes between 4pm (28 May 02) and 4.45 am (29 May 02) in isolated pools A-D. In each case the top of the bar represents the value in the afternoon and the bottom of the bar the value in the early morning.





Figs. 7-8 Dissolved oxygen and temperature changes in the Permanent Pool habitats between 4pm (29 May 02) and 5am (30 May 02), at 3 different depths (5 cm and 20 cm below the water surface, and at the pond bed).

Invertebrates

1. Taxonomic composition of the Aammiq invertebrate fauna

In the survey of 2002, 70 taxa (groups) of aquatic invertebrates were found among the various habitats that make up Aammiq Marsh (Fig. 9), and another 8 taxa were added in the 2003 survey (see Appendix 3 for a complete list of taxa). Of the 70 taxa in 2002, 51 were aquatic insects, 6 were crustaceans, 9 were molluscs and 3 were annelid worms. Note, however, that whereas most molluscs and insects could be identified to genus or species, the Diptera (true flies), crustaceans and annelid worms could only be identified to much higher taxonomic levels (mostly Order or Family), therefore these figures may underestimate the relative diversity of Diptera, crustaceans and annelids. Diptera and Crustacea in particular are likely to be more diverse groups than indicated here, with many species of Diptera belonging to the Family Chironomidae and many species of Crustacea belonging to the Order Cladocera (water fleas), and Subclass Copepoda. Note also that the sampling method, which excluded animals dwelling in the bottom mud and animals smaller than 1 mm, is an additional factor reducing the number of taxa detected, especially among the annelids and crustaceans.

Among the insects, the greatest diversity was found in the Order Coleoptera (beetles), with 22 species belonging to 18 genera (but note that more detailed identification was possible for the beetles than for other orders, allowing greater diversity to be detected in this group). Among these, 8 species in the 2002 survey and another 5 in the 2003 survey were new records for Lebanon. These were: (in Family Haliplidae) *Haliplus kulleri*, *Haliplus maculatus*, *Peltodytes caesus*; (in Family Dytiscidae) *Graptodytes sedilloti sedilloti*, *Hydroporus ineptus*, *Hygrotus lernaeus*, *Hygrotus impressopunctatus*, *Hydaticus transversalis transversalis*, *Ilybius chalconatus*, *Ilybius hulae*, *Laccophilus minutus*, and *Hydrovatus cuspidatus*; (in Family Hydrophilidae) *Helochares lividoides.* In addition, it is believed that the *Enochrus* found may be an undescribed species intermediate between *E. fuscipennis* and *E. quadripunctatus (*A. Niewenhuijzen, pers. comm.). Specimens similar to this species have been found by A. Niewenhuijzen in Albania, Macedonia and northern Greece. Furthermore, the larvae of *Graptodytes sedilloti sedilloti, Haliplus kulleri* and *Berosus dispar* are thus far undescribed, and therefore the specimens found in this study are new to science.

The Order Diptera (true flies) was also diverse, including 8 families. Within the Order Odonata (Dragonflies and Damselflies) 9 species belonging to 7 genera were identified.

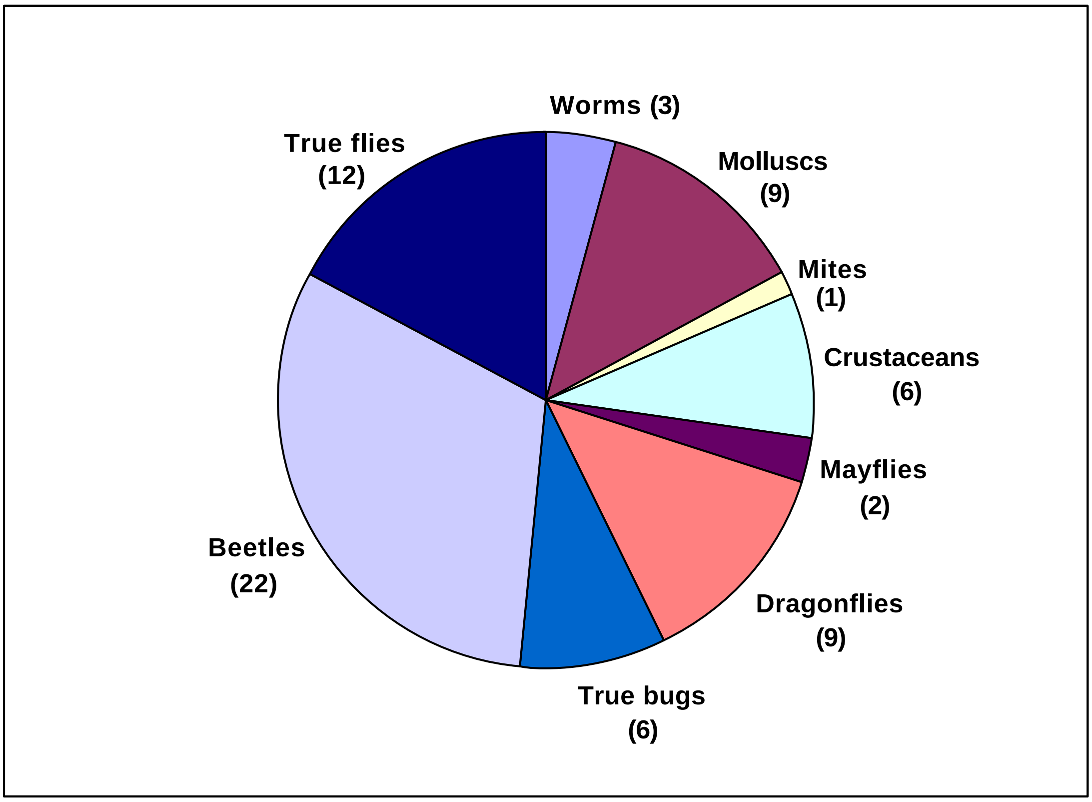


Fig. 9. Number of taxa (groups) belonging to the major groups of invertebrates.

When the abundance of animals is taken into account, the relative size of the different animal groups changes somewhat (Fig. 10). Crustaceans become the dominant group, due to the extremely high numbers of ostracods and isopods (*Proasellus*) occurring in some samples. Molluscs were another dominant group due to very high numbers of the gastropod snails *Bythinia*, *Physa* and *Planorbis* in some samples. Beetles were also moderately abundant, but true flies, dragonflies and Hemiptera (true bugs) though all diverse groups, did not occur in such high numbers as crustaceans and molluscs, and therefore were less dominant when seen from this perspective.

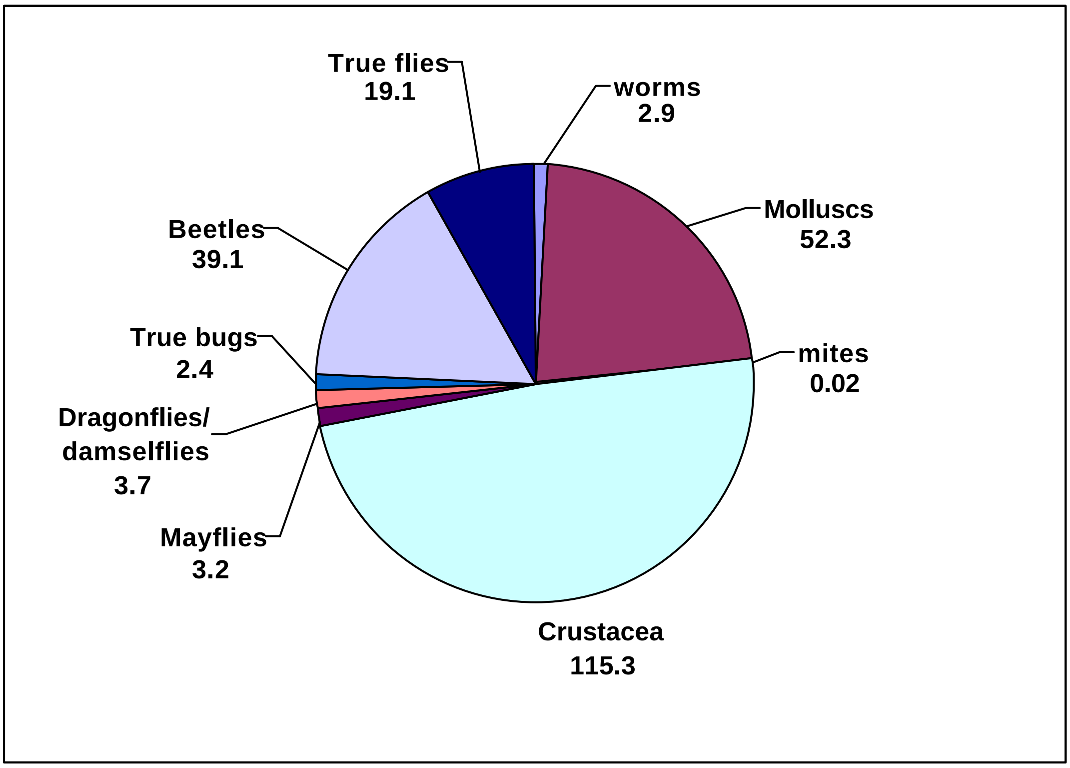


Fig. 10. Number of individuals in the major taxa (groups) of invertebrates per 0.454 m^2, averaged over all samples in the 2002 survey.

2. Comparing the different aquatic habitats

a) Invertebrate abundances

Relative abundances of the invertebrates occurring in the different aquatic habitats are shown in Fig. 11. The most striking feature of this graph is the very high variability, i.e. within each habitat type some samples had extremely high densities of invertebrates whereas others had extremely low. For this reason, and because of the unequal numbers of samples taken from the different habitat types (see Table 1) which reduces the power of statistical analyses, very few significant differences were found in total invertebrate density between the different habitat types. Analysis of Variance (ANOVA) indicated that there was a significant difference among the habitat types ($F=2.300$, $df=8,39$, $p=0.040$), but Tukey's HSD showed that only two habitat types, Macrophyte and Wet Meadow ($p=0.032$), were significantly different from each other. Nevertheless, if we partly attribute the lack of statistically significant differences to the small number of samples taken, we can still make some tentative conclusions about the different habitat types.

Habitats with the highest abundances of invertebrates were Macrophyte, Submerged Grass, Reed Edge and Isolated Pools, whereas the Inner Reed environment supported fewer invertebrates. The wet meadows, which were inundated for only a short time following the winter rains had low overall density of invertebrates. No difference was found between Macrophyte, Submerged Grass and Reed Edge habitats.

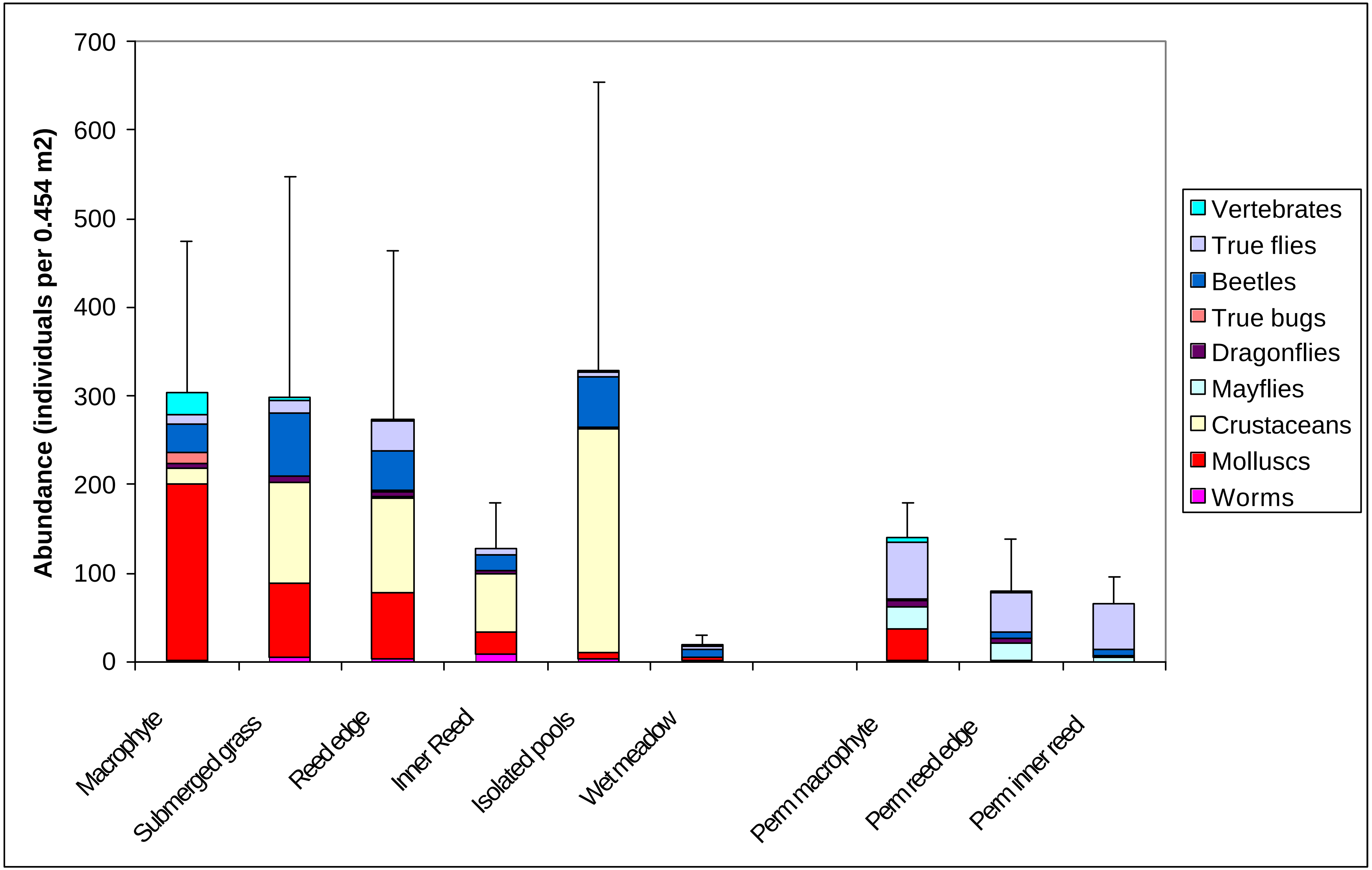


Fig. 11. Abundances of the major taxa of aquatic invertebrates in the various aquatic habitats. Error bars are ±1 standard deviation. "Perm" refers to the Permanent pool.

Interestingly, the invertebrate density in the Permanent Pool appeared to be lower overall than in the temporarily drying habitats of Aammiq. However, an ANOVA on 6 sites (Macrophyte, Perm Macrophyte, Reed Edge, Perm Reed Edge, Inner Reed and Perm Inner Reed) showed that the only significant difference among these sites was between Macrophyte and Perm Macrophyte ($F=3.551$, $df=5,19$, $p=0.020$). The power of this analysis was limited by the low number of samples taken in the Permanent Pool habitats, and therefore differences between Reed Edge and Perm Reed Edge, and between Inner Reed and Perm Inner Reed may also be real (i.e. not due to chance).

Fig. 11 also shows the composition of the invertebrate community in different habitat types. The Macrophyte habitat was dominated by high numbers of molluscs, and had relatively low numbers of other invertebrate groups. It was also the main site where vertebrates (fish and tadpoles) were found. In the Submerged Grass, Reed Edge and Inner Reed habitats the proportions of molluscs, crustaceans and beetles were more even. These habitats also had low numbers of dragonflies, damselflies and true flies. The Isolated Pools were strongly dominated by crustacea (Ostracods and the Isopod *Proasellus*), and the abundance of other animals was quite low in this habitat type.

The invertebrate composition of the Permanent Pool habitats was somewhat different from the Aammiq Marsh habitats. These habitats were dominated by true flies (almost all of which were Chironomidae), and mayflies also were relatively common, whereas beetles and crustaceans occurred only in very low numbers. Fish and tadpoles were found in the Permanent Pool, and as in Aammiq Marsh they were concentrated in the macrophyte habitat rather than among the reeds.

b) Diversity and richness of the habitat types

The diversity of invertebrates in the different habitat types can be summarised using the Shannon-Wiener diversity index, and habitat scores are shown in Fig. 12. Shannon-Wiener diversity was calculated on a per-sample basis, i.e. indicates the diversity encountered in a single 0.454 m^2 area of habitat. Fig. 12 shows that there are large differences in diversity between the different habitat types. The greatest diversity per sample occurred in the Macrophyte and Submerged Grass habitats of Aammiq Marsh, whereas the lowest diversity occurred in the Inner Reed environment of the Permanent Pool. ANOVA on the full range of habitat types showed no significant differences between habitat types ($F=2.039$, $df=8,39$, $p=0.067$), perhaps because the power of the analysis was reduced by the low number of replicates in the Permanent Pool habitats. Fig. 12 suggests that each Permanent Pool habitat had lower per-sample diversity than the corresponding habitat in Aammiq Marsh.

When only the Aammiq Marsh habitats (the first 5 habitat types in Fig. 12) were analysed, ANOVA showed that Macrophyte had significantly higher per-sample diversity than the Isolated Pools ($F=2.89$, $df=4,33$, $p=0.037$), but there were no significant differences between any of the other Marsh habitats. Nevertheless, Fig. 12 suggests that the Inner Reed environment had lower diversity than the habitats around the marsh edge. Surprisingly, the diversity of the Wet Meadow habitat was as high as that of the Isolated Pools and not very far below that of the other marsh habitats.

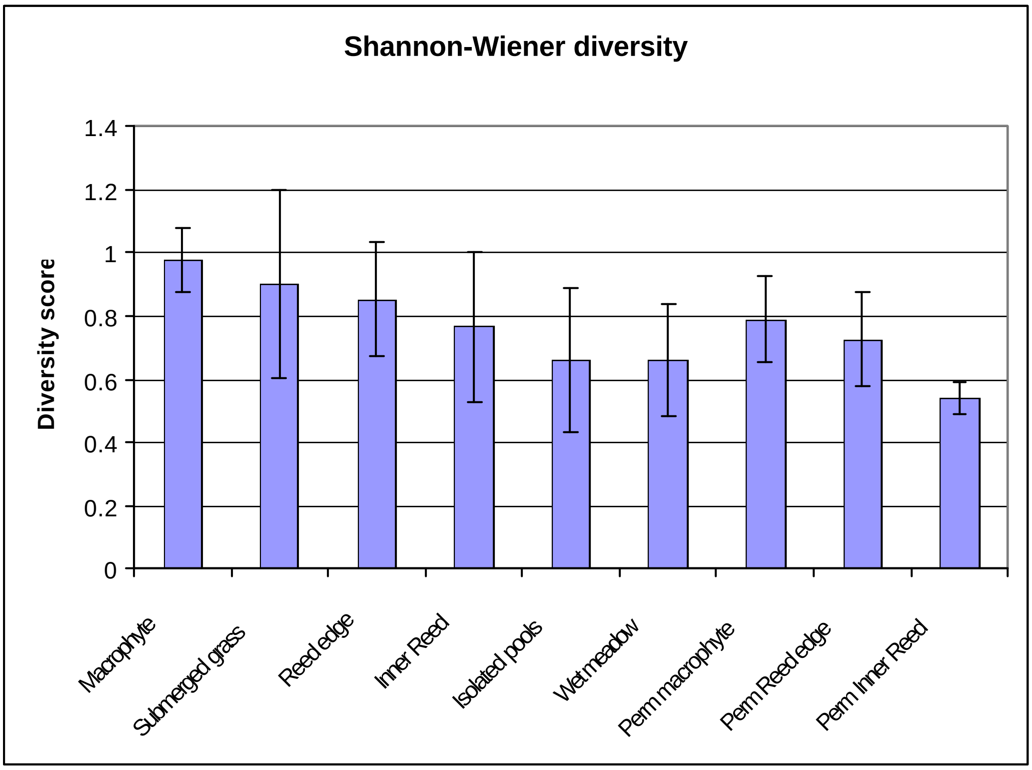


Fig. 12 Shannon-Wiener diversity index scores for the aquatic habitats. Error bars are ±1 standard deviation.

Taxonomic richness is another measure of diversity. It is similar to Shannon-Wiener, except that it considers only the total number of taxa present and ignores the relative abundance of different taxa. Differences in taxonomic richness between the different aquatic habitats (Fig. 13) were similar to those for Shannon diversity, except that the Wet Meadow and Permanent Pool habitats were relatively lower. Analysis of variance on the 5 Aammiq Marsh habitats (excluding Wet Meadows) showed that the Submerged Grass habitat had a higher per-sample taxonomic richness than the Isolated Pools habitat ($F=4.596$, $df=4,33$, $p=0.005$), but there were no other significant differences between these habitats. T-tests were used to determine whether the Aammiq Marsh habitats had significantly higher richness than their corresponding habitat in the Permanent Pool. These tests showed that Macrophyte had significantly higher richness than Perm Macrophyte ($t=4.058$, $df=7$, $p=0.005$), Reed Edge higher than Perm Reed Edge ($t=3.889$, $df=7$, $p=0.006$) and Inner Reed higher than Perm Inner Reed ($t=3.431$, $df=5$, $p=0.019$).

The different habitat types at Aammiq Marsh (except Wet Meadow) had broadly similar proportions of the major invertebrate groups. In all of these, the beetles and molluscs had the greatest number of taxa present, with the fauna of crustacean, dragonflies and true flies also quite rich. In contrast, the Wet Meadow habitat lacked dragonflies, crustaceans and True bugs, instead was dominated by beetles and true flies, with vertebrates (fish and tadpoles) also usually present. The Permanent Pool habitats had a high richness of true flies and mayflies, with several taxa of beetles and dragonflies occurring in some of the habitat types. Crustaceans were almost completely absent, and a rich mollusc fauna occurred only among the macrophytes, in the Permanent Pool.

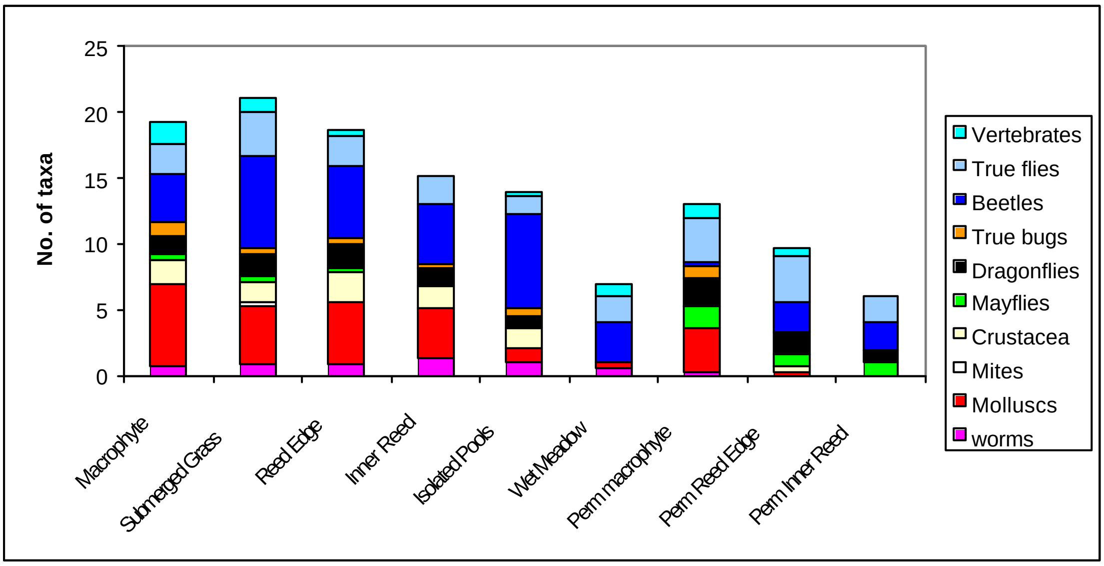


Fig. 13 Taxonomic richness (total number of taxa recorded) per sample at each aquatic habitat type, broken down by major taxon.

c) Community composition of the different habitat types

Figs. 11 and 13 can be used to compare the invertebrate community in different habitat types, but only in terms of broad categories of invertebrate groups. To look for finer differences, e.g. in the occurrence of certain species, Multidimensional Scaling (MDS), was used. MDS is a multivariate technique that displays differences in invertebrate community composition in terms of distance in space; two habitat types that are widely separated on the MDS plot have very different invertebrate communities.

Fig. 14 shows the results for the 2002 survey. Clearly the Permanent Pool habitats have a very different invertebrate community from the Aammiq Marsh habitats. In fact, all the habitat types (Macrophyte, Reed Edge and Inner Reed) in the Permanent Pool are more similar to each other than to the corresponding habitat type in Aammiq Marsh. This implies that the Permanent Pool is a very different environment for aquatic invertebrates than the Marsh. The difference between the Permanent Pool and the Aammiq Marsh habitats was mostly due to the higher numbers of mayflies and chironomids (midges), and the almost total absence of *Proasellus* isopods, ostracod crustaceans and the molluscs *Planorbis*, *Physa*, *Bythinia* and *Lymnaea* in the Permanent Pool. The Permanent Pool habitats also had almost no larval Hydrophilid and Haliplid beetles.

The two Wet Meadow samples appear to have an invertebrate community that is intermediate between the other Aammiq Marsh habitats and the Permanent Pool, however the two samples are also very different to each other, so it is hard to draw conclusions about the community of this habitat type.

Among the habitats in Aammiq Marsh, the Isolated Pools appeared to have a different invertebrate community to the other habitat types, though there was some similarity with the community in Submerged Grass. The Isolated Pools habitat was very variable, i.e. the communities in different pools varied considerably from one another. Despite this high variability, however, the communities in Isolated Pools had consistently lower abundances of the snails *Physa* and *Planorbis*, and higher abundances of ostracods, the isopod *Proasellus* and Dytscid (diving beetle) larvae than the other marsh habitats. The community in the Inner Reed habitat was also somewhat different to those of other habitats. Though it is not shown clearly in Fig. 14, statistical tests (Table 4) show that the Inner Reed community differed significantly from all other Aammiq habitats, including the Reed Edge. These differences are mainly due to low abundances of *Physa*, *Bythinia* and ostracods, and high abundances of *Proasellus* in the Inner Reed habitat. The habitats with the most similar invertebrate communities were Reed Edge and Submerged Grass; the Submerged Grass community was also quite similar to the Macrophyte community.

Statistical tests showing the degree of difference between the different marsh habitats are summarised in Table 4, and the taxa that contribute most to the differences between habitat types are listed in Appendix 4.

Table 4. R values and significance level for ANOSIM (the test of differences between the different habitat types) based on Bray-Curtis similarity of community composition. A significance level of less than 5% means there is a significant difference between the two habitat types being compared. But note that because 10 tests were done, values close to 5% should not be interpreted too closely.

	Macrophyte	Submerged Grass	Reed Edge	Inner Reed
Submerged Grass	0.228, 4.8%			
Reed Edge	0.363, 1.5%	-0.056, 64.7%		
Inner Reed	0.864, 0.2%	0.437, 0.9%	0.376, 1.7%	
Isolated Pools	0.72, 0.1%	0.301, 2.2%	0.366, 0.4%	0.252, 4.1%

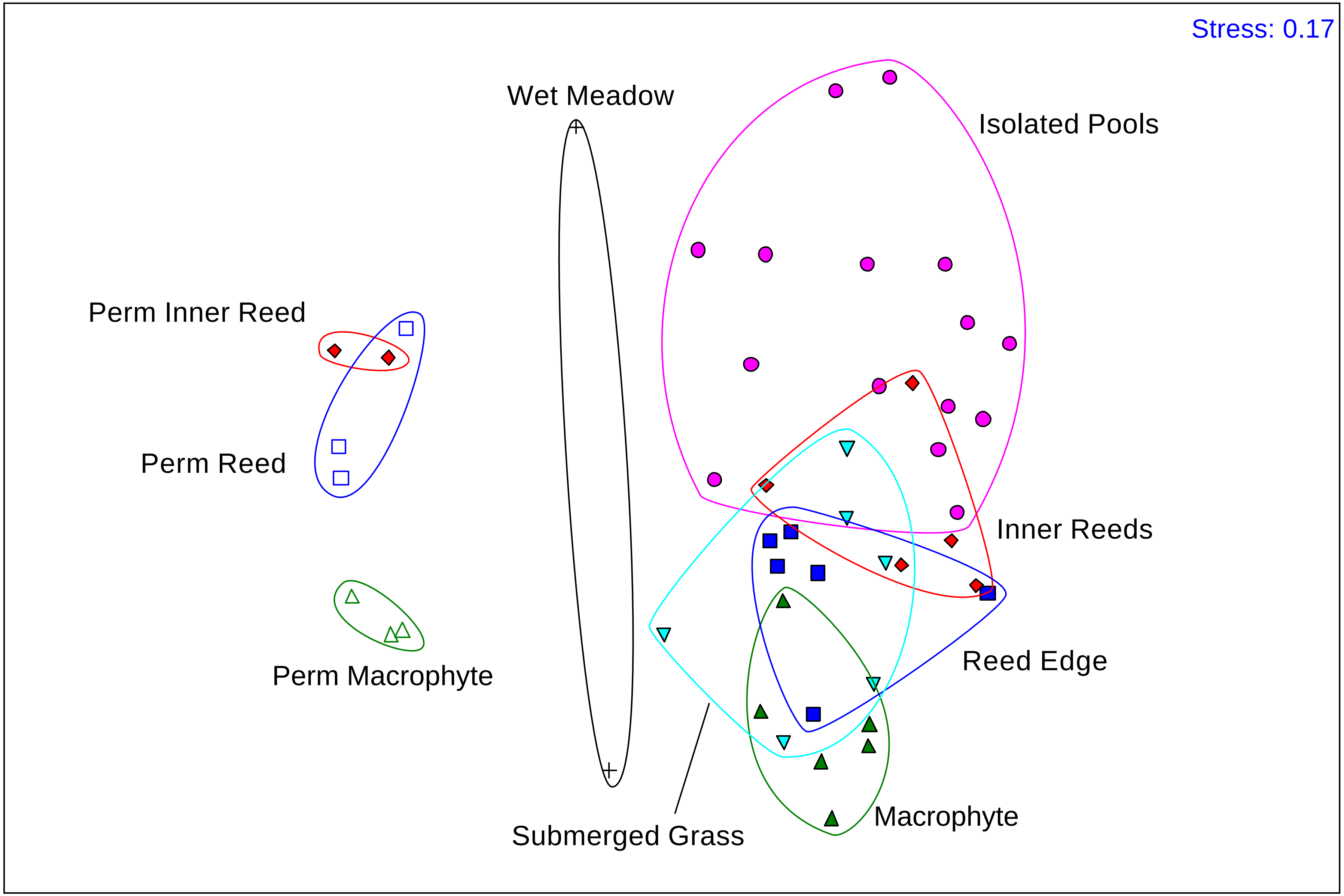


Fig. 14 Multidimensional Scaling (MDS) plot of the invertebrate community composition of the various Aammiq and Permanent Pool (Perm) sites. Points that are close together have similar community composition whereas those distant from each other have different composition. The Stress value indicates how well the plot displays the actual differences and similarities between sites. A value of 0.17 indicates a good representation overall, but the details of the plot should be interpreted with caution.

Discussion

Comments on the occurrence of particular species

This study led to the collection of 78 taxa of aquatic invertebrates between 2002 and 2003. For most taxa, the difficulties of obtaining reliable keys and checklists for the fauna meant that most specimens could not be identified beyond family or genus level. Therefore, for these groups, one can only comment that the taxa found in this study are typical of the fauna in freshwater marshes; the data presented here cannot be used for determining whether Aammiq Marsh holds rare, endemic or otherwise significant species, nor for comparing with other studies in Aammiq (e.g. ref) and nearby habitats (e.g. Dimentman et al., 1992). However, specimens of each taxon have been preserved in two collections, located at A Rocha Lebanon (care of Chris Naylor) and in the Biology Department of the American University of Beirut (care of Dr. Khouzama Knio). It is hoped that these specimens may be identified by future researchers.

In two groups, the Odonata (dragonflies and damselflies) and Coleoptera (beetles), most specimens could be identified to species. The Odonate fauna contained only species that have been described for this region by Dumont (1991). However, among the Coleoptera, 13 species were new records for Lebanon. Some of these records are of greater interest than others. *Peltodytes caesus* is a widespread Palaearctic species, so its occurrence in Lebanon is no surprise. Most of the other species, e.g. *Haliplus kulleri* and *Haliplus maculatus*, have more restricted distributions but have been reported from countries adjacent to Lebanon. However *Hygrotus impressopunctatus*, though it has a widespread distribution (Scandinavia to China), has until now not been recorded south of Turkey. Further to these, 3 beetle species were found as previously-undescribed larvae. These results suggest that species-level identification of other specimens from this study may also yield new records for Lebanon, particularly among groups that are less mobile than the beetles and dragonflies.

Aammiq Marsh as an aquatic habitat

Aammiq Marsh contained a moderate diversity of aquatic invertebrates, including some sensitive taxa such as mayflies, dragonflies and damselflies that are often used to indicate good wetland health. This shows that at the time of the study, Aammiq marsh maintained good habitat conditions overall. This was expected as the marsh is largely spring-fed, is not close to any industrial sources of toxic pollution, and has a high capacity to absorb nutrient run-off from the surrounding farmland. Agricultural toxins (pesticides and herbicides) may enter the marsh, but to date their presence in marsh water or sediments have not been tested. Their effect on aquatic invertebrates cannot be adequately gauged from this study.

Of particular note is the low number of mosquitoes in Aammiq Marsh. Larvae were rarely encountered in samples, and the author was never bitten during field work. This may be due to the introduction of *Gambusia* (mosquito fish), which apparently occurred in the 1940s, or it may be due to other naturally-occurring fish and invertebrate predators.

Comparing habitat types

1. Permanent vs temporary habitats

The Permanent Pool habitats had lower invertebrate density and significantly lower invertebrate richness than the corresponding habitats in the main marsh. This tends to indicate poorer habitat conditions. Certain groups that were very abundant in the main marsh, such as isopods, ostracods and most of the snail genera, were absent from the Permanent Pool. The invertebrate communities were dominated by chironomid (midge) larvae, which may indicate poorer habitat conditions, however beetles, dragonflies and mayflies, which tend to indicate good habitat conditions, were also present. The limited water quality data available suggest that water quality is not impaired. The high amount of decomposing reed material may be a problem, as it tends to reduce dissolved oxygen levels where it accumulates, however this cannot explain the low invertebrate richness in the macrophyte beds of the Permanent Pool where oxygen levels remained high.

It may be that the permanence of the water itself may be responsible for the low invertebrate richness and density in the Permanent Pool. Alternation of wet and dry phases is known to increase the decomposition rate of plant detritus, and detritus that has been exposed to air has a greater protein content (and hence food value for invertebrates) than detritus that hasn't (Ward, 1992). Therefore overall food quality and hence invertebrate productivity may be lower in the Permanent Pool than in Aammiq. Also, alternation of wet and dry phases may increase invertebrate diversity by allowing a variety of "temporal niches", i.e. early in the wet season there are opportunities for rapidly-colonising invertebrates to establish, whereas later in the wet season, invertebrates that are slower developing but stronger competitors become established (Williams, 2006). If the wet period is short enough, the stronger competitors do not have time to completely displace the fast colonisers, and diversity remains high.

While it is dangerous to draw conclusions based on samples from a single pool, it appears that permanent water bodies around Aammiq do not have greater invertebrate diversity and density than temporary ones, and restoring permanent water to the main marsh probably would not increase either invertebrate diversity or density. If this is so, it is because many aquatic invertebrates have strategies for surviving in temporary habitats. Strategies include migration to other permanent habitats (e.g. beetles, Hemiptera), timing of the terrestrial adult phase of the life cycle during the dry season (e.g. dragonflies and damselflies), formation of resistant stages (eggs or cysts) that remain in the bottom sediments (e.g. copepods), or remaining inside a hard shell with the opening sealed (e.g. snails, clams) (Williams, 2006). One invertebrate group that may not have such good strategies for surviving drought, the mayflies, appeared to benefit from the presence of permanent water. Mayflies were more diverse and abundant in the Permanent Pool than in most of the Aammiq habitats.

2. Marginal vs inner habitats

In both Aammiq Marsh and the Permanent Pool, the marginal habitats (i.e. around the marsh shoreline) had higher diversity and density of invertebrates than the inner reed habitat. Because diversity and density in the reed edge habitat was almost as high as in the macrophytes and submerged grass, this pattern cannot be explained simply by the greater physical complexity of macrophytes/grass vs. reed stems. It appears the edge environment itself allows for higher diversity and denser populations. This may be due to the greater sunlight at the reed edge, which allows greater growth of microalgae. Microalgae growing on submerged plant stems (periphyton) are an important food source for aquatic invertebrates (Scheffer, 1998), hence greater algal growth may be expected to support greater density and diversity of invertebrates. The low oxygen levels prevailing in the Inner Reed habitat may also explain the lower invertebrate numbers there. While invertebrates may tolerate short-term reductions in oxygen, permanently low levels may affect their survival. In a survey of a similar wetland not far from Aammiq, Dimentman et al. (1992) also found that the inner reed environment supported lower invertebrate richness than the reed bed edges, and similarly attributed this to low oxygen levels.

3. Vegetation types

Macrophytes and submerged grasses were expected to support a greater diversity and density of invertebrates than reeds due to their greater density and more complex physical structure. A denser plant bed affords more protection from fish predators (Scheffer, 1998), while a more complex leaf structure provides more surface area and a greater range of microhabitats for colonising invertebrates (Murkin and Wrublesky, 1988). Thus a number of studies have shown that different aquatic plants support different invertebrate species (e.g. Ward 1992; Williams and Feltmate, 1992; Jeffries and Mills 1990) and that invertebrate density and diversity are greater where plant beds are denser and structurally more complex (e.g. Scheffer, 1998).

In my study no differences in invertebrate diversity or density were detected between macrophyte, submerged grass and reed edge habitats, despite the greater physical complexity of the Macrophyte habitat, but this may be mainly due to the high variability within each habitat type and the low number of samples taken. In broad categories, the composition of the invertebrate community was similar among the 3 habitat types, but ANOSIM revealed that the Macrophyte had significantly different species composition to the Reed Edge.

4. Isolated pools

Pools that formed outside the main marsh area and became isolated from the marsh after the highest flooding had passed contained diverse invertebrate communities that were somewhat different to those in the main marsh and differed one from another. Densities of some invertebrate groups in some of these pools were very high.

The large fluctuations of oxygen (and possibly temperature) in these small water bodies would make them appear to be a highly stressful environment for invertebrates. In some pools, oxygen levels declined to nearly zero at night due to plant respiration. Some invertebrates (especially adult beetles and Hemiptera) have adapted to surviving in such conditions by carrying on their bodies air bubbles taken from the surface, therefore are not greatly affected by low dissolved oxygen. Other groups, such as chironomid midges, are adapted to using very little oxygen, so can also tolerate low dissolved oxygen. Most invertebrates can survive short-term exposure to low oxygen, and may be able to tolerate the regular night-time hypoxia because it occurs for only a few hours at a time. Nevertheless, oxygen may be one of the factors causing the difference in invertebrate composition among the variously sized Isolated Pools and between them and the other marsh habitats.

Oxygen may also have indirect effects on the invertebrate communities. Fish are likely to be more strongly affected by low night time oxygen than invertebrates, and this may be one reason why fish were less frequently seen in the Isolated Pools than in the main marsh. Fish prey on invertebrates, and pools without fish are known to support much higher density and diversity of invertebrates than those with fish (Ward, 1992). Therefore the effect of oxygen on fish may strongly affect the invertebrate community in isolated pools. Furthermore, invertebrate behaviour is affected by oxygen levels (e.g. air-breathing invertebrates must rise more frequently to the water surface when dissolved oxygen levels are low), and experiments have shown that predation by predatory invertebrates on other invertebrates is modified when oxygen levels are lowered (Ward, 1992). Therefore low oxygen may also affect the invertebrate community by its effect on predatory behaviour.

Water temperatures did not approach the thermal limits for invertebrates (usually around 40 ºC; Williams, 2006) during this study. However, daily peak water temperatures of up to 27 ºC may have been high enough to cause mild thermal stress in some fish and invertebrates. Thermal stress may modify behaviour as described for oxygen, and therefore have indirect effects on community composition in the Isolated Pools. Temperature was shown to decline with depth in these pools, and cool "thermal refuges" may exist at the bottom of deeper pools. Thermal refuges also can be provided by aquatic plants that trap cooler water beneath their leaves. Therefore, deeper pools and those with denser aquatic vegetation may allow more temperature-sensitive invertebrates to survive than shallower and less vegetated pools. Thus, temperature may be another factor causing differences in the invertebrate composition among the Isolated Pools.

This survey was carried out during early summer when water levels in the marsh were still high and peak summer temperatures had not yet arrived. As the Isolated Pools gradually dry out and experience warmer summer temperatures, water temperature and oxygen are likely to become more critical to the survival of aquatic invertebrates. Thus they will likely become a stronger driver of invertebrate community composition in the Isolated Pools later in the year. Furthermore, during the drying process, the various isolated pools are likely to become more different to one another in terms of oxygen, temperature and other water quality parameters (Chapman and Kramer, 1991). This is likely to lead to greater differences among the invertebrate communities of the different pools (Smith and Pearson, 1987). Therefore, among them the Isolated Pools may harbour a very high invertebrate diversity.

5. Habitats that were wet for a short time

Meadows that were flooded for a short period of 2-4 weeks after winter flooding appeared to have lower invertebrate diversity and density than habitats that remained wet for several months. Because only two wet meadow samples were taken, further sampling is needed before definite conclusions can be drawn. However, we may note that the few taxa found in the Wet Meadow were mostly highly mobile ones that can quickly colonise from outside (e.g. beetles, fish and tadpoles), and those that have very rapid life cycles (e.g. chironomids can develop to adults in as little as two weeks). It appears that this habitat may not be suitable for longer-lived and less mobile taxa. This would be consistent with other studies showing that while temporary aquatic habitats may have higher invertebrate diversity than permanent ones, diversity is lower in those where the water remains for fewer than about 70 days (Williams, 2006). Dimentman *et al.* (1992) also recorded a predominance of more mobile species in a briefly-flooded habitat.

Comments on the "habitat mosaic" concept for Aammiq Marsh

The "habitat mosaic" concept, i.e. that different habitat types will support different invertebrate communities, was supported by the invertebrate data in this study. While significant differences in invertebrate diversity and density were hard to find due to the low number of samples collected, each habitat type (except Macrophyte and Submerged Grass) had a significantly different invertebrate community. Therefore it is recommended that Aammiq Marsh be managed to maintain the greatest possible diversity of habitat types for the benefit of aquatic invertebrate diversity.

In future surveys, I recommend sampling a greater diversity of habitats, including the springs area (expected to have some groundwater fauna, some flowing water species and some species intolerant of fluctuations in temperature), open water (plankton), floating macrophytes (e.g. *Ranunculus*) and deeper-water macrophyte communities.

Further recommendations

This study has also provided baseline data for early detection of human impacts on the marsh biota. Such impacts may include deteriorating water quality, or more likely, changes in the length of the wet period due to increasing withdrawal of marsh water for irrigation and increasing use of groundwater in the region. In order to detect effects on the invertebrate community, regular monitoring should be conducted using a similar sampling technique as described here so that future species composition and density can be compared to those in this study.

If the question of providing areas of permanent water vs. allowing the marsh to dry each year becomes critical, I would recommend further sampling of other permanent water habitats (if they can be found). The conclusions derived here on the effects of water permanence were based on a single permanent pool, and the invertebrate community of this pool may be affected by various factors not recognised in this study.

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Appendix 1: GPS co-ordinates for specific sampling locations

Location name	North	East	Sampling date
Isolated Pool 1 (3 reps)	33° 43.700’	35° 47.091’	7 May 02
Isolated Pool 2 (3 reps)	33° 43.739’	35° 47.091’	7 May 02
Isolated Pool 3 (3 reps)	33° 44.179’	35° 47.614’	9 May 02
Isolated Pool 4 (3 reps)	33° 43.900’	35° 48.019’	9 May 02
Isolated Pool 5 (3 reps)	33° 43.814’	35° 48.470’	17 May 02
Submerged Grass 1	33° 43.940’	35° 47.245’	4 May 02
Submerged Grass 2	33° 43.831’	35° 47.102’	15 May 02
Submerged Grass 3	33° 43.857’	35° 47.260’	15 May 02
Submerged Grass 4	33° 43.956’	35° 47.198’	18 June 02
Submerged Grass 5	33° 43.974’	35° 47.336’	18 June 02
Submerged Grass 6	33° 43.953’	35° 47.118’	21 June 02
Reed Edge 1	33° 43.930’	35° 47.327’	4 May 02
Reed Edge 2	33° 43.941’	35° 47.348’	6 May 02
Reed Edge 3	33° 43.834’	35° 47.230’	5 June 02
Reed Edge 4	33° 43.821’	35° 47.220’	5 June 02
Reed Edge 5	33° 43.945’	35° 47.118’	21 June 02
Reed Edge 6	33° 43.973’	35° 47.178’	27 June 02
Inner Reed 1	33° 44.2’	35° 47.6’	lost
Inner Reed 2	33° 43.833’	35° 47.217’	5 June 02
Inner Reed 3	33° 43.825’	35° 47.198’	5 June 02
Inner Reed 4	33° 43.830’	35° 47.912’	14 June 02
Inner Reed 5	33° 43.862’	35° 47.861’	14 June 02
Inner Reed 6		Close to InReed5?	14 June 02
Macrophyte 1	33° 43.799’	35° 47.305’	5 June 02
Macrophyte 2	33° 43.938’	35° 47.222’	21 June 02
Macrophyte 3	33° 43.940’	35° 47.265’	21 June 02
Macrophyte 4	33° 43.975’	35° 47.159’	27 June 02
Macrophyte 5	33° 44.029’	35° 47.699’	27 June 02
Macrophyte 6	33° 44.020’	35° 47.697’	27 June 02
Wet meadow 1	33° 44.137’	35° 47.742’	16 May 02
Wet meadow 2	33° 44.162’	35° 47.579’	16 May 02
Perm Macrophyte 1	33° 42.253’	35° 48.635’	13 June 02
Perm Macrophyte 2		10 m east of Perm Macro1	13 June 02
Perm Macrophyte 3	33° 42.229’	35° 48.576’	2 July 02
Perm Reed Edge 1	33° 42.219’	35° 48.579’	13 June 02
Perm Reed Edge 2	33° 42.219’	35° 48.686’	13 June 02
Perm Reed Edge 3	33° 42.275’	35° 48.570’	2 July 02
Perm Inner Reed 1	33° 42.235’	35° 48.669’	2 July 02
Perm Inner Reed 2	33°42.223’	35° 48.682’	5 July 02

Appendix 2: Water Quality data

2-Jul-02	Springs (north)	Springs (south)	Marsh Upper	Reed bed (Marsh Lower)	Ditch
Temperature (°C)					
pH			7.59	7.6	7.29
Conductivity (mS/cm)			517	523	452
Nitrate (mg/L)			3	1.14	2.55
Nitrite (mg/L)			2.44	0.47	0.53
Organic Matter[1] (mg/L)			3.2	4.16	0.86
Organic Matter[2] (mg/L)			293	290	248
Hardness (ppm $CaCO_3$)			232	276	252
Ca (mg/L)			91	96	91
Mg (mg/L)			0.97	8.8	5.85
Na (mg/L)			5	5	5.3
K (mg/L)			0.7	0.2	0.5
Cl (mg/L)			26	22	24
SO_4 (mg/L)			40	47	0.12

[1]acid method; [2]CO_3 method

7-Jan-03	Springs (north)	Springs (south)	Marsh Middle	Marsh Lower	Ditch
Temperature (°C)	14.8		11.1		9.9
pH	7.33		7.52	7.34	7.55
Conductivity (mS/cm)	404		440	475	533
Nitrate (mg/L)	10		12	5	38
Nitrite (mg/L)	0		0.1	0.11	0.13
Organic Matter[1] (mg/L)	0		1.12	3.68	0.96
Organic Matter[2] (mg/L)	236.7		226.9	246.44	239
Hardness (ppm $CaCO_3$)	228		240	264	276
Ca (mg/L)	81.6		86.4	100.8	94.4
Mg (mg/L)	5.8		5.8	2.9	9.76
Na (mg/L)	4		5	6	7.4
K (mg/L)	0.8		1.15	2	0.97
Cl (mg/L)	20		18	26	30
SO_4 (mg/L)	5		42.5	62	41

7-Mar-03	Springs (north)	Springs (south)	Marsh Middle	Marsh Lower	Ditch
Temperature (°C)	14.5	14.1	13.5	11.9	11.2
pH	7.34	7.44	7.61	7.6	7.73
Conductivity (mS/cm)	364	369	395	383	419
Nitrate (mg/L)	7.9	8.2	7.7	5.4	17.6
Nitrite (mg/L)	0	0	0.03	0.02	0.1
Organic Matter[1] (mg/L)	0	0	0	0.9	0
Organic Matter[2] (mg/L)	239	239	251	244	227
Hardness (ppm $CaCO_3$)	204	208	228	212	236
Ca (mg/L)	76.8	76.8	83	78	78
Mg (mg/L)	2.9	3.9	4.8	3.9	9.7
Na (mg/L)	4	3.8	4.4	5.6	6.6
K (mg/L)	0.7	0.7	0.8	0.9	0.7
Cl (mg/L)	16	16	18	20	22
SO_4 (mg/L)	3.7	4.4	10.4	18	21.6

8-May-03	Springs (source)	Springs (middle)	Marsh Middle	Marsh Lower
Temperature (°C)	14.8	14.8	15.1	
pH	7.52	7.66	7.9	
Conductivity (μS/cm)	414	418	430	
Nitrate (mg/L)				
Nitrite (mg/L)	0.04	0.06	0.07	
Organic Matter[1] (mg/L)			.	
Organic Matter[2] (mg/L)	239	241	246	
Hardness (ppm $CaCO_3$)	216	216	212	
Ca (mg/L)	76.8	76.8	80	
Mg (mg/L)	5.8	5.8	2.9	
Na (mg/L)	4	4	4	
K (mg/L)	0.8	0.7	0.7	
Cl (mg/L)	18	18	20	
SO_4 (mg/L)	4	4	9	
NH_4 (mg/L)	0.37	0.38	0.39	

30-April-03 (Tell Amara labs)	Springs (north)	Springs (south)	Marsh Middle	Marsh Lower	Ditch
Temperature (°C)	14.8	14.8	15.1	14.5	13.7
pH	7.6	7.5	7.8	7.5	7.9
Conductivity (μS/cm)	410	420	440	450	420
Nitrate (mg/L)	10.2	10.2	7.65	3.63	10.1
Nitrite (mg/L)	15.4	14	12.6	5.6	4.2
Organic Matter[1] (mg/L)					
Organic Matter[2] (mg/L)					
Hardness (ppm $CaCO_3$)					
Ca (mg/L)					
Mg (mg/L)					
Na (mg/L)					
K (mg/L)	0.9	0.9	0.9	1.1	0.7
Cl (mg/L)					
SO_4 (mg/L)					
P_2O_5 (mg/L)	0.029	0.029	0.029	0.029	0.029

19-Jun-03	**Springs (north)**	**Marsh Middle**	**Marsh Lower**	**Ditch**	**Excavated pool**
Temperature (°C)	14.6	18.4	19	18.8	
pH	7.4	7.37	7.42	7.87	7.5
Conductivity (mS/cm)	415	446	497	425	275
Nitrate (mg/L)			0.4		
Nitrite (mg/L)	0	0.015	0.01	0.15	0.04
Organic Matter[1] (mg/L)					
Organic Matter[2] (mg/L)	239	256	298	246	131.7
Hardness (ppm $CaCO_3$)	200	156	252	212	124
Ca (mg/L)	65.6	36.8	93	67	38
Mg (mg/L)	8.8	15.6	4.8	10.7	6.8
Na (mg/L)	4	4	4	5	6
K (mg/L)	0.7	0.6	0.3	0.9	0.4
Cl (mg/L)	16	16	14	18	18
SO_4 (mg/L)	0.98	10	12.5	7	10

19-Jun-03 (Tell Amara labs)	**Springs (north)**	**Marsh Middle**	**Marsh Lower**	**Ditch**	**Excavated Pool**
Temperature (°C)	14.6	18.4	19	18.8	
pH	7.55	7.5	7.5	7.76	7.66
Conductivity (mS/cm)	400	420	470	410	260
Nitrate (mg/L)	3.5	0.99	0.19	3.26	0.83
Total N (mg/L)	4.2	4.2	4.2	9.3	5.6

Appendix 3 Taxon list

Major Group	Order	Family	Genus/species	Common name	New record for Lebanon?
Annelida (Oligochaeta)			Oligochaeta (unidentified)	worm	
		Lumbricidae	*Eiseniella tetraedra*		
Annelida (Hirudinea)			Hirudinea	leech	
Mollusca (Gastropoda)			*Bithynia sp.*	snail	
			Lymnaea sp.		
			Stagnicola sp.		
			Physa sp.		
			Planorbis sp.	ramshorn snail	
			Gyraulus sp.		
			Valvata sp.		
			Radix sp.		
Mollusca (Bivalvia)			*Sphaerium sp.*	clam	
			Bivalve type 1	clam	
Crustacea	Cladocera		Cladocera	water flea	
	Decapoda		Crabs (probably Potamon potamios)		
	Isopoda		*Proasellus*		
Crustacea (Copepoda)			Copepod Cyclopoid		
Crustacea (Ostracoda)			Ostracod Type 1	seed shrimp	
Crustacea (Ostracoda)			Ostracod Type 2		
Acari			Acari	mite	
Insecta	Ephemeroptera	Baetidae	Baetidae	mayfly	
			Cloeon sp.		
		Caenidae	*Caenis macrura*		
	Odonata	Aeshnidae	*Aeshna cf. mixta*	dragonfly	
			Anax sp.		

Major Group	Order	Family	Genus/species	Common name	New record for Lebanon?
		Libellulidae	*Sympetrum sanguineum*		
			Sympetrum meridionale		
		Coenagrionidae	*Ischnura elegans*	damselfly	
			Coenagrion sp.		
			Coenagrion or *Erythromma sp.*		
		Lestidae	*Lestes barbarus*		
			Lestes virens virens		
			Lestes viridis		
			Sympecma fusca		
	Hemiptera	Corixidae	*Corixa sp.*	water boatman	
			Sigara sp.		
		Notonectidae	*Notonecta viridis mediterranea*	backswimmer	
			Notonecta obliqua		
		Gerridae	*Gerris*	water strider	
			Heteroptera larvae		
	Coleoptera (larvae)	Dryopidae	*Dryops rufipes*	water beetle	
		Dytiscidae	*Hydrovatus cuspidatus*	diving beetle	Y
			Cybister lateralimarginalis		
			Hygrotus lerneus		Y
			Laccophilus minutus		Y
			Graptodytes sedilloti sedilloti		Y
		Haliplidae	*Haliplus (Neohaliplus) lineatocollis*	water beetle	
			Haliplus (Liaphlus) kulleri		Y
			Peltodytes caesus		Y
		Hydrophilidae	*Hydrophilus piceus*	water beetle	
			Berosus dispar		
			Limnoxenus/Hydrobius		
			Enochrus sp.		Y?
			Hydrochara sp.		

Major Group	Order	Family	Genus/species	Common name	New record for Lebanon?
	Coleoptera (adults)	Dryopidae	*Dryops rufipes*	water beetle	
		Dytiscidae	*Graptodytes sedilloti sedilloti*	diving beetle	Y
			Hydrovatus cuspidatus		Y
			Agabus bipustulatus		
			Agabus conspersus		
			Hygrotus impressopunctatus		Y
			Ilybius hulae		Y
			Laccophilus minutus		Y
			Hydroporus pubescens		
		Haliplidae	*Haliplus (Liaphlus) kulleri*	water beetle	Y
			Peltodytes caesus		Y
		Hydrophilidae	*Helophorus (Eutrichelophorus) micans*	water beetle	
			Helophorus syriacus		
			Helophorus brevipalpus		
			Berosus dispar		
			Hydrobius sp.		
		Noteridae	*Noterus clavicornis*	water beetle	
	Diptera	Chironomidae	Tanypodinae	midge larva	
			Orthocladiinae		
			Chironomini		
			Tanytarsini		
			Nematocera pupae		
		Syrphidae	Syrphidae	rat-tailed maggot	
		Dixidae	Dixidae		
		Empididae	Empididae	dance fly	
		Ephydridae (pupae)	Ephydridae (pupae)	shore fly	
		Ceratopogonidae	Ceratopogonidae	biting midge	
		Sciomyzidae	Sciomyzidae	marsh fly	
		Culicidae	Culicidae	mosquito	

Additional taxa found in December 2003 survey

Major Group	Order	Family	Genus/species	Common name	New record for Lebanon?
Mollusca	Gastropoda		*Physa acuta*		
Crustacea	Amphipoda		Amphipods		
Insecta	Ephemeroptera	Baetidae	*Baetis sp.*	mayfly	
	Hemiptera	Gerridae	*Gerris cf. argentatus*	water strider	
		Notonectidae	*Notonecta maculata*	backswimmer	
			Anisops sardea	backswimmer	
		Pleidae	*Plea minutissima*		
	Trichoptera	Limnephilidae		caddisfly	
	Coleoptera (adults)	Dytiscidae	*Agabus biguttatus*	diving beetle	
			Agabus nebulosus		
			Colymbetes fuscus		
			Cybister lateralimarginalis		
			Hydrovatus cuspidatus		Y
			Hygrotus impressopunctatus		Y
			Hygrotus lerneus		Y
			Hydroglyphus geminus		
		Haliplidae	*Haliplus (Neohaliplus) lineatocollis*	water beetle	
			Haliplus (Liaphlus) maculatus		Y
		Hydrophilidae	*Hydrophilus piceus*	water beetle	
			Hydrobius fuscipes		
			Helophorus abeillei		
			Helochares lividoides		
			Hydrochara dichroma		
			Laccobius syriacus		
			Limnoxenus niger		
			Ochthebius viridis		

Appendix 4 Species contributing most strongly to the differences between habitat types, according to Multidimensional Scaling (SIMPER procedure). Taxa are: Annelids (worms), *Bythinia*, *Physa*, *Planorbis*, *Lymnaea*, *Valvata*, bivalves, *Corixa*, Vertebrates, *Proasellus,* Ostracods, Ephemeroptera (mayflies), Aeshnidae (dragonflies), Coenagrionidae (damselflies), Larval Dytiscids (diving beetles), larval Haliplidae (beetles), larval Hydrophilid beetles, adult *Dryops* (beetles), chironomids.

	Macrophyte	Sub. grass	Reed edge	Inner Reed	Isolated pools	Wet meadow	Perm Macro	Perm Reed
Sub. Grass	Bythinia, Physa, Corixa, Planorb							
Reed edge	Vert, Physa, Corixa, Bythinia, Planorb	Ostra, Bythinia, Lhalip, Proas, Ldyt						
Inner Reed	Physa, Proas, Vert, Bythinia, Ostra	Proas, Ostra, Physa, Annel	Ostra, Proas, Bythinia, Physa, Lhalip, Chiron					
Isolated pools	Physa, Planorb, Proas, Vert, Ostra, Ldyt	Ostra, Proas, Physa, Planorb, Ldyt	Ostra, Proas, Chiron, Physa, Bythinia, Planorb	Proas, Ostra, Planorb, Adry, Ldyt				
Wet meadow	Planorb, Physa, Bythinia, Ostra, Corixa	Ostra, Planorb, Physa, Lymna, Proas, Lhydro	Ostra, Planorb, Chiron, Proas, Bythinia	Proas, Planorb, Annel, Lhydro, Lymna	Proas, Ostra, Adry, Ldyt, Ahydro			
Perm Macro	Physa, Ephem, Bythinia, Planorb, Ostra	Ephem, Valv, Ostra, Lhydro, Physa	Ostra, Ephem, Valv, Coen, Ldyt	Proas, Ephem, Valv, Chiron, Coen	Ephem, Valv, Chiron, Ldyt, Proas	Ephem, Chiron, Valv, Coen		
Perm Reed edge	Physa, Planorb, Ephem, Bythinia, Ostra	Ostra, Ephem, Physa, Planorb, Lhydro	Ostra, Ephem, Planorb, Physa, Proas	Proas, Ephem, Planorb, Annel, Chiron	Ephem, Proas, Chiron, Ostra, Ldyt, Adry	Ephem, Chiron, Physa, Dipt, Ldyt	Valv, Coen, Bivalv, Dipt, Vert, Planorb	
Perm Inner Reed	Physa, Planorb, Bythinia, Vert, Ostra	Ostra, Physa, Planorb, Lhydro, Chiron	Ostra, Planorb, Physa, Proas, Lhydro	Proas, Planorb, Chiron, Annel, Lhydro	Chiron, Proas, Ostra, Adry, Ldyt, Ephem	Chiron, Ephem, Adyt, Physa, Lhydro	Valv, Vert, Ephem, Coen, Bivalv	Ephem, Dipt, Chiron, Ldyt, Aesch