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Effects of seasonal variation in salinity on a population of Enochrus bicolor Fabricius 1792 (Coleoptera: Hydrophilidae) *and implications for other beetles of conservation interest*

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ABSTRACT

1. A population of *Enochrus bicolor* (Fabricius) was monitored over a 4-year period (March 1997–March 2001) from a coastal brackish pool in S.E. Essex. This water beetle, together with *Ochthebius marinus* (Payk.), *O. viridis* Peyrhiff, *O. punctatus* Steph., *Hygrotus parallelogrammus* (Ahrens), *Berosus affinis* Brulle, *Agabus conspersus,* (Marsham), *Rhantus frontalis* (Marsham), *R. suturalis* (MacLeay), *Paracymus aeneus* (Germar), and *Haliplus apicalis* Thompson, are all taxa of conservation interest.
2. *Enochrus bicolor* was present in most months, with greatest adult abundances being recorded in August and September each year.
3. During the study period salinity values ranged from 4.7 ppt (parts per thousand) to 62.6 ppt.
4. Correlation analysis and the development of regression models indicated that the highest abundances of *E. bicolor* coincided with maximum water temperature in the late summer–early autumn. However, when the natural seasonal signal was removed by standardizing the series, a relatively weak association with the relative abundance of *E. bicolor* and conductivity was observed.
5. The conservation of *E. bicolor* and other organisms associated with brackish water habitats subject to irregular marine inundation is considered.

KEY WORDS: *Enochrus bicolor*; salinity; brackish coastal pool; seasonal variation

INTRODUCTION

Knowledge regarding the distribution and conservation status of freshwater invertebrates (Wright *et al*., 1996; Williams *et al*., 1998) has significantly increased in the last decade. In contrast, our understanding of many brackish water organisms and habitats has lagged behind, despite their widely acknowledged conservation value (Sheader, 1989; Bamber *et al*., 1991,1992; Sheader *et al*., 1997; Foster, 2000). Many coastal brackish water habitats experience regular and predictable fluctuations in salinity values due to the mixing of saline and fresh water. This may create salinity zones that fluctuate over short periods of time,

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such as individual tidal cycles (Williams and Williams, 1998) to the occasional incursions, coincident with the tidal equinox of spring and autumn.

It is clear from physiological studies that tolerance of wide fluctuations in salinity requires adjustment and/or adaptation (Sutcliffe, 1961a,b; McLusky, 1971; Savage, 1981; Williams and Williams, 1998). The tolerance of Coleoptera to brackish water has received relatively limited attention (Fairchild *et al*., 2000). Aquatic Coleoptera have been recorded from a range of brackish water habitats, with taxa from the families Haliplidae, Noteridae, Dytiscidae, Hydrophilidae, Hydraenidae, Gyrinidae, Elmidae and Chrysomelidae, typically being represented (Lancaster and Scudder, 1987; Barnes, 1988, 1994; Timms and Hammer 1988; Bamber et al., 1991; Williams and Williams 1998; Foster 2000). Results from studies of brackish water habitats suggest that when assessing the conservation status of specific taxa, it is important to consider the volume of fresh and saline water inputs, the degree of chemical stability, precipitation inputs and evaporation outputs from the habitat (Sheader *et al*., 1997).

Enochrus bicolor is the most common member of a complex of five Palaearctic species (Hansen, 1996; Schodl, 1998), but in the United Kingdom is nationally notable of List B status and considered at low risk by the IUCN (Foster, 2000). Throughout the UK and Ireland, *E. bicolor* is confined to brackish water. It has been recorded in coastal ponds, slow-flowing ditches and also in the Cheshire mires (Balfour-Browne, 1958; Friday, 1988; Foster, 2000) (Figure 1). Its confinement to brackish waters provides an opportunity to examine the tolerance of this organism to changes in salinity over time. Most historic records are the annual 'species-habitat records' denoting the presence of a species in a habitat of known salinity at that point in time. For example, in a study of the impacts of the 1953 floods on aquatic insects, *E. bicolor* was recorded as

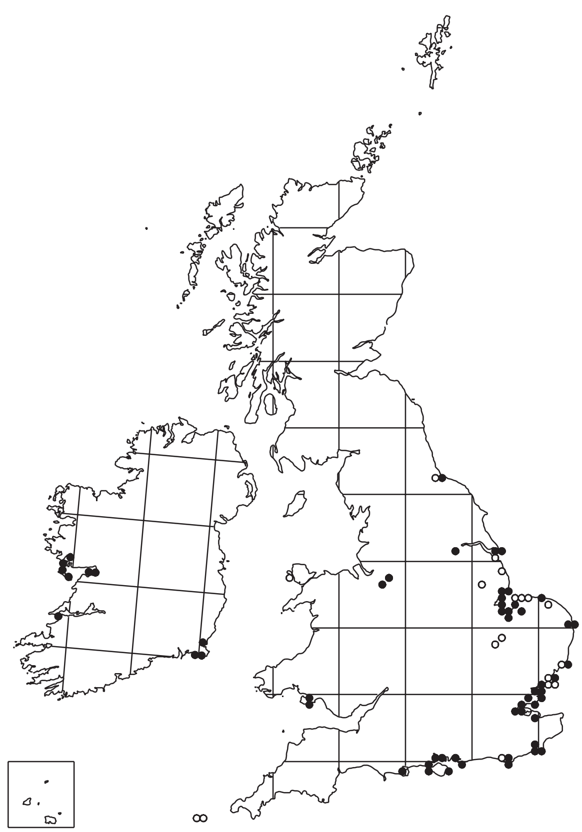

Figure 1. Distribution map of *Enochrus bicolor* in the United Kingdom and Ireland. Courtesy of the Balfour–Browne Club.

tolerating a maximum salinity of 28.4 ppt (Butler and Popham, 1958). However, relatively little is known regarding tolerance levels over longer timescales.

The current investigation examines the changes in a population of *E. bicolor* and associated taxa, over a 4-year period in a habitat where the inundation pulse of saline water is non-cyclical and if it occurs, coincides with the tidal equinox of March and October. Correlation analysis was undertaken and regression models developed to examine the relationship between salinity/conductivity, precipitation (freshwater) inputs, water temperature and the relative abundance of *E. bicolor*.

STUDY AREA

The study site is a small saltmarsh pool at the landward margin of Flag Creek, Brightlingsea, Essex (Grid Ref. TM 094 164) (Figure 2 and Figure 3). The town of Brightlingsea lies at the mouth of the River Colne and is situated on glacial sands and gravels beneath which is an impermeable layer of London Clay. Precipitation typically permeates the surface gravel only to emerge laterally at the interface of the gravel with the London Clay. A springline at a height of 8 m above sea level can be traced around the town itself and freshwater marshes fed from these springs lie adjacent to the sea (Dickin, 1939).

The study site is isolated from regular tidal inundation by a clay bund, created in 1850, to provide access to an oyster processing plant on the creek edge. The bund or pathway, allows water from the freshwater springs to accumulate behind it, and is of such a height (0.75–1 m above that of the adjacent saltmarsh),

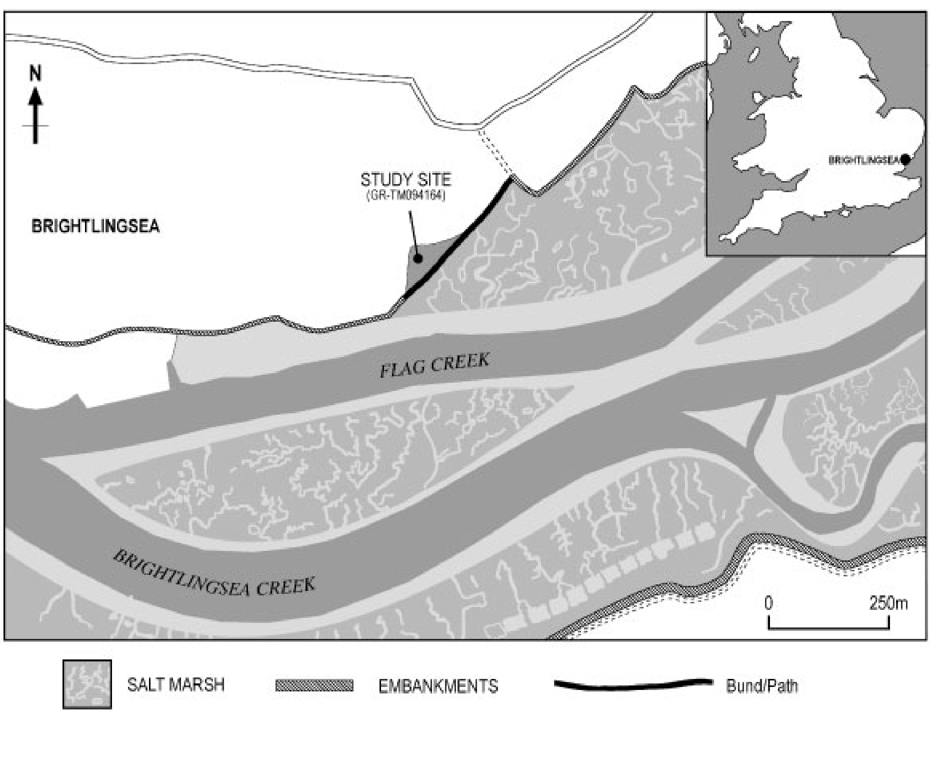

Figure 2. Location map of the Flag Creek study site, Brightlingsea, Essex.

Figure 3. The Flag Creek study site, Brightlingsea, Essex.

that the pool only experiences saline water incursion during the tidal equinox. The pool lies in a series of interlinking salt pans and has a surface area of approximately 1 ha and depth typically ranges from 30 to 70 cm. This site is composed of characteristic saltmarsh mesohabitats and flora such as: *Juncus maritimus* Lam. (sea rush), *Inula crithmoides* L. (golden-samphire), *Spartina anglica* Hubb. (common cord-grass), *Elytrigia atherica* (Link.) (sea couch grass), *Puccinellia maritima,* (Hudson) (common saltmarsh grass), *Aster tripolium* L. (sea aster), *Triglochin maritimum* L. (sea arrow grass), *Atriplex portulacoides* L. (sea puslane); it is fringed with *Phragmites australis* (Cav.) (common reed) and the pool itself contains *Ruppia maritima* L. (beaked tasselweed).

METHODS

The study site was sampled at monthly intervals between March 1997 and March 2001. Two 1 min sweep samples were collected from open water and bankside habitats around the perimeter of the pool using a standard pond net with a mesh size of 1 mm. The number of *E. bicolor* in each sample was counted at the site. Other common taxa were either recorded at the site (e.g. *Palaeomonetes varians*) or in the case of difficult taxa, such as Gammaridae, Corixidae, Odonata and Trichoptera, in the laboratory. During each visit, water temperature and conductivity measurements were recorded at the base of the water column in the pool using portable meters. Precipitation data for the study period were kindly provided for St Osyth, Lee Wick Farm (Grid Ref. TM 107 142), within 5 km of the study site, by the British Atmospheric Data Centre (BADC).

Salinity, as defined by Davidson *et al*., (1991) is the amount of inorganic material dissolved in the water, expressed as a weight in grams per kilogram of water, i.e. parts per thousand. Using such notation the salinity of seawater is ± 35 parts per thousand (ppt) and freshwater <0.5 ppt. In this study conductivity was used as a measure of the concentration of ions arising from the salts. Pool and seawater values were taken throughout the study using a portable meter and a value of 45 mS cm^{-1} (milli-Siemens) used as the marine baseline against which to measure change. Gravimetric estimates of the salts in samples were

Table 1. Definition of variables used in correlation and regression analysis of the data

	Definition	
Ecological		
ENOC	*Enochrus bicolor* — abundance	
ZENOC	*Enochrus bicolor* — standardized[a] abundance	
Water Temperature (°C)		
TEM	Water temperature	1 variable
TEM($-m$)	Water temperature lagged at month m (−1 to −12)	12 variables
ZTEM	Water temperature - standardized[a]	1 variable
ZTEM($-m$)	Water temperature lagged at month m (-1 to –12) — standardized[a]	12 variables
Precipitation (mm)		
PREC	Monthly precipitation	1 variable
PREC($-m$)	Monthly precipitation lagged at month m (−1 to –12)	12 variables
ZPREC	Monthly precipitation — standardized[a]	1 variable
ZPREC($-m$)	Monthly precipitation lagged at month m (−1 to −12) — standardized[a]	12 variables
Conductivity (mS cm^{-1})		
CON	Conductivity	1 variable
CON($-m$)	Conductivity lagged at month m (−1 to −12)	12 variables
ZCON	Conductivity — standardized[a]	1 variable
ZCON($-m$)	Conductivity lagged at month m (−1 to −12) — standardized[a]	12 variables

[a]— Standardized by the mean and standard deviation for each month within the series (z-score).

determined by evaporating the water in an oven at 130°C. The relationship between the conductivity measurement and salt content of both seawater and samples from the pool was determined throughout the study using the following regression equation:

$$y = -0.81 + 0.82x\,(r^2 = 0.985; p < 0.001)$$

where y is the mass of salts in g $litre^{-1}$ and x = conductivity value (given that seawater = 45 mS cm^{-1} and is equivalent to 36.05 g $litre^{-1}$ salt).

The relationship between *E. bicolor* and environmental variables was examined using the SPSS statistical software. Three variables were examined in detail: water temperature (°C), conductivity (mS cm^{-1}) and precipitation (mm) at lags of up to 12 months (see Table 1 for details). Correlation coefficients were computed, scattergrams were investigated and stepwise multiple linear regression was performed to select the 'best' suite of variables to describe the relative abundance of *E. bicolor*. Data were used in their raw and in a standardized form (z-scores were derived by subtracting the mean for an individual month within the series and dividing by the standard deviation for the month) to remove the strong seasonality within the series. This allowed the importance of the environmental variables to be seen more clearly.

RESULTS

Environmental variability

The site experienced a varied input of saline water during the study period. Sea water overbanked the bund at least four times during the investigation (March 1997, March 1998, November 1999 and March 2001), coinciding with the highest tides associated with the spring and autumn equinox. The resulting salinity values recorded during each site visit were primarily the result of the diluting effect of freshwater inputs (precipitation and surface water) and the concentrating effect of evapotranspiration processes.

Preliminary inspection of the data indicated that conductivity values exceeded those of sea water during May–December, 1997 and between July–October, 1998 (Figure 4). During the summer of 1997 water temperature rose to 29°C, the highest recorded throughout the study, and during 1998 it reached 27°C. Coinciding with peak water temperatures, conductivity values reached 80.5 mS cm^{-1} (62.6 ppt) during 1997 and 59.9 mS cm^{-1} (46.6 ppt) in 1998. However, after October 1998 conductivity values never exceeded 45 mS cm^{-1} (36 ppt). Throughout 1999 until March 2001 conductivity values, although showing some degree of seasonality, gradually declined to 6 mS cm^{-1} (4.7 ppt) in February 2001. No saline inundation occurred in March 1999, although it did so in late November of that year. Throughout 2000, no sea water inundation occurred resulting in a sustained decline of salinity levels.

Variability of *E. bicolor* and other taxa

A total of 31 invertebrate taxa were recorded during the study period representing the taxonomic groups: Annelida, Insecta (Odonata, Hemiptera, Trichoptera, Coleoptera, Diptera), Crustacea and Mollusca (Table 2). The most frequently occurring taxon in samples was the brackish water shrimp, *Palaeomonetes varians*, followed by *Sigara selecta* (Corixidae) and the Gastropod *Potamopyrgus antipodarum* (Hydrobiidae). A list of the taxa recorded and their current conservation status is given in Table 2.

Enochrus bicolor was present in all 4 years of the study. Its relative abundance varied between years, but was most abundant during the months of July, August and September each year (Figure 4). The population occurred within a conductivity range of 6.0 mS cm^{-1} (4.7 ppt) – 80.5 mS cm^{-1} (62.6 ppt). Throughout 1997 and 1998, when high conductivities were recorded, in addition to *E. bicolor* the coleopteran fauna of the pool only included *Ochthebius marinus*, *O. viridis* and *O. punctatus*. Other abundant taxa recorded during this period were *Palaeomonetes varians, Potamopyrgus antipodarum, Sigara selecta*, *Aedes (Ochlerotatus) detritus*, and *Ephydra riparia*. Throughout 1999, relatively little change in the invertebrate community structure was detected. However, after March 2000 significant changes to the community took place (Table 2). During the spring and summer, taxa more frequently associated with mild-brackish and freshwater were recorded for the first time including *Ischnura elegans* and *Aeschna mixta* (Odonata) together with *Notonecta viridis* and *Sigara stagnalis* (Hemiptera) (Table 2). Coleopteran larvae from the family Dytsicidae appeared for the first time in late February–March 2000, and imagines of *Hygrotus parallelogrammus*, *Agabus conspersus, Rhantus frontalis*, *R. suturalis*, *Haliplus apicalis*, *Helophorus minutus*, *Noterus clavicornis*, *Berosus affinis* and the rare hydrophilid, *Paracymus aeneus* were also collected for the first time during the summer and autumn of this year.

Investigation of the raw data using correlation analysis indicated that water temperature was the only variable to demonstrate a significant association with the abundance of *E. bicolor*. The strongest association was recorded when a lag of 1 month (TEM-1) was used (Table 3) and suggested a thermal cue for the emergence of adults from pupae. Precipitation and conductivity demonstrated no significant associations with the raw data. Following standardization of the series, using the mean and standard deviation (z-scores) for each month, no relationship was observed between temperature or precipitation, although a significant relationship with conductivity up to 12 months prior to sample collection (ZCON-7 to ZCON-12) was observed (Table 3). Stepwise multiple linear regression clearly identified the association with the abundance of *E. bicolor* and the thermal regime of the previous month (TEM-1) in the unstandardized series. However, when the series was standardized, conductivity 9 months prior to sample collection (ZCON-9) was the only variable incorporated into the model (Table 4).

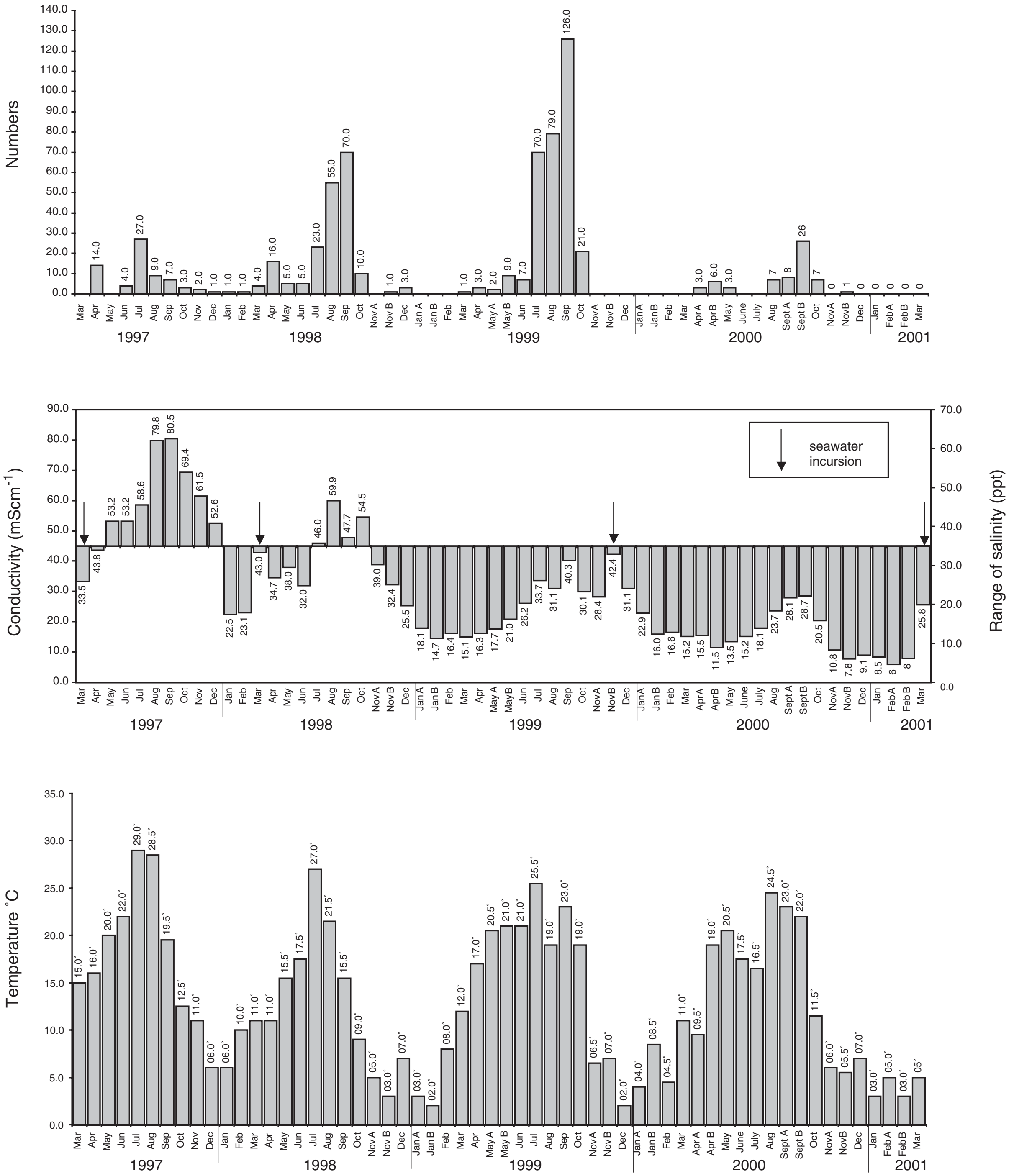

Figure 4. Seasonal changes of numbers of *Enochrus bicolor*, Conductivity (mS cm^{-1}/salinity (ppt) and water temperature (°C); March 1997–March 2001.

Table 2. Relative abundance of taxa recorded between March 1997–February 2000 and March 2000–March 2001, including conservation status

Taxa	March 1997 — February 2000	March 2000–March 2001	Conservation status[a]	
			Red data book (GB)	IUCN proposed status (GB)
Oligochaeta				
Annelida				
Nereis (*Hediste*) *diversicolor* Muller	R			
Insecta				
Odonata				
Ischnura elegans (Vander Linden)		C		
Aeschna mixta Latreille		R		
Hemiptera				
Sigara (*Halicorixa*) *selecta* (Fieber)	A	A		
Sigara stagnalis (Leach)		C		
Notonecta viridis Delcourt		C		
Trichoptera				
Limnephilus binotatus Curtis		R	Local	
Limnephilus flavicornis (Fabricius)		R		
Coleoptera				
Enochrus bicolor Fabriscius	A	F	Nb	LRnsB
Ochthebius marinus (Payk.)	C	C	Nb	LRnsB
Ochthebius viridis Peyrhiff	O	O	Nb	LRnsB
Ochthebius punctatus Steph.	R		Nb	LRnsB
Hygrotus parallelogrammus (Ahrens)		R	Nb	LRnsB
Berosus affinis Brulle		O	Nb	LRnsB
Agabus conspersus (Marsham)		R	Nb	LRnsB
Rhantus frontalis (Marsham)		R	Nb	
Rhantus suturalis (MacLeay)		R	Nb	LRnsB
Paracymus aeneus (Germar)		R	RDB1	EN
Helophorus minutus Fabricius		R		
Haliplus apicalis Thomson		R	Nb	LRnsB
Noterus clavicornis (Degeer)		R		
Diptera				
Chironomus sp.	C	C		
Aedes (*Ochlerotatus*) *detritus* Haliday	A	C		
Ephydra riparia Fallen	A	O		
Crustacea				
Cyclopoid Copepoda	C	C		
Gammarus zaddachi Sexton	C	C		
Palaeomonetes varians (Leach)	A	A		
Talitridae cf Orchestia		O		
Mollusca				
Potamopyrgus antipodarum (Gray)	A	A		
Pisces				
Gasterosteus aculeatus L.	C	C		
Pomatoschistus microps Kroyer	R			

Relative abundance of individuals in samples: Rare — R = <5; Occasional — O = 6–11; Common — C = 11 — 30; Frequent — F = 31–50; Abundant >51.[a] Based on Foster (2000); IUCN = The World Conservation Union; Nb = Nationally Notable List B; RDB 1 = Red Data Book category 1; LRnsB = IUCN Red List Category — Lower Risk, Nationally scarce, list B; En = IUNC Red List Category — Endangered.

Table 3. Summary of selected Pearson correlation coefficients between the raw and standardised abundance of *E. bicolor* and environmental variables

	ENOC	ZENOC
TEM	**0.451****	0.080
TEM-1	**0.465****	-0.002
TEM-2	**0.438****	-0.037
TEM-3	0.220	-0.035
ZTEM	−0.003	0.265
ZTEM-1	−0.050	0.125
ZTEM-2	0.015	0.014
ZTEM-3	−0.023	0.189
PREC	0.138	0.083
PREC-1	0.202	0.147
PREC-2	−0.105	0.098
PREC-3	0.097	−0.070
ZPREC	0.101	−0.133
ZPREC-1	0.014	−0.082
ZPREC-2	−0.170	0.091
ZPREC-3	−0.089	−0.242
CON	0.224	0.052
CON-1	0.131	0.114
CON-2	−0.014	0.184
CON-3	−0.165	0.250
CON-4	−0.227	0.278
CON-5	−0.280	**0.311***
CON-6	−0.299	0.280
CON-7	−0.269	**0.331***
CON-8	−0.254	**0.324***
CON-9	−0.216	0.285
ZCON	−0.065	0.182
ZCON-1	−0.042	0.254
ZCON-2	−0.058	0.228
ZCON-3	−0.096	0.261
ZCON-4	−0.129	0.269
ZCON-5	−0.082	0.276
ZCON-6	−0.019	0.287
ZCON-7	0.094	**0.391***
ZCON-8	0.092	**0.466****
ZCON-9	0.122	**0.609****
ZCON-10	0.124	**0.477****
ZCON-11	0.176	**0.387***
ZCON-12	0.133	**0.422****
	$n = 48$	$n = 48$

**$p < 0.005$, * $p < 0.05$.

Table 4. Stepwise multiple regression analysis of raw and standardised abundance of *E. bicolor* and environmental variables

Model	Adjusted R^2	F	Predictor variables plus sign
ENOC	0.543**	13.06	+ TEM-1, -PREC-3
ZENOC	0.371*	9.727	+ ZCON-9

**$p < 0.005$, * $p < 0.05$

DISCUSSION

Brackish habitats

Brackish water habitats are important ecotones and support communities of particular conservation interest. Many of the locations where examples exist are under threat from rising sea levels or anthropogenic disturbance associated with the construction of sea defences, coastal reclamation and drainage, and pollution (Barnes, 1989, 1994; Sheader, 1989). Regularly flooded coastal saltmarshes are characteristic of low-energy coasts in temperate and high latitudes (Allen and Pye, 1992). In Great Britain, there are extensive saltmarshes in the east and south-east, with Essex containing 20% (5000 ha) of the national resource (Mason *et al*., 1991). Nationally, 70% of the total area of saltmarsh of nature conservation value is contained within sites listed in the Nature Conservation Review (Ratcliffe, 1977); although in practice only 20% is protected (Mason *et al*., 1991).

The salinity of the water at any given location is largely determined by the tidal regime leading to inundation, and the degree of isolation of the site from the marine influence. This fluctuation has been called the 'water dynamic' and can be used to describe the cycle or periodicity of mixing of saline and freshwater (Davidson *et al*., 1991). This temporal variability plays an essential role in determining the invertebrate community structure (Savage, 1981; Barnes, 1988; Williams and Williams, 1998) and therefore an understanding and record of changing salinity over a longer timescale is essential to the conservation of these habitats.

In a detailed study of the Afon Aber estuary, North Wales, several taxa typically associated with freshwater habitats were able to survive short-term variability of salinity. The distribution of aquatic insect taxa within this dynamic environment was strongly influenced by the diel tidal cycle (Williams and Williams, 1998). However, in the current investigation saline intrusion was episodic and if it did occur, coincided with the highest tides. The predictability of the tidal influence was largely removed and operated over a much longer time-scale. The annual variability and evolution of invertebrate populations subject to naturally erratic saline inundation, as recorded in this investigation, may be marked by continual resetting episodes similar to hydrological disturbances associated with floods or drought (Lake, 2000). These events clearly affect the life-history characteristics of the organisms within the pool and influence community structure. However, our knowledge of community change over time is poor, making attempts to understand and model variability difficult in the absence of suitable long-term datasets. This is reinforced by this study and the relatively weak association recorded between the relative abundance of *E. bicolor* and conductivity up to 12 months prior to sample collection.

Brackish water Coleoptera

Relatively little research has been undertaken regarding the tolerances of Coleoptera to variations in salinity over time. Taxa from habitats regarded as brackish are often described using the upper limits of salinity at the time of sampling, but few studies offer insights into medium or long-term changes in salinity, or the rate at which the community changes as a result. The effects of changes in salinity on the community structure may be direct through physiological tolerances, or indirect through fluctuations in food resources or biological interactions (Lancaster and Scudder, 1987).

In a detailed study of saline lakes in Saskatchewan, Canada, five families of Coleoptera were represented, Gyrinidae, Haliplidae, Dytiscidae, Hydrophilidae, Curculionidae (Timms and Hammer, 1988). The most widespread species was *Enochrus diffusus* (Hydrophilidae), which was recorded in lakes covering a salinity range of 3–49 ppt (3.9–63 mS cm^{-1}). *Rhantus frontalis* (Dytiscidae), a species also recorded in the current investigation, was found at sites with salinities ranging between 3 and 27 ppt. Tones (1976) and Wallis (1973) suggest that *E. diffusus* has the widest salinity tolerance range of any water beetle (0–107 ppt = 137.6 mS cm^{-1}), followed by *R. frontalis* (0–80 ppt = 102.9 mS cm^{-1}). In mainland Europe brackish water beetle faunas are also dominated by the Hydrophilidae (Bernick, 1926) although, in common with North America, as salinity declines members of the family Dytiscidae become increasingly common (Hansen, 1987; Sage, 1996; Timms and Hammer, 1988).

Approximately 350 species of water beetle occur in UK and less than 7% are confined to saltmarsh/brackish water. Many of the fauna recorded are 'generalists' and only 6, including *E. bicolor*, are regarded as 'halobionts' (Foster, 2000). Despite a large number of records of Coleoptera from brackish water sites, relatively little information exists regarding the salinity at which they were recorded. For example, Sage (1996) recorded 77 water beetle taxa from Holkham nature reserve (North Norfolk coast) including *Agabus conspersus*, *Hygrotus parallelogrammus*, *E. bicolor*, *H. apicali*s and *O. marinus*, but salinity was not measured. Much has yet to be learnt about field salinity tolerances of the species encountered in this study. Dytiscidae are typically found in salinities <10 ppt, although *Colymbetes fuscus* has been recorded in waterbodies twice this concentration (Sutcliffe, 1961b). Haliplidae have been found at salinities <10 ppt although *Haliplus apicalis* has been recorded at greater concentrations, (Barnes, 1994).

Enochrus bicolor (Hydrophilidae) has been recorded from a number of locations in the UK although its salinity tolerances are poorly documented. Published records of salinities at sites where *E. bicolor* has been found to range from 17.5–28.4 ppt in Yorkshire (Butler and Popham, 1958) to 14–35 ppt in Lincolnshire and Norfolk (Foster *et al*., 1990). This present study indicates a much wider salinity tolerance range of 4.7–62.6 ppt. Further details of the salinity tolerances of Coleoptera recorded in the current investigation and from available published sources are given in Table 5.

A total of 13 Coleoptera were recorded at the Flag Creek site, of which 11 were either nationally notable or endangered (*Paracymus aeneus*) (Table 2). Examination of historic records indicate that this beetle is currently confined to two–ten km grid squares in England, having only ever been recorded from a total of six. *P. aeneus* lives in saline pools above the high-water mark, usually in association with vegetation at the edge of ponds. In the UK this species is currently classified as endangered and has been given full protection under Schedule 5 of the Wildlife and Countryside Act 1981. A Biodiversity Action Plan has been developed for *P. aeneus* with an emphasis on the protection of existing populations from damaging activities and through the creation of additional habitats (shallow ponds with vegetation at the edges) around the high-water mark (Foster, 1999).

It is evident from this study that the invertebrate community changed following a sustained period of dilution coinciding with high precipitation and no saline inundation. The continued survival of populations of brackish taxa, such as *Enochrus bicolor*, demonstrates a relatively wide tolerance of salinity. It is possible that during periods of high salinity, physiological processes control community composition in brackish waters. As a site becomes less saline, and additional taxa are able to colonize, biological/ecological factors become more important (Lancaster and Scudder, 1987). However, this inference is speculative and further detailed research regarding species interactions with *E. bicolor* are required as validation.

Conservation and Management

Brackish water habitats experiencing irregular mixing of both fresh and saline water have been identified as sites of particular conservation interest in the UK (Sherwood *et al*., 2000) and internationally (Abbiati and Basset, 2000). However, due to the unpredictability of the environment, combined with the vulnerability of existing sites to anthropogenic disturbance, the conservation and management of these habitats raise a number of concerns. Coastal engineering and the increase in leisure pursuits around our coasts has resulted in fringe/ecotonal habitats, such as lagoons and saltmarsh pools, becoming modified. Changes to the periodicity of saline inundation will modify the physiological balances and cause alterations to the community composition. However, the Flag Creek site is an example of an anthropogenic habitat, being created in 1850, that has provided a refugium for a number of taxa that may have been excluded from 'natural' habitats in the areas, subject to drainage and/or disturbance.

Table 5. Salinity tolerances for taxa recorded during this study and those from other sources

Taxon	Range of salinity (in ppt)	Source
Haliplus apicalis	1–3.5	Butler & Popham 1958
	1–5	Foster *et al* 1990
	15.9	This study
Noterus clavicornis	18.4	This study
Rhantus frontalis	1–10	Lancaster & Scudder 1987
	1–80	Timms - Hammer 1988
	14.1	This study
Rhantus suturalis	18.4	This study
Agabus conpersus	17.5–21.0	Butler & Popham 1958
	8.4–18.4	This study
Hygrotus parallelogrammus	9–15	Butler & Popham 1958
	18.4–21.9	This study
Helophorus minutus	13.5–18.4	This study
Berosus affinis	11.8–23.4	This study
Enochrus bicolor	14–35	Foster *et al* 1990
	19.3	Linberg 1948
	17.5–28.4	Butler & Popham 1958
	4.7–62.2	This study.
Paracymus aeneus	8.9–23.4	This study
Ochthebius marinus	14–35	Foster *et al* 1990
	16.8	Linberg 1948
	17.5–28.4	Butler & Popham 1958
	7.1–34.1	This study
Ochthebius viridis	8.4–34.1	This study
Ochthebius punctatus	17.5–18.0	This study

Many of the taxa presently found in irregularly inundated brackish habitats may occur somewhat infrequently and a greater awareness of the changes taking place in these habitats is necessary for their conservation. There is clearly a need to undertake medium to long-term studies of brackish water sites, to examine the wide range of environmental conditions encountered and the resulting changes in the faunal communities within them. The current paucity of data available reflects an absence of studies attempting to integrate hydrological, ecological and management data. Greater emphasis should be given to the long-term monitoring of such sites to provide datasets that will form the basis for the successful development of models to describe hydrological and ecological variability and ultimately provide data for sustainable management practices. However, in the short term, the protection of existing sites from damage associated with anthropogenic activities is required. The prevention of pollution, drainage and/or the isolation of brackish pools and ponds from both fresh and saline water sources needs to be ensured so that further research regarding both the habitats and individual species (autecology) associated with brackish water, can be undertaken. This research will provide valuable information to ensure the continued survival of individual sites and, where appropriate, provide the scientific basis to enable the creation and/or enhancement of further sites.

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REFERENCES

Abbiati M, Basset A. 2001. Ecological research and conservation of coastal ecosystems. *Aquatic Conservation: Marine and Freshwater Ecosystems* **11**: 233–234.

Allen JRC, Pye K. 1992. *Saltmarshes* Cambridge University Press: Cambridge.

Balfour-Browne F. 1958. *British Water Beetles*, Vol. 3. Ray Society: London.

Bamber RN, Batten SD, Bridgewater ND. 1991. The brackish ponds at Killingholme, Humberside, UK. *Aquatic Conservation: Marine and Freshwater Ecosystems* **1**: 173–181.

Bamber RN, Batten SD, Sheader M. 1992. On the ecology of brackish water lagoons in Great Britain. *Aquatic Conservation: Marine and Freshwater Ecosystems* **2**: 65–94.

Barnes RSK. 1988. The faunas of land-locked lagoons: chance differences and the problems of dispersal. *Estuarine, Coastal and Shelf Science* **26**: 309–318.

Barnes RSK. 1989. The coastal lagoons of Britain: An overview and conservation appraisal. *Biological Conservation* **49**: 295–313.

Barnes RSK. 1994. *The Brackish Water Fauna of Northwestern Europe*. Cambridge University Press: Cambridge.

Bernick L. 1926. Die Kafer der Oldesloe Salzstellen. *Mitteilungen Geographische Gesellschaft Naturhistorisches Museum Lubeck* **31**: 59–90.

Butler PM, Popham EJ. 1958. The effects of the floods of 1953 on the Aquatic Insect fauna of Spurn (Yorkshire). *Proceedings of the Royal Entomological Society, London* (A) **33**: 149–158.

Davidson NC, Laffoley d'A, Doody JP, Way LS, Gordon J, Key R, Pienkowski MW, Mitchell R, Duff KL. 1991. *Nature Conservation and Estuaries in Great Britain*. Nature Conservancy Council. Peterborough.

Dickin EP. 1939. *A History of Brightlingsea*. Wiley & Sons Ltd. Colchester.

Fairchild GW, Faulds AM, Matta JF. 2000. Beetle assemblages in ponds: effects of habitat and site age. *Freshwater Biology* **44**: 523–534.

Foster GN, Foster AP, Eyre MD, Bilton DT. 1990. Classification of water beetle assemblages in arable fenland and ranking of sites in relation to conservation value. *Freshwater Biology* **22**: 343–354.

Foster GN. 1999. Biodiversity action plans for British water beetles. *Latissimus* **11**: 1–13.

Foster GN. 2000. The aquatic Coleoptera of British saltmarshes: extremes of generalism and specialism, In: Sherwood BR, Gardiner BG, Harris, T. (eds). *British Saltmarshes*, Linnean Society. London; 223-233.

Friday LE. 1988. A key to the adults of British water beetles. *Field Studies* **7**: 1–151.

Hansen M. 1987. The Hydrophiloidea (Coleoptera) of Fennoscandia and Denmark. In *Fauna Entomologica Scandinavica*, vol. 18. Brill EJ. (ed.). Scandinavian Science Press Ltd. Leiden.

Hansen M. 1996. Coleoptera Hydrophiloidea and Hydraeidae, Water Scavenger Beetles. In *Aquatic Insects of North Europe, A Taxonomic Handbook*. Nilsson AN. (ed.).Apollo Books: Stenstrup.

Lake PS. 2000. Disturbance, patchiness, and diversity in streams. *Journal of the North American Benthological Society* **19**: 573–592.

Lancaster J, Scudder GGE. 1987. Aquatic Coleoptera and Hemiptera in some Canadian saline lakes: patterns in community structure. *Canadian Journal of Zoology* **65**: 1383–1390.

Lindberg H. 1948. Zur Kenntniss der Insektenfauna im Brackwasser des Baltischen Meeres. *Societas scientiorum Fennica Commentationes biologicae* **10**: 1–206.

Mason CF, Heath DJ, Gibbs DJ. 1991. Invertebrate assemblages of Essex salt marshes and their conservation importance. *Aquatic Conservation: Marine and Freshwater Ecosystems* **1**: 123–137.
McLusky DS. 1971. *Ecology of Estuaries*. Heinemann Educational: London.
Ratcliffe DA. 1977. *A Nature Conservation Review,* vol.1. Cambridge University Press. Cambridge.
Sage B. 1996. Coleoptera of Holkham national nature reserve, Norfolk. *Transactions of the Norfolk and Norwich Naturalists Society* **30**: 523–551.
Savage AA. 1981. The Gammaridae and Corixidae of an inland saline lake from 1975–1978. *Hydrobiologia* **76**: 33–44.
Schodl S. 1998. Taxonomic revision of *Enochrus* (Coleoptera : Hydrophilidae) 1. The *Enochrus bicolor* species complex. *Entomological Problems* **29**: 111–127.
Sheader MA. 1989. Coastal saline ponds of England and Wales: an overview, (Contractor. Department of Oceanography, University of Southampton). Nature Conservancy Council, CSD Report No. 1009.
Sheader M, Suwailem AM, Rowe GA. 1997. The anemone, *Nematostella vectensis*, in Britain: considerations for conservation management. *Aquatic Conservation: Marine and Freshwater Ecosystems* **7**: 13–25.
Sherwood BR, Gardiner BG, Harris T. 2000. *British Saltmarshes*. Linnean Society: London.
Sutcliffe DW. 1961a. Studies on saltwater balance in caddis larvae (Trichoptera) I. *Journal of Experimental Biology* **38**: 501–519.
Sutcliffe DW. 1961b. Salinity fluctuations and the fauna in a salt marsh with special reference to aquatic insects. *Transactions of the Natural History Society of Northumberland and Durham* **14**: 37–56.
Timms BV, Hammer UT. 1988. Water beetles of some saline lakes in Saskatchewan. *Canadian Field Naturalist* **102**: 246–250.
Tones PI. 1976. Factors influencing selected littoral fauna in saline lakes in Saskatchewan. PhD thesis, University of Saskatchewan, Saskatoon, Saskatchewan, 185 pp.
Wallis JB. 1973. An annotated list of the Hydroadephaga (Coleoptera: Insecta) of Manitoba and Minnesota. *Quaestiones Entomologicae* **9**: 99–114.
Williams DD, Williams NE. 1998. Aquatic insects in an estuarine environment: densities, distribution and salinity tolerance. *Freshwater Biology* **39**: 411–421.
Williams PJ, Biggs J, Barr CJ, Cummins CP, Gillespie MK, Rich TCG, Baker A, Baker J, Beesely J, Corfield A, Dobson D, Culling AS, Fox G, Howard DC, Luursema K, Rich M, Samson D, Scott WA, White R, Whitfield M. 1998. *Lowland Pond Survey, 1996*. Department of the Environment Transport and the Regions, London, 120 pp.
Wright JF, Blackburn JH, Gunn RJM, Furse MT, Armitage PD, Winder JM, Symes KL. 1996. Macroinvertebrate frequency data for the RIVPACS III sites in Great Britain and their use in conservation evaluation. *Aquatic Conservation: Marine and Freshwater Ecosystems* **6**: 141–167.

