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A survey of *Pseudanodonta complanata* Rossmäller in Norfolk

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Summary

Pseudanodonta complanata was surveyed in 1996 and 1997 in large rivers of Broadland (Yare, Bure, Ant, Thurne and Waveney, and some associated Broads), and large rivers and drains of the Great Ouse catchment (Great and Little Ouse, New and Old Bedford, Counter Drain, Wissey, Cut-off Channel, Flood Relief Channel). All species of mussels and sometimes other molluscs were recorded. Algae and chemistry were recorded at some rivers.

The past and present distribution of *Pseudanodonta complanata* in Norfolk shows that it has two main centres of distribution, one in Broadland on the River Waveney and River Yare, and another on the River Great Ouse and some of its tributaries.

The current distribution of *Pseudanondonta complanata* is influenced by several factors. The mussel is intolerant of brackish water which may block colonisation of some rivers with tidal sections. Saline incursions may have caused recent mortality in two rivers. Although the mussel is apparently tolerant of some pollution (plant nutrients and sewage inputs), it has increased its range and population size where quality has improved through better sewage treatment. Mussels were usually found in water shallower than 2m although occasionally lived in deeper water. The effects of dredging could not be assessed but mussels did occur in sites which are infrequently dredged, and had re-colonised a mud-pumped Broad within four years. Populations may be kept low by frequent weed-clearance.

Introduction

The Compressed or Depressed River Mussel *Pseudanodonta complanata* Rossmässler inhabits slow flowing rivers. It is a western European species and is known from the Ipswichian Interglacial. Since unionids have comparatively long life spans and their parasitic larval stages make them particularly vulnerable to environmental changes such as pollution and alterations to waterways, their current status and the factors affecting them is of importance in the conservation of the species. The vulnerability is closely linked to that of their fish hosts in the larval phase of their life cycle.

The mussel is known to be threatened throughout its range in western Europe (Wells & Chatfield, 1992). In the UK since 1950 it has been recorded from only 63 ten kilometre sites from Somerset through the Welsh borders to south Yorkshire. The UK has probably the healthiest populations of the mussel in Europe, with the possible exception of Finland.

The conservation importance of the mussel has been endorsed by the Government's placing it as a priority species in the UK's Biodiversity Action programmes (Biodiversity Steering Group, 1995). The plan requires research to establish the distribution and presence of key populations, and to undertake studies to determine the habitat requirements of the species. This report provides a current survey of the mussel in the County of Norfolk and examines some of the causal factors affecting its distribution and survival.

Status in Norfolk

Broadland Rivers

The River Yare and its three principal tributaries, the Wensum, the Waveney and the Bure, drain some $3500km^2$ of land in Norfolk and north Suffolk. The lower reaches of these rivers are tidal to points 40 to 50km from the mouth at Great Yarmouth. All of the broads area lies below the highest river levels and thus is susceptible to flooding. The most damaging events occur when marine surges and tides combine to cause abnormally high sea levels. The salt waters flowing into the rivers increase and penetrate far upstream. These saline intrusions cause serious damage to the ecology of the normally freshwater reaches and can lead to heavy fish kills. These intrusions normally occur in the winter but they can also occur in summers when freshwater flows are low.

Possible early records

The specimen (usually regarded as the type) of *Mytilus anatinus* L. in the collection of the Linnean Society of London, and another in the Museum Ludovicae in Uppsala (which collection formed a partial basis for Linnaeus's *Systema Naturae*) are referable not to *Anodonta anatina* but to *Pseudanodonta complanata* (Bowden & Heppell, 1968).

In 1784 Sir James Edward Smith purchased nearly all of Linnaeus's scientific effects, including his shells. Sir James Smith retained the collection until his death in 1828. It was then purchased by the Linnean Society of London in whose possession it remains. However, Sir James Smith sold and added to the collection during his life (Dance, 1967). He lived during this period in Surrey St, Norwich where the collection was housed. *Pseudanodonta complanata* is found in the River Yare at Norwich and it is of speculative interest to wonder whether the Linnean shells are in fact from Norfolk.

Pre-1996 Norfolk status

Pseudanondonta complanata was first recorded in Norfolk by Arthur Mayfield in 1909 in the River Yare from Norwich to Surlingham. Arthur E. Ellis in 1940 found it in the River Yare below the city. He recorded one shell having a length of 87mm, which is towards the upper size range for the species, ie 88-90mm. A.E. Ellis (1965) wrote in E.A. Ellis *The Broads*, "The River Yare provides an outlying station for this species". A.E. Ellis (1941) did not record the species from either Wheatfen Broad or from the main dykes linking the Wheatfen marshes to the River Yare. E.A. Ellis in his lifetime studies of both Wheatfen and Rockland Broads also failed to record its presence. The infererence from the lack of records for these two major sites suggest that these southern broads had not, at that time, been colonized by the mussel.

In 1994 Derek Howlett found a small colony in the Short Dyke leading from the River Yare to Rockland Broad (*Transactions Norfolk Norwich Naturalists' Society*, 1994). In both 1994 and 1995 the species was recorded by the authors from Wheatfen Broad. The Conchological Society of Great Britain and Ireland on a field visit to Wheatfen and Rockland Broads on 27th July 1996 dredged living specimens from both sites. The evidence points to the mussel having recently colonized both these linked broadland systems.

In terms of conservation it seems to have survived in the mid-Yare river valley the serious pollution levels between the early 1950 and 1990s. It appears to have always been rare but when present it can be dredged, albeit in small numbers.

On the Norfolk-Suffolk border Ian Killeen (1992) records *Pseudanodonta complanata* from the River Waveney below Beccles where it has been collected on only four occasions. It was unknown before 1973 when three dead specimens were dredged at North Cove. In 1985 live specimens were collected at Beccles and in 1990 at Share Mill. The numbers remained very small in the River Waveney.

In west Norfolk the mussel has been found only once in the River Great Ouse at Hilgay in depths of 3-4 metres with a river bottom composed of very fluid silty-clay material (Preece & Wilmot, 1979). The river is slow flowing and calcium concentrations of 153mg/l Ca and an alkalinity of 224mg/l calcium carbonate have been recorded.

Current Broadland distribution

The current distribution of *Pseudanodonta complanata* in the Norfolk-Suffolk Broads is shown in Figure 1. This map incorporates all results up to and including 1997. Essentially the species is restricted to the mid-Yare and Waveney rivers and their linked broads and dykes. There is evidence that the mussel is slightly increasing its distribution in the Yare valley as water quality improves.

River Yare and associated Broads

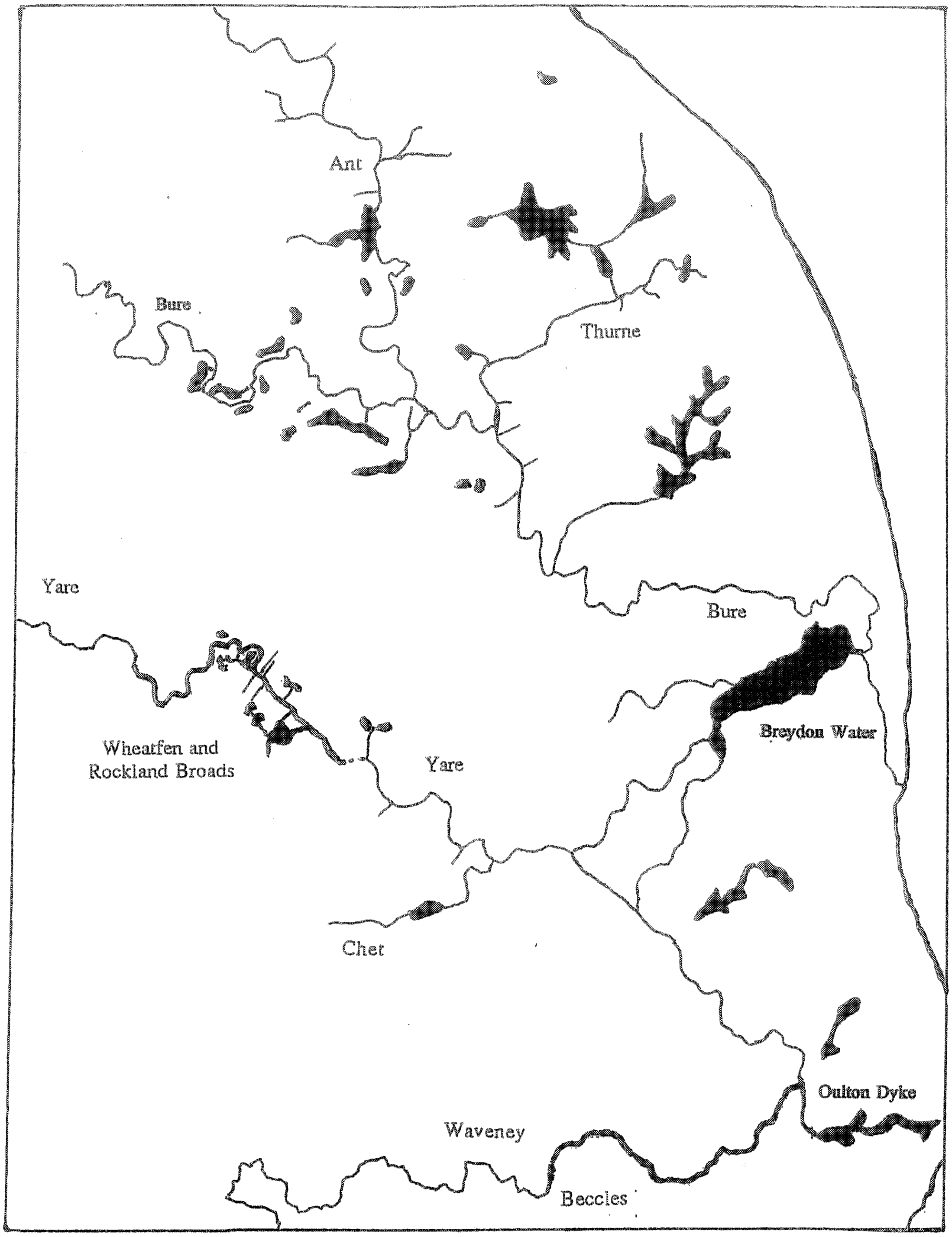
Survey results

In August 1996 English Nature commissioned the Ted Ellis Trust to survey the River Yare and associated broads for the presence of *Pseudanodonta complanata*. The river was dredged to determine the distribution and nature of the mussel population. The trawl was more or less continuous between Whitlingham Marshes and Cantley. The river was dredged on one side on the flooding tide and the other on the ebbing tide. In addition to the river, the broads at Surlingham, Rockland and Wheatfen were trawled. A profile across the river was undertaken

Figure 1. Distribution of *Pseudanodonta complanata* in Broadland: October 1997.

Key ——— Living mussels

- - - - Dead mussels



The Ted Ellis Trust
Wheatfen Broad, Norfolk

between the Surlingham and Strumpshaw banks (Figure 2). Sub-aqua divers checked the effectiveness of the trawl.

The lower edge of the dredge has an angled metal sheet blade and a series of ten centimetre-long metal probes to sift through the surface silts. The dredge was trawled 20 metres astern of a powered boat and the angle adjusted by touch to gain the maximum sifting of the river silts and peats. Mussels were retained in the catch nets.

The River Yare and its tributaries, the Wensum and Tas, drain an area of 988km² across a low lying plateau standing 30-50m above sea level. The river flows in an east-south-easterly direction until it reaches Breydon Water at the confluence to the River Waveney. The shallow bed gradient of approximately 3cm fall per km together with the moderating capacity of the broads, produces a mean daily flow of 6.74 cumecs. The tidal limit reaches upstream as far as Norwich. The saline interface normally occurs at Cantley.

The geology of the area comprises Cretaceous chalk covered with mixed drift, boulder clays and fluvio-glacial sands and gravels. The excavation of brushwood peats in the alluvial plain during the 12th-14th centuries has resulted in small water-filled broads linked to the river. These are now rapidly filling with soft uncompacted organic, calcareous mud at a rate of approximately 1cm per year (Garrard, 1984). At Wheatfen Broad the chalk lies at a depth of 18.3m beneath fluvial-glacial sands and Norwich Crag of the Bramerton Beds.

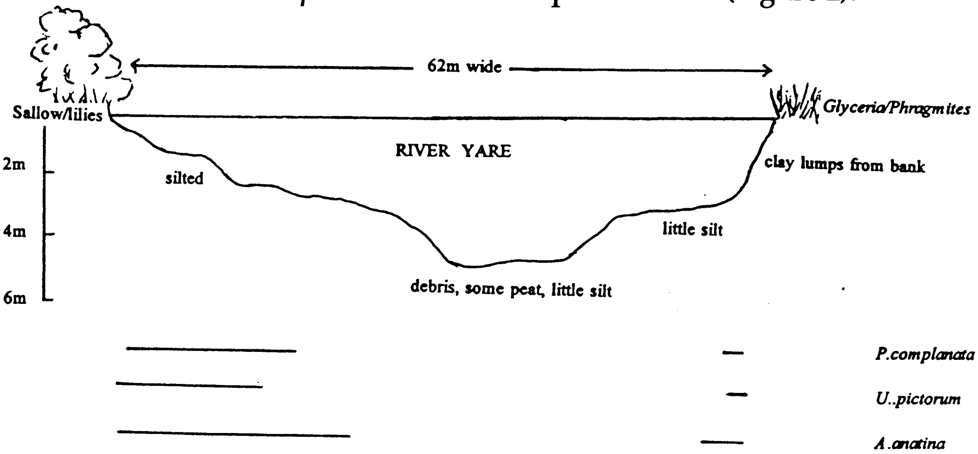
In August 1996 a total of 389 unionid specimens of *Anodonta cygnea* (L.), *Anodonta anatina* (L.), *Unio pictorum* (L.) and *Pseudanodonta complanata* were dredged from the River Yare. 54 specimens of *Pseudanodonta complanata* were found in this initial series of trawls. These represented 14% of the catch. The size ranged from 21mm to 87mm. Later, specimens of 90mm were noted. Initially the dredge had a width of 0.5m and a mesh which effectively caught only the larger, >50mm mussels. Smaller shells were collected randomly amongst the litter debris. The early data thus under-recorded smaller specimens. Further dredging using a smaller mesh size ensured that some of the younger mussels were also collected, although the very small post-glochidial stages were not sampled.

Pseudanodonta complanata is absent above Hall Farm (TG 288-068) along the Postwick reach of the river; in fact nearer the Whitlingham sewage outfall both up and down river there is a dramatic fall in unionid numbers. The species is absent from the river near Whitlingham Marshes where dense patches of aquatic vegetation including *Elodea canadensis* Michx. and *Ceratophyllum demersum* L. are found. The mussel is present from Hall Farm to the Beauchamp Arms (TG 348-044). The highest densities are to be found between Brundall (TG 320-080) and just down river from the Short Dyke leading to Rockland Broad (TG 345-052). There are large populations in the entrance to the Fleet Dyke leading to Rockland Broad. In both Rockland and Wheatfen Broads the species can be described as being occasional. No specimens were collected in Surlingham Broad which has a thick silty bottom with dense algal mats. Surlingham Broad is in serious decline as an open water because of the accumulation of silts into mud flats which are exposed at both medium and low tides. A single mussel was collected from Surlingham Dyke. This had been eaten and only the stumps of the adductor muscles remained.

Whilst the numbers collected between Whitlingham Marshes and Cantley represented 14% of the total unionids dredged, the numbers within the area where *Pseudanodonta complanata* are to be found gave a value of 15% of the total unionid catch. In the Fleet Dyke the numbers were of the order of 11% of the total catch. Both dredging and hand searching by subaqua-diving gave similar values. On 8th November 1996 a dramatic drop in the water levels of Rockland Broad resulted in most of the Short Dyke being exposed. *Pseudanodonta complanata* made up 10% of the unionids present in the dyke, although in Rockland Broad itself it was absent. *Anodonta anatina* was the dominant species in the broad. In the current study no accurate estimates of the density of the mussel were obtained, but Negus (1966) gave estimated densities of $0.4m^{-2}$ in the River Thames at Reading.

In the Yare system the largest numbers of mussels were collected near the edges of the reed beds and adjacent to the older boat mooring stages. The number declined in areas of dense tree cover, usually sallows, and where steel sheet or timber piling form the river banks. At Postwick the banks formed from flints also supported reduced densities. This irregular distribution is probably linked to the nature of the river beds, current velocities, and to the fact that it is in reed beds that some fish species congregate to breed and thus provide maximum opportunities for glochidia to attach themselves. Where there are ronds colonized in front of the piling by reeds then the mussels are unaffected but where piling is directly onto the river then the ecological balance is adversely affected. The Short Dyke to Rockland Broad has reed on one side and piling on the other and this offers a sharp contrast in suitability for freshwater creatures.

A study of the distribution across the River Yare between the Surlingham and Strumpshaw banks showed that *Pseuadanodonta complanata* occurs in depths to 2.7m. (Figure 2).



Pseudanodonta complanata on beds with sediment deposited. Numerous to 2.7m.
Unio pictorum density highest in shallow water, *Anodonta anatina* in deeper water.

Figure 2. Cross-section of the River Yare showing the distribution of unionids

The largest numbers were collected from the Surlingham bends where current velocities are lower and where silt is deposited. Consequently the river bed shelves less dramatically on this bank. In contrast fewer mussels were collected on the Strumpshaw bank where the profile falls sharply and where little silt is deposited. The river bed on this side shows clay lump, presumably from banking work. No unionids were dredged in mid-river where the depths approached 4.5 metres.

Stone *et al.* (1982) found the greatest unionid biomasses in Budworth Mere, Cheshire, are found in depths below 1 metre in sandy regions clear of macrophytes. At depths greater than 3 metres unionids are rare. Their study, however, did not include *Pseudanodonta complanata* but the study by Rands (1986) in the River Great Ouse shows that the species favours deep clear water. Benthem Jutting (1959) noted that most Dutch rivers are lowland rivers of high silt-mud content where *Pseudanodonta complanata* is found in mud in quieter parts of the meanders of rivers.

Down river of the Beauchamp Arms the limit of mussel distribution is probably related to the degree of saline incursions into the river which are known to cause serious damage to the ecology of normally freshwater reaches. Cantley represents the normal limit of saline incursion on the surface but no data are available for the saline wedge on the mud surface beneath the freshwater.

The chloride levels in the Yare river valley were investigated in 1993. Chloride levels were estimated using the Mohr method whereby chromate ions are unable to form silver chromate in the presence of free chloride ions. The data showed very high levels at Breydon Water and decreasing levels to Reedham Ferry. Above Reedham Ferry there were minimal changes in chloride levels. The concentrations at five stations in the Wheatfen Broad complex ranged from 80 to 84mg/l Cl^- and were found to be similar to those noted in the adjacent river. These data were collected on the top of the flowing tide and at a time of very high flow of land water. Summer 1995 levels on the silt surface at Wheatfen recorded levels of 230mg/l Cl^- at times of low river freshwater flow resulting from prolonged summer drought.

Table 1. Salinity levels in the River Yare surface waters of the spring flooding tide; 10th December 1993

TG 475-060	Top end of Breydon Water	8600mg/l Cl^-
TG 465-040	Berney Arms	3400mg/l Cl^-
TG 458-043	Ravenhall	2100mg/l Cl^-
TG 460-043	Wickhampton Marsh	1800mg/l Cl^-
TG 453-034	Six Mile House	960mg/l Cl^-
TG 446-028	Upper Seven Mile House	360mg/l Cl^-
TG 408-016	Reedham Ferry	108mg/l Cl^-
TG 380-033	Cantley	80mg/l Cl^-
TG 350-043	Beauchamp Arms	76mg/l Cl^-
TG 329-056	Wheatfen Broad	84mg/l Cl^-

The standing crop of mussels in the Yare system represent a large amount of energy of no immediate value to the trophic level above. The food value of this standing crop will become available only after the mussels have died since they appear to have few natural predators. The mussels have comparatively long lives so there is an accumulation of stored energy over several years. Negus (1966) showed that the standing crop of mussels in the River Thames, excluding shells, represents more than 90% of the biomass of the bottom fauna and is twice that of the fish populations.

The size-frequency data for unionids cannot be relied upon to illustrate year groups. Figure 3 represents the size-frequency data for August 1996 from specimens collected in the River Yare. These data exclude immature specimens because of the mesh size of the nets used in the survey. Annual growth rings are more accurate. Growth is thought not to occur in winter and is greatest in the first three to four years. Dr John Reynolds, University of East Anglia, has initiated studies of shell growth and the development of annual rings from marked mussels in both the New Bedford River and the Fleet Dyke at Rockland Broad.

Breeding continues from late summer until spring when the glochidia held within the mussels are released.

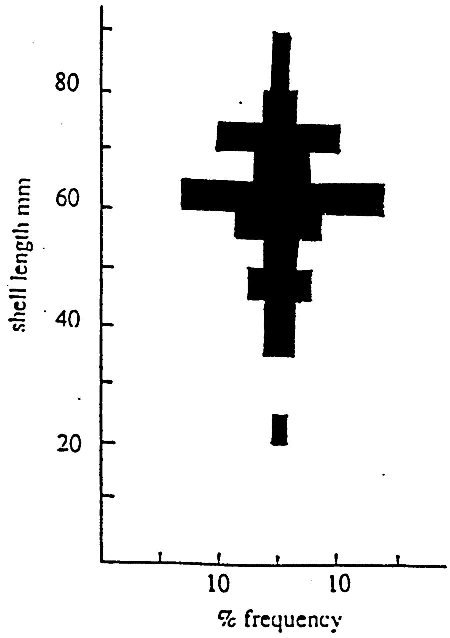


Figure 3.

% Size-frequency data for *Pseudanodonta complanata* in the River Yare: August 1996

Factors influencing distribution of *Pseudanodonta complanata* in the Yare

Fish Migration

In unionids embryos are developed on the gill filaments and these hatch into minute free swimming larvae called glochidia. These clamp onto fish where they develop as tiny blisters in the skin, usually the fins, where they live as minor parasites for several weeks before undergoing histolysis and leaving as tiny mussels. The presence of healthy fish populations is essential for the survival of the mussel. All species of European mussel favour cyprinid fish as hosts.

The recent colonization of Rockland and Wheatfen Broads and the discovery of *Pseudanodonta complanata* in the River Waveney at Beccles is probably linked to the glochidial stage of the life cycle on fish. Glochidia represent the major free moving phase of the life cycle on unionid mussels and the spread of the species beyond its immediate habitat sites. In the River Yare the increasingly salinity of the water below Cantley probably acts to prevent fish vectors carrying larvae into the Rivers Chet, Bure, Ant and Waveney systems. It is possible, however, that at low tides with minimal water movement that saline levels are low enough for fish and attached larvae to enter the River Chet. Breydon Water with its essentially saline water acts as an effective barrier to the major broadland rivers in facilitating the spread of the mussel. Some fish species move from saline to freshwater sites, e.g. the salt water flounder is now found in large numbers in the surface silts of Wheatfen Broad (Ellis, 1955; Baker, pers. observation 1995) and is thus able, in principle, to carry glochidia throughout the broadland system. Knowledge of fish migratory patterns in broadland and the influence of chloride in the water on glochidia would be beneficial to an understanding of the distribution of the mussel in Norfolk and Suffolk.

Water quality

Water quality is known to be an important factor in maintaining healthy populations of freshwater mussels. Wheatfen Nature Reserve lies on the River Yare 14km below Norwich. In the immediate post-war period the water quality in Wheatfen Broad underwent a grave deterioration. The waters became turbid and the many aquatic macrophytes disappeared. This was accompanied by a loss of invertebrates associated with the freshwater plants and by a loss of fish and the bird life dependent upon the fish as food. A similar pattern was apparent in other Yare broads and the river itself. The unionid populations were in sharp decline during this period (Howlett, pers. observation).

The outfall at Whitlingham Sewage Treatment Works is 10km upriver from Wheatfen. Since the new sewage works improvements were commissioned in November 1991 there has been an improvement in water quality at Wheatfen. A comparison of the 24 months after commissioning (summer 1992 to summer 1994) with the period studied by Ives (summer 1987 to summer 1989) was used to monitor changes which may have taken place in the five year interval, and these are summarised here from Clarke & Ives (1996).

Ammonia

In the two year period studied by Ives, before the Whitlingham improvements came into use, the mean value for ammonia at Coldham Hall was 315µg/l nitrogen. The figure for the period 1992-1994 was 87µg/l.N. The effluent standard at Whitlingham was 40mg/l of nitrogen in ammonia before the standard was reduced to 7mg/l in 1992 by the National Rivers Authority (now Environment Agency). The new works have been able to meet this dramatic lowering of the consent and in fact they have achieved a standard of only 1mg/l ammonia.

The mean value of ammonia nitrogen at Buckenham was almost the same as Coldham Hall in 1992-94. Ives found that the mean ammonia value fell from 406.62μg/l to 281.48μg/l between Coldham Hall and Buckenham Ferry in the earlier period. The present lack of difference between Coldham Hall and Buckenham could be taken to indicate, perhaps, that the current ammonia nitrogen level is incapable of further reduction by natural means in the river.

Nitrate etc

Total oxidised nitrogen TON, which is predominantly nitrates, reduced only slightly as the water passed downstream in the earlier period (2.9% drop). The situation is the same today. There is in fact a slight increase. Overall the TON value has decreased at Coldham Hall by 0.04% since the improvements were made at Whitlingham and increased by 4% at Buckenham Ferry. Whitlingham does not include a nitrate removal phase. A high proportion of oxidised nitrogen in the lower Yare is derived from agricultural run-off (Edwards, 1971).

Phosphorus

Ives found that phosphorus values remained unchanged as the water passed down river from Coldham Hall to Buckenham Ferry. This is still so today. Values have reduced by 8% and 12% at the two sites.

Mercury

It is now two decades since mercury was discharged into the river so meaningful analyses of its uptake by the mussels cannot be made. However, methyl and dimethyl mercury remain at low levels in the Yare valley surface muds and stable mercuric sulphide in the deeper river bed sediments. Studies on the flesh of the four unionid species in the Yare for mercury would provide some insights into its uptake by benthic animals even two decades after the curtailment of the pollution.

Turbidity

While chemical changes in the river water quality following the improvements at Whitlingham would be evident relatively quickly, the desired changes in biology might be much slower. One such change is the turbidity of the water. Turbidity at Wheatfen and in the Coldham Hall-Buckenham reaches of the river is a complex phenomenon. It is derived in part from land run-off, in part from the Whitlingham effluent, in part from phytoplankton growing in the water and in part from the sediment moving into the reaches from the lower estuary. The Whitlingham effluent consent standard has been lowered in 1992 by the National Rivers Authority from 50mg/l to 40mg/l (total dissolved solids). In actual fact the works achieve their own standard of 20mg/l. The improvement in quality might have affected the mobility of sediments within the area.

Whatever the cause there has been a dramatic improvement in the turbidity of the river water. At Coldham Hall there has been a steady reduction to less than half the turbidity at the beginning of the period. At Buckenham, where the influence of lower estuary imports of turbidity is more marked, the results are not so consistent but even here there has been a distinct reduction. From August 1992 until January 1993 the turbidity at Buckenham Ferry was in excess of 19FTU, the upper limit of reporting. From October 1993 until August 1995 it only exceeded 10 FTU on three occasions. (Clarke & Ives, 1996).

Algae

Counts of planktonic algae were carried out for various reasons at irregular intervals from the end of 1990. The data are shown in Table 2.

The bulk of the algae in these peaks was centric diatoms. Evidently there has been no dramatic reduction of the numbers of planktonic algae present in the Wheatfen waters. The summer peaks were usually *Skeletonema subsalsum* (Cleve-Euler) Bethge. (Clarke & Baker, 1995).

Table 2. Maximum counts of the number of algal cells per ml

	Spring	Summer	Autumn
1991	16,900		<20
1992	8,400	13,616	93
1993			132
1994		5,283	13,419
1995	350	2,569	80
1996	5,306		

Summary of water quality

The apparent improvements in water quality at Wheatfen have been borne out by chemical results. These improvements had already been noted by the National Rivers Authority in respect to the River Yare. The greatest changes have been the reduction in turbidity and a drop in ammonia which are having an affect on aquatic plants and animals. The lack of change in the diatom populations is not really surprising when one looks at the nutrient situation. There is no radical change in the availability of nutrients, nitrogen, phosphorus and silica as a result of the improvements at Whitlingham Sewage Treatment Works. There is a change in the form of nitrogen present in the river, a considerable lowering of ammonia levels. These have fallen so as to reduce their toxicity to invertebrates but not so much as to deprive diatoms of nutrients. There has nowhere been any sign that ammonia levels sank so low to restrict diatom growth. In any case many diatoms are capable of using nitrate as a nitrogen source.

Water mites

Unionicola intermedia (Koen), identified as both nymphs and adults from *Pseudanodonta complanata* in Fleet Dyke, Rockland Broad, September 1997 (det. Dr R.K.H. Jones). The only other record from *Pseudanodonta complanata* is by Hever (1975) at Kiel, Germany where the mites were observed attached to the gills.

Unionicola ypsilophora (Bonz.). Recorded previously at Potter Heigham by Soar 1905. This mite is known only from *Anodonta cygnea*. Four adults (1 & 3) collected from two *Pseudanodonta complanata* (det Dr R.K.H. Jones). First record for this mite in a mussel species other than *Anodonta cygnea*. Jeffreys (1862) observed that in *Anodonta* this species of mite is so tenacious of life that it can survive boiling water sufficient to kill the swan mussel.

Unionicola crassipes (Müller) was noted living within freshwater sponges encrusting the shells near the siphon exits from mussels collected in the River Great Ouse in May 1997. (det. Dr R. Hamond).

River Waveney

Mussels

Trawls of the River Waveney from Flixton Marsh down river from the Fleet to Beccles, to include the first hundred metres of Oulton Broad Dyke. The river was dredged on the Norfolk side on the ebbing tide and the Suffolk side on the flooding tide. Total river distance surveyed was approximately 13.5km. The dredge run was normally for 100m of the river.

Table 3. River Waveney: October 1996

TM 501-941	Oulton Dyke to junction with River Waveney	1 live mussel
TM 498-941	Burgh Marshes	1 dead
TM 494-928	Share Mill	1 live
TM 466-912	Cove Staithe	1 live: 1 dead
TM 438-928	Disused railway bridge	1 live
TM 424-923	Hill Farm-Gillingham Marshes	3 live
TM 423-916	Ditto	1 dead

The Oulton Broad Dyke and the River Waveney from Flixton Marshes to Burgh Marshes have a peat bed whilst the river from Share Mill to Beccles is of a fine silt. In some stretches where sallow trees overhang the river the dredge filled with willow leaves and abundant fingers of river sponge. It is possible that in these reaches this surface litter prevented the dredge probes from sifting the muds to dig out the mussels. However, earlier studies in the River Yare indicate that the mussel is rarely found beneath sallow tree cover even when leaf litter is minimal.

Two shells collected near the Gillingham Marshes were at the maximum size for the species (90mm & 84mm) and at first glance appeared to be *Anodonta anatina* except that they were slender when viewed end-on. They were confirmed as *Pseudanodonta complanata* from their hinge and muscle characteristics.

The evidence from this survey confirms the observation of Killeen (1992) that the species occurs in the River Waveney below Beccles but only in small numbers. The river is far less productive of unionids than the River Yare. A total of only 74 live unionids was collected in this survey. The swan mussel *Anodonta cygnea* has been reported by Killeen (1992) below Beccles but only very old shells were dredged in the current study and no live specimens were obtained. The sub-fossil swan mussels were numerous in some reaches of the river such that their presence is indicative of a once healthy population.

Water quality

Until the completion of the Waveney Parishes Scheme, the sewage from Beccles was discharged untreated into dykes on the Beccles Marshes and was then pumped from these into the river by a pump just upstream of the old Stanley Carrs Railway Bridge. This must have caused considerable pollution of the river.

The new sewage works in Marsh Lane, Worlingham gives full treatment to the sewage from Beccles and a number of other parishes. It has adopted a similar system for disposal of the effluent, that is, it goes into the system of marsh dykes to the east of Worlingham Wall and is finally pumped into the river a few hundred metres upstream of the Long Dam Pump. The outfall is situated at TM 458-912.

The consent conditions for the sewage treatment works are fairly lax in view of this discharge into the dykes rather than the main river. It allows a maximum suspended solids content of 55 mg/l, a BOD of 40 and an ammonia content of 20 mg/l. These values are met by the works, their worst output has only been about half of the consent figures. A study by Chris Adams of the Environmental Agency has shown that a great improvement takes place in the marsh dykes, but at the expense of the flora and fauna of these dykes.

The post-war period led to a great increase in sewage delivered to the Beccles Marsh Dykes and the discharge from the Railway Bridge Pump must have killed off much of the bottom-living fauna of the river.

Algal numbers were very small in a series of samples taken along the river from Burgh St Peters to Beccles.

It has been suggested that to improve the quality of the marsh dykes the sewage works should discharge directly into the river by a pipeline costing in excess of one million pounds. The present system in which dyke water is pumped to the river gives a good effluent, apart from it being low in oxygen and high in chlorides. But it is pumped into the river at a high rate when pumping becomes necessary due to rainfall. A new outfall would put water into the river at a steady rate and the discharge consent could be made strict enough by the Environment Agency to minimise the damaging effect of the new outfall. It would appear that the choice is between improvement of the marsh dykes and the protection of this stretch of the River Waveney.

Oulton Broad and Dyke

Salinity

Oulton Broad is in contact with the sea by means of a lock at the Wherry Hotel. It also connects with the River Waveney by means of a navigable dyke 1.5 km long, the Oulton Dyke. The lock fails to prevent seawater seepage. The River Waveney is tidal and this means that the ebb water flows from the Broad and mixes with landwater from the Waveney. The "mixing zone" is usually in the Oulton Dyke at high water and above Burgh St Peter on the River Waveney. Seawater coming from Breydon Water has an effect on the Waveney as far as Somerleyton. Table 4.

Table 4. Showing the chloride levels in Oulton Broad, Oulton Dyke & River Waveney. May 1997

TM 521-928	Near lock Wherry Hotel, Oulton Broad	900 mg/l Cl^-
TM 517-924	Broadlands Holiday Centre	350 mg/l Cl^-
TM 513-926	Opposite Ivy Farm	230 mg/l Cl^-
TM 508-927	Entrance to Broad	200 mg/l Cl^-
TM 506-927	End of Broad	230 mg/l Cl^-
TM 501-929	Bend of Oulton Dyke	240 mg/l Cl^-
TM 501-936	Halfway along Oulton Dyke	230 mg/l Cl^-
TM 501-943	R. Waveney at Dyke end	240 mg/l Cl^-
TM 493-958	By Wicker Well Sluice	250 mg/l Cl^-
TM 475-967	Somerleyton Bridge	300 mg/l Cl^-
TM 465-976	Herringfleet Mill	420 mg/l Cl^-

The chloride levels in Oulton Dyke are similar to those noted at Wheatfen and Rockland Broad during occasional tidal surges and at times of low freshwater outflow. The River Yare levels are at the maxima of the distribution of the *Pseudanodonta complanata* in the broadland river system.

Phytoplankton

Oulton Broad is rich in phytoplankton, many being brackish water species. These get washed into Oulton Dyke which has a similar phytoplankton community. The Dyke has a retention period of between 40-50 days so the plankton remain in the system long enough to allow substantial populations of algae to build up and to provide ample food for the filter-feeding mussels. In contrast the River Waveney has a less rich phytoplankton population. The different densities of unionid mussels in the two systems, although linked, is probably a reflection of the plankton generated in the broad and not in the river.

In Oulton Dyke only small numbers of centric diatoms were present. At the Dyke bend (TM 501-929) there were 45 cells/ml *Thalassiosira* sp. and 90 cells/ml *Skeletonema subsalsum*. Halfway along the Oulton Dyke numbers were slightly higher being 265 cells/ml *Thalassiosira* and 317 cells/ml *Skeletonmea subsalsum*. Both these species normally live in slightly brackish water.

Mussels

Between the River Waveney at its junction with Oulton Dyke and Oulton Broad *Pseudanodonta complanata* is relatively plentiful. It represents 6% of the unionid population sampled (n = 277). At the Oulton Broad end the mussel numbers decrease. They are most plentiful in the reaches leading to the junction with the River Waveney. The banks are lined with reed and reed sweet grass. There are few overhanging trees. The dyke bed is of silt and peat.

Anodonta anatina is a very common mussel in Oulton Dyke where it represents 72% of the unionid population. A few specimens were collected in the thick silts of Oulton Broad. Oulton Dyke is a good habitat for *Unio pictorum* where it represents 22% of the total unionid population. Many of the shells of both mussel species were covered with thick mats of bryozoa and up to 30 small Zebra mussel shells representing last year s spat. To date no Zebra mussels have been found at any site attached to *Pseudanodonta complanata*. This may be an indication of the relative exposure of the shells of the different unionid species in the peats and silts of the river beds.

Analyses of the gut contents of four specimens of *Pseudanodonta complanata* taken from Oulton Dyke near the junction with the River Waveney contained a dark mass of mud particles and diatoms of the genus *Thalassiosira;* the species will be determined later from prepared slides. The absence of mud diatoms is surprising.

River Bure and associated Broads

Pseudanodonta complanata is absent from the freshwaters of the River Bure between Thurne Mouth 395-152 and Coltishall 280-196. Downstream of the Thurne Mouth the River Bure is brackish from the tidal ebb and flow of sea water from Yarmouth.

The river and associated broads showed healthy populations of the swan mussel, especially so in the river and broads above Wroxham. This mussel is reported as living between 50 and 100 years yet the large specimens found in Belaugh Broad which was mud-pumped in 1988-89 suggest that this is an overestimate. *Anodonta anatina* is a common mussel of the river, whilst *Unio pictorum* is present in very low numbers in both the river and broads.

Table 5. Counts of planktonic algae in the River Bure; November 1st 1996

Locality	Hall Fen	Wroxham Church	Grange Farm
Map reference	TG 323-158	TG 295-175	TG 285-188
Stephanodiscus hantzschii	9450	134	39
Asterionella formosa	895	0	0
Scenedesmus quadricauda	537	90	178
Cryptomonas sp.	0	45	0
Navicula tripunctata	0	45	0
Nizschia acicularis	0	0	5

The absence of bryozoa samples from above Wroxham Bridge is interesting. About Wroxham Bridge there is a sudden change in the clarity of the water, the turbidity between there and the head of the estuary at Coltishall is very much lower. From Table 5 it will be seen that only about 1% of the food available at Hall Fen was available above Wroxham Bridge.

River Ant

No specimens of *Pseudanodonta complanata* were collected between the junction with the River Bure and Barton Broad. At Irstead the river bottom is of sandy gravels with small pockets of silt. The lower reaches of the River Ant are very silty.

Anodonta anatina is a common mussel of the River Ant. The only previous record from How Hill (Paul Cobb, 1968) is *Anodonta cygnea* (L.) which, if in the river, is probably a misidentification for *A. anatina*.

River Thurne and associated Broads

No specimens of *Pseudanodonta complanata* were collected from the River Thurne, Hickling Broad, Horsey Mere or Martham Broad. There are no previous records for the species from the River Thurne and its associated broads.

The River Thurne and the associated broads occasionally receive saline waters from the tidal ebb and flow from Great Yarmouth along the lower reaches of the River Bure. They mostly receive saline water from pumped waters from the coastal grazing marshes in the Waxham area. The levels are of the order of 2500mg/l Cl^- at Horsey Mere where water is pumped from the Waxham Dyke into the broad. Hickling Broad and Heigham Sound also retain relatively high chloride levels. Salinity is probably the causal factor in preventing the mussel from colonizing these northern broads and river.

The peat beds of Hickling Broad are compacted and little silt forms in the navigation channels. This may limit mussel digging and available food. However, *Pseudanodonta complanata* has been found in compacted peats at other sites in Broadland so this is probably not a major limiting factor.

Arthur Mayfield noted the presence of *Unio pictorum* in the Thurne Stream and Heigham Sound in 1909. In the current survey two dead shells of *Unio pictorum* and four shells of *Anodonta anatina* were dredged from Heigham Sound. Only two healthy living specimens were collected from

River Thurne near Thurne Mill TG 398-163. All unionids were absent from river near Womack Water.

Ormesby Broad complex

Pseudanodonta complanata is absent from the Ormesby Broad complex of landlocked waters. *Anodonta cygnea* is the dominant unionid species with healthy specimens reaching 143mm. *Unio pictorum* is rare.

Fenland rivers and drains

River Great Ouse - Little Ouse & Wissey

In west Norfolk *Pseudanodonta complanata* has only been found once previously in the River Great Ouse at Hilgay - the reach between Willow Farm and the Great West Fen TL 599-977 (Preece and Wilmot, 1979). The authors report that the river at this point has depths of between 3-4 metres with a bottom composed of very fluid silty-clay material. The river is slow-flowing with an estimated water velocity of the order of $15cmsec^{-1}$, although occasionally this may rise to $1msec^{-1}$. The Great Ouse and its tributaries drain the Chalk and Chalky Boulder Clay and this is reflected in the mean calcium concentration of the water (153mg/l Ca) and mean alkalinity (224mg/l $CaCO_3$). Preece and Wilmot note that during very low flow conditions some saline intrusion occurs at Denver Sluice, although the molluscan assemblage shows no evidence of this reaching as far upstream as Hilgay. Measurements in May 1997 during the current survey showed that the river was all freshwater with chloride levels of 72 mg/l Cl^-. There was no evidence of seawater penetration.

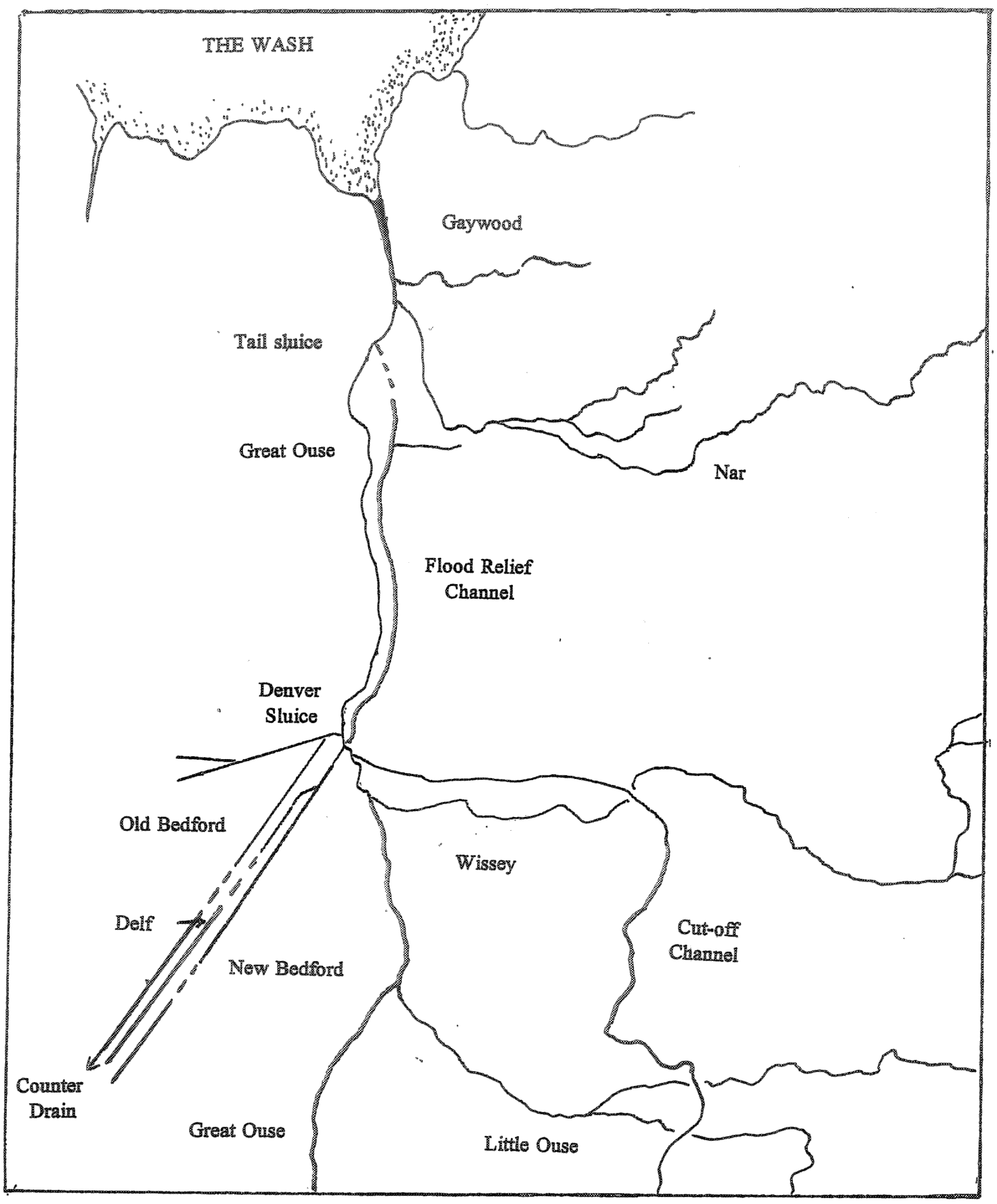
The River Great Ouse is an artificially banked river with steep vertical sides held in place with asbestos piling sheets. The water depths near the margins are of the order of 1 metre and this allows marginal aquatics to form stable plant communities. Common species include reed, reed sweet-grass, reedmace, bulrush and yellow water lilies.

The planktonic diatom *Stephanodiscus* increased gradually seaward from 5,500 cells/ml at Plantation Farm, 12,000 cells/ml at Horse Fen Farm and 13,000 cells/ml at Ten Mile Bank. In the River Little Ouse at its confluence with the River Great Ouse the levels were 6,200 cells/ml. The surface scum collected at Ten Mile Bank was full of bryozoan statoblasts. The bryozoan species *Paludicella articulata* (Ehrenberg) was recorded.

In the current survey *Pseudanodonta complanata* was recorded along the length of the River Great Ouse in Norfolk. The numbers are small but this may reflect the problems associated with using a dredge armed with metal probes through beds of reed and water lilies where it rapidly becomes snagged in the rhizomes. Successful dredging in the waters immediately beyond the marginal vegetation at depths of 1 metre succeeded in significant catches being taken. Evidence of relative densities within the marginal communities will be achieved only when the river banks are repaired and major river dredging allows examination of the spoil heaps on the banks. Alternatively these margins could be examined using subaqua-diving techniques.

Figure 4. Distribution of *Pseudanodonta complanata* in Fenland; October 1997.

Key — Living mussels; - - - - Dead mussels



The Ted Ellis Trust
Wheatfen Broad, Norfolk

Pseudanodonta complanata was noted at Horse Fen Farm (TL 610-923); Willow Farm (TL 595-982) and along the reach near the junction with the River Wissey (TL 610-923). At the latter site the river bed was dredged at a depth between 1- 2 metres in silts and muds. A total of 44 unionids were collected in a single trawl: *Pseudanodonta complanata* (5 specimens), *Anodonta anatina* (36) and *Unio pictorum* (3). The Depressed Mussel represented 8% of the total catch. Elsewhere occasional specimens of *Unio tumidus* were collected in the trawls.

The numbers of unionids in the deeper waters of the river were very small. At Ten Mile Bridge (TL 601-965) only a single specimen of *Unio pictorum* was collected at a depth of 6 metres. The evidence from this survey indicated that unionid populations are restricted to the shallower parts of the rivers in depths less than 2 metres, although occasional specimens may be found at greater depths.

Associated mollusca

These have been described from the Hilgay reach of the Great Ouse by Preece and Wilmot (1979). In the current survey the unionids *Anodonta anatina* (L.), *Unio pictorum* (L.) and *Unio tumidus* Philipsson were recorded. The river is rich in the Zebra Mussel *Dreissena polymorpha* (Pallas), *Sphaerium corneum* (L.), *Bithynia tentaculata* (L.) and *Viviparus viviparus* (L.). Occasional specimens of *Acroloxus lacustris* (Müller) and *Theodoxus fluviatilis* (L.) were also noted.

River Little Ouse

Samples taken along Brandon Creek between TL 608-910 and TL 613-908 indicated very low numbers of *Anodonta anatina, Unio pictorum* and *Unio tumidus. Viviparus viviparus, Bithynia tentaculata* and *Sphaerium corneum* were all abundant. Killeen (1992) records all three species from the River Little Ouse but notes that shells collected by E.B. Rands at Hockwold cum Wilton (TL 725-868) in May 1988 were on the Norfolk bank. *Unio tumidus* remains unrecorded from Suffolk. The current survey discoveries in the River Little Ouse are from the Norfolk-Cambridgeshire border.

River Wissey

No unionids were noted in the River Wissey below Hilgay. The river is choked with algal mats of *Cladophora* and Canadian Pondweed *Elodea canadensis*. Snails noted included *Bithynia tentaculata, Lymnaea auricularia* and *Potamopyrgus jenkinsi*. The algal mats were full of small bivalves. The absence of unionid species may reflect the difficulties encountered in dredging through dense vegetation for mussels. It may prove more successful to re-examine this river in the winter when vegetative die-back has occurred.

A comparison of the River Wissey with the River Great Ouse data from Preece and Wilmot in 1979 shows that in both rivers the molluscan fauna is very rich in both species and numbers. On the River Great Ouse the 1997 survey focused on unionid species such that smaller species were only incidentally noted and are thus under-represented. On the River Wissey the focus remained on the dredging of unionids but in this river the thick algal masses brought up by the dredge were retained for examination later. Data from 1997 Hilgay (TL 610-985) and 1996 from the sugar beet factory (TL 665-977) are given in Table 6.

Table 6. Mollusca in Rivers Great Ouse and Wissey in the parish of Hilgay, Norfolk

	Great Ouse		Wissey	
	1979	1997	1997	1996
Viviparus viviparus (L.)	+	+	+	
Valvata cristata (Müller)	+		+	+
Valvata piscinalis (Müller)	+		+	+
Theodoxus fluviatilis (L.)		+	+	
Potamopyrgus jenkinsi (Smith)	+	+	+	+
Marstoniopsis scholltzi (Schmidt)	+			
Bithynia tentaculata (L.)	+	+	+	+
Bithynia leachii (Sheppard)	+	+	+	+
Physa fontinalis (L.)	+		+	+
Lymnaea truncatula (Müller)	+			
Lymnaea palustris (Müller)	+			
Lymnaea stagnalis (L.)	+			+
Lymnaea peregra (Müller)	+		+	
Lymnaea auricularia (L.)	+	+	+	+
Anisus vortex (L.)	+		+	+
Planorbis carinatus Müller	+			
Planorbarius corneus (L.)	+			
Planorbis planorbis (L.)			+	+
Bathyomphalus contortus (L.)	+			+
Gyraulus albus (Müller)	+		+	+
Armiger crista (L.)	+		+	+
Hippeutis complanatus (L.)	+		+	+
Ancylus fluviatilis Müller	+			
Ferrissia wautieri (Mirolli)	+			
Acroloxus lacustris (L.)	+	+	+	+
Unio tumidus Philipsson	+	+		
Unio pictorum (L.)		+	+	
Anodonta cygnea (L.)	+			
Anodonta anatina (L.)	+	+		+
Pseudanodonta complanata (Ross.)	+	+		
Sphaerium corneum (L.)	+	+	+	+
Pisidium amnicum (Müller)	+		+	+
Pisidium casertanum (Poli)	+		+	+
Pisidium subtruncatum Malm	+		+	
Pisidium henslowanum (Sheppard)	+		+	+
Pisidium nitidum Jenyns	+		+	+
Pisidium pulchellum Jenyns	+			
Pisidium milium Held			+	
Pisidium moitessieranum Paladilhe	+			
Dreissena polymorpha Pallas	+	+		

Cut-off channel; Fen flood relief scheme

The Cut-off Channel is a man made waterway completed in the early 1960 s as part of an integrated fen flood relief scheme for Norfolk and Cambridgeshire. The channel joins with the River Great Ouse at Denver Sluice. In the sections near Fordham and West Dereham the bottom is composed of coarse, pebbly, quartz sands (Sandringham Sands) with dense aquatic mats of the thread alga *Cladophora glomerata* and Canadian Pondweed *Elodea canadensis*. Near Methwold and Feltwell the channel cuts through chalky substrata and the bed is made up of fine silts with little aquatic vegetation. On the county border at Hockwold cum Wilton the channel is dominated by *Potamogeton luscens* L. , *Elodea canadensis* and other aquatics. There is little water flow through the system.

Pseudanodonta complanata was collected in the fine chalky silts at Brookville near Methwold (TL 717-960). This is the first record of the species from the channel and is of value in providing some indication of the speed of colonization and spread of the mussel since its construction. The specimen was 30mm long. Further dredging trawls of the channel are necessary to provide a fuller picture of the distribution and size range of the species. At Blackdyke Farm, Feltwell. TL 69-88 is the intake pumping site for water to be transferred through pipes to Suffolk and Essex. The weed and surface silts are drag-line dredged annually to prevent clogging of the intakes and problems associated with decaying weeds in the late autumn. The clearance is for about 1km either side of the intake. The channel at this site has been cut through chalk; it is 4m deep with aquatics and blanket weed near the sides; chalk silt bottom. Examination of the spoil in September 1997 showed that *Pseudanodonta complanata* is irregularly distributed along the channel. It appears that favoured habitats may be between 100 and 150m apart. It can be described as being rare and unevenly distributed along the dyke. The major part of the Channel towards Denver Sluices has irregular weed cutting and removal of debris by boats.

Associated mollusca

Anodonta cygnea.	Brookville; Methwold TL 717-960. Rare
Anodonta anatina.	Feltwell TL 699-904; Brookville, Methwold TL 717-960; West Dereham TL 655997, Fordham TL 613994. Common at all these sites. Absent at Hockwold cum Wilton.
Unio pictorum..	Feltwell TL 699-904; West Dereham TL 655997; Fordham TL 613-994. Occasional.
Unio tumidus.	Feltwell TL 699-904; West Dereham TL 655-997; Fordham TL 613994. Occasional.
Dreissena polymorpha.	Fordham TL 613-994. Rare.
Pisidium subtruncatum	Hockwold cum Wilton TL 725-875. Occasional; Fordham TL 613-994, Common attached to algal threads.
Pisidium nitidum.	West Dereham TL 655-997; Fordham TL 613-994. Common attached to algal threads.
Pisidium milium.	West Dereham TL 655997; Fordham TL 613-994. Common attached to algal threads.

Gastropods noted included *Lymnaea stagnalis* (Hockwold, West Dereham): *Lymnaea auricularia* (Hockwold, Brookville): *Viviparus viviparus* (West Dereham, Fordham): *Bithynia tentaculata*

(Hockwold, Fordham): *Physa fontinalis* (Hockwold, West Dereham): *Valvata piscinalis* (Hockwold): *Gyraulis albus* (Hockwold): *Planorbis planorbis* (Hockwold): *Anisus vortex* (Fordham): *Planorbis carinatus* (Hockwold).

Flood relief channel

Below Denver Sluice a flood relief channel was built in the early 1960 s to King s Lynn. It carries water at times of high run-off from Denver to the tidal Great Ouse at King s Lynn. Flow is controlled by an inlet sluice at Denver and a tail sluice at King s Lynn The channel is 10km long and 80m wide. The depth is normally between 2-3m (Environment Agency: pers. comm.), although in October 1997 the depths had fallen to between 1m and 1.5m. The margins are either reed-fringed or have piling, often constructed from tyres. The channel bottom is mainly of fine silt with reed debris. *Pseudanodonta complanata* occurs in small numbers in the channel. In October 1997 major mortalities amongst unionid mussels were noted. The water was tepid since there had been no flushing movement because of the extreme summer drought. Measurement of chloride levels by the Environment Agency show summer concentrations of 150mg/l Cl^- whilst those taken during the October survey gave levels of 300mg/l Cl^- near Magdalen road bridge, about midway along the channel. These levels indicate that there is some contamination by brackish water from the estuary, presumably through the tail sluice. Oxygen levels for August were between 150-200% and for September between 70-80%. Chlorophyll *a* readings for August gave values of 8 microgrammes/l and for September 15 microgrammes/l. These were at the surface. (Data kindly supplied by Environment Agency).

The trawling evidence from early October 1997 indicated that the mortality amongst the unionid mussels, *Pseudanodonta complanata, Anodonta cygnea, Unio Pictorum* and *Unio tumidus,* is a recent event. A possible explanation may be found from a similar situation at the lock at Oulton Broad in Suffolk. There may be some leaking back through the sluices at certain times from pressure by the tidal waters of the Ouse. The lack of flow and flushing in the channel would then result in a saline layer lying beneath the freshwater on the bottom silts. Plant material in the silts decompose using up the oxygen from the saline layer. The mussels then die-off. Evidence to support this hypothesis comes from the low phytoplankton counts in the surface waters. The planktonic diatoms fall into the saline layer where they are effectively retained. There is no lifting into the upper layers and they are effectively trapped. This would explain the low Chlorophyll *a* counts noted for August and September.

Various diatom habitats were sampled on stones, water plants and bridge piers as well as the plankton. Trawls were also made with a zooplankton net. Prepared slides were examined by the Diatom Group of the University of East Anglia. The data are shown in Table 7. The most important diatom in the phytoplankton is *Actinocyclus normanii* for *subsalsum.* This diatom is known by Keith Clarke in such numbers only from Barton Broad, Alton Water and the west London reservoirs of Thames Valley. All are large bodies of water. It is surprising to find it in what might be regarded as a river channel. However, the retention time is probably high and the fetch of southerly or northerly winds is 10km. Numerically a very small centric diatom (diameter 5μm) is also important. Because of lack of detail it cannot be identified with the light microscope and will have to await identification by the scanning electron microscope.

A survey some years ago of the distribution of *Cyclostephanos dubius* in Norfolk found this diatom absent from the Fens. It was shown to be dependent upon having a water body of sufficient size. This is provided by the Flood Relief Channel and several specimens were identified.

The presence of *Amphora veneta* at the tail sluice indicates brackish influence. A better indicator was the discovery at the University of East Anglia Diatom Group meeting by Michael Jackson of *Raphoneis amphiceros* which is confined to brackish water.

Table 7. Diatoms in Flood Relief Channel: Denver to King's Lynn. October 3rd 1997

Species	plankton	stones Tail sluice	Elodea	Myrioph yllum	Reed	Benthos OLS	Bridge
Achanthes hungarica			1		1		
Acanthes lanceolata							1
Achanthes minutissima						13	
Actinocyclus normanii	14						
Amphora copulata						1	1
Amphora veneta		1	1				
Aulacoseira granulata	1						
Cocconeis placentula	2		72	76	34	12	
Cocconeis pediculus			1				1
Cyclostepanos dubius	3						
Cyclotella sp.	58					2	
Cyclotella atomus		1	5	2			
Cyclotella meneghiniana	11	2	4	2		5	
Diatoma elongatum			1	1		2	
Fallacia pygmaea		1					
Fragillaria construens			1				
Fragillaris vaucheri	1						
Gomphonema parvalum					1		
Gomphonema truncatum							4
Melosira varians						2	
Navicula capitata	2						
Navicula capitatoradiata				1		5	
Navicula cari				1			
Navicula cryptocephala						4	22
Navicula cryptotenella					2		
Navicula gregaria		19		5		20	
Navicula meniscula				1		3	
Navicula mutica							1
Navicula pelliculosa			1				
Navicula radiosa		4				5	
Navicula rhynchocephala						1	
Navicula tripunctata		6	5	4	4		61
Navicula veneta	1	1				4	
Nitzschia achibaldii	1						5
Nitzschia acicularis							
Nitzschia amphibia							
Nitzschia dissipata							2
Nitzschia gracilis						6	
Nitzschia inconspicua							2
Nitzschia microcephala	1	29				3	
Nitzschia palea		27		2		3	
Nitzschia recta						6	
Nitzschia sigmoidea		1					
Rhoicosphenis abbreviata	4		2	5	57	1	
Stephanodiscus parvus	1		2				
S. hantzschii fo tenuis			2		1		
Surirella brebissonii		4				1	
Synedra ulna						1	
Tabularia tabulata			2				
Tryblionella hungariaca		4					
Check sum	100	100	100	100	100	100	100

The chief epiphyte was *Cocconeis placentula*. No plants were found with a growth of *Achnanthes minutissima*. This suggests that grazing by gastropods, which would differentially remove the *Achnanthes* fustules, is relatively heavy. The stones, mud and piers provide ideal habitats for the genus *Navicula*. 16 taxa occurred at 1% or more but other taxa were present. The bridge piers gave *Navicula tripunctata, N. cryptotenella* and *N. mutica*. A closer study of all the *Navicula* species in the Flood Relief Channel is being undertaken

New Bedford River; Hundred Foot Drain

The New Bedford River is 32km long and connects directly with the tidal River Great Ouse near Denver Sluice. The drain often has high levels of suspended sediments which normally settle on the outside of bends in the system. Dredging until ten years ago was on a regular 8-10 yearly basis but is now carried out on a "needs" basis as and when silts accumulate in the drains. This flexible strategy is probably beneficial for *Pseudanodonta complanata*.

The tidal flow at Mepal is of the order of 16 cumecs. There is some evidence of occasional saline incursions as far as Earith. This is usually associated with low river flow and high spring tides. It has been observed (Environment Agency) that the tidal waters form a "plug" as they flow in from the Wash and that this plug reaches upstream as far as Welney. These observation indicated that there is little or no stratification of freshwaters and salts waters in the system. If this is an accurate observation then it would be useful to have a detailed study of the tidal flow/ebb in the New Bedford River. Environment Agency data show conductivity levels rarely 2000µS/cm at Welney. Duckweeds are a problem in reducing oxygen levels in the system of drains and rivers.; sometimes levels fall to between 12% and zero.

Dr John Reynolds University of East Anglia (pers. comm.) has found healthy *Pseudanodonta complanata* populations near Mepal TL 44-81 at the Earith end of the New Bedford River. Chloride levels are normally low in this section. The mussels are on a clay bed with some gravel. Silt levels are low. Depths range between 2-3m. Water level range about 1.5m. Dr Reynolds has marked 87 mussels for growth studies. Collection has been by subaqua diving and hand sorting. The density noted is of the order of $2m^{-2}$. This represents about 10% of the unionid population in the site. The maximum size noted was 70mm, which shows a smaller-shelled mussel than the 90mm specimens from both the Waveney and Yare rivers.

Counter Drain (Welney Marshes)

Examination of over 7km of dredged spoil in August 1997 confirmed the irregular distribution of *Pseudanodonta complanata* along what is a uniform man-made waterway. Weeds are cut annually and in some sections a weed rake is used from the banks; in effect a shallow dredge which can scrape the silt/mud bottom. Essentially the Counter Drain is a freshwater drain which picks up water from the higher lands around Earith. At the pumping station for Block Fen the marine clays provide sulphide and sulphate ions which, following the irregular pumping, reduce the pH to between 5-6. This can seriously affect the acidity levels in the Counter Drain and Old Bedford River. Pumping is irregular and dependent upon rainfall conditions etc prevailing at the time. Levels of ammonia in the pumped water also fluctuate.

Old Bedford River - River Delph

These linked rivers have slow flowing freshwater which pick up lots of silts. The sluice gates at Earith control flooding. The water depths range from 1-1.2m. Aquatic weeds are cut annually. Weed raking from bank can remove silts - carried out about 2-3 years. At the seaward end the waters at Salters Loke Sluice are monitored such that conductivity levels rarely exceed

1500μS/cm in the system. *Pseudanodonta complanata* is present along these reaches, although evidence from dredged spoil banks show that the distribution is irregular and sparse.

Dredging

We have scant knowledge of how, if at all, *Pseudanodonta complanata* is affected by commercial dredging and mud-pumping. In the mid-Yare the unionid mussels survived the major dredging programmes of the river before ships stopped coming to the Port of Norwich in the late 1980 s. Today one can foresee the need to dredge the reach below the sewage outfall near Postwick where a glutinous mud is settling but this will cause few problems for mussels which are few in number in this mud.

The navigable dykes leading to the broads are still infrequently dredged for tourist and local boats but there is little evidence on how this affects mussel populations. A monitoring programme for Rockland Dyke is described later in this report and it is hoped that this will provide data for guiding future dredging work in the system.

Rockland Broad, Wheatfen Broad, Surlingham Broad, and the basins/broads linked to the Yare at Brundall are in need of long term dredging or mud-pumping. The open waters at Wheatfen Broad in 1959 were described as, " the bottom is everywhere an inoffensive mud which dries out locally only on exceptionally low tides". This situation changed rapidly such that by the 1980 s at low water much of the mud surface became exposed and in time this became compacted and devoid of life. Silt deposition in the reserve amounted to about 1cm per year. Wheatfen Broad was mud-pumped by the Broads Authority in 1994 and now has deep tidal waters with many mussels present. These are all recolonizers from populations elsewhere in the reserve and from Rockland Broad. Wheatfen Broad is a comparatively small area to mud-pump and its smallness readily allows species to invade the open waters. The basins and broads of Brundall, when dredged, should show a similar pattern of recolonization.

Rockland Broad is showing much of the infilling of its open waters by sediments noted earlier at Wheatfen. The depth of water is decreasing and exposed muds will inevitably form. Already this is having a serious effect on the unionid populations. The costs and questions of toxicity of the muds will mean that this will be a major project to restore, even if phased over many years. Surlingham Broad has deteriorated such that it is questionable whether it is now worthy of restoration.

In the River Waveney and Oulton Dyke there are infrequent dredging programmes. In Oulton Dyke the evidence indicates that numbers of *Pseudanodonta complanata* are not seriously affected over the years by the work. In the Waveney the numbers are low which may be the result of dredging or pollution or saline incursions or the fact that this represents an outpost for the species in the broadland system. It may be a combination of some or all of these factors.

In the Fens dredging is not a major problem. For instance the Fen Relief Channel built over thirty years ago has yet to be dredged. Dredging programmes are now related to a needs basis and are used at specific sites on an infrequent timescale. This should benefit the mussel populations in these rivers, channels and drains. The problem in the fens is one related to growth and removal of aquatic weeds. Drag-line techniques to remove the weeds do collect mussels. Examination of spoil banks, mainly of decaying mats of algae and macrophytes, along 11km of the Ouse Washes (TL 495-892 to TL 437-813) in February 1996 shows that the numbers removed are large and irregularly distributed (Table 8). Of the 2319 shells collected, 1159 (50%) were living mussels. There was a high mortality amongst juvenile *Anodonta* sp.

Table 8. Showing the numbers of unionid mussels removed by drag-line methods along 11km of the Ouse Washes (Old and New Bedford Rivers) February 1996

Pseudanodonta complanata	8
Anodonta cygnea	621
Anodonta anatina	1282
Unio pictorum	406
Unio tumidus	2

It would be of value to link future drag-line collections with prior subaqua-diving of undisturbed populations to gain some clear indication of how damaging the technique is. One suspects from the evidence above that the method will prove to be detrimental to mussels but hard evidence would be useful.

Rockland Broad; Broads Authority dredging programme 1997

Rockland Broad

Rockland Broad is connected to the River Yare by two regularly dredged channels - the Fleet Dyke to the north and the Short Dyke to the south. Dredging of these dykes is to a standard depth of 2m at low water leaving a firm bottom of mud, peat or a mixture of these, and occasionally sandy gravel in parts of Short Dyke.

Rockland Dyke

This is a short dyke of approximately 500m leading to the staithe or boat basin at Rockland St Mary. The dyke is subject to tidal fluctuations. It receives freshwater from Hellington Beck at its distal end. The Beck is a small stream which collects water from a catchment area of $15km^2$ of arable farmland and from parts of the villages of Rockland St Mary, Bramerton, Yelverton and Poringland. Once Hellington Beck flowed directly through the Claxton Levels (as Claxton Fleet) into the River Yare below the Short Dyke. The Claxton Marshes are now drained and lie below the level of both Rockland Broad and the river. Hellington Beck was redirected to flow into a raised dyke which opens into Rockland Dyke through a tidal flap. This prevents the flow of water back into the Beck during flood tides, the stream waters damming up behind the flap to a maximum stage of 0.6m when an overspill route allows flow into the dyke system of Claxton Marshes. The water flow in the Beck occurs two hours after high water and three hours before the next high water. The flow velocity has been measured as $0.1msec^{-1}$. Discharge decreased from 0.187 cumecs to 0.065 cumecs. The discharge rate is low and probably not significant in the overall hydrology of Rockland Broad (Darby 1982). However, the hydrology of the whole system is such that interference from high flows from Hellington Beck and from north-easterly winds, which can cause ponding up of water in the southern part of the Broad, can directly affect the movement of water in and out of Rockland Dyke.

Dredging programme

In the current programme the Broads Authority intend dredging out the silts and peats of Rockland Dyke which is a navigation channel. The aim is to dredge the whole width of the dyke to the banks or pilings. This will necessitate the removal of moored boats from the staithe and banks. The timing of the programme is dependent upon analysis of mercury levels in the silts. These are extremely low and unlikely to cause any pollution problems.

Ecological programme

Twenty years ago this dyke had no mussel populations but recent changes in water quality have encouraged the colonization of this and other adjacent waters. *Pseudanodonta complanata* has been shown to live in Rockland Dyke together with *Anodonta anatina* and *Unio pictorum.*

Before the dredging programme began it was agreed that the Ted Ellis Trust would systematically trawl Rockland Dyke to collect as many mussels as possible. These would be replanted in either Wheatfen Broad or the Fleet/Short Dykes. The clearing of mussels from the dyke provides an opportunity to monitor the recolonization of the dyke. *Pseudanodonta complanata* is known to live in the Fen Channel at Wheatfen Broad, in the Fleet Dyke and in the Short Dyke. It has not to date been discovered in the broad itself. Since fish, the host of the glochidial larval stage of the mussel, move freely throughout the system then recolonization could occur quickly. This study has the attraction of providing direct data on the effects of dredging and recolonization.

The Ted Ellis Trust speculate that mussels may aggregate beneath the hulls of the moored boats since disturbance from the passing holiday boats is minimal and fish often gather in the same sites. The mussels require close proximity to fish for larval transfer so any habitats where aggregations occur may be significant. A detailed examination of muds from one or two of the moorings may provide some further insights into the microdistribution of *Pseudanodonta complanata*. However, it is recognised that at very low tides the boats in Rockland Dyke settle directly onto the mud and thus may counteract the speculated benefits of the moored habitats.

Survey data

On March 1st 1997 an extremely low tide exposed the dyke bed near the staithe. A total of 60 mussels (54 *Anodonta anatina*, 3 *Unio pictorum* and 3 *Pseudanodonta complanata*) were hand netted from the bank and replanted in the Short Dyke.

On March 7th 1997 Rockland Dyke was trawled. The dredge was trawled for 100 metre lengths between seven and eight times along the dyke from bank to bank. A total of 220 mussels were collected. *Anodonta anatina* (193) dominated the community, whilst there were 19 specimens of *Unio pictorum* and 8 of *Pseudanodonta complanata.* In the River Yare the percentage of *Pseudanodonta complanata* in the unionid populations is between 14-15%, whilst in the Rockland Dyke this is much lower at 5%. The sizes ranged between 52mm and 70mm. No small specimens were collected because of the mesh size used in the dredge. However, small specimens of both *Anodonta anatina* and *Unio pictorum* were occasionally found caught in the litter debris.

Numbers of *Pseudanodonta complanata* remain low in this dyke. They were found in the silted reach near Rockland Broad, in the sandy-gravelly reach nearer the staithe and in the staithe basin silts.

Pseudanodonta complanata was replanted in the Fen Channel near Dove Passage in the Wheatfen Broad Nature Reserve. This is a channel leading from Wheatfen Broad and its associated dykes and fens into Rockland Broad. It is a channel with relatively fast flowing tidal waters, a peaty-silted bottom and where the beds are often exposed at low spring tides. This is the site where the mussel was first recorded in the Reserve in 1994.

Anodonta anatina and *Unio pictorum* were replanted in Deep Waters in the Wheatfen tidal complex. This is a small broad which was mud-pumped by the Broads Authority in 1994. Both species have been collected from Deep Waters in the recent past.

Rockland Dyke appears to be an unsuitable habitat for other molluscs. In the sandy-gravelled reaches near the dyke banks numerous specimens of the Horny Orb Mussel *Sphaerium corneum* (L.) were collected and a single specimen of the River Pea Mussel *Pisidium amnicum* (Müller) The prosobranch snails *Bithynia tentaculata* (L.) and *Viviparus contec*tus (Millet) were occasionally noted. A single living specimen of *Lymnaea auricularia* (L.) was collected.

In May 1998, Rockland Dyke was trawled again. The 80 mussels caught included 65 *Anodonta anatina*, one *A. cygnea* three *Unio pictorum* and 11 *Pseudanodonta complanata*. The percentage of *Pseudanodonta complanata* was 14% compared to 5% in the previous year. When both year's data are combined, this species represents about 7% of the mussels in the dyke; although smaller than their proportion in the river (15%), it is still a significant population. It was estimated that about 70% of the mussels collected in 1998 would have fallen through the mesh of the trawl in the previous year, so the 1998 specimens represent mainly a growing population. The mussels were replanted in the Fen Channel.

Outcomes

The Broads Authority dredging programme will begin some time in 1998, having been delayed because of toxic mercury levels in the silts. The spoil will be examined for young specimens. It is anticipated that monitoring of Rockland Dyke will continue for a number of years to provide a picture of colonization rates following dredging. This will provide data in guiding future dredging programmes and will hopefully part answer questions relating to management procedures and economic viability in conserving the mussel.

Conclusions and recommendations

The current survey shows that *Pseudanodonta complanata* has two major strongholds in Norfolk: the southern rivers of the Yare and Waveney and the fenland Great Ouse with its associated channels and drains. The species, given suitable conditions of water quality and food, has extended its range in both areas, especially into the man-made channels and dykes of the fens.

Water quality is a factor in the maintenance of healthy mussel populations. The evidence from the River Yare shows that *Pseudanodonta complanata* can withstand adverse levels of pollution over many decades but, given improved water quality, it can rapidly build up its densities and extend its distribution. In contrast the water quality of the River Waveney indicates less optimal levels for the mussel. The fen rivers, channels and drains are less directly affected by sewage. Here the issues are associated with water extraction, saline incursions, oxygen depletion and irregular flushing timetables.

Salinity is a factor restricting the distribution of the mussel. In the Norfolk Broads the limits are effectively set by Breydon Water, although some seepage through the Oulton locks does directly affect the species in Oulton Broad. In the fens the system is man-managed by sluices and this results in a more complex problem relating to the control of water levels and water extraction.

During the current survey the death of so many unionid mussels in the Flood Relief Channel suggested that there is leakage of brackish water through the tail sluice which causes a chemocline at the bottom of the channel. We recommend that a conductivity survey be undertaken to provide data relevant to the maintenance of water levels, flushing procedures, oxygen depletion and healthy mussel populations.

Related to this survey, an investigation of salt water penetration into the fen drainage system, especially the occurrence of a "plug" of salt water in the New Bedford River should be undertaken. Conductivity measurements should be linked to diatom collections to give an idea of the eutrophication status of the river and indicate whether there is a turbidity maximum associated with the upstream face of the "plug".

Dredging in all Norfolk rivers, channels and drains has recently been made dependent upon "needs basis" analyses. A consequence of this is that there will be minimal disturbance of mussel populations, although the detailed study of Rockland Short Dyke should provide some hard evidence on this issue. Drag-line procedures aimed at removing weeds from fenland channels and drains does appear, from the current survey, to have a detrimental effect on unionids. This requires more detailed examination. There is a complex balance between weed regulation, decomposition of the weeds, oxygen depletion and mussel numbers.

Research on the animal itself should focus on population dynamics, age-frequency analyses, age determination data, energy flow both at the population and ecosystem levels and colonization rates.

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