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The impacts of dredging and weed cutting on a population of freshwater mussels (Bivalvia: Unionidae)

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Abstract

Regulated lowland rivers generally require management to control macrophytic vegetation and sediment build-up. Such management can have deleterious effects on much of the biota. It has long been a concern that indiscriminant river management has played a part in the world-wide decline in freshwater mussel populations. This study investigated the impact of dredging and weed-cutting on the population size, structure and distribution of four species of unionid mussel: *Anodonta anatina, A. cygnea, Unio pictorum* and *U. tumidus*. Dredging removed between 3% (*A. anatina*) and 23% (*A. cygnea*) of the mussel population. The weed bucket removed a maximum of 3% of any species, but its higher frequency of use results in removing a similar number of mussels to dredging in the long-term. Marked stones placed in the river during dredging suggest that the excavator drags mussels across the river bed. This is supported by the relatively high density of mussels in the channel closest to the bank from which the excavator habitually operates. Tagged mussels moved only small distances following dredging (generally <15 cm after 55 days) and showed no tendency to disperse. The impact of river management on unionid populations can be reduced, while retaining its channel maintenance function, by dredging and weed cutting only within the centre of the channel. Marginal vegetation should be cut to 5 cm above the river bed using weed boats with an annual alternation between banks to preserve refugia of invertebrates and fish.
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1. Introduction

Many lowland rivers fulfil a number of varied roles, including drainage of surrounding farmland and as a recreational resource for angling and pleasure cruising. In such rivers the aquatic vegetation can reach such high densities during the summer that flow is seriously impeded (Swales, 1982) and drainage function is consequently reduced. In sites which experience highly variable discharges, impeded flow can increase the risk of 'flash' flooding (Hearne and Armitage, 1993). Anglers generally favour a moderate diversity and density of vegetation which can support a large and diverse population of fish. However, extreme densities of macrophytes are undesirable and sometimes 'swims' must be cut to provide weed-free areas for unobstructed angling (Monahan and Caffrey, 1996). Slowing of water flow by aquatic vegetation also increases the rate of deposition of fine particulate matter within the site, which reduces the depth of the channel, and can prevent access by boats. Boats are also affected by high densities of filamentous algae such as *Cladophora* spp. and submerged macrophytes, which can become entangled in the propellers.

It is, therefore, clear that if the growth of aquatic vegetation remains unchecked, the waterway can fail to perform its drainage and recreational functions effectively. Aquatic vegetation can be cut by hand, by mechanical devices on boats, or by a 'mowing bucket' mounted on a vehicle on the river bank (Darby and Thorne, 1995). Biological control of vegetation by grass carp (*Ctenopharyngodon idella*) has been used effectively in some sites (Stott, 1977), as have chemical herbicides (Monahan and Caffrey, 1996). Shading has been used to limit light availability and so reduce aquatic plant growth. This can be provided by the planting of trees, the use of polythene sheeting, or by increasing the turbidity of the water (Darby and Thorne, 1995).

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In relatively narrow channels silt accumulation is usually controlled by dredging with a bucket on a bankside vehicle. Wider water bodies must be dredged from a boat (Jonge et al., 1993; Darby and Thorne, 1995).

In riverine systems that serve as important economic resources, such as shipping channels in tidal freshwaters (Diaz, 1994), the river management regime (primarily dredging) takes little consideration of the impact on the local biota. Where an opportunity exists for conservation measures to be considered, however, few data are available to make informed management decisions. The method by which the channel is managed will not only affect the proportion of weed and sediment removed, but will affect the extent to which the whole ecosystem is disturbed, and, therefore, its recovery time. Woodin (1978, p. 274) states that "disturbance ... is a significant mortality source in many assemblages and thus, a community structuring force of importance". Of the few previous assessments of the disturbance caused by weed cutting, most have focused on the impact on fisheries (e.g. Swales, 1982; Garner, 1996). Where the effects on invertebrate communities have been studied, only those groups that are important in fish diet have been considered (e.g. Monahan and Caffrey, 1996).

In many British rivers, the spoil left on the bankside following dredging and weed cutting operations is littered with live unionid mussels (e.g Killeen et al., 1998) and this suggests that such management can have an important effect on the mussel population. Understanding these effects is extremely important for a number of reasons. First, unionid populations represent the largest part of the total biomass in many aquatic systems (Negus, 1966), filtering large volumes of water and sometimes modifying the phytoplankton community (Matteson, 1955). Secondly, the mussels' parasitic larval stage (glochidia) makes them important parasites of fish (Kat, 1984; Aldridge and Horne, 1998). Thirdly, river management may influence the distribution of mussels within the channel. Despite much research, few satisfactory explanations have been proposed for the determination of unionid spatial distributions. Indeed, Strayer et al. (1994) state that they "... seriously doubt whether it is worthwhile to focus on ... traditional habitat descriptors (water depth, current speed, sediment granulometry, etc.) ... in future studies of unionid ecology". Fourthly, mussel populations are declining internationally (Watters, 1994; White et al., 1996) and it is thought that habitat destruction is a major cause (Bogan, 1993). A fifth reason for studying the impact of management in lowland waterways is that they are the most important habitats for the depressed river mussel (*Pseudanodonta complanata*, Rossmässler). Eastern England holds one of the world's largest populations of this threatened unionid (Aldridge, McIvor and Müller, unpublished data) which is listed as a priority species for conservation on the UK Biodiversity Action Plan (BAP) (HMSO, 1995). Understanding and controlling both the direct and indirect effects of weed cutting and dredging on mussel populations may be of great conservation value to the entire ecosystem.

The long-term impact of river management regimes on unionid populations has never previously been assessed. This study considers not only the immediate impact of the management regime on a mussel population, but also the subsequent recovery of unionids and their recolonization of the dredged channel. In the light of these findings, possible changes in current river management practices are discussed which may minimise adverse effects on the unionid fauna.

2. Materials and methods

2.1. Study site

Studies were undertaken in Wicken Lode, Cambridgeshire, UK (National Grid Reference TL 563705 to TL 543697). This waterway flows through Wicken Fen National Nature Reserve c. 15 km north-east of the city of Cambridge. A detailed description of the site can be found in Aldridge (1999). Studies focused on the main channel of the Lode, a navigable waterway which receives input from the surrounding arable farmland and is 1.9 km long, 8–10 m wide and <1.5 m deep at any point. Detailed surveys throughout the channel show that profile, vegetation type, substrate and mussel distribution are relatively uniform (Aldridge, 1997).

2.2. Channel management

The channel management of Wicken Lode is undertaken by the Environment Agency and three techniques are used:

(a) Weed boats. Since 1992, weeds have been cut annually prior to June. This work is carried out by two weed cutting boats: one cuts the submerged vegetation to the channel bed with a fixed cutting arm held horizontally beneath the boat; the other cuts the marginal emergent macrophytes, primarily reeds (*Phragmites australis*), to the river bed with a hydraulic cutting arm (analogous to a heavy duty hedge trimmer), before gathering up the cut weeds on forks mounted on the front of the boat and dumping the weeds on the lode bank. Up until the 1980s, a similar autumnal cut was made, although in recent years this has been superseded by the Bradshaw bucket (see below). Prior to 1980, weeds were controlled in Wicken Lode by hand.

(b) Bradshaw bucket. Every autumn, the vegetation within the main channel is cut with a Bradshaw bucket. This device is 2.5 m wide, with elongate apertures 10 cm wide to enable water and small debris to fall through, and with cutting teeth on its leading edge. The bucket is mounted onto a mechanical excavator which works along the southern bank, cutting vegetation at the sediment-water interface in sweeps from the far to the near bank, and dumping the spoil and weed on the near bank.

(c) Dredging. Sediment within the main channel of Wicken Lode is dredged on a cycle of c. 10 years. In 1985, this was carried out from November, and in 1995 from March. In 1995, the dredge (an enclosed bucket, measuring c. 1 m in length, and mounted on a mechanical excavator) removed mud along the entire length of Wicken Lode's main channel, with the vehicle working down river in a standardised manner: the dredge bucket was placed into the sediment at the far (north) bank and drawn towards the near bank, where the bucket was turned upright to scoop up sediment. Three adjacent cross-channel dredges were taken from each point of the bank, and the spoil deposited on the near bank. The vehicle then moved a short distance along the bank and the procedure was repeated.

2.3. *Effects of dredging on channel characteristics*

Two sites were chosen in Wicken Lode's main channel to study the effects of dredging on the channel's profile. The sites were located far apart, so that variability in the effects of dredging on the channel might be identified. Cross-channel transects to measure depth were made one day prior to dredging and repeated at the same site at least 7 days afterwards, by which time the water levels had returned to pre-dredge levels.

2.4. *Assessment of mussel population*

The mussel population was surveyed in early March 1995, by hand sampling within four 1-m-wide cross-channel transects. The transects were located to account for the variation in microhabitat and mussel distributions within the channel. These data were supplemented by hand sampling within 37 random 0.25 m^2 quadrats within 1 m of the south bank and 27 quadrats within 1 m of the north bank. The species and maximum length of every mussel was noted. Hand sampling ensures all mussels >3 cm maximum length are removed (Aldridge, 1997).

2.5. *Bradshaw cutting*

During late August and early September 1994 a stretch of Wicken Lode's main channel was visually searched for mussels removed by the Bradshaw bucket. The study area was a 1200 m length of the south bank, where all spoil had been deposited.

Searching was carried out by zig-zagging along an approximately 5 m wide strip on the bank where cut vegetation had been discarded. In total, the 1200 m zone was searched visually along its length six times. Mussels were recorded only if they were alive, or the shells contained flesh. The species and maximum length of each individual was noted, before the mussel was returned to the Lode.

2.6. *Dredging*

Four areas of spoil (three 7 m-long and one 5 m-long) were sampled along the 1200 m stretch. Mussels were collected by systematically hand sampling through the entire depth of the mud. All zones were surveyed within 1 h of the mud's removal whilst the mud remained in its most 'liquid' state, which increased searching efficiency. Only live or freshly dead mussels were measured, before being returned to the Lode.

2.7. *Redistribution of mussels by dredging as revealed by marked stones*

Stones were chosen to assess the selectivity of the dredge because a large number of a suitable size and shape can be readily collected and marked; to have collected over 300 mussels and marked them such that they could readily be relocated would not have been feasible. A total of 336 stones was selected to match as closely as possible the size-frequency distribution of the mussel population in Wicken Lode.

Six sets of 56 stones were made up comprising similar size-frequency distributions. Enamel paint was sprayed on such that two sets were marked red, two green, and two yellow. In one site, 56 yellow stones were placed 0–1 m from the far bank (with respect to the dredger), 56 red stones in a 1-m-wide band in the centre of the channel, and 56 green stones at 0–1 m from the near (south) bank, each band being c. 3 m long. Stones were similarly distributed at the second site, except that the green and yellow stones were placed 1–2 m from their respective banks.

After the sites had been dredged, the adjacent spoil was searched by hand over a 7 m strip. Searching along 7 m ensured that sufficient spoil was sampled to be confident that all dredged stones had been found. The colours and lengths of the stones dredged out were noted. The sites within the channel were also thoroughly re-searched by hand to record any changes in the distribution of stones.

2.8. *Mussel movements*

In order to assess the ability of mussels to redistribute themselves and recolonize the channel following dredging , 50 recently dredged mussels were collected: 15 *Anodonta anatina* L., 10 *A. cygnea* L., 15 *Unio pictorum* L. and 10 *U. tumidus* Philipsson. Mussels were marked using a technique adapted from Englund and Heino (1994) which allows mussels to be followed without disturbance. A waterproof tag was affixed midway along a 20 cm piece of nylon fishing line. A polystyrene float was attached to one end and the other end was affixed to the posterior end of the mussel's shell using rapid-drying epoxy resin.

A 1×0.5 m quadrat was placed with its longest edge parallel to and 1.5 m from the south bank. The quadrat was subdivided into fifty 10×10 cm squares, into each of which a tagged mussel was placed, in a pattern described in the results. Once all mussels had been positioned, the quadrat was removed.

The positions of the mussels were surveyed after 4 and 55 days. The site was visited by snorkelling and the quadrat repositioned on permanent marker floats. By approaching from above, the sediment and the mussels were not disturbed.

3. Results

3.1. Effects of dredging on channel characteristics

The channel profile following dredging was very similar at the two transect sites (e.g. Fig. 1): the far bank shelved much more steeply than the near bank. The centre of the channel was lowered by about 30 cm to a depth of 120 cm at both sites and the 1.5 m of channel closest to the near bank remained undredged at both sites. On the far side, the mud was dredged to within 1.5 m of the bank at one site and 0.5 m at the other. The mean volume of mud removed per 1 m length of channel is estimated to be 1.29 ± 0.24 m^3 ($n = 2$ sites).

3.2. Initial distribution of mussels in the channel

The channel closest to the south bank contained the highest densities of mussels, predominantly *A. anatina* and *U. pictorum* (Fig. 2).

3.3. Bradshaw cutting

Within the 1200 m-long study zone, only 115 live and freshly dead mussels were collected from the bank. The fact that no mussels were retrieved on the last (6th) search suggests that most of the removed mussels had been found. Between 1 and 3% of the total population of each mussel species estimated to be present was removed by this operation (Table 1).

When the lengths of all mussel species are compared between those removed by the Bradshaw and those present within the Lode, it is apparent that the Bradshaw selectively removes larger sizes of mussels ($t = 5.532$, df= 369, $P < 0.0001$; Fig. 3). Because *A. cygnea* grows much larger than the other species (Aldridge, 1999), this results in a higher proportion of the *A. cygnea* being removed from the channel (Fig. 4), compared with *A. anatina* and *U. pictorum* [$\chi^2 = 12.882$, df= 2, $P < 0.005$; comparing the number of *A. anatina* ($n = 147$), *A. cygnea* ($n = 36$) and *U. pictorum* ($n = 51$) collected by hand in the Lode with the numbers removed from the Bradshaw ($n = 54, 36, 21$ respectively); expected values for *U. tumidus* and *P. complanata* were less than five and this precluded them from the analysis].

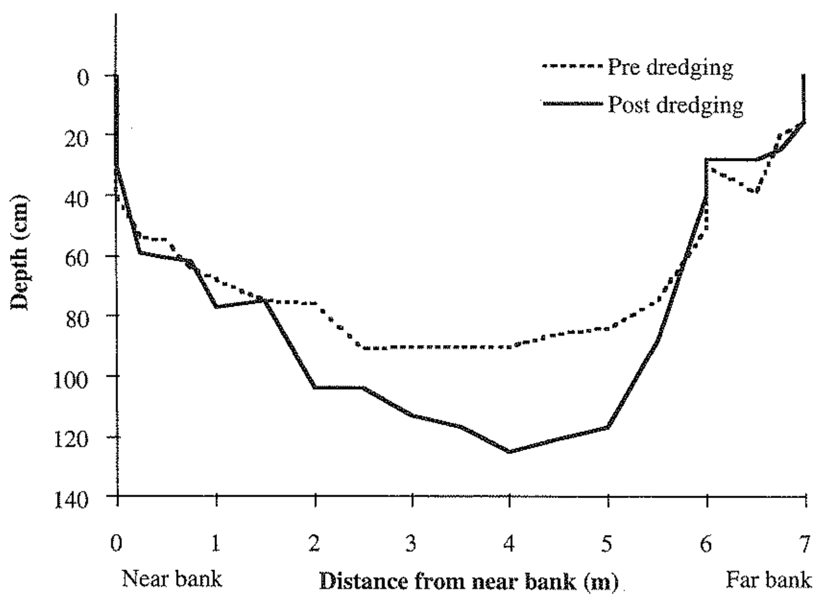

Fig. 1. Profile of the river bed at a representative site in Wicken Lode before and after dredging. The vertical scale is c. 3.5 times that of the horizontal.

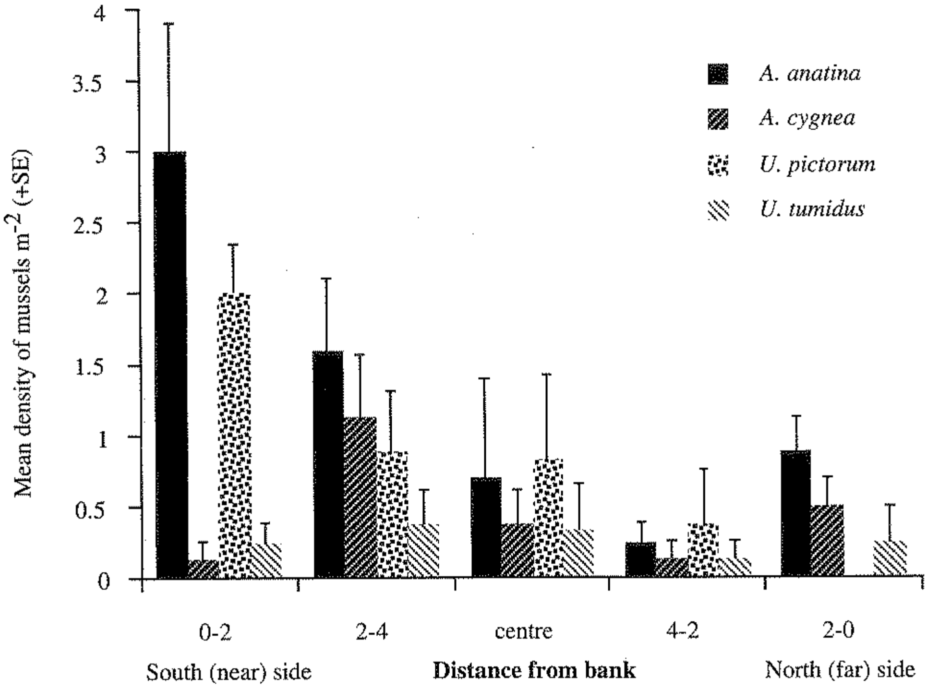

Fig. 2. The mean density of unionids across Wicken Lode.

Table 1
The number and proportion of mussels removed from 1200 m length of Wicken Lode as a result of weed cutting with a Bradshaw bucket

	Anodonta anatina	*Anodonta cygnea*	*Unio pictorum*	*Unio tumidus*	*Pseudanodonta complanata*
Estimated total present	5160	1320	1800	240	38
Number removed	54	36	20	4	1
% Removed	1%	3%	1%	2%	3%

A number of the live mussel shells, particularly of *A. cygnea,* collected from the bank were damaged. Small perch (*Perca fluviatilis*) and pike (*Esox lucius*) of c. 15 cm length were also found among the spoil.

3.4. Dredging

The water level dropped some 20 cm during the dredging work, while no change was seen during Bradshaw cutting. Perch, pike and eels (*Anguilla anguilla*) were removed by the dredge, and, because large quantities of mud and macrophytes were removed by dredging, the impact on small invertebrates was much greater. A greater proportion of the Lode's mussel population was removed by the dredge than by the Bradshaw bucket. However, dredging resulted in a lower proportion of damaged mussels in the spoil than did Bradshaw cutting.

The proportion of the mussel population estimated to have been removed from the Lode through dredging was 3–23% depending on species (Table 2), with *A. cygnea* and *U. tumidus*, which are relatively uncommon representatives of the population as a whole, preferentially selected ($\chi^2 = 23.905$, df= 3, $P < 0.001$; comparing the species of 153 mussels collected from dredged spoil in a general survey along the entire bank with 241 collected from the channel during hand sampling). However, there was difference in length between the mussels dredged out and those present in the Lode before dredging ($t = 0.728$, df= 406, $P = 0.467$; Fig. 3).

While dredging removes significantly more mussels than does Bradshaw cutting, the frequency of dredging is only once in 10 years compared with yearly for the Bradshaw. Over a 10 year period, the total numbers of mussels removed by both methods are estimated to be similar: in a 1000 m stretch of channel, I would estimate removal of 300 vs. 270 *A. cygnea*, 450 vs. 115 *A. anatina*, 170 vs. 115 *U. pictorum* and 30 vs. 38 *U. tumidus* by the Bradshaw and dredge respectively.

3.5. Redistribution of mussels by dredging as revealed by marked stones

At the first site, where yellow and green stones were placed 0–1 m from the far and near banks respectively, and red stones in the centre of the channel, only red

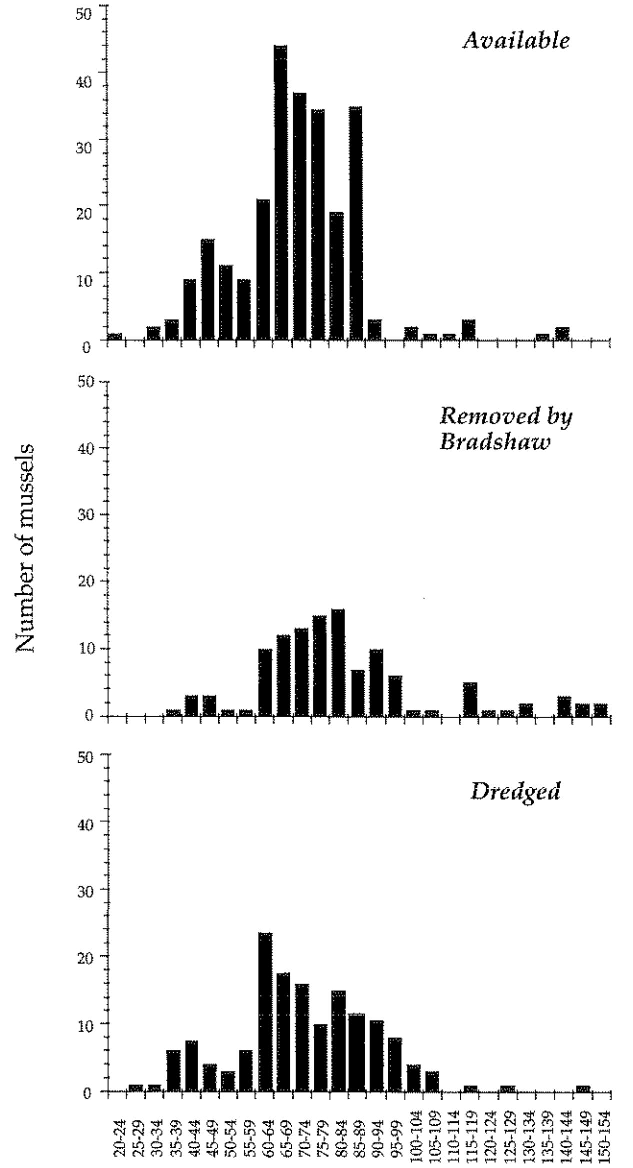

Fig. 3. Size-frequency distributions for the mussel population within Wicken Lode's main channel, the mussels removed by Bradshaw bucket, and mussels removed by dredging. Data are for all species combined. The distribution for 'available' mussels is from a subsample of the population.

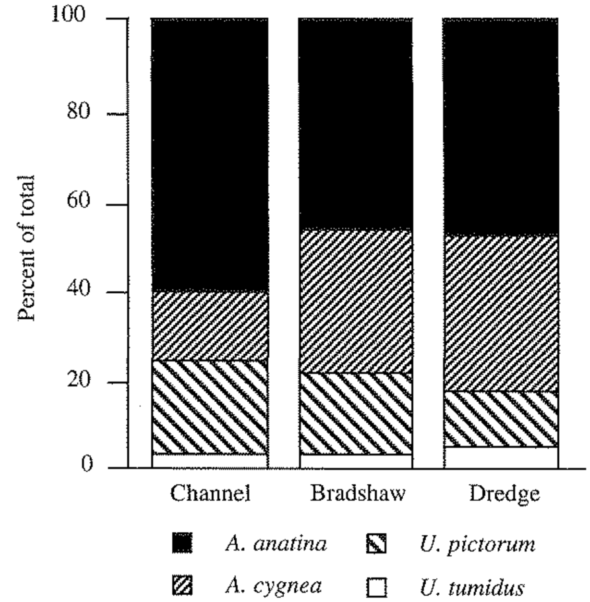

Fig. 4. Percent composition of mussels collected in spoil following Bradshaw cutting and dredging compared with the population in Wicken Lode's main channel.

Table 2
The proportion of mussels removed from a 26 m stretch of Wicken Lode as a result of dredging[a]

	Anodonta anatina	*Anodonta cygnea*	*Unio pictorum*	*Unio tumidus*
Total present	116	30	41	5
Number removed	3	7	3	1
% Removed	3%	23%	7%	20%

[a] Data are combined from four separate searches of spoil along the Lode bank.

stones were collected from the spoil, a total of 12 out of the 56 (21%) being recovered. At the second site, where stones were placed 1–2 m from the bank, only yellow stones, which originated at the far bank, were collected in the spoil, in this case 11 (20%) being recovered. The lengths of the 23 stones removed by dredging from the two sites were not significantly different from those of the 336 stones placed within the river (Mann-Whitney $U = 828.5$, $P = 0.2997$).

After dredging at the second site (from which yellow stones were removed) the channel was too deep to hand sample except within 2 m of the near bank. From this region, which initially contained only green stones, 20 green (out of 56), 3 red and 4 yellow stones were collected. The redistribution of the stones, which is schematically shown in Fig. 5, reflects the way in which the dredge transports material across the river bed.

3.6. Mussel movements

The tagging technique proved highly effective in allowing repeated identification of individual mussels: after 55 days 38 of the original 50 marked mussels were accounted for. Of the remaining 12 mussels, the tags of seven were found amongst vegetation, suggesting that the loss of marked mussels was due to the detachment of tags, rather than the mussels moving out of range. A wider area was searched for the remaining mussels, but none was located.

The distance moved by mussels was small (Fig. 6); *A. cygnea* and *U. tumidus* moved no further from their original positions after 55 days than they had after 4

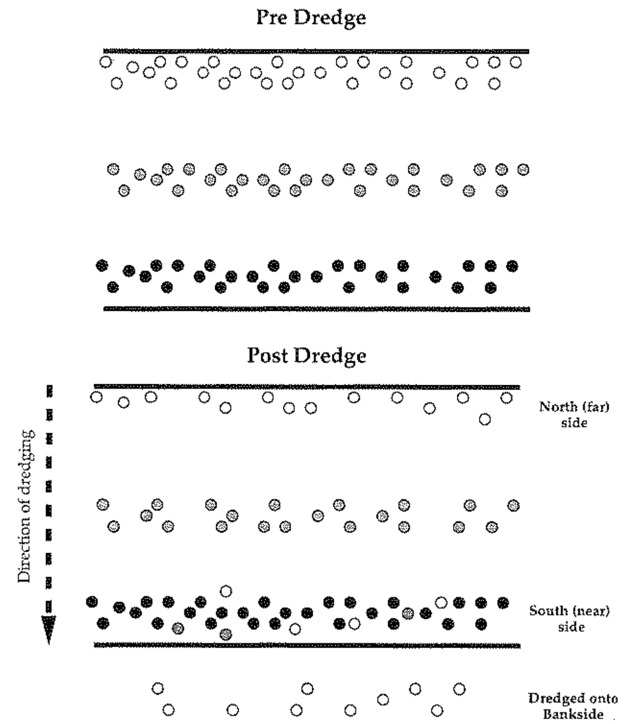

Fig. 5. Schematic diagram to illustrate the effect of dredging on the distribution of marked stones placed on the river bed in Wicken Lode's main channel. Because the far side and central channel were too deep to sample following dredging, the numbers of stones represented in the diagram are not quantitative. Open circles = yellow stones, grey circles = red stones, black circles = green stones.

days. There was much variation in the distance moved by each species and the distance moved by individuals was not related to mussel size (correlation coefficients for all species not significant). By the fourth day, there was no significant difference between species in the distance travelled ($H=6.166$, df = 3, $P=0.104$). However, by 55 days, there was an interspecific difference ($H=8.944$, df = 3, $P=0.030$), *U. pictorum* being the most mobile species (Fig. 6).

Although the mussels were initially placed at high density, there was no overall tendency to move away from other mussels (Fig. 7). Equal numbers of mussels (5 individuals) moved away from the near bank as moved towards it, although the three mussels which moved furthest from their initial site after 55 days were all located nearer to the centre of the channel, and slightly upriver from where they had started.

4. Discussion

4.1. Immediate impact

The immediate effects of dredging on the mussel population in Wicken Lode was dramatic: between 3 and 23% of the population, depending on species, was found in the spoil. While Bradshaw cutting removes only 1–3% of mussels, its cumulative effect over a 10 year cycle is to remove similar numbers to dredging. The lesser impact of Bradshaw cutting on the population per cut can be explained partly by its infrequent intrusion into the sediment where mussels reside. Indeed, most mussels removed by the Bradshaw were found adjacent to patches of removed mud, suggesting that the bucket had penetrated the sediment in these regions. Furthermore, some mussels were seen to drop back into the Lode through the apertures of the Bradshaw as the bucket was lifted from the water.

An additional effect of the Bradshaw bucket's apertures is selectively to remove larger mussels. This may partly explain why the Bradshaw removed a greater proportion of *A. cygnea* and *U. tumidus* compared with *A. anatina* and *U. pictorum* within the Lode; *A. cygnea* and *U. tumidus* attain the greatest lengths of the four mussel species (Aldridge, 1999) and, therefore, a lower proportion is likely to pass through the bucket apertures and back into the channel. However, a greater proportion of the *A. cygnea* and *U. tumidus* were also observed in spoil removed by the dredge, which was not size-selective.

The primary cause for species selectivity is likely to be the tendency of the Bradshaw and dredge to leave the marginal 0.5–1.0 m of the channel untouched. For dredging, this is confirmed by the transect studies and the finding that marked stones were not removed from the 0–1 m zones on either bank. Similarly, after cutting by the Bradshaw, a fringing stand of reed (*P. australis*) 0.5–1.0 m wide remained at each bank. Cross-channel surveys of the mussel population in Wicken Lode (Fig. 2) show that *A. cygnea* and *U. tumidus* are more evenly distributed across the entire channel than *A. anatina* and *U. pictorum*, which are more abundant in the marginal zone than in the centre of the channel. By removing only central sediments, dredging will most heavily affect *A. cygnea* and *U. tumidus*.

Dredging and weed cutting may have far-reaching effects on river communities. Monahan and Caffrey (1996) give an example where one million macroinvertebrates were estimated to be removed with each tonne of *Ranunculus* from the River Avon. Disturbance can also cause increased invertebrate drift (Statzner and Stechman, 1977, cited in Swales, 1982; Pearson and Jones, 1978) and lead to fish starvation (Garner et al., 1996). The large number of macroinvertebrates dredged from Wicken Lode may reduce the food resources available particularly to benthic-feeding fish, such as tench (*Tinca tinca*). This could be particularly important to the *Unio* spp. because their glochidia larvae may target benthic-foraging fish (Aldridge, 1997). Displacement of fish populations and disruption to recruitment will have the knock-on effect of reducing the number of

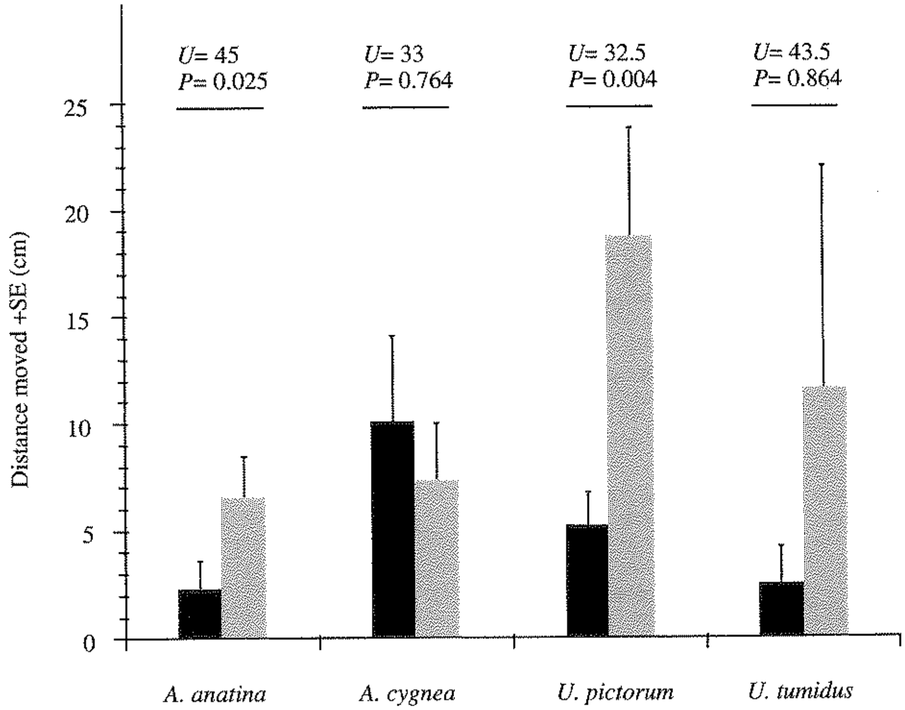

Fig. 6. The mean distance travelled by tagged mussels after dredging. Mann–Whitney U-tests compare the distance moved by each species at 4 (black) and 55 (grey) days. 'Distance moved' refers to the distance between the original site at which a mussel was introduced, and its location at 4 or 55 days afterwards.

potential host fish to which the mussels' glochidia must attach.

The direct action of weed cutting and dredging can seriously affect the fish populations. Machinery physically removes some species, and pike (*E. lucius*) have been found in Wicken Lode with severe gashes indicative of damage by weed cutters (D. Aldridge, personal observation). Swales (1982) found that the disturbance caused by weed cutting led to movement of fish out of the area, and Garner et al. (1996) showed that the removal of macrophytic refugia can cause young-of-the-year fish to be washed out of the system during heavy flows. The drop in water level during dredging in Wicken Lode, also observed by Hearne and Armitage (1993) during weed cutting of a stream in southern England, may expose fish eggs, such as those of roach, to desiccation.

The increased water turbidity associated with weed management, particularly dredging (Jonge et al., 1993; D. Aldridge, personal observation), is a relatively short-lived phenomenon. However, the effects on aquatic organisms can be catastrophic, causing interference with respiration and food collection (Diaz, 1994). Less mobile species and suspension feeders, such as unionid mussels, may be particularly affected (Burky, 1983). Layzer et al. (1993) implicate the subsequent silt deposition associated with turbidity as a major factor in the decline of mussels in the Tennessee River, with juveniles being most heavily affected.

4.2. Recovery of biota

In areas exposed to regular natural disturbance, such as tidal freshwaters, sediment disturbance by dredging may have little effect on the macrobenthos, with populations recovering within three weeks (Diaz, 1994). However, the time for the system to recover depends on the management practice used. For example, dredging as a method of weed control results in much slower recovery (two or three years) of the aquatic vegetation, compared with one year for other cutting methods (Darby and Thorne, 1995). This is because rhizomes and other reproductive parts of the plant below the bed surface are removed by dredging. Monahan and Caffrey (1996) found that a land-based 'Mowing Bucket', similar to a Bradshaw, produced the slowest natural recruitment of macroinvertebrates, while the herbicide dichlobenil did not alter the normal seasonal trends in macroinvertebrate numbers. Monahan and Caffrey conclude that "... in the interests of ecological sustainability ... mechanical cutting [should be] carefully controlled".

Fish and many macroinvertebrates within freshwater systems may recover relatively fast because of their motility, which enables both escape during the management regime and recolonization afterwards. It would be predicted that relatively immobile species, such as unionid mussels, would be less quick to recover. The slow redistribution rate of marked mussels after 55 days

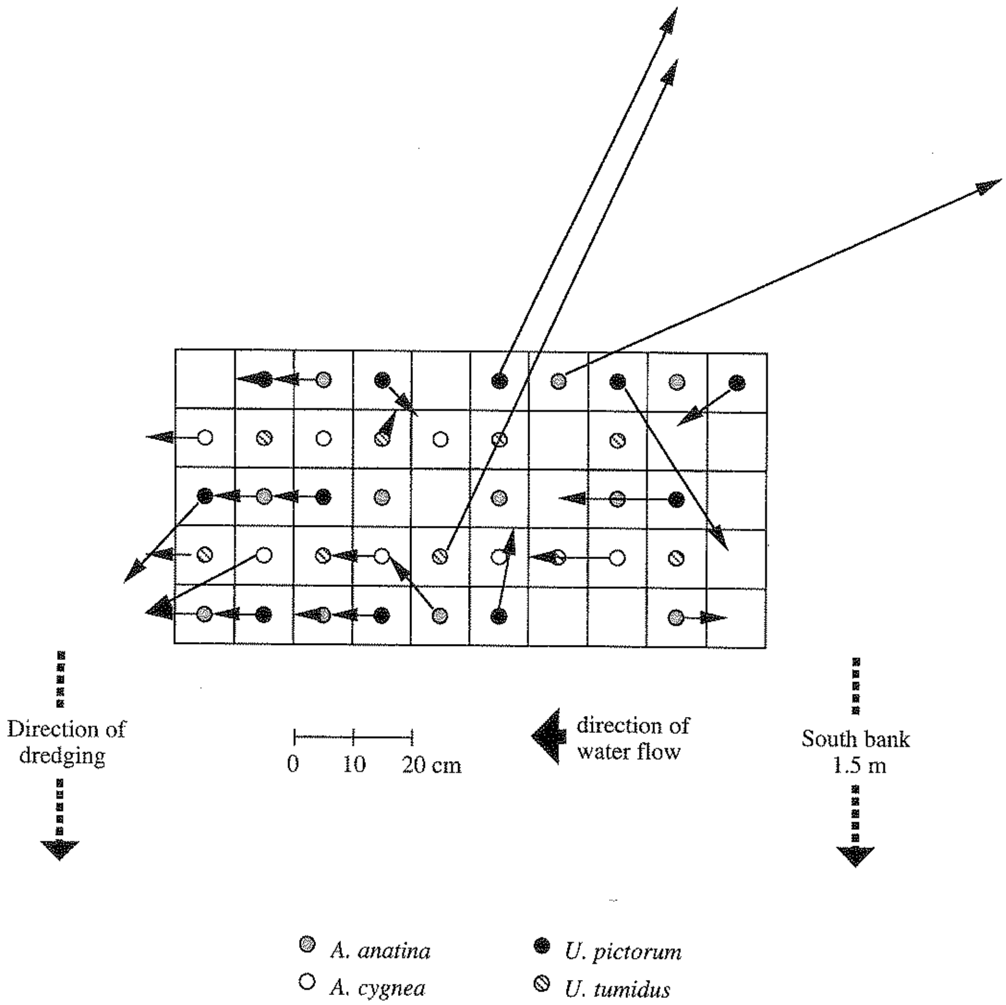

Fig. 7. The distance and direction moved by tagged mussels after 55 days. Empty spaces in the quadrat represent mussels which were not refound on day 55. These included four *Anodonta anatina*, three *Anodonta cygnea*, three *Unio pictorum* and one *Unio tumidus*.

suggests that recolonization of dredged areas by adult mussels may take a long time. Similar records for slight movements of unionids under natural conditions were observed for *Elliptio complanata*, for which fewer than 10% of individuals moved on a particular day, with a mean distance moved of <3 cm day^{-1} (Amyot and Downing, 1997). Some mussels are capable of moving great distances ($>$ 5 m day^{-1}), although this is generally a response to environmental stresses, such as high temperature or low dissolved oxygen (D. Aldridge, pers. observ.).

The small movement of mussels supports the observation that adult unionids do not exhibit strong preferences for particular microhabitats (A. McIvor and A. van der Kolk, pers. comm.). This may be the reason why the traditional approach of describing aquatic mollusc distributions by environmental parameters, as initiated by Boycott (1936), is sometimes so unsatisfactory (Strayer et al., 1994).

A factor which has never been considered as a structuring force of unionid populations, but which appears to be of overriding importance within Wicken Lode, is the impact of waterway management regimes. The greater mussel densities on the south (near) side of Wicken Lode suggest that, like the marked stones, mussels are dragged across the channel by dredging, and possibly by Bradshaw cutting, resulting in a prevalence of mussels on the near bank (Fig. 2). Once the mussels have re-buried themselves, the environmental conditions may be such that no benefits are accrued by moving away from their new locality. Therefore, in future studies of unionid spatial distributions and abundance, the importance of the site's disturbance regimes must not be overlooked. Furthermore, it is likely that management regimes are central to explaining distributions of many other freshwater organisms, particularly those which are relatively immobile.

4.3. Conclusions

From this, and other studies discussed in this paper, a number of constructive suggestions can be proposed for the future management of rivers, which can prove mutually acceptable to all the users of the waterway, but greatly reduce the impact on the ecosystem. Furthermore, specific proposals can be suggested for the conservation of unionid populations.

4.3.1. Frequency

It is sometimes unclear whether control measures, such as dredging, are necessary within a site. In Wicken Lode, as in other channels (Darby and Thorne, 1995), the frequency of dredging has more to do with established rule-of-thumb estimates than with direct monitoring of sediment build up. If a critical discharge can be determined for a particular site, above which the channel can function efficiently as a drainage system, dredging frequency may be reduced, resulting in a reduced cost to river management authorities (e.g. Environment Agency) and less impact on the ecosystem.

4.3.2. Timing

The timing of weed cutting and dredging is critical in determining environmental costs. The early weed cut of Wicken Lode by boat prior to June, and the spring-time dredging, are likely to have great impacts on fish recruitment. Disruption to breeding birds [such as reed warblers (*Acrocephalus scirpaceus*) and coot (*Fulica atra*)] is also likely to be substantial. Although it would be preferable to avoid all weed cutting during the fish spawning season, this is usually not practicable since weed growth is often maximal at this time. By switching dredging to the late autumn or winter, disruption to fish recruitment would be avoided, and the impact on mussels may be reduced because many species become endobenthic at this time of year (Amyot and Downing, 1997).

4.3.3. Method of weed control

Monahan and Caffrey (1996) showed that land-based Mowing Buckets are the most environmentally destructive methods of weed control. The weed boats used in Wicken Lode prior to June are effective in removing weeds, and do not remove any mussels (although a small number are damaged within the channel). Implementation of less damaging weed control measures than Bradshaw cutting should be considered in environmentally sensitive sites.

4.3.4. Selective cutting

The impact of the Bradshaw and dredge on mussel populations could be greatly reduced if only the centre of the channel is managed. This would maintain the drainage function of the channel, retain navigational access, and provide areas for unobstructed angling. The remaining marginal vegetation would provide habitats for invertebrates and fish, and serve as refugia for rapid recolonization of the centre of the channel. However, if fringing macrophytes, particularly *P. australis*, are left permanently unchecked, a build-up of fine sediment could result, along with a decrease in channel depth. It, is, therefore, necessary that some management of marginal zones is carried out. An effective system would be to cut marginal zones to 5 cm above the river bed during the autumnal cut, by means of a weed boat, rather than Bradshaw. This would not adversely affect mussel populations, and would slow the accumulation of fine silt and plant debris. If this regime is coupled with a yearly alternation between banks, refugia for invertebrates and fish can be preserved.

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