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AN INVESTIGATION INTO THE DISAPPEARANCE OF *AUSTROPOTAMOBIUS PALLIPES* (LEREBOULLET) POPULATIONS IN THE HEADWATERS OF THE NORE RIVER, IRELAND AND THE CORRELATION TO WATER QUALITY

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ABSTRACT

Monitoring of the protected white-clawed crayfish *Austropotamobius pallipes* (Lereboullet) has been carried out in the headwaters of the Nore River since 1995. In recent years a reduction in crayfish abundance had become apparent. Some populations had completely disappeared. Adult crayfish were sampled using the baited trap method while juveniles were sampled using a modified surber sampler. The temporal variation in baited trap data was found to be significant at three of the sites while significant variation in enclosure sampling data was found at two sites. In an effort to ascertain why the populations had disappeared a possible relationship between water quality and adult and juvenile crayfish numbers was investigated. Water quality was assessed using both chemical and macroinvertebrate data. Macroinvertebrate sampling revealed deterioration in water quality at all sites. Results also showed the disappearance of crayfish from both Q3 and Q3-4 waters at some sites yet crayfish remain at these Q-ratings at other sites. Therefore the Q-rating below which crayfish cannot survive cannot clearly be defined. However, no clear correlation was observed between the water chemistry data and the crayfish data. Crayfish populations at the Fertagh (FRT) site appear to be surviving intermittent pollution and eutrophic conditions where pre-dawn oxygen sags reach lows of 4.4 mg/l O_2. Deterioration in water quality as indicated by the Q-value biotic index coincided with reduced crayfish catches. There is no evidence to suggest that predation be it of aquatic or terrestrial origin is a major contributing factor.

Key-words: white-clawed crayfish, *Austropotamobius pallipes*, temporal variation, water quality, intermittent pollution, eutrophic, correlation.

INVESTIGATION SUR LA DISPARITION DES POPULATIONS D'*AUSTROPOTAMOBIUS PALLIPES* (LEREBOULLET) SUR LA PARTIE AMONT DE LA RIVIÈRE NORE, IRLANDE, ET CORRÉLATION AVEC LA QUALITÉ DE L'EAU

RÉSUMÉ

Un suivi de l'écrevisse à pattes blanches *Austropotamobius pallipes* (Lereboullet), espèce protégée, a été mené sur la partie amont de la rivière Nore depuis 1995. Ces

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dernières années ces écrevisses sont de moins en moins abondantes. Quelques populations ont complètement disparu. Les écrevisses adultes ont été capturées avec des nasses avec appât, tandis que les juvéniles ont été capturés à l'aide de filets Surber modifiés. Les variations temporelles des données des nasses avec appât sont significatives sur trois des sites suivis, tandis que les variations des données obtenues avec les filets Surber sont significatives sur deux sites. Une investigation a été faite sur la relation possible entre la qualité de l'eau et le nombre d'écrevisses adultes ou juvéniles, pour tenter d'expliquer la disparition de populations. La qualité de l'eau a été suivie sur la base à la fois de caractéristiques chimiques et de données de macroinvertébrés. Les échantillons de macroinvertébrés ont démontré une détérioration de la qualité de l'eau sur tous les sites. Les résultats ont aussi montré la disparition des écrevisses à la fois sur certains sites de qualité d'eau Q3 et Q3-4, et cependant des écrevisses ont été trouvées sur d'autres sites ayant des qualités d'eau identiques. Par conséquent la valeur de la qualité de l'eau en dessous de laquelle les écrevisses ne peuvent pas survivre ne peut pas être clairement définie. Aucune franche corrélation n'a été observée entre la qualité chimique de l'eau et les données sur les écrevisses. Les populations d'écrevisse sur le site Fertagh (FRT) semblent survivre à des pollutions intermittentes et à des conditions eutrophiques où la dépression d'oxygène dissous d'avant l'aube atteint 4,4 mg/l d'O_2. La détérioration de qualité de l'eau indiquée par la valeur de l'indice biotique coïncide avec une réduction des captures d'écrevisses. Il n'y a pas d'évidence que la prédation, d'origine terrestre ou aquatique, est un facteur majeur.

Mots-clés : écrevisse à pattes blanches, *Austropotamobius pallipes*, variation temporelle, qualité de l'eau, pollution intermittente, eutrophisation, corrélation.

INTRODUCTION

In Ireland over 30 percent of the river channels are polluted (LEHANE *et al*., 2002). This can be largely attributed to two main sources ((1) moderate pollution arising from nutrient enrichment from agricultural runoff, (2) point discharges from wastewater treatment plants) (MCGARRIGLE *et al*., 2002). Eutrophication leads to increased productivity, which could result in increased crayfish production. However, a combination of biotic and abiotic effects, associated with eutrophic conditions, may have a negative impact on crayfish populations (LODGE and HILL, 1994). For example eutrophic systems experience pre-dawn oxygen sags and increased mineralization of organic matter causing reduced oxygen concentrations.

Austropotamobius pallipes Lereboullet is widely distributed in lowland Irish systems overlying particularly limestone geology (MORIARTY, 1973; REYNOLDS, 1982; LUCEY and MCGARRIGLE, 1987). Irish crayfish populations commonly occur in lakes and rivers, which is in marked contrast to the rest of Europe. They are relatively free from such pressures as serious pollution, over-fishing, habitat destruction and competition from alien crayfish species. However, deteriorating water quality (increased moderately polluted channels, see LUCEY *et al*., 1999) as well as crayfish plague may threaten the Irish populations, the strongest remaining stocks in Europe (REYNOLDS, 1997).

The populations of *Austropotamobius pallipes* in the eutrophic headwaters of the Nore River, County Laois, south-east Ireland, have been monitored annually since 1995. This paper reports on variation in the crayfish catches over the five-year time period from 1998 to 2002 when methods had been standardized to allow comparisons to be made between years. The analysis explores the possible impact of poor water quality on the crayfish and assesses crayfish tolerance to extreme concentrations of a range of chemical parameters.

MATERIALS AND METHODS

Study Area

Five eutrophic sites, located on three headwater streams in the River Nore were examined (Figure 1). These include three locations on the River Goul, at Ballinafrase (BLF), Fertagh (FRT) and Ballybooden (BLB). One site was located on the Erkina River at Durrow (DUR) and one site on the River Gully (GLY). All sites were eroding in nature, habitat-rich with instream vegetation (mainly *Myriophyllum* spp. and *Cladophora* sp.) exceeding 60% cover.

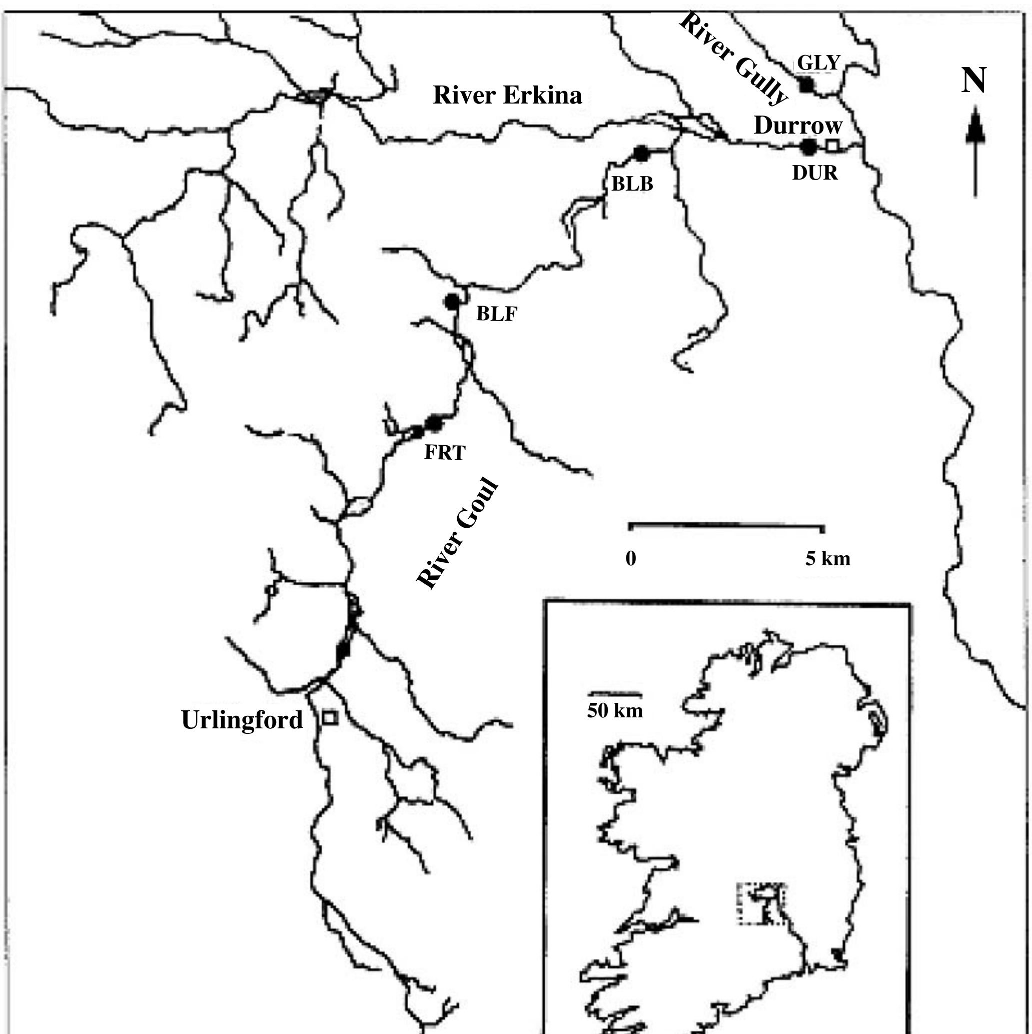

Figure 1

Sampling sites FRT, BLF, BLB, DUR and GLY located on the Rivers Erkina, Goul and Gully. The location of the catchment in the south of Ireland is shown as an inset.

Figure 1

Sites échantillonnés FRT, BLF, BLB, DUR, et GLY situés sur les rivières Erkina, Goul et Gully. La localisation du bassin dans le sud de l’Irlande est indiquée dans l’encadré.

Crayfish Sampling

To successfully estimate crayfish stocks it is imperative to sample both the adult and juvenile animals. As the habitat preferences of the adults differ from that of the juveniles two different methods were employed. Baited traps were used to collect the adults and a modified Surber sampler (BYRNE *et al*., 1995) was used to recover the juveniles within the populations. Surber sampling took place prior to baited trapping at each site. Adult crayfish stocks were expressed in terms of catch per unit effort, while the juveniles were expressed in terms of numbers per meter squared. The sampling effort was confined to one visit per site in August of each year. A brief description of each of these methods follows.

Baited Traps

Sets of ten traps were baited with beef liver and set 2m apart across the river channel camouflaged under instream and marginal vegetation. The same length of river was fished at each site. The traps were *in situ* for 24hrs and then lifted. The relative abundance of the adult crayfish, their size distribution and general condition were assessed. The trap data were expressed in terms of catch per unit effort (MORIARTY, 1973) to allow valid comparisons to be made with data from other years.

Enclosure Sampling

This method was employed specifically to maximize collection of the juveniles. Ten Surber (area $0.25m^2$) samples were taken over a section of channel within the 10m stretch sampled for adults. The samples were located at 1m intervals. All the substrate material was removed from the area enclosed by the Surber and sorted thoroughly for crayfish.

Data Analyses

The temporal variation in crayfish baited trap (see Table I) and enclosure sampling (see Table II) data were examined. A chi-squared test was performed on these data sets separately. Due to the differing sampling methods with different sources of error, these data sets were not pooled to represent crayfish abundance. The derived expected number of crayfish in each year at a particular site was based on an average, calculated for each site, over the five years 1998-2002. A critical limit of 0.05% with 20 df was applied to the data.

Spearman Rank Correlation was employed to test for possible relationships between water quality parameters and crayfish stocks. Correlations were performed using CPUE data and juvenile abundance data.

Water Sampling

Three sources of water chemistry data were used for analyses. Firstly, the site at FRT acts as a monitoring station for a local industry who provided water chemistry data based on a frequency of five samples per month over a three year period (2000-2002). Oxygen data was provided based on hourly readings taken by an autosampler located at the same site (see Figure 2(a-c)). The data obtained for this site formed the main basis of the correlation analyses. Data for other sites was limited and based on once-off annual sampling over four years (1998-2001). Other data used were received from the Environmental Protection Agency and involved five yearly samples at two sites namely, the Gully (GLY) and Durrow (DUR), over a two-year period (2001-2002). The main parameters included were pH, dissolved oxygen, oxygen saturation, ammonia, nitrite and orthophosphate.

Macroinvertebrate Sampling

Five kick samples, each of twenty seconds duration, were taken once yearly in riffle/glide areas as recommended by PINDER *et al*., (1987). The dislodged fauna were collected in a standard pond net (mesh size c.1mm). The samples were then transferred to plastic bags and preserved in 70% alcohol. In the laboratory the macroinvertebrates were sorted and identified to the lowest possible taxonomic level using appropriate Freshwater Biology Association identification keys. A biological water quality index (Q-value) based on the sensitivity of macroinvertebrate communities was employed to assess water quality. The Q-value scale, developed for Irish rivers by the EPA, is a five point score based on the proportions of five groups of organisms with differing pollution tolerances.

RESULTS

The results of the chi-squared test on the baited trap data revealed the variation over the five-year period at three sites namely, BLF, BLB and GLY to be highly significant (see Table III). The most significant variation was observed at GLY, which showed a decline since 1999 (7.6 CPUE) to a complete absence in 2002. A similar pattern was observed at BLB where numbers peaked in 1999 (10.6 CPUE) and declined thereafter, disappearing in 2002. The least significant variation occurred at BLF. Here, crayfish numbers peaked in 1999 (24.4 CPUE) and fell to 11.7 CPUE the following year. Numbers have increased every year since at this site. FRT showed no significant annual variation. The numbers of crayfish trapped at this site have fluctuated slightly over the five-year period reaching a low of 8.1 CPUE in 2002. In general, the numbers have remained stable. No significant variation was found at DUR where consistently low numbers were caught up to and including 2000. Crayfish were absent from this site in 2001 and 2002.

The results of the test on the enclosure sampling (mostly juveniles) showed significant variation at two sites, namely, BLB and FRT (see Table III). Crayfish numbers obtained from the enclosure sampling at BLB exhibited a peak in 2000 followed by lows thereafter. A complete absence in 2002 was observed (as in the baited trap data). A peak was observed at FRT in 1999 where a total of 181 crayfish were obtained. In 2002 numbers fell to 28 and further again to 15 (2002), the lowest in five years. Numbers at BLF have fluctuated between 21 and 71 over the five-year period, but the variation was

Table I

Crayfish numbers (N) at each site from the baited trap sampling methods (ten traps per site) 1998-2002. Catch Per Unit Effort (CPUE) (one trap for 24 hrs) data are included.

Tableau I

Nombre d'écrevisses (N) capturées sur chaque site avec dix nasses 1998-2002. Capture par unité d'effort (CPUE) (une nasse pendant 24 h).

	BLF		BLB		DUR		GLY		FRT	
	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N	CPUE
1998	105	10.5	53	5.3	09	0.9	65	6.5	124	12.4
1999	244	24.4	106	10.6	18	1.8	76	7.6	161	16.1
2000	117	11.7	87	8.7	11	1.1	58	5.8	107	10.7
2001	125	12.5	71	7.1	0	0	01	0.1	120	12.0
2002	171	17.1	0	0	0	0	0	0	81	8.1

Table II
Crayfish numbers (all Surbers combined) at each site from the enclosure sampling methods 1998-2002. (All: total catch, J: juveniles).

Tableau II
Nombre d'écrevisses capturées à l'aide des filets Surber sur chaque site de 1998-2002 (ALL : total des captures, J : Juvéniles).

	BLF		BLB		DUR		GLY		FRT	
	ALL	J	ALL	J	ALL	J	ALL	J	ALL	J
1998	55	41	61	24	8	5	15	5	40	33
1999	31	27	31	7	10	4	38	23	33	24
2000	71	46	72	44	16	9	17	6	181	166
2001	21	0	14	0	0	0	7	0	28	1
2002	66	28	0	0	0	0	0	0	15	8

Table III
Results of the Chi-squared test performed on the baited trap and enclosure sampling crayfish data 1998-2002.

Tableau III
Résultats du test de chi carré réalisé sur les données obtenues par les nasses et par les filets Surber de 1998 à 2002.

X^2	BLF	BLB	DUR	GLY	FRT
Baited Trap	85.22	103.43	31.21	134.15	28.48
Enclosure Sampling	39.28	104.64	27.76	53.32	316.79

not significant. No significant variation was found at DUR where consistently low numbers were found up to and including 2000. Similarly, crayfish were not recorded at this site in 2001 and 2002 as was the case using the baited trap method. At the GLY a steady decline in numbers was seen from 1999 onward to a complete absence in 2002, however the variation was not significant.

The macroinvertebrate data indicated deterioration in water quality at all sites (Table IV). Every site dropped down a Q-rating in the five years. One site in particular, Ballybooden (BLB) changed from a Q4 (1998 & 1999) to Q3-4 (2000 & 2001) to a Q3 in 2002. It was in this year (2002) that the crayfish completely disappeared. However, good crayfish stocks were found present at a Q3 site, FRT 1999-2002. Crayfish were absent from DUR 2001-2002 when a Q-rating of Q3-4 was assigned.

No significant results were obtained from the Spearman Rank Correlation analysis.

Habitat effects were dismissed as none of the sites had been impacted by changes in the physical habitat over the five-year study period. The hydrochemical data were subsequently viewed to highlight the tolerance of the crayfish to eutrophic conditions. Again most of the observations relate to FRT where the autosampler provided an intensive record of prevailing hydrochemical conditions. The crayfish population at the FRT site has been exposed to oxygen concentrations as low as 4.4 mg/l O_2 (2002). They are apparently tolerating pre-dawn oxygen sags between 5 and 7 mg/l O_2 for periods of up to six hours

Table IV
Macroinvertebrate water quality Q-ratings assigned to each site 1998-2002.

Tableau IV
Valeur de l'indice biotique Q pour chaque site de 1998 à 2002.

	BLF	BLB	DUR	GLY	FRT
1998	Q4	Q4	Q4	–	Q3-4
1999	Q3-4	Q4	Q4	–	Q3
2000	Q3-4	Q3-4	Q4	–	Q3
2001	Q3-4	Q3-4	Q3-4	–	Q3
2002	Q3-4	Q3	Q3-4	–	Q3

(data from July 1999 see Figures 2(a-c)). They are also tolerating BOD levels as high as 18 mg/l O_2 on occasion. At this location it is also clear that the crayfish can survive periods of relatively high ammonia (un-ionized ammonia levels have reached 3.55 µg/l NH_3) and nitrite (0.76 mg/l NO_2 (2002)).

DISCUSSION

Significant temporal variation in the catches of trapped crayfish occurred at three sites (BLF, BLB and GLY). This is representative of the adult crayfish as only a few juveniles if any are caught in traps. Significant variation in crayfish enclosure sampling data occurred at two sites (BLB and FRT). This is representative of the fluctuations in juvenile crayfish numbers as it is predominantly juveniles that are captured by this method (see Table II). The reasons for the variation are unclear. It is not possible to state whether or not this is a natural phenomenon or the results of anthropogenic impacts on the physico-chemical environment. While it is well documented that the physical habitat of the white-clawed crayfish is of vital importance in determining its presence and abundance (REYNOLDS and MATTHEWS, 1995; SMITH *et al*., 1996), the physical habitat characteristics at the sites have remained relatively unchanged since 1998. The incidence of disease (burn spot/porcelain) has never exceeded more than 3 percent of the total population of each site. Similarly low levels of incidence of porcelain disease have been reported by SMITH *et al*., 1990 (2.9%) and LILLEY *et al*., 1979 (3.4%). Burn spot disease is often seen in dense populations and is not thought to have a harmful effect on crayfish (UNESTAM, 1973). However, reduction in catches due to disease cannot be totally ruled out as sampling was confined to one date in each year. Other possible explanations may include reduced catchability, deteriorating water quality and predation.

Significant variation in both sets of data was found at one site (BLB). Crayfish declines since 2000 had occurred at this site and they were not caught in 2002. Since the whole crayfish population is being affected it is possible that poor water quality is impacting on the crayfish. Inside a year, notably, prolific growth of *Cladophora glomerata* was present at this site in 2002, with almost complete cover of the riverbed. This was probably due to increased nutrient rich run-off from the surrounding agricultural land. This apparent deterioration in water quality was reflected in the Q-rating assigned to BLB. It dropped from a Q3-4 or slightly polluted (2001) to a Q3 or moderately polluted water in 2002.

Although the variation in enclosure sampling was not significant at DUR and GLY the fact remains that the juveniles have not been caught since 2001, as well as the adults. As both sectors of the population have been affected, it is likely that poor water quality is the causative factor. Crayfish numbers at GLY had been decreasing since 1999 until

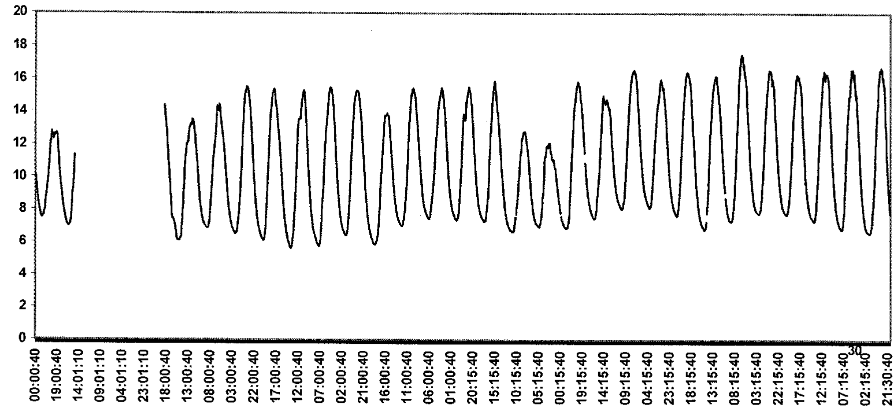

Figure 2(a)
Diurnal dissolved oxygen concentration for month of July at FRT.

Figure 2(a)
Variation diurne du taux de concentration en oxygène dissous en juillet à Fertagh (FRT).

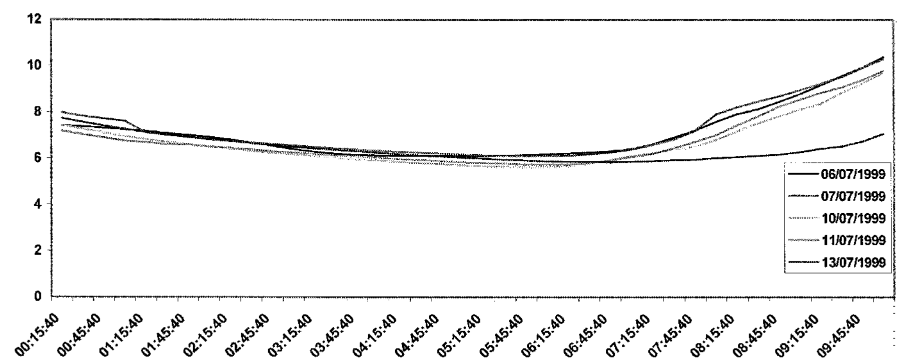

Figure 2(b)
Pre-dawn oxygen sag (< 7 mg/l O_2) for six days in the month of July at FRT.

Figure 2(b)
Concentrations en oxygène juste avant l'aube en juillet à FRT, moyennes sur 6 jours.

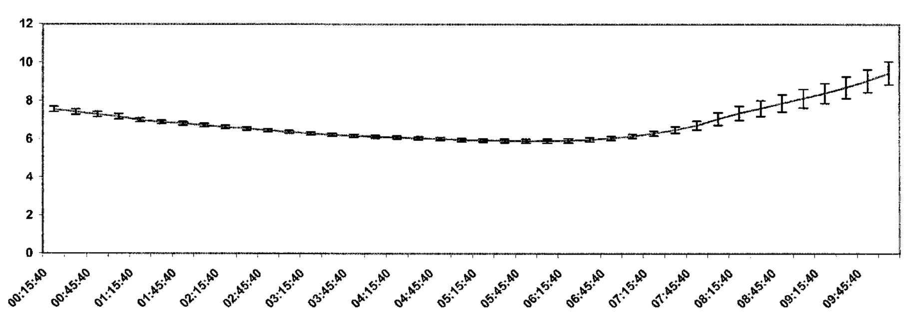

Figure 2(c)
The mean pre-dawn oxygen sag (< 7 mg/l O_2) for six days in July at FRT.

Figure 2(c)
Concentration moyenne sur 6 jours en oxygène dissous (< 7 mg/l O_2) avant l'aube en juillet à FRT.

they completely disappeared in 2002. The population disappeared from DUR in 2001 this coincided with a drop in the macroinvertebrate quality index from Q4 to Q3-4. Sewage fungus was a constant feature at this site. It is worth noting that crayfish are surviving in Q3 (moderately polluted) water at FRT, therefore the nature of the contamination may be a factor. However, any drop in the Q-rating appears to coincide with reductions in crayfish numbers.

The population at BLF is also being impacted. The significant variation in the adults at this site may be due to the activities of a resident otter. Evidence of otter predation was present at this site over the five-year period in the form of spraint and crayfish remains. However, HOGGER (1988) showed that not many of the potential crayfish predators are known to have a significant affect on crayfish abundance with the exception of fish (ENGLUND, 1999). Interestingly, no juveniles were found at this site in 2001. This year was particularly bad in terms of juvenile numbers, where only one individual (FRT) was found across all the sites. Numbers recovered slightly at two sites, BLF and FRT the following year. This pattern was not reflected in the adult (baited trap data) sector. Poor quality water may have been a factor, as the juvenile stages are the most vulnerable period in the crayfish life-cycle (LAURENT, 1988). Fluctuations in CPUE at FRT may be natural or due to catchability (BROWN and BREWIS, 1979). The peculiar behaviour of the crayfish, including burrowing into banks, and the movement in and out of traps (HARLIOGLU, 1999) as well as trap location may all influence the CPUE. The significant variation in juveniles was due mostly to an exceptionally high number recorded in 2000 (181). The juveniles may have been more successful in seeking out refuges eg cobble, (STEIN and MAGNUSON, 1976; STEIN, 1977) escaping predation from fish.

The analysis of the hydrochemical data has also been inconclusive. This may be due to the small crayfish data set entered into the correlation. However, the data gathered to date provide some insight into the tolerance of crayfish to intermittent pollution. The distribution of crayfish is considered to be largely determined by the underlying geology and water quality. Principally they are mostly found in clean waters however they can also survive in waters where intermittent pollution occurs (HOLDICH and REEVE, 1991; TROSCHEL, 1997; DEMERS and REYNOLDS, 2003). LAURENT (1988), states that changes in chemical water quality may, if acute, eliminate whole crayfish populations or, if chronic, reduce crayfish numbers indirectly by altering the trophic relationships within the ecosystem. In contrast, TROSCHEL (1997), investigating the distribution of *A. pallipes* in Germany, monitored the structure and hydrochemistry of native streams. He concluded that the wide variation of water parameters encountered indicated that the presence of *A. pallipes* was not dependent on the water chemistry. Crayfish prefer (though not entirely necessary) pH range of 6.5-9.0 and Ca levels > 5 mg/l (CHAISEMARTIN, 1967; HOLDICH and JAY, 1977). SMITH *et al*., (1996) concluded that the chemistry of the water had little influence on crayfish once these threshold concentrations are exceeded. The rivers in question in the surveys are hard water rivers and all have pH values within the desired range. Dissolved oxygen concentrations have been found to be critical in the successful culture of several crayfish species (ACKEFORS, 1996). The crayfish population at the FRT site had been exposed to oxygen concentrations as low as 4.4 mg/l O_2 (2002). They are tolerating pre-dawn oxygen sags of < 7 mg/l O_2 and > 5 mg/l O_2 for a duration of up to six hours (data from July 1999 see Figures 2(a-c)). According to WESTMAN (1985), stress is induced by exposure to DO levels < 5 mg/l O_2 of a few days in the summer months. Crayfish tend to be sensitive to acute pollution incidents, spills of high organic content, with a high BOD (FOSTER and TURNER, 1993). At FRT, crayfish are surviving BOD levels which are occasionally as high as 18 mg/l O_2. Significant mortalities of the white-clawed crayfish have been reported in simulated farm waste episodes rich in nitrite (FOSTER and TURNER, 1993). Ambient nitrite concentrations are elevated by nitrogenous pollution. Experimental laboratory trials indicated that *Astacus astacus* was sensitive to this toxicant (JENSEN, 1996). Maximum nitrite levels of 0.76 mg/l NO_2 (2002) have been recorded at

FRT. This concentration exceeds the existing regulation for Salmonid Waters < 0.05 mg/l NO_2 (FLANAGAN, 1990). However this limit is considered unduly low and the proposed EPA limit is 0.2 mg/l NO_2. Levels in the study area have also exceeded this value on a number of occasions. Free ammonia was shown to be more toxic than nitrite to juvenile *Cherax quadricarinatus* in studies run by LIU *et al*., (1995). Un-ionized ammonia levels have reached 3.55 µg/l NH_3 at this site. However, according to the USEPA, levels of free ammonia in excess of 10 µg/l NH_3 can adversely affect aquatic communities.

This study suggests that deteriorating water quality, measured in terms of the macroinvertebrate communities often coincide with dramatic reductions in *Austropotamobius pallipes* catches. Crayfish probably tolerate increasing moderate pollution to a certain level beyond which losses are observed. The Q-rating below which crayfish cannot survive cannot clearly be defined. As the population at FRT is quite stable one can conclude that the crayfish seem to survive well in Q3 waters and exposure to levels of various parameters such as were discussed previously. In terms of the conservation of the species further studies should concentrate on defining this critical point and distinguishing it from natural fluctuations in populations.

CONCLUSION

Over the five-year study period, crayfish have disappeared from three of the sites, which have been verified using too sampling methods. The temporal variation in crayfish from baited traps at three of the five study sites was found to be significant. Two sites showed significant variation in crayfish numbers from enclosure sampling.

Deterioration in water quality was observed across all sites using biological indices and it often coincided with reduction in crayfish catches. However, the analysis of the hydrochemical data has not highlighted any parameter, which is correlated with the observed changes in crayfish catches.

The hydrochemical data has provided some insight into the tolerance of crayfish to intermittent pollution. The crayfish population at the FRT site has been exposed to oxygen concentrations as low as 4.4 mg/l O_2 (2002). They are tolerating pre-dawn oxygen sags of < 7 mg/l O_2 and > 5 mg/l O_2 for a duration of up to six hours. They also appear to be relatively tolerant of intermittent pollution with high BODs, nitrite and ammonia levels.

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