Impact of the signal crayfish *Pacifastacus leniusculus* and its associated crayfishery on the River Thame

Institute of Freshwater Ecology

Operational Investigation Report

Impact of the signal crayfish *Pacifastacus leniusculus* and its associated crayfishery on the River Thame

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Operational Investigation Report

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EXECUTIVE SUMMARY

1. Three reaches of the River Thame were selected to determine the impacts of the signal crayfish *Pacifastacus leniusculus* and its associated crayfishery on the fauna and flora of the river. In the first reach the crayfish population was exploited by a commercial fishery; another reach contained an unexploited crayfish population; and the third reach had no crayfish at the beginning of the study.

2 In each month for a complete year each reach was sampled with the use of baited traps. All crayfish captured were measured, sexed and either tagged with individually numbered tags or given date coded uropodal or pleopodal clips before being returned alive to the river.

3 To reduce the possibility that any observed differences in the three study reaches were due to differences in physical habitat, they were compared using multi-variate techniques. This demonstrated that the range of variation between the reaches was small and there was considerable overlap between the site value ranges of individual variables.

4 The growth-for-age of the signal crayfish population in the River Thame is comparable to other populations found in Britain. Carapace lengths (CL) of 4.2 cm were achieved after three years. Males grew faster than females and achieved a greater maximum size. The smallest female found to be carrying eggs was 4.2 cm (CL), but it is thought probable that smaller and younger crayfish be mature.

5 Estimates of population abundance and biomass were made for signal crayfish in an exploited and unexploited reach of the River Thame, by a mark-recapture experiment performed throughout 1996. Population estimates for the two reaches were 3,458 ± 3,303 (90% C.L.) crayfish larger than 2.7 cm (CL) per 600 m of length of river in the unexploited reach and 818 ± 2,329 (90% C.L.) crayfish of the same size per 600 m of length of river in the exploited reach. This equates to a population density of 0.86 (44g) crayfish per m^2 and 0.17 (8.9g) crayfish per m^2 in the unexploited and exploited reaches respectively.

6. Migration rates for signal crayfish in the River Thame were estimated from the recapture of individually tagged crayfish. They were found to be 146 m $month^{-1}$.

7. Crayfish abundance, during the winter, in an unexploited reach of the River Thame was related significantly to aspect, depth, width, percentage of macrophyte cover in May and the change in percentage cover of macrophytes between May and September. All these variables correlated with one another and thus it was not possible to say which variable the crayfish population was responding to. Variation in signal crayfish abundance, in the summer months, could not be explained by physical habitat.

8. Macro-invertebrate assemblages in the reach without crayfish were significantly different to the assemblages found the in the two reaches which had established signal crayfish populations. The taxa which appear to have been eliminated from the reaches where crayfish were present were primarily slow moving species without rapid escape mechanisms. These included gastropods, leeches and caddis, together with several species of crawling or slow swimming beetles. Conversely several species of water bugs and mayfly were present in the reaches with crayfish but were absent from the reach without crayfish. The most likely reason for the observed differences in the faunal composition

of the three reaches is the between-site differences in the density of the crayfish populations but the possibility of differential toxic pollutant effects has not been eliminated by the current sampling programme.

9. Attempts to monitor the catches of the commercial fishery were not very successful. Therefore the commercial catches at Shabbington Island were estimated from tagged and clipped crayfish recapture and loss rates. In 1996, it is estimated that catches from Shabbington Island alone were approximately 1.46 tonnes.

10. The commercial fishery at Shabbington Island acts like a sink, drawing crayfish from neighbouring unfished reaches as crayfish are removed from the Shabbington Island site. There is evidence that the influence of this may be felt at least 2 km in either direction of the fishery.

11. Not enough is known about the impacts of this fishery on the signal crayfish population, the recruitment of juvenile signal crayfish to neighbouring unfished reaches and the knock-on effects to conservation interests. It is concluded that the commercial fishery does not necessarily reduce the impact of signal crayfish on the other flora and fauna.

12. It is recommended that the current situation of the commerial fishery being unregulated is changed and that consideration is given to a wide variety of regulatory measures including the implementation of licence fees for commercial fishermen, which take account of the true commercial value of these fisheries.

13. A list of future work is recommended including more detailed studies on the impact of the signal crayfish on the flora and fauna and studies of the potential for management of the signal crayfish populations.

1. GENERAL INTRODUCTION

1.1. Background

The white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet), is the only species native to Great Britain. This species is listed and protected under Schedule 5 of the Wildlife and Countryside Act 1981 and is one of only four British, non-insect invertebrates listed and protected under Appendix III of the Bern Convention on the Conservation of European Wildlife and Natural Habitats. Recently, it has become protected under the Import of Live Fish Act through the Prohibition of Keeping of Live Fish (Crayfish) Order 1996.

Since the late 1970's several alien crayfish have been introduced to the United Kingdom including the American signal crayfish *Pacifastacus leniusculus* (Dana) for farming (Holdich, 1988). In 1991 there were at least 23 wild populations of signal crayfish in England and Wales (Holdich & Reeve, 1991) including one in the River Thame which has supported a commercial fishery from at least the early 1980's.

The Environment Agency has duties and corporate priorities to actively encourage conservation of natural flora and fauna, assess the state of the environment and freshwater fisheries. Since the signal crayfish is a comparatively large alien introduction, it has potential to have enormous conservational impacts in the rivers that populations become established. As yet, many of these impacts are largely unquantified. In order to complete its duty to encourage conservation it is first necessary for the Agency to quantify the likely impacts of these introductions before deciding on the potential and value of control measures.

The signal crayfish now supports substantial commercial fisheries in both the River Thame and other rivers. As these are relatively new fisheries they are largely unregulated or regulated by laws designed for other types of fisheries, which may be inappropriate. The current fisheries byelaw review provides an opportunity to regulate these new fisheries in a way that takes account of both conservation and fisheries interests.

The current study was undertaken to provide information on the impacts of the signal crayfish on the flora and fauna of the River Thame and the likely effects of the commercial fishery.

1.2. Primary objectives

- To determine the environmental impact of the signal crayfish on the flora and fauna of the River Thame.

- To establish the likely effects of the fishery on native crayfish populations.

1.3. Specific objectives

- To undertake detailed studies of the microhabitats, macrophytes and macro-invertebrates of three separate study reaches of the River Thame: a reach where the crayfish population is exploited, a reach where the crayfish population is unexploited and a reach which has no crayfish present.

- To conduct a detailed study of crayfish populations in each of the three study reaches. The measurements obtained will include the numbers of native and alien species, their size (carapace length) and weight and the ratio of these two measures, the population age structure and the seasonality of the data collected.

- To determine the distribution of crayfish at each site in relation to the distribution of microhabitats.

- To undertake mark-recapture experiments in order to estimate population sizes and growth rates of native and alien species.

- To collate the commercial fishery statistics for the impact reach.

2. GENERAL METHODS

2.1. Selection of study reaches

From information collected during a survey of the River Thame in November 1995 (Ibbotson, Furse & Dewey, 1995) three 1 km reaches were selected with the following characteristics; a reach where the crayfish population is exploited by a commercial fishery; a reach where the crayfish population is unexploited; and a reach which has no crayfish at all. Sampling occured at the last of these reaches throughout the year to check that it was free from crayfish. However in June one male signal crayfish was captured in this site; a further capture was made in September and then three were captured in October. No crayfish were captured in this site in any of the other months. Although, this technically meant that the reach was not entirely free of crayfish, it was regarded as such for the purposes of this study because the very low catches indicated that this was not the site of an established population.

The selection of each reach was influenced by the regular dredging that occurs in the River Thame. It was probable that recent dredging would adversely impact the crayfish populations and areas where this had occurred were not selected (Ibbotson *et al.*, 1995). The high level of dredging activity on the River Thame thus reduced the potential for selecting sites which conformed with the requirements of the present study. This resulted in the reach containing the commercial fishery consisting of a braided channel (Fig 2.1), the 1 km length comprising the sum total of the two channel branches.

2.2. Trapping protocol

Each of the three reaches were divided into five lengths of 200 m. Three non-adjacent lengths or sites were selected for sampling, once in each month between January and December 1996.

Sampling for crayfish was by use of baited traps left overnight at ten trapping stations evenly distributed through each site. Thus each trapping station was situated 20 m apart. Three trap sizes were used at each trapping station in order that different sized crayfish could be sampled. The mesh sizes of the three traps were 30 mm, 15 mm and 5 mm. However, the trap with the smallest mesh size was ineffective at catching crayfish and in the first six months of sampling, equivalent to 540 trap nights, only one crayfish was retained by this trap and therefore its use was discontinued. Since it had been specifically designed to catch the smallest forms of crayfish, an alternative kick sampling method was employed to catch these whenever the river conditions made access possible.

In each month the captured crayfish were removed from the traps, identified, measured to the nearest mm carapace length (CL), sexed and given date coded uropodal and pleopodal clips or tagged with individually numbered streamer tags. Numbered tags were polyethylene streamer tags manufactured by Hallprint. These tags were inserted with a needle into the dorsal tail muscle immediately behind the carapace. Each tag had dual barbs to reduce the probability of it falling out. The crayfish were then returned to the river alive. The exception to this was July when a number of crayfish were taken by Environment Agency staff from the commercially fished reach (Reach 2) for diet analysis.

Recaptures of tagged and clipped crayfish tended to be low. Therefore in an attempt to increase these recaptures larger netted traps (mesh size 1 inch knot to knot) were employed at one site of the unexploited reach (Reach 1) in every month from July onwards with the exception of August. This was in addition to the standard trapping protocol.

All traps were disinfected with fungicide before sampling the reach without crayfish (Reach 3).

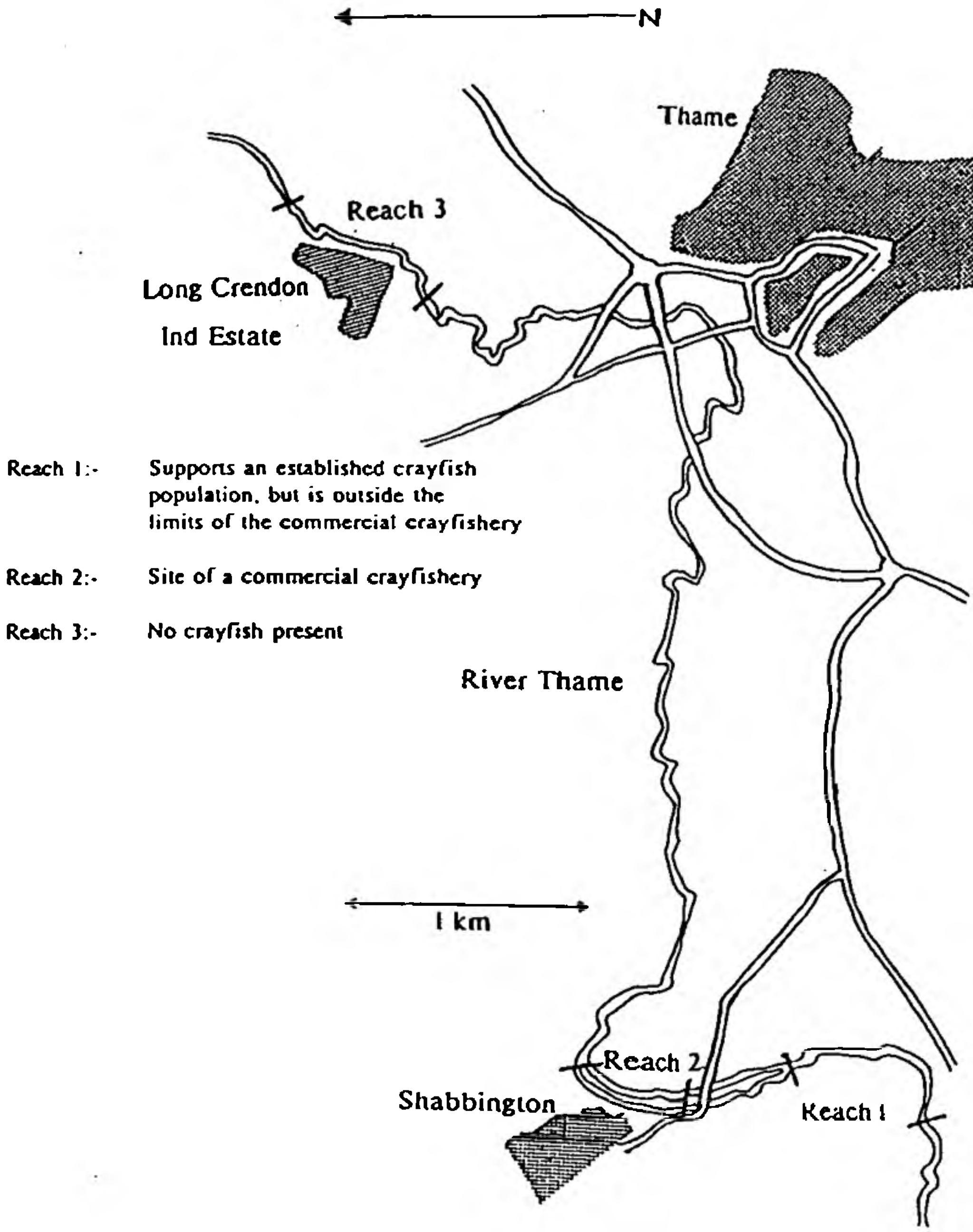


Figure 2.1 **A schematic diagram showing the geographical location of the the three reaches used in the current study**

3. PHYSICAL CHARACTERISTICS OF THE THREE REACHES

3.1 Introduction

With two independent primary objectives and only three reaches there was no scientific replication. Therefore any observed differences between reaches may not be due to impact of the signal crayfish, but could have alternative explanations. To eliminate the potential that differences in physical habitat could be responsible for observed differences in biotic assemblages the physical characteristics of the three reaches were measured.

3.2 Methods

Habitat characteristics were considered at three scales; 500m sections of the three study reaches, transects of each trapping site and the precise points in the river at which each trap was set. These survey procedures also provided data for comparison with differences in the macro-invertebrate assemblages of each reach.

3.2.1. Survey of 500m sections (River Habitat Surveys)

These surveys were based on the River Habitat Survey (RHS) which is used extensively by the National Rivers Authority (NRA) and the Environment Agency for river corridor studies A full description of RHS procedures can be found in the Field Methodology Guidance Manual (NRA, 1995). These standard techniques involve recording physical, geomorphological and vegetational characteristics of the watercourse and its banks over a 500m stretch of river, including the use of ten spot check points spaced 50m apart. Each spot check was a transect 10m wide across the river and here environmental data were recorded in greater detail.

Each reach of the River Thame on which crayfish trapping took place was 1 km long and therefore comprised the equivalent of two RHS lengths (upstream and downstream sections of the reach). These six river sections were each surveyed in standard fashion in May 1996, at the same time as the spring macro-invertebrate sampling.

3.2.2. Survey of each trapping station

In the transect surveys, the standard RHS techniques were modified in order to provide more details on those features thought to be particularly relevant to crayfish habitat preferences (Appendix A). The amended procedures differed from the standard method in the following ways:

- Channel substrata were recorded as dominant and subdominant and a percentage estimated for the area covered by each recognised category (section E of form - see Appendix A).

- Channel vegetation types were recorded as a percentage of the area of the transect covered (section G).

- Land use within 50m of banktop was not recorded (section H).

- At each trapping point, rather than once for each 500m survey length, the main channel width was estimated with a range finder; water depth was measured or estimated where it was too deep to enter the river at one quarter, one half and three quarters distance from right bank.

- A compass bearing was used to determine the aspect of left and right banks.

- The visible non-wetted bank profile type was noted and the angle of slope estimated. The degree of slope of the submerged bank could not be measured with any accuracy because of flow conditions, low bankside vegetation and safety considerations.

- The degree of shading was estimated as a percentage of the channel area affected within the transect (section J).

- The percentage area of the channel within the transect overhung by boughs greater or less than 0.5m above the water was also recorded (section J).

Full surveys of this kind were carried out in May 1996 at each of the trapping stations in the two reaches with established crayfish populations. Each trapping station was treated as a 10 m wide transect for these purposes. The reach without crayfish was not surveyed is this way. Transect surveying coincided with the full RHS surveys and the spring macro-invertebrate sampling.

A reduced survey of all three reaches was undertaken in the autumn when percentage cover by substrata and vegetation types at each trap point were the only habitat characters recorded.

3.2.3. Monthly surveys of trap position

Each time that any crayfish trap was set for the monthly sampling protocol a range of habitat features was recorded for the trap position.

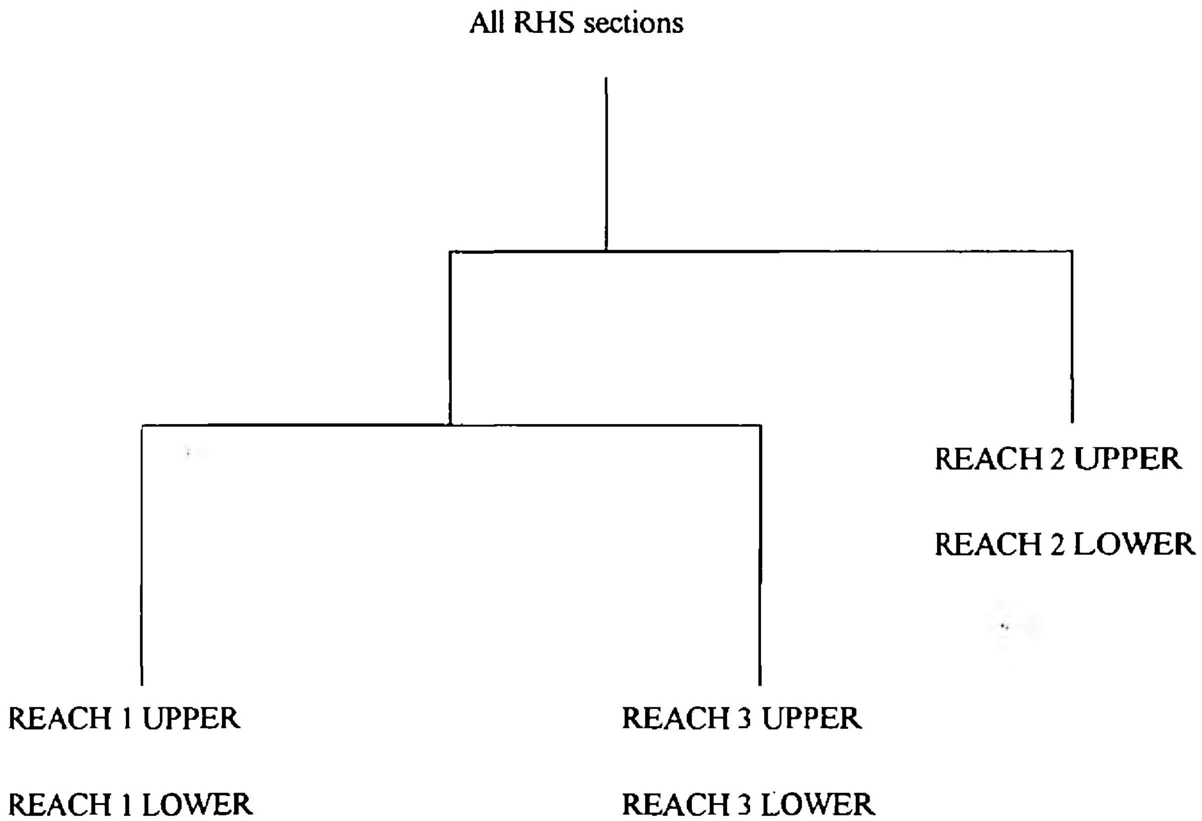
Measured features were depth, distance from the nearest bank and distance of the trap from the nearest example of each of a range of different substratum types and vegetation (Appendix B).

3.3 Results

3.3.1. Survey of 500m sections (River Habitat Surveys)

A sub-set of those environmental features whose measured values showed variation between the sections was used for classification by Two-Way Indicator Analysis, TWINSPAN, (Hill 1979). This involved first standardising all variables of a common value range (0-100) and re-structuring the data-set to condensed Cornell Format. The analysis separated the three reaches into discrete groups (Fig. 3.1).

Figure 3.1 **A TWINSPAN classification of the six 500m sections comprising the three surveyed reaches.**



The first reach to separate out, and thus the most distinctive of the three, was the exploited reach (Reach 2). On the basis of the differential features of each division, as identified by TWINSPAN, Reach 2 was distinguished from the other two reaches by its more silty substratum, particularly in the upper 500m section; by the comparatively high extent of channel restructuring in this reach; and by the presence of regularly spaced bankside trees. Conversely, Reach 2 had a relatively low frequency of occurrence of emergent broad-leaved plants in comparison with the other reaches and a narrower banktop width and greater banktop height. Its left-hand bank also tended to be shallower in slope than the stable earth cliff form commonly found at the other two reaches.

Two features which distinguished the unexploited reach (Reach 1) from the reach without crayfish (Reach 3) were the former's riparian embankment, in-stream impoundment and relatively high cover of floating-leaved, rooted vegetation. Reach 1 also had more vegetated mid-channel bars and more vegetated side-bars and eroding earth cliffs on the right-hand bank. In contrast Reach 3 was distinguished by having predominantly stable earth cliffs forming the right-hand bank, greater evidence of re-sectioning of the left-hand bank, which tended to be of a vertical and toe profile, and by more exposed tree roots than Reach 1. Reach 3 also had a weak berm alongside each bank whilst the right bank uniquely had the appearance of an artificial two-stage profile.

Despite these apparent distinctions, the eigenvalues of thc primary and secondary divisions of the classification of such a small number of sections were very low (0.290 and 0.214) indicating that there were not substantial differences between the overall character of any of the reaches.

3.3.2. Survey of each trapping station

The mean values of the principal environmental features of reaches 1 and 2 are given in Table 3.1. These data confirm the indications from the previous section that the differences between the study reaches were small. Thus, the average depth differed by only 20 cm and the width by just over a metre. Both reaches had a predominantly gravel/pebble substratum and each had a similar, predominantly "smooth boundary turbulent" flow type (not shown in Table 3.1). Neither reach was heavily shaded.

The main differences between the reaches were that Reach 1 had not been re-sectioned, whereas approximately half of Reach 2 had been modified in this manner. Apparent differences in macrophyte cover also existed between the reaches with Reach 1 having almost twice the channel cover of Reach 2 and a similar difference in the number of distinctive macrophyte growth forms at each sampling transect.

Within each reach, the variation between sites was often greater than between the two reaches as a whole with extensive overlap between the mean values of sites in the two reaches (Table 3.2). For example, the mean midstream depth of the Reach 1 sites ranged from 0.9 to 1.3 m and those from Reach 2 varied from 1.0 to 1.5m. All variables showed some overlap in mean values of sites in the two different reaches although recent channel re-sectioning was confined to Reach 2. However, even here Reach 2, Site 3 showed no evidence of re-sectioning.

This latter site, which was the only site on the western branch of the divided watercourse at Shabbington Island, was the most distinctive of the six. The site was slow-flowing with a silty, depositing substratum. It was also the most shaded of the sites, had the lowest mean variety of macrophyte growth forms per transect and had the most gently sloping banks.

Table 3.1 Mean values ± standard deviations of selected environmental variables for trapping transects in reaches one and two.

VARIABLE	REACH ONE	REACH TWO
Depth (m) at 0.25 channel width from right bank	0.8 ± 0.2	1.0 ± 0.3
Depth (m) at 0.5 channel width from right bank	1.1 ± 0.2	1.3 ± 0.3
Depth (m) at 0.75 channel width from right bank	0.8 ± 0.2	1.0 ± 0.3
Water width (m)	6.7 ± 1.3	7.9 ± 0.8
% cover of stream-bed with gravel and pebbles	70 ± 15.8	53 ± 38
% cover of water width with macrophytes	45 ± 28.9	24.7 ± 19.6
Number of growth forms of macrophytes/transect	3.1 ± 1.2	1.8 ± 1.1
Left bank slope °	63 ± 21	69 ± 12.3
Right bank slope °	39 ± 31	53 ± 32
Right bank aspect °	105 ± 44	124 ± 30
% of channel shaded	3.1 ± 7.7	6.4 ± 9.5
% of channel re-sectioned	0	60 ± 50
% of right bank embanked	90 ± 30	60 ± 50

Table 3.2 Mean values ± standard deviations of selected environmental variables for trapping transects for each of the three sites in each of reaches one and two.

VARIABLE	REACH (R) AND SITE (S) NUMBERS					
	R1S1	R1S2	R1S3	R2S1	R2S2	R2S3
Depth (m) at 0.25 channel width from right bank	0.9 ± 0.1	1.0 ± 0.2	0.6 ± 0.1	1.2 ± 0.3	1.2 ± 0.2	0.7 ± 0.2
Depth (cm) at 0.5 channel width from right bank	1.1 ± 0.1	1.3 ± 0.2	0.9 ± 0.1	1.4 ± 0.2	1.5 ± 0.2	1.0 ± 0.1
Depth (cm) at 0.75 channel width from right bank	0.8 ± 0.1	1.0 ± 0.2	0.6 ± 0.1	1.2 ± 0.3	1.2 ± 0.2	0.7 ± 0.2
Water width (m)	7.8 ± 0.9	7.0 ± 0.8	5.4 ± 0.5	7.5 ± 0.8	8.0 ± 0.8	8.2 ± 0.4
% cover of stream-bed with gravel and pebbles	81 ± 5.1	58 ± 17.1	70 ± 13.2	83 ± 11.0	76 ± 7.7	1.5 ± 3.4
% cover of water width with macrophytes	20.7 ± 8.5	40 ± 23.5	75 ± 20.1	14.0 ± 10.2	29.6 ± 16.6	31 ± 25.8
Number of growth forms of macrophytes present	2.9 ± 0.7	2.4 ± 0.7	4.0 ± 1.3	1.4 ± 0.7	2.7 ± 1.1	1.2 ± 0.8
Left bank slope °	64 ± 8.0	64 ± 28.3	62 ± 22.0	76 ± 13.0	70 ± 11.9	61 ± 6.9
Right bank slope °	35 ± 26.8	50 ± 37.6	32 ± 27.6	56 ± 22.7	81 ± 20.6	23.0 ± 21.8
Right bank aspect °	72 ± 28.6	90 ± 18.3	152 ± 31	89 ± 25.6	144 ± 14.3	139 ± 8.2
% of channel shaded	0.4 ± 0.8	2.0 ± 2.6	7.0 ± 12.5	3.7 ± 6.3	1.9 ± 2.7	13.7 ± 12.3
% of channel re-sectioned	0	0	0	90 ± 30	100 ± 0	0
% of right bank embanked	80 ± 40	100 ± 0	100 ± 0	90 ± 30	100 ± 0	0

In Reach 1 the most distinctive of the three sites was number 3, which was the shallowest and narrowest of the six sites considered here. It also had the highest number of macrophyte growth forms per transect and by far the greatest macrophyte cover (74.5%), and was the second most shaded site.

3.3.3. Monthly surveys of trap position

The data for individual trapping points is too extensive to detail here but is considered later in relation to individual trap catches.

3.4 Discussion

In comparing crayfish population statistics and ecological impacts in exploited and unexploited reaches, as in the current study, the ideal is that sites being used for comparison are identical in their environmental characteristics. The same should apply to any sites where crayfish populations are nominally absent.

This is never achievable in practice. Inevitably sites will differ in their distance downstream and in their annual mean discharge. It is also difficult to find successive sites where no other environmental influence, such as towns, tributaries or differential land uses are operating.

In the case of the River Thame the situation is made even more difficult by different histories of dredging in different reaches, by tendency for the river to braid in some reaches and by the lack of documented evidence of commercial fishing activities.

Under these circumstances, the three study reaches represent the best matching that could be obtained. Although the three reaches are not continuous and are sometimes separated by major conurbations, such as the town of Thame, or by inflowing tributaries, and although each has a distinctive identity (Fig. 3.1), the range of variation exhibited by the reaches is small. Indeed when trapping transects at the two reaches supporting established crayfish populations are compared there is considerable overlap between the site value ranges of individual variables.

Populations of signal crayfish at study reaches 1 and 2 are believed to be equally well established but have been subjected to very different fishing regimes over recent years. It is not considered that the small level of inter-site variation in environmental characteristics will have a substantial influence on crayfish abundances in the exploited and unexploited study reaches. Any observed differences between the reaches are likely to have resulted from the activities of the commercial fishery.

4. AGE, GROWTH AND REPRODUCTION OF CRAYFISH IN THE RIVER THAME

4.1. Introduction

Although the presence of the signal crayfish in the River Thame has been common knowledge and there has been an established commercial fishery for approximately 15 years there is no published data on the growth and structure of the current signal crayfish population in this river.

Since this information is useful when considering potential management of this species and any commercial fishery activity its derivation was a major component of the present study.

4.2. Methods

Crayfish were captured monthly throughout 1996 in both the unfished and commercially fished reaches using the traps and methods described in section 2.

When captured they were measured, sexed and a number were tagged with individually numbered streamer tags in the tail muscle. All crayfish were then released alive at the same point they were captured from.

Determining the age and growth of crayfish is difficult because they moult regularly and do not retain any permanent feature. The process of ageing and describing population structure becomes even more difficult when a population is only studied for one year because individual crayfish growth cannot be monitored for longer than the period of the study.

Thus ages were determined for the young crayfish using size frequency distributions and for the older crayfish from size frequency distributions and growth rates observed from the recaptured individually tagged crayfish. The size frequency distributions used were those for July since this was the month that most crayfish were captured and in other months some age and size groups were missing from samples. Separation of different ages was thus by selecting non-overlapping size categories for both males and females and then assigning an age to them. This method does not allow for overlapping sizes of different age groups, but does give a reasonable approximation to age and growth.

A proportion of crayfish were measured to carapace length, total body length and weight, so that a relationship could be developed between the three measurements and all crayfish could have weight and total body length estimated from measures of carapace length.

The sexual condition of all female crayfish was noted.

4.3 Results

4.3.1 Carapace length, total body length and weight relationships

Carapace length and body length were related linearly and both length measurements were related non-linearly with weight (Fig 4.1, Table 4.1)

Table 4.1 Regression coefficients and R^2 values for mathematical relationships between carapace length (cm), body length (cm) and weight (g) of signal crayfish.

Body Length (cm) = a + b Carapace Length (cm)			
	a	b	R^2
Male	0.57	1.82	99.2%
Female	0.62	1.83	99.3%
0+ age group	0.33	1.74	77.1%
All	0.21	1.90	99.8%
Log_e Weight (g) = a + b Log_e Carapace Length (cm)			
	a	b	R^2
Male	-1.51	3.17	93.3%
Female	-2.32	3.61	87.1%
All	-1.91	3.39	91.5%
Log_e Weight (g) = a + b Log_e Body Length (cm)			
	a	b	R^2
Male	-3.76	3.24	93.4%
Female	-5.04	3.74	84.2%
All	-4.41	3.51	90.0%

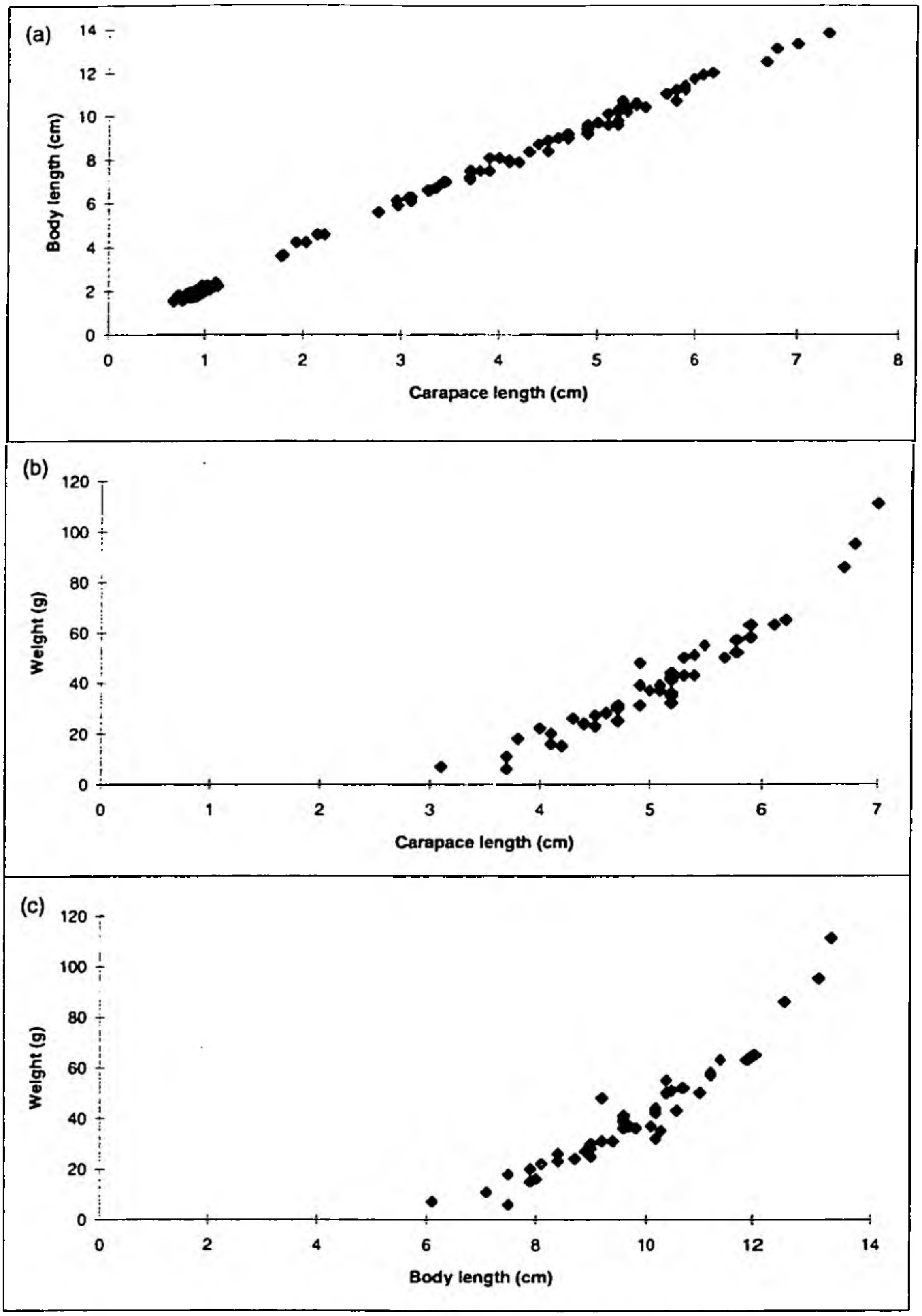


Figure 4.1 Relationships between (a) carapace length (cm) and body length (cm); (b) carapace length (cm) and weight (g); and (c) body length (cm) and weight (g).

4.3.2 Growth of signal crayfish

Sizes of signal crayfish captured by all methods during the year ranged from 0.7 cm (CL) to 8.4 cm (CL) (Fig 4.2a). Crayfish less than one year old were easily separated from the other crayfish by their size in July. However there appears to be an age class that has been undersampled in the size range 1.8 cm (CL) to 2.4 cm (CL) (Fig. 4.2a). These crayfish are too small to be retained in the smallest trap and are too mobile to be taken efficiently in pond nets. However despite low numbers of these being captured it was concluded that they represented a seperate year class since they were too large to be 0+ crayfish and too small to be 2+.

Beyond the size associated with 1+ crayfish no clear size groups are apparent in the size frequency histogram (Fig 4.2a). Thus separate size frequency histograms for male (Fig 4.2b) and female (Fig 4.2c) crayfish were generated. From these and the observed growth of individually tagged crayfish the mean size (CL) and weight of each age class was estimated (Fig 4.3).

Males grew faster than females (Table 4.3) reaching 3.6 cm (CL) in July of their third year compared to 3.3 cm (CL) for females (Fig. 4.3). They also appear to reach a greater maximum size 8.4 cm (CL) compared to 7.8 cm (CL) for females. However females appeared to live longer with the oldest male being 6+ compared to the oldest female estimated at 7+.

Table 4.3 Mean weights (g) for age and instantaeous growth rates (IGR) for male and female signal crayfish

Age (years)	Male weight (g)	Male IGR	Female weight (g)	Female IGR
0.17	0.214		0.214	
1.17	2.03	2.25	2.03	2.25
2.17	12.8	1.84	7.7	1.33
3.17	39	1.12	28.9	1.32
4.17	74	0.64	49	0.53
5.17	105	0.34	68	0.32
6.17	136	0.26	87	0.255
7.17			112	0.250

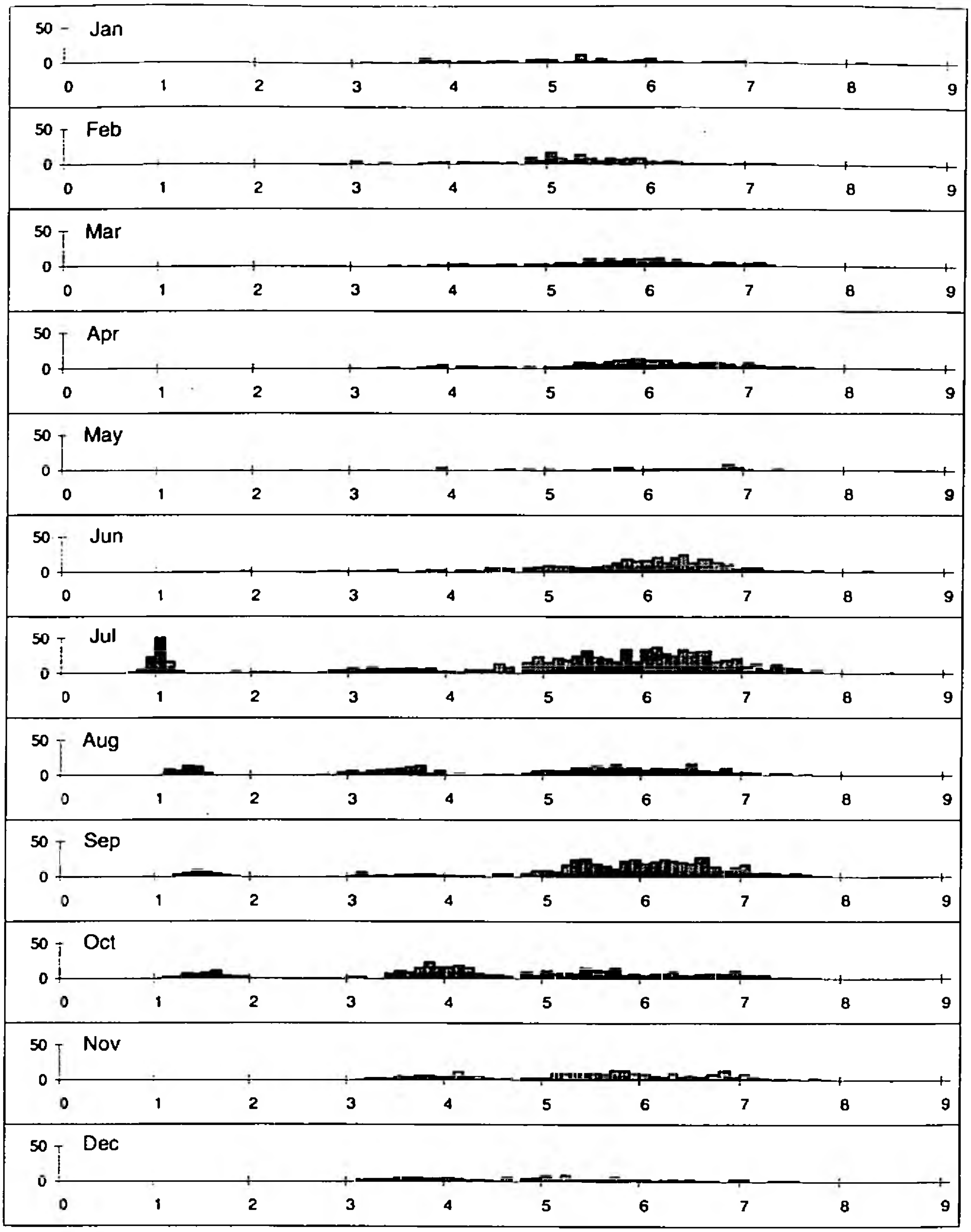


Figure 4.2a Length frequency histograms of all signal crayfish captured by all methods from the River Thame between January and December 1996.

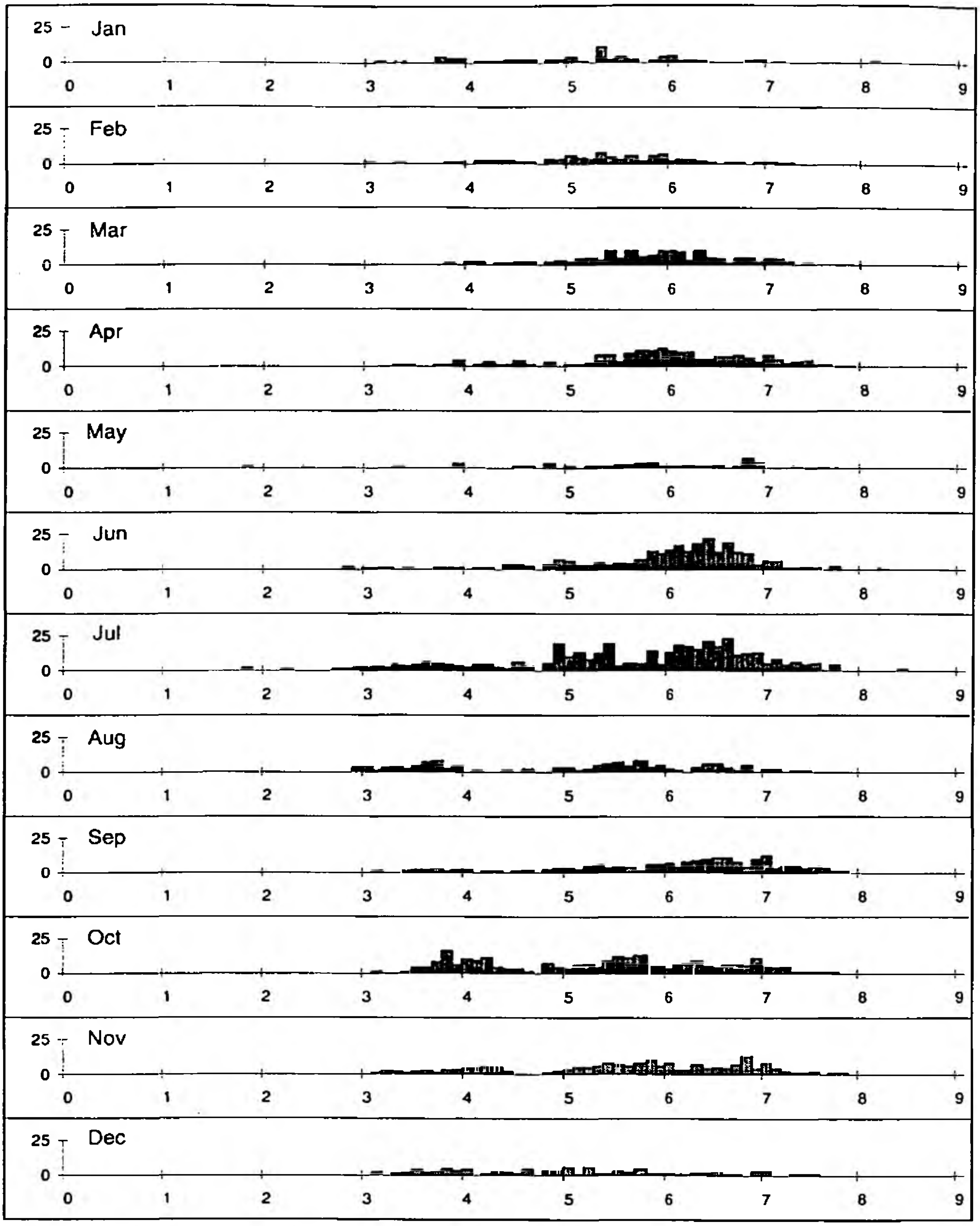


Figure 4.2b **Length frequency histograms of all male signal crayfish (excluding 0+ age group) captured by all methods from the River Thame between January and December 1996.**

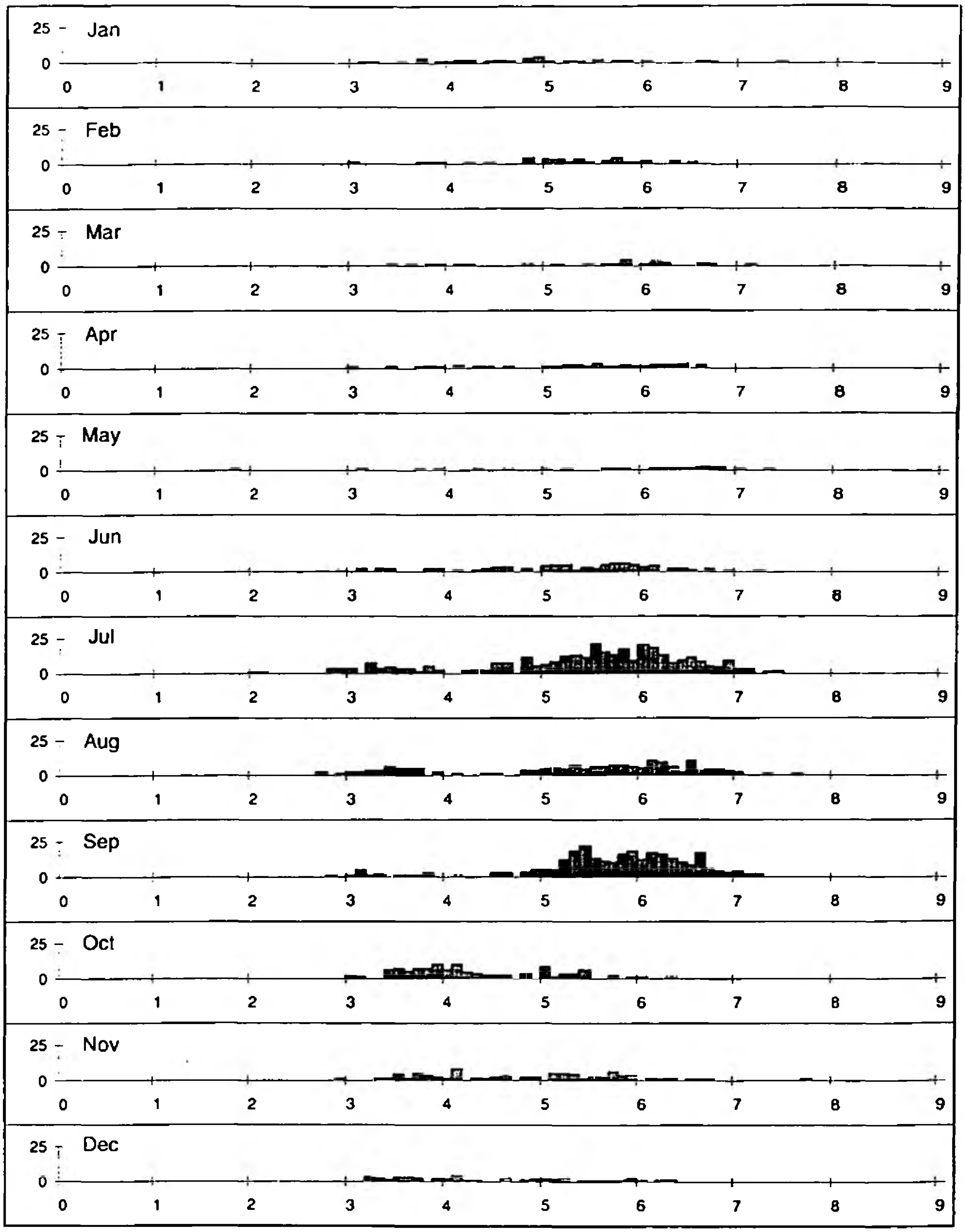


Figure 4.2c **Length frequency histograms of all female signal crayfish (excluding 0+ age group) captured by all methods from the River Thame between January and December 1996.**

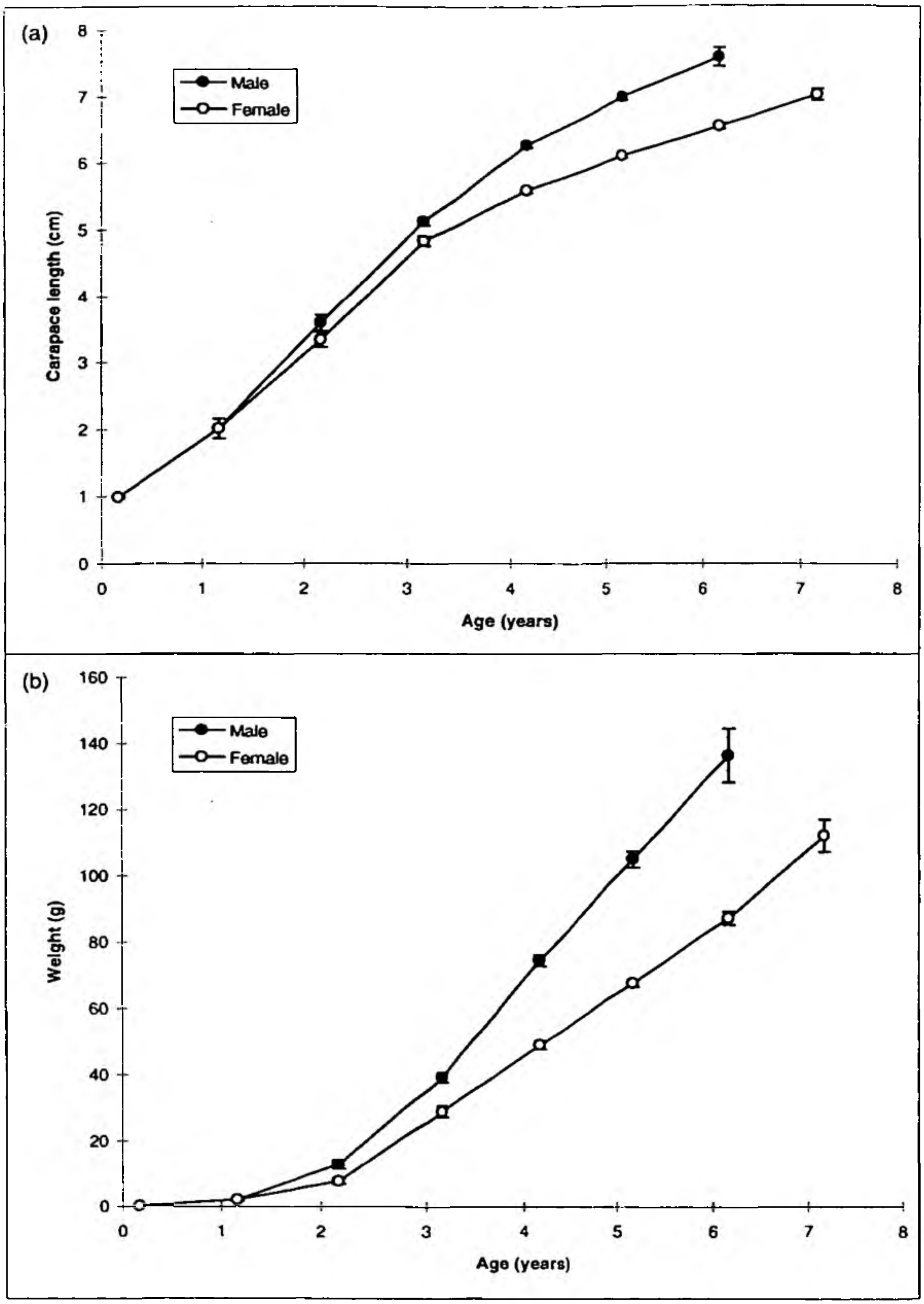


Figure 4.3 (a) The mean length (cm) (CL) and (b) mean weight of male and female crayfish at different ages captured from the River Thame in July 1996. (Eror bars represent 95% confidence limits)

4.3.3 Reproduction and age and size at maturity

Spermatophores and eggs were first observed to be carried by females in early November (Fig 4.4a). This follows a decline in catches in October which is probably due to the synchronised pre-reproductive moult (Fig 4.2a). The smallest captured female found to be carrying eggs was 4.2 cm (CL) and would be in its third year (Fig. 4.4b). As the captured females increase in size the proportion that carry eggs increases from less than 10%, for the smallest captured females, to over 70% at 5.8 cm (CL). Thereafter the proportion of captured females carrying eggs declines as size increases (Fig. 4.4).

Juveniles appeared to leave the females during May, with very few females found to be carrying eggs at this time. Catches of crayfish in May were reduced dramatically, presumably as a result of the synchronised spring moult. No females were found to be carrying eggs in June.

4.4 Discussion

4.4.1 Age and growth of signal crayfish

In comparison to the native crayfish the signal crayfish is a faster growing animal, indeed it may be the fastest growing of the temperate species of crayfish and reaches a greater maximum size than the native crayfish (Lowery, 1988).

Hogger (1984), quoted by Lowery (1988), found signal crayfish had reached 62 mm (CL) after three years in a southern England. There is, however, a wide variation in the growth rate of this species with quoted carapace lengths, at three years, being 28 mm from L. Tahoe, USA (Goldman & Rundquist, 1977), 33 mm from the same place (Flint, 1975), 34 mm in Canada (Mason, 1974), 39 mm in the Sacramento River, USA (Shimizu & Goldman, 1983), 52 mm in USSR (Cukerzis, 1979) and 60 mm in Sweden (Abrahamsson, 1973).

Even in Britian there are variations with carapace lengths after three years being 41.6 mm in the River Great Ouse (Guan & Wiles, 1996) and 51 mm in a southern English lake (Hogger, 1986a). In the present study carapace lengths of 42 mm were achieved after three years.

In general, the growth rate of these crayfish is greatest in populations which have recently invaded an unexploited habitat. Once the population has been established for some time the growth rate starts to decrease, probably as a result of increased density (Hogger, 1986a; b). The population in the River Thame has been established for at least 15 years.

Factors, other than density, that influence growth rate of crayfish include temperature with crayfish from colder latitudes growing more slowly than crayfish from warmer latitudes (Lowery, 1988).

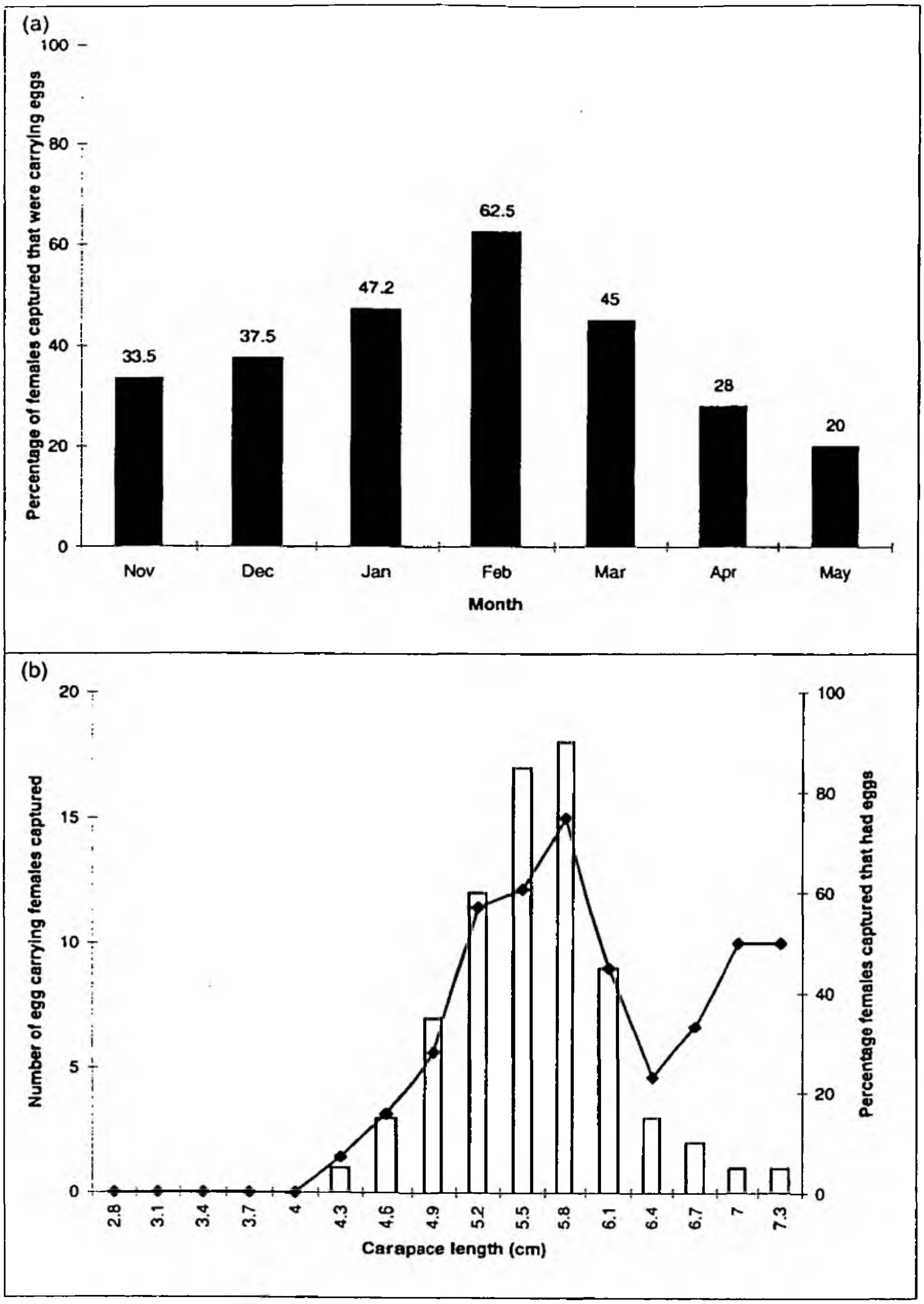


Figure 4.4 (a) Percentage of female crayfish captured that were found to be carrying eggs; and (b) the number and percentage of females of each size group found to be carrying eggs.

With these crayfish reaching a large size, 42mm (CL), within three years, any impact of exploitation on the older and larger sized crayfish is relatively short lived, since the younger age groups will replace those removed in a small number of years. This has implications for the frequency of any planned control measures.

4.4.2 Reproduction

The only data collected which gave information on reproduction of signal crayfish in the River Thame came from trap catches. These catches probably give unreliable information about minimum size and ages that crayfish reach maturity.

Age at maturity varies between populations, with animals usually maturing in their second summer (Lowery & Holdich, 1988). In the colder waters maturity can be delayed until their third or even fourth year. Maturity is dependent on growth rate (Lowery & Holdich, 1988). In the present study the smallest female found to be carrying eggs was 4.2 cm (CL) and was probably in its third year. However, because of the inadequacies of the trapping method of capture, it is probable that smaller and younger female crayfish were mature.

5. THE DENSITY AND BIOMASS OF SIGNAL CRAYFISH IN THE RIVER THAME

5.1 Introduction

It is thought that the signal crayfish have been in the River Thame since the early 1980's. Although the population distribution within the Thame catchment is still very discontinous and limited to the main river below Thame (Ibbotson *et al.*, 1995, 1996) there has been plenty of time for it to establish a mature population in the parts that it has been introduced.

Locally, density and biomass will be affected by both the recent dredging history, the activities of the commercial fisherman as well as the habitat availability (see Section 6) and thus density and biomass will be highly variable between sections of the river.

However a major part of this study was to assess the actual and potential impacts of this signal crayfish population and to determine the impact of the commercial fishery on that population. In order to do this effectively, it is necessary to estimate population density and biomass of this species. Thus, in 1996, density and biomass were estimated in both an exploited and unexploited reach of the River Thame.

5.2 Methods

A description of the sites used and the sampling regime is given in Chapter 2.

5.2.1 Tagging procedure

In each of the two reaches crayfish were captured monthly and either tagged with individually numbered tags or given date coded pleopodal or uropodal clips.

In subsequent months the numbers of recaptured tagged and clipped crayfish were recorded and because of the individual numbering and date coding it was possible to assign each recapture to a month of original capture.

5.2.2 Estimation of population density and biomass

Clipping of pleopods and uropods is a well established technique for marking mass numbers of crayfish. The clips are easy to observe and will remain in the same condition until moulting occurs. The clips are relatively minor and are therefore unlikely to impact on crayfish behaviour and it can be assumed that they will both mix freely with the unclipped population and have an equal chance of recapture. There will be clip loss as the animals moult, but these minor clips are unlikely to have a significant impact on mortality.

The use of streamer tags to mark crayfish, however, is not a well established technique and we cannot be certain of the efficiency or impacts of these tags. Certainly the positioning of them behind the carapace means that they are unlikely to interfere with crayfish mobility or their ability to enter traps. A potential problem is that the tags may fall out almost immediately they are inserted. Inspection of recaptured animals with tags showed that tags which had remained in the animal for at least one month were encased in a chitin sheath and were extremely difficult to remove, but until this sheath has been built the tags may be susceptible to easy loss.

This technique was adapted from the use of these tags in lobsters which grow to a much larger size. In comparison the muscular space above the dorsal abdominal artery is quite small in crayfish and there is a risk with insertion of this type of tag that the artery could be ruptured. However, provided the insertion was done with care and only relatively large animals were tagged in this way there is no reason to believe that this technique would add significantly to mortality.

It is possible that with an external tag a crayfish would become more susceptible to predation, but the tags used were dark blue in colour and were not very conspicuous. And since crayfish forage chiefly at night it was thought that the visibility of the tags was unlikely to have an impact on mortality rates through differential predation pressures.

In estimating population abundance we assumed that the total crayfish population in each reach was constant throughout the year. Obviously this was not the case because of annual mortality, migration and in the exploited reach, the impacts of the fishery. However, this assumption is the equivalent of averaging the population estimates from each month. This was the preferred method for estimating population because the rate of tag and clip recaptures was low on a monthly basis resulting in huge variations in inter-month estimates of population.

The smallest crayfish captured was 2.7 cm (CL) and thus all estimates of population density and biomass refer to crayfish equal to, and larger than this size.

Estimates of population abundance were made from recaptures of tagged and clipped crayfish assuming that the number of tagged or clipped individuals, $m_i(t)$ (where i represents a month of tagging or clipping) in each reach will decline over time as a result of migration from the study reach, mortality and tag or clip loss. Assuming that a constant proportion of tagged individuals is lost per unit of time, m(t) decays exponentially (equation 1).

$$m(t) = m(0)e^{-\lambda t} \qquad 1$$

where m(0) is the number of tagged individuals at time zero.

If $f_{ij}(t)$ represents the fraction of individuals re-captured in month j which were tagged at time i then:

$$f_{ij}(t) = \frac{r_{ij}}{c_j} = \frac{m_i}{N}e^{-\lambda(j-i)} \qquad 2$$

where r_{ij} is the number of re-captured individuals at time j which were tagged or clipped in month i and c_j is the total number of crayfish captured in month j. The values used for $f_{ij}(t)$ for each (j-i) interval were mean values over the 12 month period. Means were not used unless more than five individual measures contributed to them, otherwise it was considered that these means could be influenced disproportionately by the chance recapture of individual crayfish.

Re-stating equation 2 gives:

$$\frac{r_{ij}}{m_i c_j} = \frac{1}{N} e^{-\lambda(j-i)} \qquad 3$$

and then taking natural logarithms of both sides of equation 3:

$$\ln\left[\frac{r_{ij}}{m_i c_j}\right] = \ln\left[\frac{1}{N}\right] - \lambda(j-i) \qquad 4$$

A plot of $\ln[r_{ij}/m_i c_j]$ against (j-i) therefore has slope $-\lambda$ and intercept $\ln[1/N]$. Linear regression was used to calculate two values of λ and N (± 90% CL) for each reach using the recaptures of tagged and clipped crayfish separately. Independent calculations of equation 4 were made for males and females, as well as for total numbers of crayfish.

Regressions of $\ln[r_{ij}/m_i c_j]$ on (j-i) are plotted for both tag and clip recaptures in Figs 5.1 and 5.2, where the slope of the regression line represents the rate of loss of tags or clips and it's intercept of the y axis is the estimate of the population size.

Since, the population size estimated from the recaptures of tagged crayfish should be the same as that estimated from the recapture of clipped crayfish, any difference in the point of intercept of the y axis will be due to differential loss rates of tags and clips during the month immediately after tagging or clipping..

5.2.3 Estimation of migration rates

It is possible for the crayfish to migrate between the exploited and unexploited reaches, and this movement could bias the population estimates if there was a net movement of clipped or tagged crayfish from one reach to the other. This could not be detected in the clipped crayfish since there was no way of knowing which reach each recapture had originated from. However, of all the individually tagged recaptures made in the two reaches none had come from the other reach. Thus, for the purposes of population estimation, it was assumed that none of the clipped or tagged crayfish had migrated between the two reaches. This was in spite of evidence that this migration did occur from reported catches of tagged crayfish by the commercial fisherman (see Section 8).

It is also worth attaining some measure of migration rate to gain an impression of the activity of these animals. To do this all individually tagged recaptures from the routine monthly trapping were traced back to their original point and time of capture. Then migration rate is equal to:

$$\sqrt{d^2} \qquad 5$$

for each (j-i) interval, where d is equal to the distance travelled in metres between captures.

Since there were only enough recaptures to estimate migration rate for the time interval of one month, migration has only been estimated for recaptures made one month from the time of release.

5.3 Results

5.3.2 Estimation of population density and biomass

In the unexploited reach a total of 757 crayfish were tagged and 1,022 were clipped during the course of the year (Table 5.1). In the exploited reach the corresponding numbers were 238 and 391 respectively. The lower numbers of crayfish marked in the exploited reach represented the lower numbers of crayfish captured not preferential marking in the unexploited reach. Recaptures of both tagged and clipped crayfish were generally low with 51 tagged and 77 clipped crayfish recaptures being made in the unexploited reach and only 3 tagged and 9 clipped being made in the exploited reach (Table 5.1)

Table 5.1 Number of signal crayfish captured (all methods) in an unexploited and exploited reach of the River Thame in each month, together with total numbers of recaptured tagged and clipped crayfish in that month.

	Unexploited reach			Exploited reach		
Month	Total number captured	Number of clipped recaptures	Number of tagged recaptures	Total number captured	Number of clipped recaptures	Number of tagged recaptures
January	251	--	--	21	--	--
February	92	0	0	30	0	0
March	154	0	1	13	0	0
April	174	6	3	49	0	1
May	52	2	1	23	2	0
June	226	6	6	109	2	0
July	471	13	11	148	1	1
August	188	3	4	103	0	0
September	436	10	12	59	1	0
October	267	11	6	84	1	0
November	221	17	5	44	1	1
December	88	9	2	52	1	0

The generally low numbers of tag and clipped recaptures particularly for females and for tags in the exploited reach meant that linear regressions for estimating λ and N, could only be completed for clipped males and combined sexes in the two reaches and only for tagged males and combined sexes in the exploited reach (Fig. 5.1).

The rate of loss of both the tags and clips could only be estimated from the period one month after the tags and clips were made. The rate of loss of these marking techniques within one month of the date of marking is not known. That is we do not know what the rates for tag retention, migration and mortality are during the first month after marking.

Using the data for combined sexes in the unexploited reach (Fig 5.2a) it can be seen that the rate of loss, post one month, for tagged and clipped crayfish is identical (-0.39). However, although the lines are parallel they have different intercepts which means that the rate of loss for the two types of marking techniques differ at some stage in the first month.

This difference has been assigned to streamer tag loss immediately after tagging. It is unlikely that clips would not be observed after only one month and that clipping would impact on mortality or migration and therefore it is assumed that the rate of loss for this type of marking remains constant from the day they were marked. If this assumption holds it is estimated that 65% of the individually numbered tags are lost within the first month, before they become coated in a chitin sheath. The mechanism of loss is not known.

Therefore, population estimates for both reaches are only presented using the data from the clipped recaptures and the individually tagged crayfish recaptures were only used for estimates of migration rates.

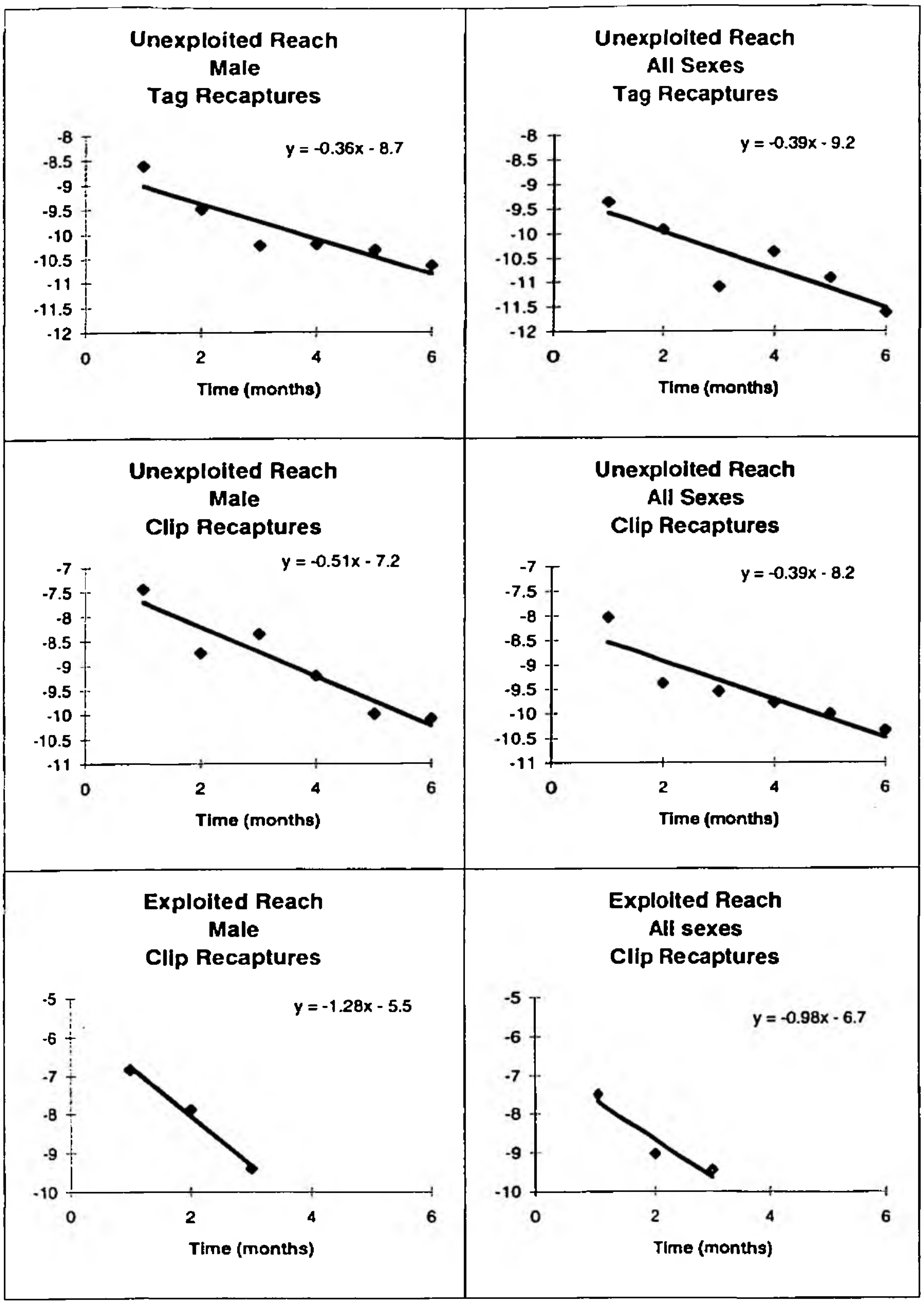


Figure 5.1 The rate of loss of tagged and clipped crayfish in an exploited and unexploited reach of the river Thame. The y axis is $\ln[r_{ij}/m_ic_j]$ (see text for explanation).

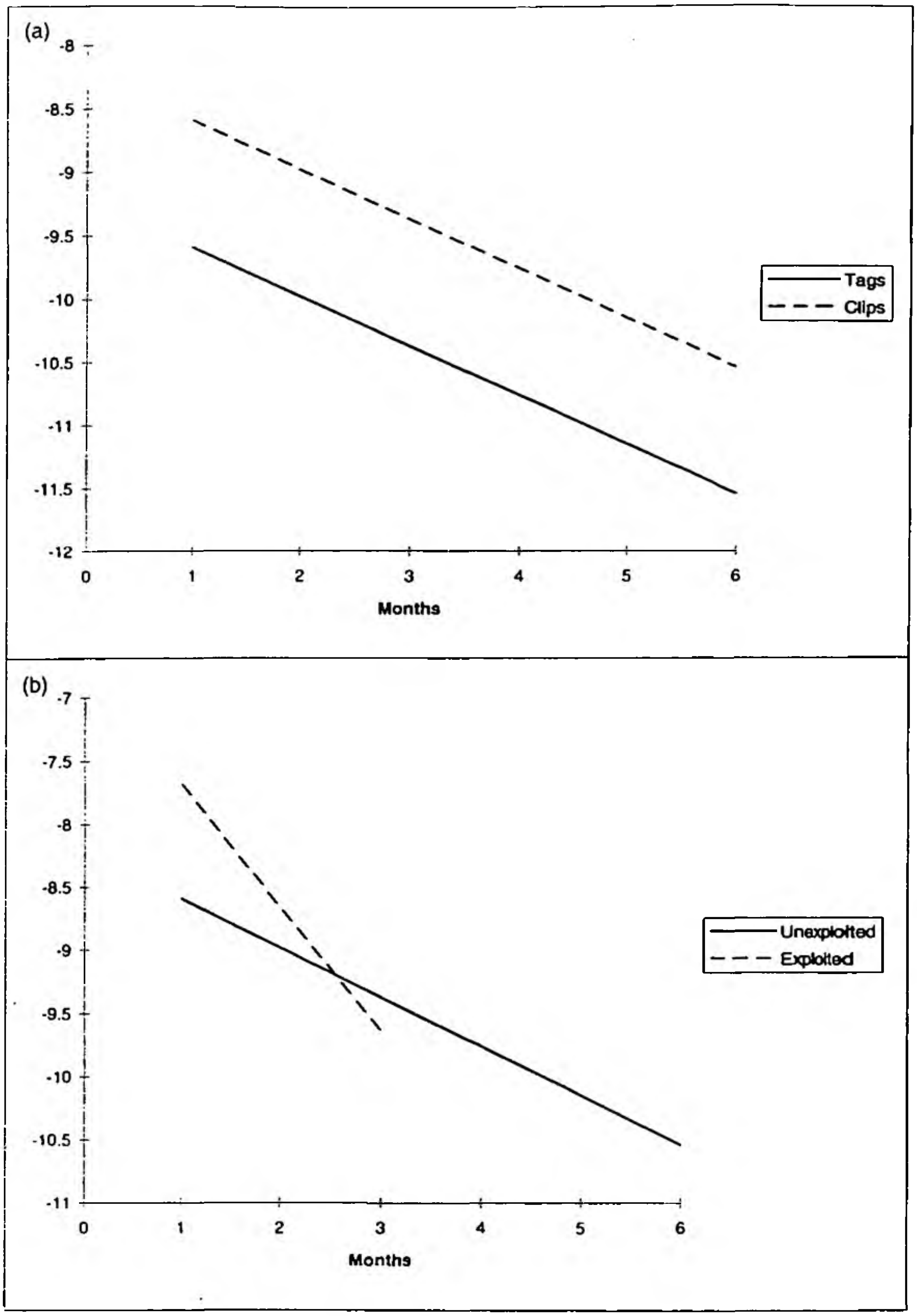


Figure 5.2 (a) Decay rates for tagged and clipped crayfish as estimated from recaptures; (b) decay rates for clipped crayfish in an exploited and unexploited reach. The y axis is $\ln[r_{ij}/m_i c_j]$ (see text for explanation).

Population estimates for the two reaches were 3,458 ± 3,303 (90% C.L.) crayfish larger than 2.7 cm (CL) per 600 m of length of river in the unexploited reach and 818 ± 2,329 (90% C.L.) crayfish of the same size per 600 m of length of river in the exploited reach. The average weight of a crayfish over 2.7 cm (C.L.) is 51 g and the area of the unexploited and exploited reaches were 4,000 m^2 and 4700 m^2 respectively. This equates to a population density of 0.86 (44g) crayfish per m^2 and 0.17 (8.9g) crayfish per m^2 in the unexploited and exploited reaches respectively.

5.3.3 Estimation of migration rates

The distance travelled by each individually tagged crayfish recaptured is recorded in Appendix E. The majority of crayfish did not migrate large distances and it was common to recapture individuals in exactly the same place they were released even after several months.

Using equation (5) migration rate was estimated to be 146 m $month^{-1}$.

5.4 Discussion

5.4.1 Recaptures of clipped and tagged crayfish

The recaptures of clipped and tagged crayfish was disappointingly low. This was particularly the case for the tagged crayfish. In part, the low recaptures of clipped and tagged crayfish was due to the high rate of tag loss from either natural mortality, clips and tags disappearing, migration or fishing mortality. However the biggest single cause of the low number of recaptures was, most probably, that only a very small proportion of the crayfish population was sampled by the traps in each month.

The apparent high immediate loss rate for the individually numbered tags needs to be tested experimentally, in controlled conditions. It is possible that because the tags used were normally used on adult lobsters they were too large for the size of animal tagged in this case. The needle diameter may have been so large that it damaged the tissue resulting in the tag being ejected. These types of tags have great potential for marking crayfish in their natural environment, because they are easy to observe and thus all animals do not have to be checked as with other internal tags such as PIT tags; and once they have been in long enough for the animal to build a chitin sheath around them they appear to survive through at least two moults and possibly survival through future moults is very high. Smaller versions of these tags could be tailored so that they operated more effectively.

5.4.2 Signal crayfish population density and biomass

Guan & Wiles (1996) estimated density and biomass in a riffle and pool of the River Great Ouse. Although, density and biomass were not measured in different habitats in the present study they produced very similar results with 0.86 crayfish per m^2 compared to 0.8 m^2 for the study of the Ouse and 44 g m^{-2}, compared with 37 g m^{-2} in the Ouse. Hogger (1986), estimated density to be 1.8 m^{-2} in an enclosed pond in southern Britain.

Estimates in other habitats range from 0.9 to 1.07 m^{-2} in Lake Tahoe (Abrahamsson & Goldman, 1970; Flint, 1975), which compares with a density of 0.16 m^{-2} in a riverine environment (Abrahamsson & Goldman, 1970; Flint, 1975; Flint & Goldman, 1975). In a gravel pit lake in France estimates ranged from 4.2 to 7.3 m^{-2} for a population that had been introduced (Laurent & Vey, 1986).

Thus the population in the River Thame is at the higher limits of population density and biomass experienced in riverine environments but lakes can occasionally produce higher densities.

The much lower density experienced in the exploited reach is the result of the direct effects of the fishery and this is discussed more fully in Section 8.

5.4.3 Estimates of migration rates

Migration of the signal crayfish is important for two reasons. Firstly, it is the mechanism by which the signal crayfish will colonise areas, within the same catchment, that it is currently absent from. This includes large parts of the Thames catchment and areas where the native crayfish is still present. Secondly, it has been observed to contribute a significant portion of the catches in a static commercial fishery.

Unfortunately, the low number of individually tagged crayfish that were recaptured in this study made accurate estimation of migration rates difficult, and the figure of 146 m $month^{-1}$ should be regarded with some caution. In a study on home range of the signal crayfish in the River Great Ouse Guan & Wiles (1997) found that adult signal crayfish only migrated a maximum of 250 m from a point of release even after two years. This suggests a much lower migration rate than that found in the River Thame.

A greater understanding of the factors that influence migration rates in this animal is needed, since the migration rates recorded in the River Thame suggest that signal crayfish could colonise rivers at the rate of 2 km $year^{-1}$ in an upstream and downstream direction, whereas this rate would be much lower using the data from Guan & Wiles (1997). In particular an understanding of the influence of density, commercial crayfisheries and habitat on migration would result in the greatest management benefits.

6. RELATIONSHIP BETWEEN CRAYFISH DISTRIBUTION AND HABITAT

6.1 Introduction

Section 3 describes the environmental variables recorded for the current study. In that section they are used to compare the differences and similarities between the reaches selected for study. The present section deals with the effect that these variables have on signal crayfish distribution.

Amongst factors shown to control the abundance of native crayfish have been the steepness of the channel banks, the presence of riparian shrubs and trees and the extension of their roots into the water (Smith *et al.*, 1996). It is not known whether the signal crayfish has similar habitat requirements to the native crayfish but knowledge of these would help management of habitat to favour one species over another.

6.2 Methods

6.2.1 Survey of each trapping station

Section 3 describes the methods for collecting the environmental variables. In summary, standard RHS techniques (NRA, 1995) were modified to record environmental variables at each trapping station in May. A reduced survey was completed in September when vegetation types were recorded at each trapping point.

6.2.2 Monthly surveys of trap position

Throughout the year, each time a trap was set, the depth, distance from the nearest bank and distance of the trap from the nearest example of each of a range of different substratum types and aquatic macrophytes were recorded.

6.2.3 Exploration of environmental variables and crayfish distribution

The combination of the two methods of collecting environmental data produced 65 variables. These were mostly taken from the modified RHS technique completed in May. The monthly survey of the trap positions produced no additional data deemed to be of any value with the exception of distance of trap from the nearest bank and this was the only variable extracted for use in this study.

Initially a simple regression analysis on the numbers of crayfish at each trapping station in May and all the variables recorded during that month was completed, as well as on the numbers of crayfish and the macrophyte types in September. This exploratory analysis generated no significant relationships between crayfish number and environmental variable (Appendix C).

However crayfish were collected in every month between January and December (Fig. 6.1 a-f) and it was considered that the distribution may respond variously to different environmental variables throughout the year. Although, the environmental variables were collected in May some of these (e.g. aspect) were of a permanent nature and would remain identical in any month of the year. Some others (e.g. depth) would vary from month to month but each trapping point would retain the same relative depth to other trapping points. Therefore it was decided that both these types of variables could be used to explore relationships between crayfish distribution and environmental variable. A large number of other variables that would vary unpredictably between months and variables that had the same value, or showed very little variation between most trapping stations were rejected from the analysis.

In total 15 variables were deemed suitable for further analysis with monthly crayfish catches. The selected variables were left bank profile and slope, right bank profile and slope, right bank aspect and percentage of gravel and pebbles, flow type, depth, width, percentage of shading and distance of the trap from the bank side. In addition, number of macrophyte types, percentage cover of macrophytes in May and September and change in total macrophyte cover between these months were included as measures of the habitat diversity and variation with time (Appendix C). All environmental variables were tested for correlations.

The dependent variables (crayfish statistics) used in the regression analysis included the numbers of crayfish, numbers of males, numbers of egg carrying and non-egg carrying females and mean sizes of crayfish. Each month's catches were treated separately.

The results of simple regressions for the crayfish population in both the exploited and unexploited reaches is presented in Appendix C. However, since any significant regressions in the exploited reach are likely to be heavily impacted by the exploitation, it was decided that only the results from the unexploited reach would be presented in the main body of this chapter.

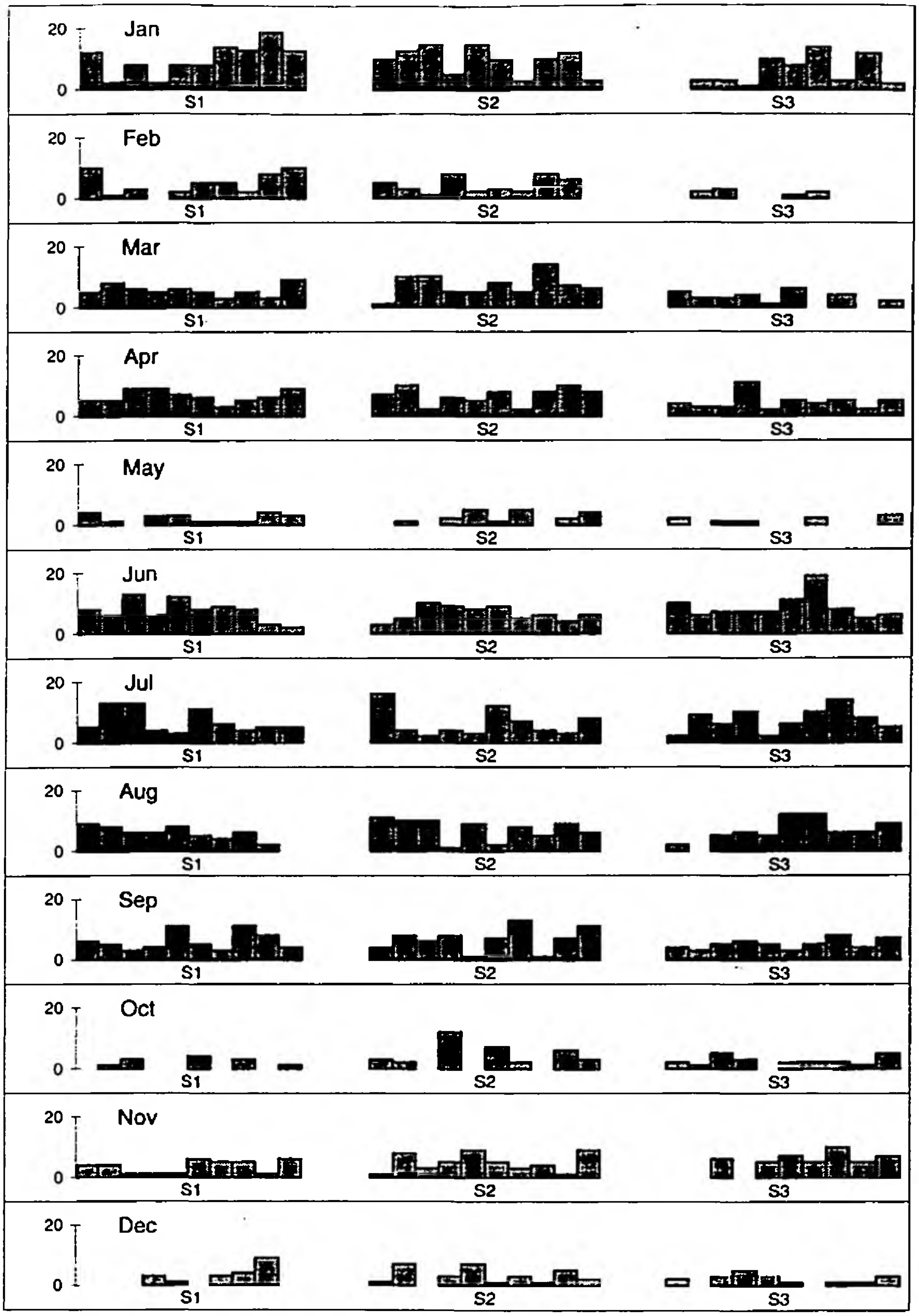


Figure 6.1a **The total number of crayfish captured at each of ten trapping points, at each of three sites (S1-S3) in each month in the unexploited reach.**

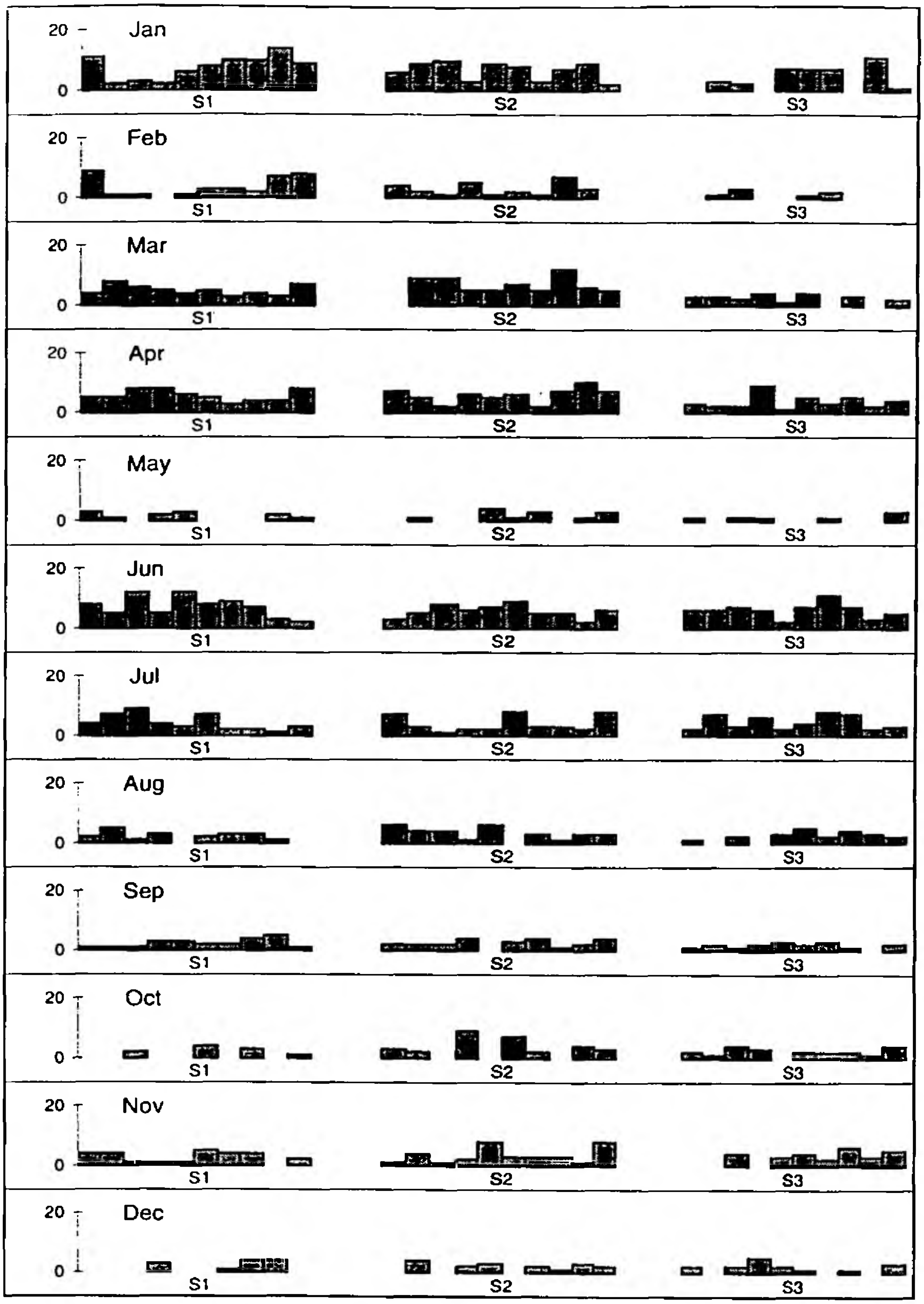


Figure 6.1b The number of male crayfish captured at each of ten trapping points, at each of three sites (S1-S3) in each month in the unexploited reach.

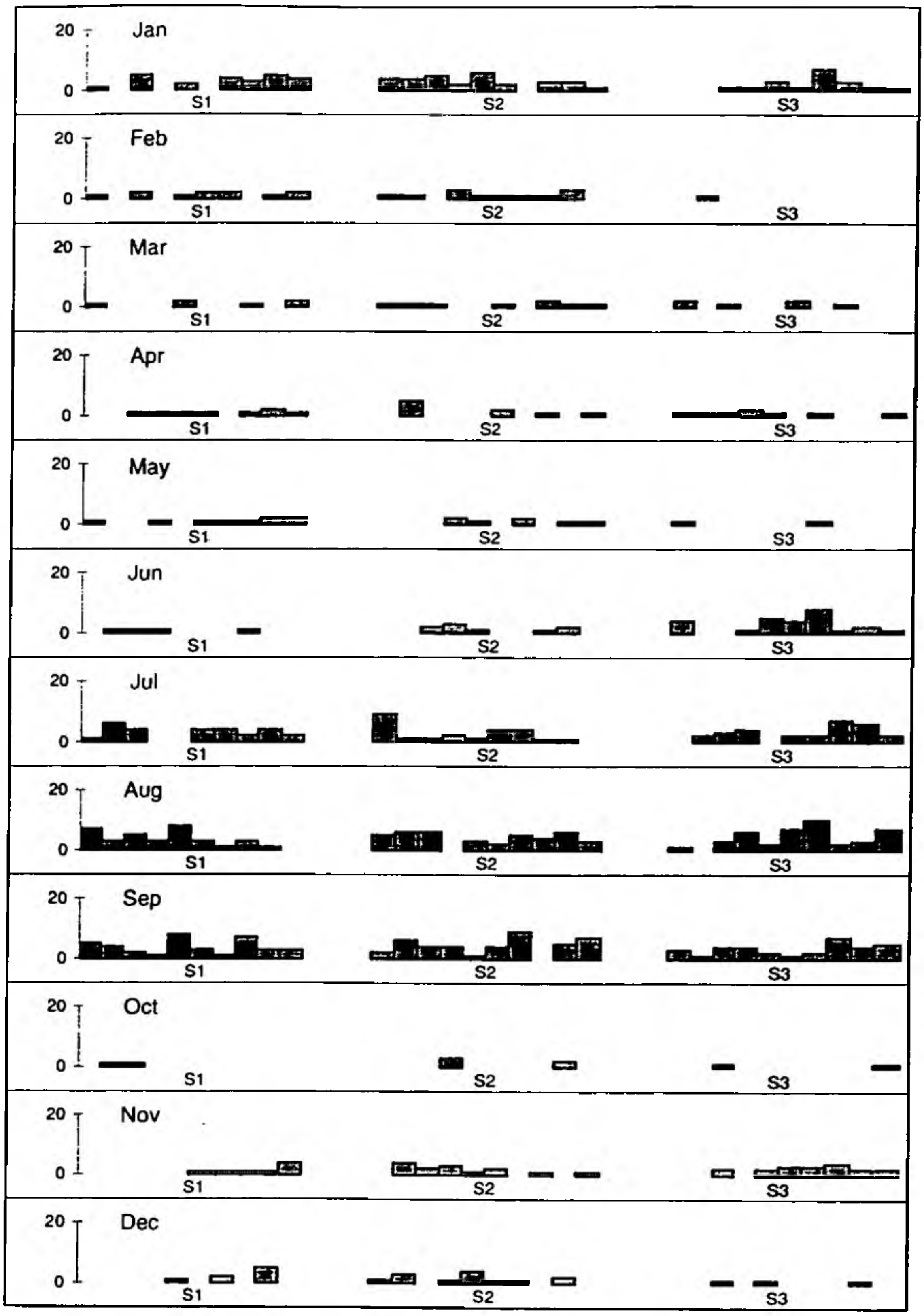


Figure 6.1c The number of female crayfish captured at each of ten trapping points, at each of three sites (S1-S3) in each month in the unexploited reach.

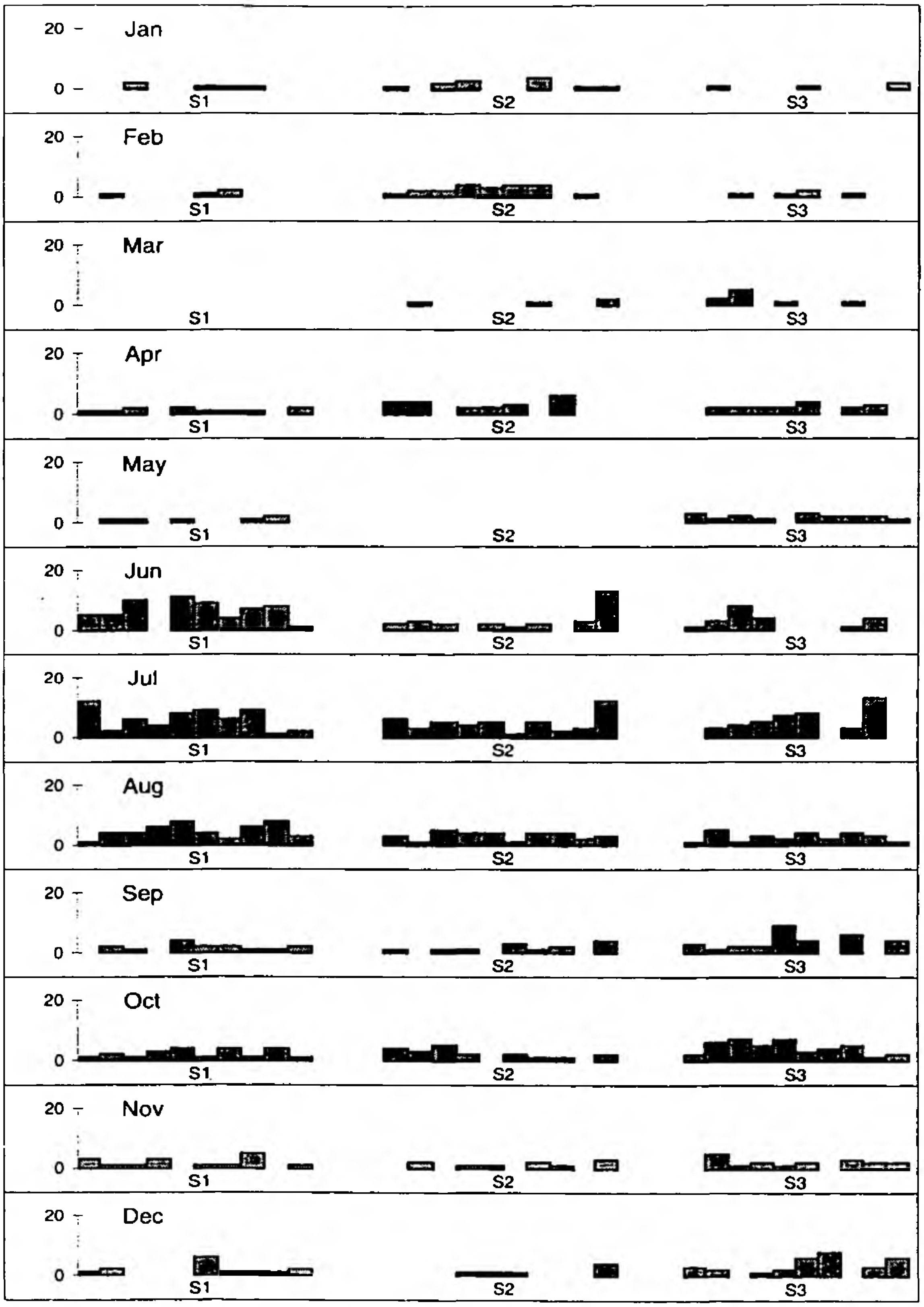


Figure 6.1d **The total number of crayfish captured at each of ten trapping points, at each of three sites (S1-S3) in each month in the exploited reach.**

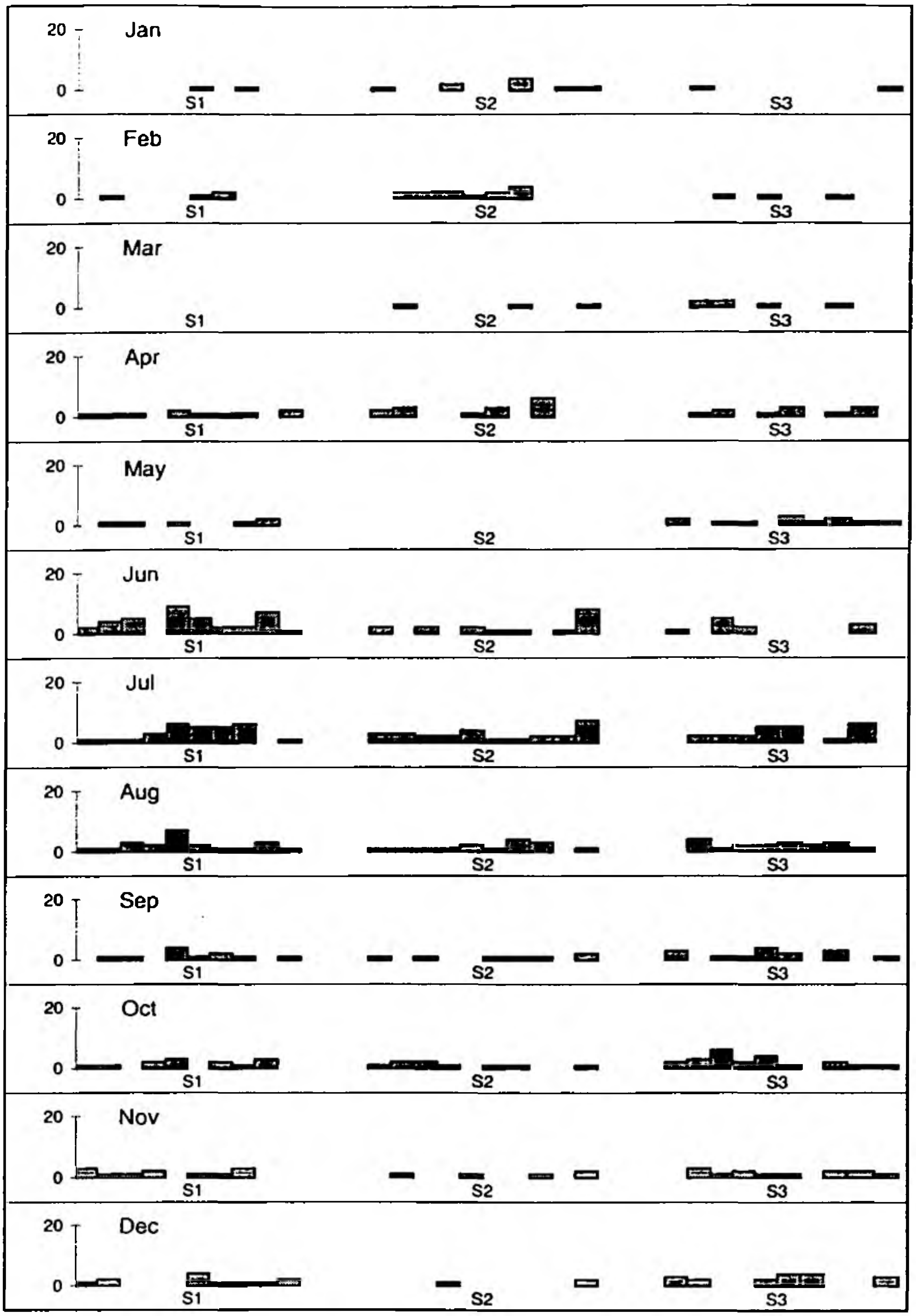


Figure 6.1e The number of male crayfish captured at each of ten trapping points, at each of three sites (S1-S3) in each month in the exploited reach.

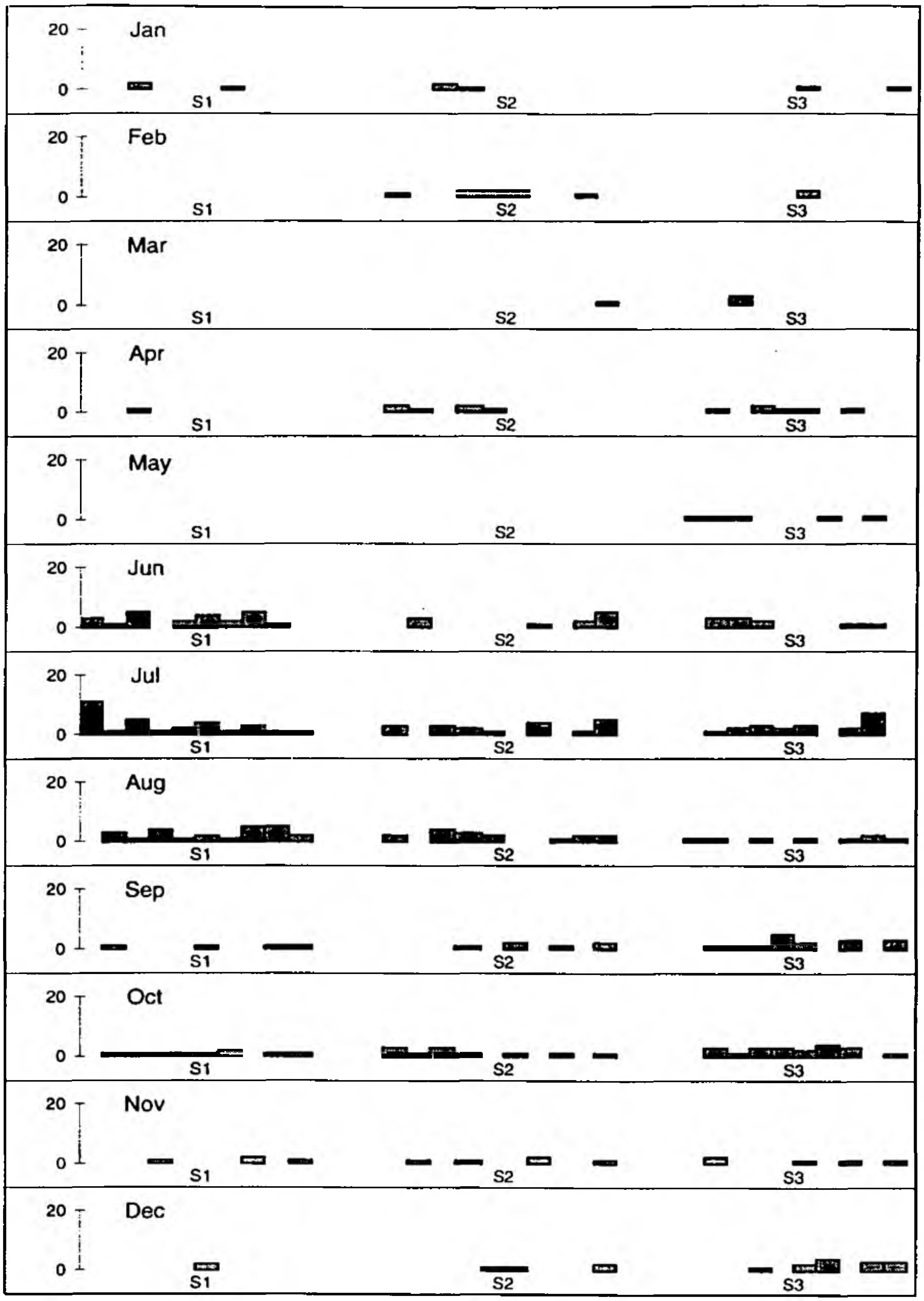


Figure 6.1f The number of female crayfish captured at each of ten trapping points, at each of three sites (S1-S3) in each month in the exploited reach.

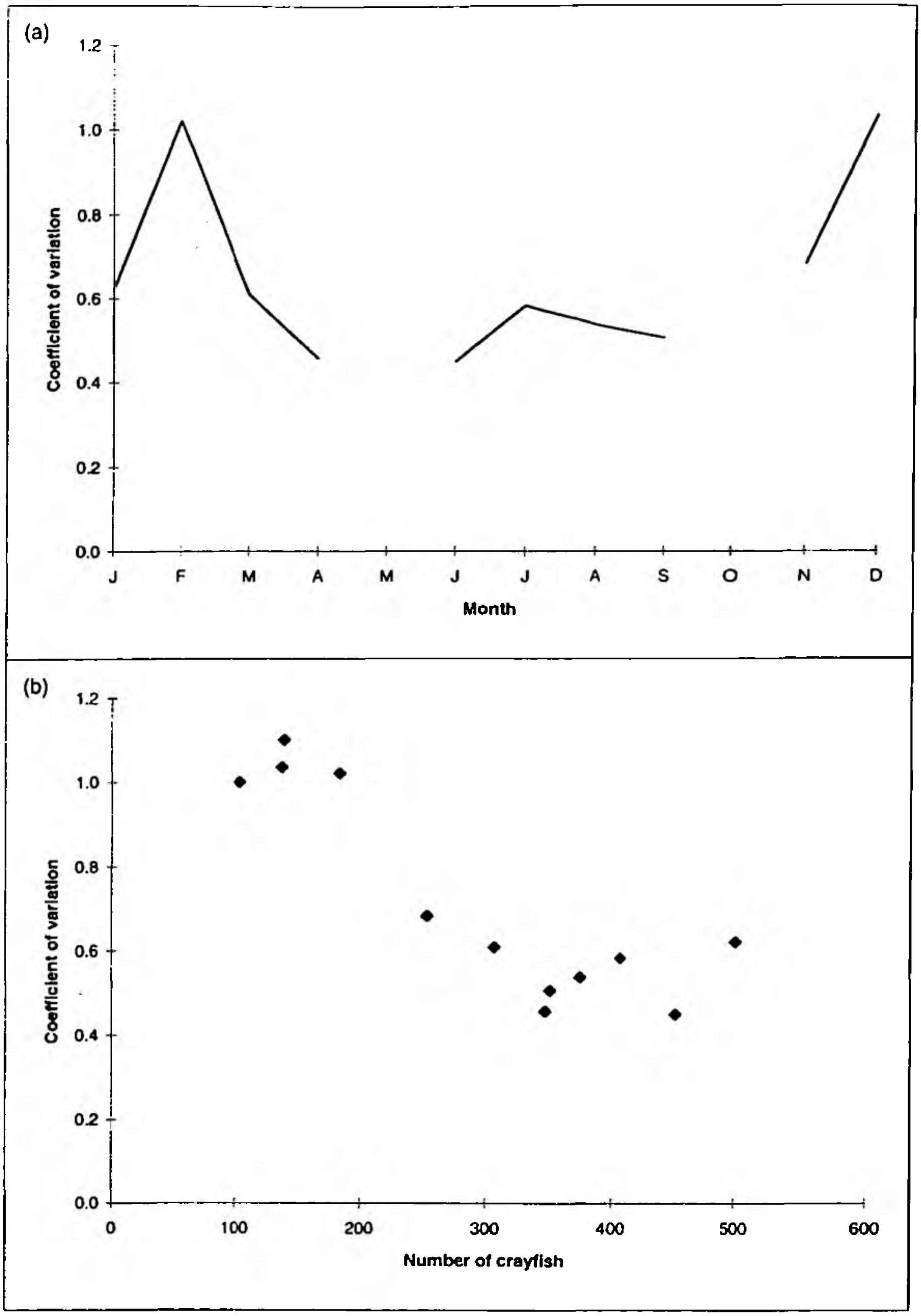


Figure 6.2 (a) Coefficient of variation of numbers of crayfish captured in each transect of the unexploited reach in each month;
(b) plot of coefficient of variation against total numbers of crayfish captured in the unexploited reach in each month.

The monthly catches of crayfish in the unexploited reach (Fig. 6.1a) give a visual impression that the crayfish are much more evenly distributed through the reach during the summer months (June-September) than in the winter months. This was tested by calculating the coefficient of variation of trap catches in each month (Fig. 6.2). The months of May and October were omitted from this analysis because these were the periods associated with synchronised moults and crayfish catches were low. The coefficient of variation of mean catches tended to be lower during the summer months (Fig. 6.2a) suggesting that the crayfish catches were more evenly distributed throughout the reach during this period. However, the coefficient of variation also correlated negatively with trap catches (Fig. 6.2b) making it difficult to separate the influence of season and the numbers of crayfish captured on the coefficient of variation.

Despite this, it was decided to perform a separate analysis on the crayfish catches from the winter months independently, when their distribution was less even and more likely to be related to habitat variability. The months January to April 1996 were selected for this process. Those in November and December 1996 were omitted since they come from a different winter season.

6.3. <u>Results</u>

6.3.1 Crayfish distribution in relation to environmental variables

There were not many consistent, and therefore convincing, significant relationships between crayfish distribution in each month and the environmental variables, in any months after April (Appendix C). However significant relationships were found consistently in the months January to April for aspect, depth, width, percentage of macrophyte cover, number of macrophyte types in May and the change in macrophyte cover between May and September (Appendix C)

When these were regressed with the total number of crayfish captured between January and April 1996, significant R^2 values were found (Appendix C; Fig. 6.3).

6.3.2 Crayfish size in relation to environmental variables

There is some evidence that the average size of the crayfish found in the traps was related to shading and bank profile (Appendix C). However these were very weak relationships dependent on one point. When this point was removed these relationships were no longer significant and they are not considered further.

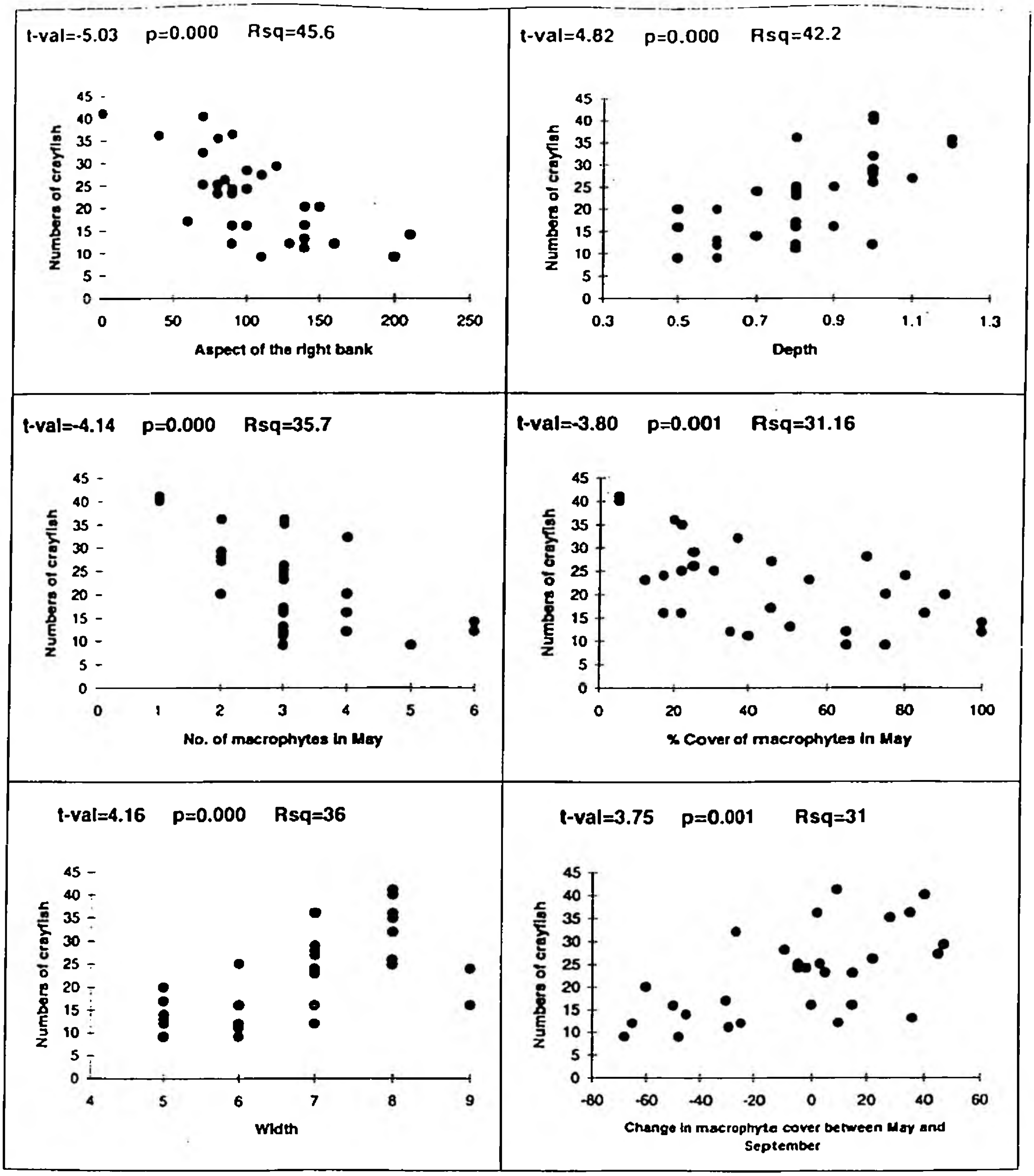


Figure 6.3 Significant regressions for the total number of crayfish captured between January and April 1996 and measured environmental variables.

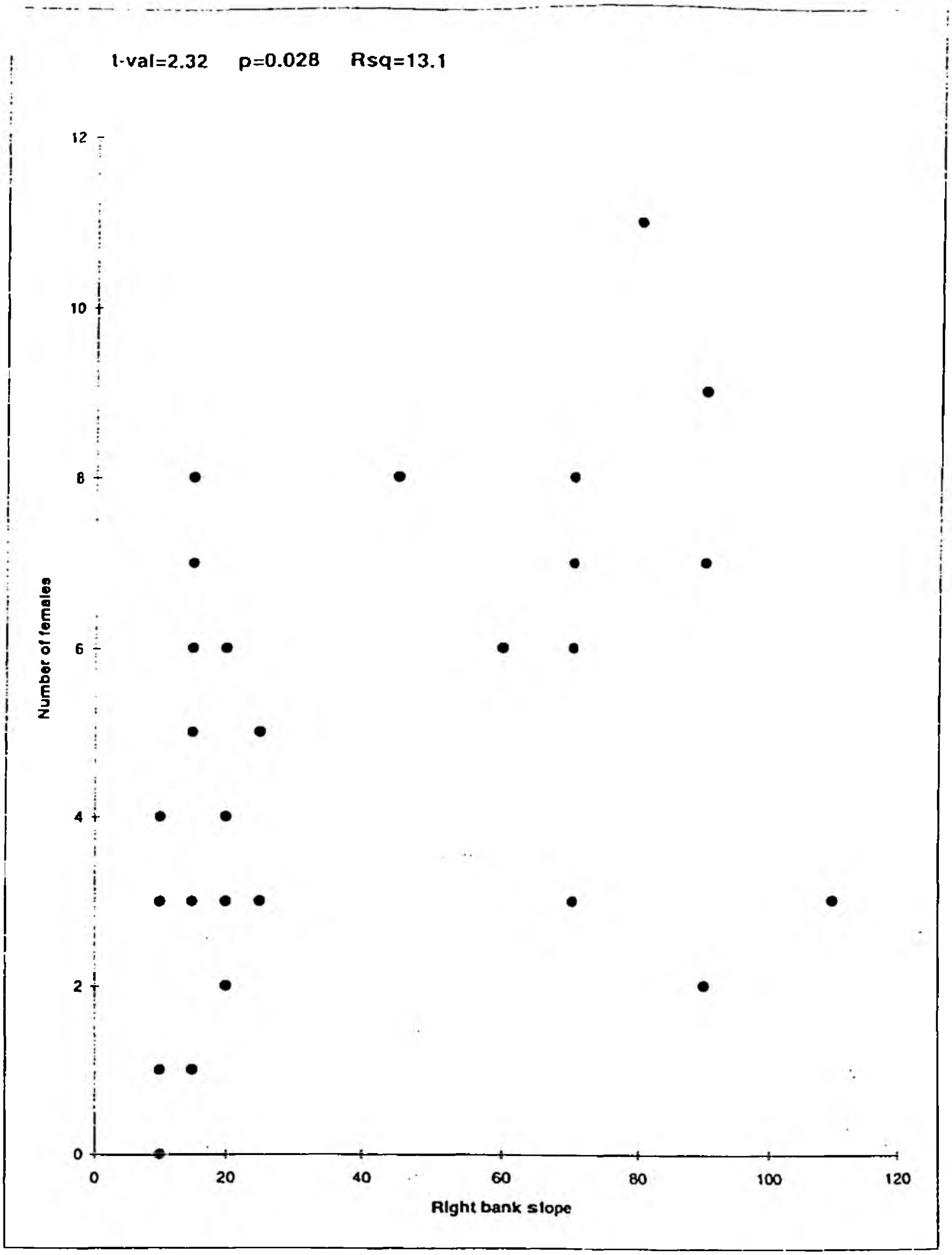


Figure 6.4 **Relationship between number of females captured between January and April 1996 and the slope of the river bank.**

6.3.3. Correlations amongst environmental variables

Many of the environmental variables correlated significantly with one another (Appendix C), including the variables found to have significant relationships with crayfish number which all correlate with one another.

6.4 Discussion

In the present study very little of the variation in crayfish distribution or abundance could be explained by the measured physical environmental variables. Only crayfish distribution during the first four months of the year appeared to be influenced by any of the measured variables. These were six in number and were aspect, depth, width, percentage of macrophyte cover in May, the number of macrophyte types in May and the change in percentage cover of macrophytes between May and September.

The problem is that selecting which of these is responsible for influencing crayfish distribution, if any, is difficult because they are all correlated with one another. This study was completed in a relatively homogeneous section of river with a high signal crayfish population level. In a study of the importance of habitat features this reach would ideally be one of many study reaches from which observations came.

Another problem, and the one that is probably responsible for the generally poor response of crayfish abundance to any environmental variable, is that the method of capturing crayfish was by baited trap which may attract individuals from a wide area of river outside the trapping transect.

Similar problems arise when the average size of crayfish captured is compared to the environmental variables in the locality in which they are captured. This is because large crayfish exclude small crayfish from the traps and since it is likely that baited traps attract crayfish from a significant distance the average size of crayfish found in the traps will reflect the size of the largest crayfish in the area of attraction. It is interesting that the most noticable size differences were between the exploited and unexploited reaches, smaller crayfish being being found in the exploited reach (see Section 8). This is the result of the large crayfish already being removed by the commercial fishermen, allowing the remaining smaller individuals free access to the baited traps.

However, despite these problems there were some relationships between crayfish abundance and habitat variable during the first four months of the year. More success in detecting influence of habitat may have been achieved because of the lower level of activity of the crayfish in the colder months. Additionally, there was greater variation in the trap catches in that period (Fig. 6.2a).

Amongst habitat variables that have seemed to influence distribution of signal crayfish and other crayfish species, other authors have reported steepness of the channel banks, the presence of riparian shrubs and trees, and the extension of their roots into the water (Smith *et al.*, 1996), substrate type (Kershner & Lodge 1995, Flint 1975) and the ability of banks to support burrows (Shimizu & Goldman 1983, Guan 1994).

Generally, most of the environmental variables considered important in determining crayfish distribution are associated with quality and quantity of refuges, because they are vulnerable to predation from fish, birds, mammals and themselves. Of the features observed to be important in the present study it is difficult to see which is related directly to the presence of refuges without further experimental studies.

The numbers of crayfish showed a negative relationship with the percentage cover of macrophytes in May and the number of macrophyte types in May. A positive relationship was found between crayfish abundance and the change in macrophyte cover between May and September. The relevance of this latter observation to crayfish abundance in the winter is not easy to see.

Other authors have reported negative relationships of crayfish populations with various measures of macrophytes abundance (Creed, 1994; Nyström & Strand, 1996; Nyström *et al.*, 1996) and this has been assigned to the crayfish grazing of macrophytes.

Gender differences did occur with female abundance responding positively to the slope of the bank during the first four months of the year, but males apparently not. A possible explanation is that the egg carrying females are more dependent on burrows normally found in steep banks than the males.

Lowery & Holdich (1988) state that juvenile crayfish tend to favour the shallower parts of rivers and then move to the deeper parts as they grow larger. The significant and positive relationship between depth and crayfish abundance probably reflects the tendency of the traps to catch the larger crayfish.

Other significant relationships with aspect and width may simply be a result of their correlations with depth, which in turn are the result of the use of such a short study reach where the deepest point coincided with the one change in aspect.

7. IMPACT OF SIGNAL CRAYFISH ON THE FAUNA OF THE RIVER THAME

7.1 Introduction

In their literature review of the ecology of *Pacifastacus leniusculus*, Ibbotson and Furse (1995) listed published evidence that this species was often an important component of the food webs of the habitats in which they live. This was particularly true in rivers, like the Thame, where a substantial population density has been established.

The diet of this species is very varied (Momot *et al.*, 1978) and in different locations, seasons and life stages it has been shown to be herbivorous, detrivorous, predatory, cannibalistic or omnivorous (Lormann & Magnusson 1978, Hogger 1988, Huner & Barr 1980). Thus signal crayfish could have significant impacts on aquatic macro-invertebrates either by consuming them directly, especially by juvenile crayfish (Mason 1975, Goddard 1988), or indirectly by altering the habitat for invertebrates.

One objective of the current study was to determine whether there were observable differences amongst the composition of macro-invertebrate assemblages of the exploited, unexploited and crayfish free reaches of the River Thame which might result from the presence of *P. leniusculus*.

7.2 Methods

7.2.1 Selection of sampling location

Macro-invertebrate samples were collected in each of the three sites in each of the three study reaches.

Each site was relatively homogenous in character and the precise sampling location was situated at a representative point along their length. Safe accessibility of the river was often a relevant factor in site selection.

On a few occasions the river was too deep or the substratum was too soft and deep to allow safe access and, in these cases, sampling was undertaken from the water's edge.

Table 7.1 **Macro-invertebrate sample codes and dates of collection. Samples marked with an asterisk were taken from the water's edge only.**

REACH	SITE	SAMPLE CODES		SAMPLING DATE	
		SPRING	AUTUMN	SPRING	AUTUMN
ONE	ONE	R1S1SP	R1S1AU	21-05-96	10-09-96
	TWO	R1S2SP	R1S2AU	21-05-96	10-09-96
	THREE	R1S3SP	R1S3AU	21-05-96	10-09-96
TWO	ONE	R2S1SP*	R2S1AU	22-05-96	10-09-96
	TWO	R2S2SP	R2S2AU	22-05-96	10-09-96
	THREE	R2S3SP*	R2S3AU*	22-05-96	10-09-96
THREE	ONE	R3S1SP*	R3S1AU*	22-05-96	09-09-96
	TWO	R3S2SP	R3S2AU	22-05-96	09-09-96
	THREE	R3S3SP*	R3S3AU	22-05-96	09-09-96

7.2.2 Sampling procedures

Samples were collected in both spring and autumn (Table 7.1). Individual samples were coded by their reach and site number and season of collection. Thus the spring sample from site two of reach three was identified by the code R3S2SP (Table 7.1).

All samples were collected using the standard pond-netting techniques recommended for use with the 1995 GQA Survey (Murray-Bligh *et al.*, 1997). This involved three minutes of active sampling, in an upstream direction with the objective of capturing as many as possible of the taxa present at the site.

Sampling of all habitats was undertaken in proportion to their occurrence in the accessible collecting area. Where the river channel could be accessed this normally meant a longitudinal section of the river of about 10m length. In general the full width of the river was sampled on all occasions when the watercourse could be accessed but on two occasions, R1S1SP and R1S2SP, sampling was confined to the proximal third of the river channel. Habitats included the marginal and midstream stream bed and all forms of emergent, floating, submerged and marginal macrophytes.

Where the river channel could not be accessed, most forms of vegetation grew near the water's edge and could be readily sampled from the bankside. The same applied to the marginal stream-bed but the midstream bed material could not be sampled from the bankside. Only at Reach 2, Site 3 and Reach 3, Site 1 could neither the summer nor autumn sample be collected from within the river channel (Table 7.1).

Where feasible, i.e. where suitable large particles and/or sticks occurred, samples were supplemented by a minute's continuous searching in order to find and remove individual specimens of families which may not have been captured by pond-netting.

All samples were fixed at bankside, immediately after collection, using 4% formaldehyde solution. Fixed samples were held in labelled, heavy duty plastic bags placed within labelled 1.25 l storage jars. Samples were taken to the IFE River Laboratory for sorting and identification.

7.2.3 Sample processing

Preparatory to sorting, samples were washed in a brass sieve of 500 μm mesh size. This had the effect of removing the fixative and cleansing the sample of silt, clay and fine sand. Some very small animals, such as first instar chironomid larvae may have been lost during the process. However, procedures were consistent between samples and also with those adopted by the Environment Agency (Murray-Bligh *et al.*, 1997).

Samples were sorted and animals removed from flat-bottomed white trays of approximate dimensions 24 x 32cm. Samples were sorted in a series of small aliquots in order to maximise the visibility of macro-invertebrate specimens amongst the other organic and inorganic material present.

All specimens removed from the sample were preserved in industrial methylated spirit (IMS) with 10% by volume of glycerol added to prevent desiccation, and stored in a single labelled vial.

Most picked specimens were identified to species level, using the most recent taxonomic keys (Environment Agency in preparation). The notable exceptions were the Oligochaeta, Hydracarina, Chironomidae and Empididae which were recorded as such.

All specimens were identified by an experienced staff member who had attained the Natural History Museum IdQ qualification in the identification of aquatic macro-invertebrate taxa at family level and who was also experienced in species level identification. Any specimens whose identity was uncertain was checked by another staff member who had attained the Natural History Museum IdQ qualification in the identification of aquatic macro-invertebrate taxa to species level.

7.2.4 Data analysis

All species lists for individual samples were stored on a specially created Microsoft Access 2 relational data-base.

Additionally, the species lists for each site were used to calculate Biological Monitoring Working Party (BMWP) index values of sample score, number of scoring taxa and Average Score Per Taxon (ASPT) (Armitage *et al.*, 1983).

7.3 Results

7.3.1 Faunal lists

A total of 73 distinct taxa were recorded from the nine sites in the three study reaches (Appendix D). All records of *Pacifastacus leniusculus* found in macro-invertebrate samples are excluded from the total faunal lists and all other analyses in this chapter.

The most diverse fauna was recorded at Reach 3, the upstream reach without crayfish. With one single exception (Reach 3, Site 2, September) samples from all three sites in this reach had a wider range of taxa present in them than samples from the same season in all sites on the other two reaches. The total faunal lists for each of the three Reach 3 sites were more diverse than those for any of the six sites in the other two reaches.

In addition to having a higher number of taxa per site, Reach 3 as a whole had a greater number of taxa than either of the other two reaches (Table 7.2). Reach 3 had records of 86% of the 73 taxa collected during the full sampling programme whilst the comparative proportions for reaches 1 and 2 respectively were just 51% and 59%.

Table 7.2 The number of distinct macro-invertebrate taxa present in samples collected from each site in each study reach during May and September 1996

INDEX	MONTH	REACH 1 (UNFISHED REACH)			REACH 2 (COMMERCIALLY FISHED REACH)			REACH 3 (REACH WITHOUT CRAYFISH)		
		SITE 1	SITE 2	SITE 3	SITE 1	SITE 2	SITE 3	SITE 1	SITE 2	SITE
NUMBER OF TAXA	MAY	14	21	18	17	22	16	27	32	36
	SEPTEMBER	16	13	23	13	17	12	31	18	31
	TOTAL/SITE	21	27	30	24	26	19	41	36	54
	TOTAL/REACH	37			43			63		
	TOTAL ALL REACHES	73								

Reach 3 had records of 28 taxa which were absent from all sites in both of the other two reaches (Table 7.3). In comparison no taxa were unique to samples collected from Reach 1 and only four were unique to Reach 2. A further six taxa were present in both reaches 1 and 2 but absent from Reach 3 (Table 7.3).

When direct comparisons were made of individual pairs of reaches, thirty taxa taken from Reach 3 were not collected from Reach 3. On the same basis, Reach 1 samples lacked 32 taxa netted at Reach 2. Conversely, a total of ten taxa were caught at Reach 2 but not Reach 3 and six were captured at Reach 1 but not Reach 3.

The majority of taxa which were exclusive to the Reach 3, which had no or very few crayfish present, were gastropod molluscs (nine taxa), leeches (four taxa), beetles (four taxa) and caddis (eight taxa).

In contrast, those taxa present at either or both of the reaches 1 and 2, with large crayfish populations, were predominantly mayflies (four taxa) or water bugs (two taxa).

Although the full faunal list for the 18 samples contained a diverse range of taxa, few species of particular conservation importance were recorded amongst them. All three reaches supported populations of the locally distributed mayfly, *Ephemera vulgata* whilst the snail *Viviparus contectus*, which is rare in flowing water, was found at Reach 3.

Table 7.3 **Taxa exclusively present in either reaches 1 and/or 2 (reaches present in parentheses) or in Reach 3.**

TAXON GROUP	REACHES 1 AND/OR 2	REACH 3
Mollusca	*Theodoxus fluviatilis* (1,2)	*Viviparus contectus*
		Valvata piscinalis
		Bithynia tentaculata
		Lymnaea peregra
		Lymnaea stagnalis
		Planorbis carinatus
		Anisus vortex
		Gyraulus albus
		Armiger crista
Oligochaeta		*Eiseniella tetraedra*
Hirudinea		*Hemiclepsis marginata*
		Glossiphonia complanata
		Erpobdella octoculata
		Trocheta subviridis
Ephemeroptera	*Baetis rhodani* (2)	
	Baetis vernus (1,2)	
	Procloeon bifidum (1,2)	
	Habrophlebia fusca (1,2)	
Odonata		*Coenagrion puella* group
Hemiptera/Heteroptera	*Gerris* sp. (2)	
	Sigara (Subsigara) falleni (2)	
Coleoptera		*Haliplus fluviatilis*
		Haliplus immaculatus
		Potamonectes depressus
		Elmis aenea
Trichoptera	*Cyrnus trimaculatus* (1,2)	*Lype* sp.
		Polycentropus flavomaculatus
		Hydropsyche siltalai
		Phryganea sp.
		Halesus radiatus
		Anabolia nervosa
		Limnephilus lunatus
		Molanna angustata
Diptera	Empididae (1,2)	Culicidae
	Hydrellia sp. (2)	

7.3.2 Biotic indices

The number of scoring BMWP taxa for each sample (Table 7.4) inevitably reflected the pattern illustrated by differences in numbers of taxa recorded at the more precise taxonomic levels (Table 7.2). Sample BMWP scores are directly related to the number of taxa contributing to those scores and therefore also exhibit the same trends in inter-reach differences (Table 7.4).

However, the ASPT values represent the quality, i.e. average tolerance to organic pollution, of the taxa present, rather than the quantity of taxa present (Armitage *et al.*, 1983). Here the differences between sites do not follow the patterns established by numbers of taxa or sample scores. In general, in either season, the three values for a given reach show considerable overlap with the equivalent values for any other reach. The only exception is Reach 3 in spring, where the three values are all lower than the three values from Reach 1.

Table 7.4 The BMWP index values derived from macro-invertebrate samples collected from each site in each study reach during May and September 1996

INDEX	MONTH	REACH 1 (UNFISHED REACH)			REACH 2 (COMMERCIALLY FISHED REACH)			REACH 3 (REACH WITHOUT CRAYFISH)		
		SITE 1	SITE 2	SITE 3	SITE 1	SITE 2	SITE 3	SITE 1	SITE 2	SITE 3
No. OF BMWP TAXA	MAY	12	15	13	13	15	13	23	23	25
	SEPTEMBER	12	12	18	13	14	11	23	16	24
BMWP SCORE	MAY	69	89	78	71	91	63	110	119	142
	SEPTEMBER	58	57	98	69	71	49	120	77	125
ASPT	MAY	5.75	5.93	6.00	5.46	6.07	4.85	4.78	5.17	5.68
	SEPTEMBER	4.83	4.75	5.44	5.31	5.07	4.46	5.22	4.81	5.21

Whilst individual sample ASPT's provide a reasonable estimate of the true site value more reliable estimates may be obtained by combining the taxon lists from all samples collected from a site in a single year's sampling (Furse *et al.*, 1995).

The combined season values for individual sites and for each of the three reaches as a whole (Table 7.5) are very similar reflecting an apparently similar ecological quality for the three reaches.

Table 7.5 **The BMWP index values derived from macro-invertebrate samples collected from each site in each study reach during May and September 1996**

RIVER SECTION	REACH 1 (UN-FISHED REACH)			REACH 2 (COMMERCIALLY FISHED			REACH 3 (REACH "WITHOUT" CRAYFISH)		
	SITE 1	SITE 2	SITE 3	SITE 1	SITE 2	SITE 3	SITE 1	SITE 2	SITE 3
INDIVIDUAL SITE	5.64	5.53	5.90	5.24	5.72	4.86	5.19	5.17	5.48
INDIVIDUAL REACH	5.78			5.81			5.53		

7.4 Discussion

The three study reaches are situated within a 6 km section of a single watercourse and, if subject to no differential environmental stresses or changes in environmental characteristics, can reasonably be expected to have similar macro-invertebrate assemblages and biotic index values. However, the results of the current study show there to be a considerably higher species richness at the site supporting a very low density, probably recently established signal crayfish population.

The four most probable explanations for the differences in species richness are:

- differences in sampling efficiency at the three reaches
- differences in the environmental character of the three reaches
- differences in the environmental stresses/pollution influences operating on the three reaches
- differences due to the impact of signal crayfish populations

Each of these are considered in turn.

7.4.1 Differences resulting from sampling efficiency

Accompanying the development of the RIVPACS system for evaluating the ecological quality of sites from their macro-invertebrate assemblages (Wright *et al.*, 1993) has been a move towards greater standardisation of sampling techniques. This move has been re-inforced by the increasing prominence accorded to the use of biological monitoring in the 1990 River Quality Survey and 1995 General Quality Assessment of England and Wales. The need for a common national procedure has resulted in the imminent publication of a manual of sampling methods for use with RIVPACS (Murray-Bligh *et al.*, 1997). The same techniques were used during the 1995 GQA and similar national surveys of Scotland and Northern Ireland.

The Institute of Freshwater Ecology (IFE) was heavily involved in the development of the standard technique and in the writing of the methods manual. The IFE staff member who collected the macro-invertebrate samples in the Thame had considerable previous experience of the application of the methodology.

Thus, in principle, differences in sampling efficiency should not have played a significant role in producing the observed differences in species richness between the sites. Nevertheless, in practice, the methodology requires that all habitats within a given sampling area are sampled in proportion to their relative cover for a total duration of three minutes active pond-netting. In shallow, easily accessible sites this is easily achieved but in deeper channels active collecting may have to be limited to those habitats that can be safely accessed. In some instances this may lead to all collecting being undertaken in those marginal reaches that can be sampled from the bankside.

In the Thame it was not always possible to enter the water course to collect each sample and this may have led to some differences in collecting efficiency. However, examination of the available evidence suggests that this influence is likely to be trivial.

Only two sites were never sampled from within the river, Site 3 in Reach 2 and Site 1 in Reach 3. Whilst the former site did have the lowest species richness of all sites there was an alternative explanation for this based on substratum characteristics (see Section 7.4.2). In contrast the diversity of macro-invertebrates at Reach 3, Site 1 was about average for the reach (Table 7.2) and higher than any site in the other two reaches. The mean species richness of sites in Reach 1 (26 taxa), where all samples were collected by the sampler entering the watercourse was only slightly higher than Reach 2 (23) where 50% of samples were taken from the bankside.

Whilst differences between the species richness of reaches 1 and 3 are unlikely to result from sampling differences the situation with Reach 2 is less clear. Here the mean number of taxa per site is only 53.5% of the total taxon list for the reach. This compares with respective values of 70.2% and 69.3% for reaches 1 and 3 respectively. This difference could be explained either by less efficient sampling of Reach 2 sites or by greater between-site differences within this reach than at the other two reaches. Examination of the proportion of additional taxa captured at each site in the autumn sampling, but not in spring, lends stronger support to the second explanation. On average, at Reach 2, the autumn sampling increased the spring taxon list by 26% whereas the respective gains at reaches 1 and 3 were 48.4% and 38.1%.

7.4.2 Differences due to environmental variation

Accepted ecological theory is that the greatest rate of change in both the environmental character and the composition of biotic assemblages is in headwaters and that the rate of change in the structure of biotic assemblages progressively decreases in a downstream direction (Verneaux, 1976).

The results of the RIVPACS research programme shows that the precise composition of macro-invertebrate assemblages can be predicted from a range of geographical, physical and chemical characteristics of sites (Wright *et al.*, 1993). The strongest predictors have been shown to be total alkalinity and substratum characteristics but other important predictors are altitude and a suite of variables which represent the size of the watercourse such as its width, depth, discharge and distance from source at the sampling point.

No chemical sampling was undertaken during this survey but there is no evidence from the catchment geology, which is principally Kimmeridge Clay, Portland Beds and Upper Greensand, nor from the comparatively short section of river under study, to suggest that the alkalinity values will differ markedly between the reaches. Of the few tributaries which enter the Thame over the study section, the largest is the Cuttle Brook which enters at Thame between Reach 3 and Reach 2. This tributary flows mainly over Greensand although there are chalk influences in its headwaters. If the impact of the Cuttle Brook is to increase alkalinity levels downstream of Reach 3, this is more likely to lead to an increase in diversity, rather than the observed decreases. Any such change is also likely to be more, rather than less, conducive to the presence of molluscs due to the accompanying increase in calcium concentrations.

At the local level the left bank of all reaches is predominantly Greensand. The right bank of reaches 1 and 2 is mainly Kimmeridge Clay whereas at Reach 3 it is Portland Beds. This small difference is unlikely to have significant impact upon differences in either water chemistry or macro-invertebrate assemblage composition.

With one exception the substratum of all sampling sites is predominantly pebbles and gravel with silt and clay sub-dominant. Thus substratum characteristics had no important differential value when 500 m sections of each reach were classified using TWINSPAN (Figure 3.1). There were similarly minor differences in the width and depth of each reach and these again were not features which differentiated between reaches when these were classified. The mean widths of reaches 3, 2 and 1, as measured during the River Habitat Survey were 7.8 m, 7.5 m and 8.5 m respectively. Equivalent mean depths were 95 cm, 115 cm and 105 cm.

Reaches were also closely matched for distance from source of their mid-points at 30 km (Reach 3), 35 km (Reach 2) and 36 km (Reach 1). The overall distance downstream was sufficient to make major changes in macro-invertebrate assemblages improbable on the basis of this variable alone. Reach 3 had an annual mean flow in the 0.31 - 0.62 cumecs category, as shown on the 1985 River Quality Survey maps, with reaches 2 and 3 one category higher (0.62 - 1.25 cumecs) due to the input of Cuttle Brook water. The altitudes of the middle of each reach, in downstream order, were around 65 m, 62 m and 58 m.

The one site to exhibit marked substratum differences was Reach 2, Site 3. The stream bed here was almost completely covered with deep, soft silt, probably resulting from much slower current speeds at this ponded site. It is this uniform substratum type which was the most likely cause of the low species richness of samples collected at this site (Table 7.2).

When the two RHS sections within each of the three reaches were classified (Table 3.1) it was not Reach 3, the taxon rich site which was distinctive but Reach 2. The reasons for the distinction were largely connected with the restructuring of the channel and the impact this had upon channel width, rather than water width. Bankside trees, the relatively lower cover of emergent, broad-leaved plants, differences in bank slope and the siltier conditions at Site 3 were also influential.

Some of these factors may contribute to the lower diversity of invertebrates in Reach 2 than Reach 3 although they do not seem to result in any substantial differences between the numbers of taxa caught in reaches 2 and 1. Furthermore, the distinctive features of Reach 2, Site 3 are particularly influential in segregating out this reach even though they are not specifically relevant to sites 1 and 2, of the same reach, which are also both species-poor in relation to sites in Reach 3.

The factors which distinguish Reach 3 from Reach 1 in the classification are the effects of differential channel management. Thus, the upper reach (3) had evidence of weak berms along each bank but lacked the earth embankment adjacent to the watercourse at Reach 1. This lower reach also had a small weir which impounded its upper two sites (1,2) which on average were around 33% (ca 30cm) deeper than the lower one (3). Reach 1 also had more vegetated mid-channel bars (ie midstream"islands") whereas Reach 3 had differentially more exposed, but not submerged tree roots. It is unlikely that any of these features will have led to major differences in the in-stream diversity in macro-invertebrates.

Of greater possible influence could be the greater extent of floating-leaved, rooted vegetation in Reach 1 compared to Reach 3. This was primarily *Nuphar lutea*. Contrary to observed results in the two reaches this plant species supported a diverse range of gastropod species in the Thames (Furse, 1977).

In summary, the three reaches are relatively similar in character and even those features which distinguish their overall river corridor characteristics are often not those with obvious direct bearing on aquatic macro-invertebrate taxon richness.

7.4.3 Differences in water quality

Although the study reaches are within 6 km of each other a number of external influences could lead to differences in water quality between them, particularly those resulting from organic pollution.

One consideration is that Reach 3 is the only study reach upstream of the possible influence of any discharge from the small industrial site at Long Crendon. It is also upstream of both the town of Thame and the confluence with the Cuttle Brook whereas the other two reaches are both downstream of these possible pollution sources. A wide variety of other small tributaries enter the Thame and any one may carry a pollution load. Additionally there are also some small hamlets and isolated farmhouses and dwellings along the river which may be operating septic tanks or soakaways which are not functioning perfectly. More likely sources of organic stress are the chronic or acute pollution loads which may result from agriculture of the intensity carried out over the study reaches.

The most widely used British biotic index for detecting organic pollution, in particular, is the Average Score Per Taxa (ASPT) derived from the Biological Monitoring Working Party (BMWP) score system (Armitage *et al.*, 1983). River sites of different environmental character will have different intrinsic ASPT values, according to their physical and chemical nature, when not subject to environmental stresses (Wright *et al.*, 1993). However, sections of river located as close together as the three current study reaches and with environmental characteristics as similar as demonstrated in the previous section should have very similar ASPT values in their unstressed state. Differences in ASPT between sites and reaches would therefore be indicative of varying levels of organic pollution.

The current results do not indicate major differences in the ecological condition of the majority of the study sites

The individual ASPT values for the paired season samples from the nine sites show almost overlapping ranges for the three sites. Only reaches 1 and 3 show non-overlapping ranges for individual sites. Even then, the differences between their individual values are not much greater than the normal range of variation to be expected from combined spring and autumn samples taken at any given site due to the imprecision of the sampling process (see Table 2.12 of Furse *et al.*, 1995). The more reliable values of ASPT are those associated with the combined faunal lists derived from multiple (in this study paired season) sampling and here again the differences between sites (Table 7.5) are within the normal range of variability that might be expected, due to sampling effects, at any one site subject to replicate sampling.

Although the differences between the upper sites and the two lower sites are not sufficient to indicate substantial differences in water quality, due to organic pollution, the slightly lower ASPT values at Reach 3 are not consistent with the greater faunal diversity at this site. Under these circumstances, differential degrees of organic pollution do not seem to be operating between reaches and are not a likely cause of their observed differences in species richness.

However, an alternative explanation is that the two lower reaches may be subject to toxic pollution, from industrial or other sources, which enters the river between Reach 3 and Reach 2. The phenomenon of comparatively high BMWP score and relatively low ASPT at Reach 3, as opposed to reaches 1 and 2, is consistent with observations made by the Environment Agency, Thames Region at sites upstream and downstream of sources of toxic pollution (Bywater personal communication).

The data collected during the current study are insufficient to eliminate this possibility. Much more detailed chemical monitoring of the study reach would be required to clarify the possible role of toxic pollutants and, even then, it would be difficult to analyse for the full range of potentially harmful substances.

Only at Reach 2, Site 3 is there a distinct departure from the range of site values (Table 7.5). Here the lower value of 4.86 is influenced by the different physical character of the site. Slower flowing sites with uniform silty substrata lack many of the high scoring BMWP taxa that occur in faster flowing, more oxygenated sites of otherwise similar water chemistry.

7.4.4 Differences due to the impact of crayfish populations

Given that differences in sampling efficiency, site environmental character or levels of environmental stress are unlikely to be responsible for the large differences in taxon richness in Reach 3 and the other two reaches, a very possible cause is the presence of large populations of signal crayfish in Reaches 1 and 2.

Signal crayfish are known to be voracious feeders (Lormann & Magnusson, 1978) and the estimated population sizes in Reaches 1 and 2 (see Section 5) will inevitably have a substantial impact on the food web in these sections of the river (Nyström *et al.*, 1996). No comparative figures are available for this study but Momot *et al.*, (1978) reported that crayfish populations can represent up to 30% of the biomass of freshwater ecosystems.

In a recent study of Swedish ponds with different densities of signal crayfish Nyström *et al.*, (1996) investigated the hypothesis that selective predation by crayfish on invertebrates causes a decrease in taxon richness accompanied by a shift towards assemblages more dominated by sediment-dwelling animals and those with good escape reactions.

Their results strongly substantiated this theory with the species richness of macrophyte associated invertebrate taxa declining significantly with increasing abundance of signal crayfish. They undertook their experiments in ponds classified into high and low alkalinity and showed some common trends and others that differed in the two waterbody types. Amongst the strong common trends was a significant negative correlation between the abundance of gastropods and the density of crayfish populations. In high alkalinity ponds (mean 2.56 mEqv l^{-1} : SD 0.27 mEqv l^{-1}) there were also decreases in abundance of leeches and beetles with increasing crayfish density. Although the abundance of caddis increased with greater crayfish densities in high alkalinity ponds, the reverse trend was observed in low alkalinity ponds. The authors concluded that the apparent contradiction may be associated with the type of caddis present in each type of pond. They postulated that crayfish were less likely to impact on heavy cased caddis such as *Anabolia* but more likely to impact on soft-cased taxa such as *Triaenodes*.

The results of the current study are largely consistent with those obtained by Nyström *et al.*, (1996). The most evident difference between the macro-invertebrate assemblages in the high and low density crayfish sites in the Thame was the much greater variety of gastropods in Reach 3, where crayfish were rarely found. Several authors have reported that loss of taxa such as these are associated with the impact of crayfish consumption of macrophyte species which support these taxa (e.g. Gregg & Rose, 1985) including the loss of permanence of stands (Hargeby, 1990) and the reduction in macrophyte taxon richness (Brown *et al.*, 1988). Others have reported the direct predation effect of crayfish species on snails (e.g. Hanson *et al.*, 1990, Lodge *et al.*, 1994).

In common with the findings of Nyström *et al.*, (1996), Reach 3 of the River Thame was characterised by the presence of a diverse leech fauna comprising four species absent from the two reaches with high crayfish densities. Abrahamsson (1966) noted a similar but reversed trend with both leeches and molluscs increasing in numbers after populations of crayfish were reduced by the outbreak of crayfish plague.

The third major group which appears to be heavily impacted in the Thame are the Trichoptera. Whereas Nyström *et al.*, (1996) found ambivalent results in study ponds of different alkalinities and also between heavy and lightly-cased species, all types of taxa appeared to be affected in the current study. Thus, the variety of species that were absent from the Thame when crayfish populations were high included three caseless taxa, *Lype* sp., *Polycentropus flavomaculatus* and *Hydropsyche siltalai* and five that are heavily cased, *Phryganea* sp., *Halesus radiatus, Anabolia nervosa, Limnephilus lunatus and Molanna angustata*. In other studies Matthews and Reynolds (1992) found Trichoptera to be one of the taxonomic groups to increase in total numbers when crayfish populations were reduced by the plague. However, Charlebois and Lamberti (1996) reported that the abundance of the hydroptilid, *Leucotrichia* sp. increased in the presence of the rusty crayfish *Orconectes rusticus*, possibly due to the combined effects of the caddis being inaccessible to the crayfish because of its habit of living with its case closely appressed to rocks and the impact of reduced inter-specific competition from other taxa adversely affected by the crayfish's presence.

The final group that appears to be impacted in the Thame are the beetles with four taxa, *Haliplus fluviatilis*, *Haliplus immaculatus*, *Potamonectes depressus* and *Elmis aenea*, absent from both reaches 1 and 2 but present in Reach 3. Whilst Nyström *et al.*, (1996) reported higher percentage biomass of beetles in high alkalinity ponds with low crayfish densities no other reported instances of crayfish adversely affecting beetle populations have been found.

The large majority of taxa which appear to be impacted by the presence of signal crayfish in the River Thame are slow moving species with no rapid escape mechanism. This phenomenon has been reported elsewhere by Abrahamsson (1966), who noted that macro-invertebrate assemblages in a pond with a dense population of *Astacus astacus* were dominated by active species and by Lodge *et al.*, (1994) who reported that many non-snail taxa are able to move quickly enough to avoid crayfish predation. Nyström *et al.*, (1996) argued that one of the reasons why *Gammarus* populations were not readily eaten by crayfish in their study ponds was because they were more able to evade capture than less mobile alternative prey species.

Other taxa shown by Nyström *et al.*, (1996) to be disadvantaged in some trials by high crayfish abundance were *Pisidium* sp and Ephemeroptera which dominated in high alkalinity ponds with few crayfish present and *Asellus aquaticus* which exhibited a similar trend in low alkalinity ponds. Of these taxa, Matthews and Reynolds (1992) regarded both *Asellus* and *Pisidium* sp. as "macrophyte-associated" and noted that their numbers increased when crayfish abundance fell. There was no evidence from the present survey to indicate that these groups were disadvantaged in the two reaches with high numbers of signal crayfish present.

In addition to *Gammarus*, the other taxa reported to benefit from the presence of signal crayfish in the ponds studied by Nyström *et al.*, (1996) were the sediment dwelling taxa, *Sialis* sp. and Chironomidae. The Chironomidae may benefit from the crayfish's action of converting leaf-litter to fine organic particles (Huryn & Wallace, 1987) although Nyström *et al.*, (1996) report that one of the impacts of crayfish in their study ponds is to decrease the organic content of the sediment caused by their direct consumption of detritus and indirectly through their consumption of macrophytes.

In the current study, the only two major taxonomic groups to be better represented in reaches with a high crayfish density were Hemiptera/Heteroptera and Ephemeroptera.

In the case of the water-bugs, similar results were reported by Nyström *et al.*, (1996) who recorded an increase in percentage biomass of Heteroptera, principally Corixidae, in high alkalinity ponds where crayfish densities were also high. Reynolds (1978) noted that Corixidae were amongst the few macro-invertebrate taxa not readily consumed by the native British crayfish, *Austropotamobius pallipes*.

Of the Ephemeroptera, the situation in the Thame, appears to be contrary to the findings of Nyström *et al.*, (1996). In the current study four mayfly species absent from Reach 3 were found at one or both of reaches 1 and 2. These were *Baetis rhodani*, captured at Reach 2 only, and *B. vernus*, *Procloeon bifidum* and *Habrophlebia fusca* which were each present in both reaches with high crayfish densities.

The reason for this seemingly anomalous result is not obvious. One tentative possibility, in need of further experimental study, may lie in the trophic structure of the macro-invertebrate assemblages of the three reaches. The majority of the gastropods present at Reach 3 are predominantly grazers (Moog, 1996), feeding on periphyton. Their presence in Reach 3 may competitively exclude or limit the available feeding niches of *B.rhodani*, *B.vernus* and *H. fusca* which utilise the same resource. In contrast, the virtual absence of gastropods in reaches 1 or 2 may enable the mayfly species to exploit the food supply no longer grazed by the molluscs.

Although direct consumption of crayfish may reduce the extent of available macrophyte substratum for colonisation by periphyton, the tendency for gastropod abundance to be reduced results in loss of grazing pressure which benefits periphyton production. Whilst Nyström *et al.*, (1996) found these two contrasting pressures to be in approximate balance, with no apparent affect on periphyton, Flint and Goldman (1975) found that high crayfish densities led to the periphyton being overgrazed. In contrast, Lodge *et al.*, (1994) found that a decline in snail abundance in enclosures containing crayfish was accompanied by an increase in periphyton chlorophyll *a*, although reduced macrophyte area may have led to an overall reduction of periphyton abundance in the view of Charlebois and Lamberti (1996).

In their own study, Charlebois and Lamberti (1996) showed that the presence of *Orconectes rusticus* led to an increase in benthic chlorophyll *a* and primary periphyton productivity but restricted the accumulation of periphyton biomass. They proposed three factors which could contribute to these paradoxical results. In their view primary productivity could be enhanced by direct crayfish predation on algivorous macro-invertebrates and by the fertilisation of periphyton growth through crayfish waste products but that the consumption and dislodgement of periphyton by crayfish feeding and movement activities would tend to restrict its biomass. The same foraging activity that removes periphyton growth may also stimulate further primary production by exposing live algal cells to higher light and nutrient concentrations (Lamberti & Resh 1983).

Nyström *et al.*, (1996) and Charlebois and Lamberti (1996) also considered the role of crayfish in the trophic cascade model. The former authors concluded that in their ponds, where fish were absent, crayfish were "keystone" consumers affecting the biomass and abundance of macrophytes and invertebrates and also decreasing the amount of organic material in the sediment. However, in their studies, the lower trophic levels, particularly periphyton did not show any discernible response to changing crayfish abundances that were consistent with an impact on the trophic cascade. Charlebois and Lamberti (1996) concur that omnivorous crayfish, such as *O.rusticus* in their study stream, play an important role in structuring other stream benthic communities and that, for this species at least, "major changes" will occur in stream benthic systems when it invades. Furthermore, unlike Nyström *et al.*, (1996), they conclude that the rusty crayfish initiated a weak trophic cascade which comprised a moderate increase in chlorophyll *a*, but no concominant increase in periphyton biomass. In support of this interpretation they quote Lodge *et al.*, (1994) who found that the presence of omnivorous crayfish in a Wisconsin lake led to a considerably more complex food web.

Charlebois and Lamberti (1996) also considered that, although crayfish were subject to predation by some fish, their impact on macro-invertebrate and periphyton populations may decrease overall food availability and thus may affect fish growth and recruitment. Decreased growth rate of indigenous fish species due to the competitive predation of macro-invertebrates has been claimed by Hepworth & Duffield (1987). On the other hand crayfish may be intimidated from feeding by some fish species (Garvey *et al.*, 1994) and this may lead to decreased food consumption by the crustaceans (Stein & Magnusson 1976, Hill & Lodge 1995). The impact of signal crayfish on the fish populations of the River Thame, including the possibility of predation by the former on the eggs of the latter, or the reverse impact of fish on juvenile crayfish, has not been part of the current study but is worthy of further investigation.

7.5 Summary

Evaluation of the affects of variation in sampling efficiency, the environmental characteristics of the study reaches and differential environmental stresses do not offer credible explanations for the differences in the composition and taxon richness of macro-invertebrate assemblages. The most likely of these, the possibility that toxic effects may be operating, cannot be fully evaluated without a considerable amount of additional chemical monitoring.

However, the higher species richness at Reach 3 of the Thame, where signal crayfish appeared to be in the very early stages of colonisation, is entirely consistent with the published literature on the impacts of crayfish on macro-invertebrate assemblages.

The taxa which appeared to have been eliminated from the reaches where crayfish were present in large numbers were primarily slow moving species without rapid escape mechanisms. These included gastropods, leeches and caddis, together with several species of crawling or slow swimming beetles.

Present at the high crayfish density reaches, 1 and 2, but absent from control Reach 3 were several species of water bugs and mayfly. The pattern for water bugs is consistent with the published literature but the opposite appears to be the case for mayflies.

The absence of the mayfly species from Reach 3 but their presence in reaches 1 & 2 may result from the absence or reduced abundance, due to the impact of the crayfish, of other taxa, such as gastropods, in the latter reaches which utilise the same food resource. This latter theory is tentative and unsupported by the literature or by new experimental evidence.

The two most obvious processes by which the signal crayfish impact upon macro-invertebrate assemblages are direct predation and the indirect effects of reduction in food supply and available habitats caused by the avid consumption of macrophytes by the crayfish. Other processes which have been postulated by Charlebois and Lamberti (1996) are increased macro-invertebrate drift through prey escape and dislodgement by foraging crayfish and the inhibition of invertebrate colonization resulting from the crayfish presence.

8. COMMERCIAL FISHERY

8.1 Introduction

Signal crayfish have a high food value in Europe and fishing for them can be a profitable business. There is considerable exploitation of this species in the River Thame with commercial, semi-commercial and part-time fishermen operating in the areas of greatest crayfish density.

Access to the river is often granted freely to the commercial crayfishermen because the crayfish are considered to be a nuisance by some groups, in particular anglers whose bait is removed from the hooks by these animals. In the past angling groups have invited commercial fishermen to reduce the numbers of crayfish and thus the level of nuisance they cause.

However, the real impact of the commercial fishermen on the crayfish population is not known and has not been quantified. Thus in 1996 a study was commenced in two reaches each 1 km in length. One reach was occasionally trapped by it's owner but was largely unexploited and the other reach was exploited, supporting an intensive commercial fishery.

8.2 Methods

8.2.1 Regular trapping

Each month the two reaches were trapped with exactly the same traps and following the same protocol (see Chapter 2). All crayfish were sexed, measured to the nearest mm (CL) and clipped or tagged before returning them to the river at the point of capture.

8.2.2 Monitoring of the commercial fisherman's catches

In the original proposal we were tasked with monitoring the commercial fisherman's catches. Despite regular discussions with the man concerned as well as written requests the commercial fisherman has so far provided no data on the level of catches on this particular site. This is undoubtedly because of the commercial sensitivity of this information. In an attempt to circum-navigate this problem attempts were made to attend on site overnight whenever commercial trapping was taking place.

However by the time finance and liaison with the commercial fisherman was achieved the crayfishing season was already under way and because of the intensity of the exploitation the population quickly fell to a level where fishing was no longer commercially viable. However, two overnight visits were made; one on 3 September 1996 and the other on 19 September 1996.

On each occasion, all traps removed from the site were inspected for the presence of crayfish with individually numbered tags. Because of the speed at which the traps were collected it was not possible to inspect each crayfish for uropodal or pleopodal clips. Neither was it possible to count the numbers of crayfish in each trap. However, it was possible to estimate the numbers in each trap and using a mean weight derived from the monthly captures of the regular trapping it was possible to estimate the weight of crayfish removed on each of the two occasions.

The commercial fisherman had also been asked to monitor all his catches in the year and collect any individually numbered tags that were found on the crayfish he captured. The reporting of these numbers was sporadic but a list of tagged crayfish captured at this site was given in early August (Table 8.2). Subsequent catches have not been reported despite requests and it is possible that this information may not be available any more.

8.2.3 Estimates of commercial catches at Shabbington Island

Since the commercial fisherman did not supply information on his annual catches from Shabbington Island, an estimate of these was made using the clip and tag recaptures from both the unexploited and exploited reaches.

In Section 5, estimates were made of the rate of clip loss in both the unexploited and exploited reaches (Fig. 5.2b). If it is assumed that natural loss in both reaches is identical, then the difference in the loss rates between the two reaches must be due to the activities of the commercial fisherman.

If λ_e represents the rate of loss of clipped individuals as a result of clip loss, mortality and migration from the reach and λ_f represents the rate of removal of clipped individuals as a result of the commercial fishery, then the rate of change of clipped crayfish, m, is given by

$$\frac{dm}{dt} = -\lambda_e m - \lambda_f m, \qquad 6$$

leading to

$$m(t) = m(0)\, e^{-(\lambda_e + \lambda_f)t} \qquad 7$$

i.e. rate of decline in clipped individuals, λ, can be written

$$\lambda = \lambda_e + \lambda_f . \qquad 8$$

In the unexploited reach, the natural rate of loss of clipped crayfish is $\lambda_e = \lambda$ since λ_f is zero. The rate of removal by fishing in the exploited reach is therefore given by: $\lambda_f = \lambda - \lambda_e$

Table 8.1. **Mean carapace length (cm) (CL) ± sd of male and female signal crayfish captured in an unexploited reach and an exploited reach in each month.**

Month	Unexploited Reach			Exploited Reach			All
	Male	Female	All	Male	Female	All	
Jan	5.2 ± 0.78	4.9 ± 0.96	5.1 ± 0.85	4.7 ± 1.46	4.1 ± 0.57	4.5 ± 1.22	5.0 ± 0.96
Feb	5.4 ± 0.73	5.3 ± 0.73	5.4 ± 0.73	4.9 ± 0.75	4.7 ± 0.69	4.8 ± 0.73	5.2 ± 0.77
Mar	5.8 ± 0.68	5.6 ± 0.80	5.8 ± 0.69	4.9 ± 0.92	3.8 ± 0.29	4.6 ± 0.93	5.7 ± 0.78
Apr	6.0 ± 0.78	5.6 ± 0.81	5.9 ± 0.79	5.3 ± 0.93	4.4 ± 0.63	5.1 ± 0.95	5.7 ± 0.90
May	6.0 ± 0.76	5.9 ± 1.27	6.0 ± 0.97	4.7 ± 1.18	4.2 ± 0.70	4.6 ± 1.11	5.6 ± 1.20
Jun	6.2 ± 0.54	5.6 ± 0.66	6.1 ± 0.60	5.0 ± 0.92	4.6 ± 1.02	4.8 ± 0.98	5.7 ± 0.96
July	5.9 ± 1.02	5.8 ± 0.73	5.9 ± 0.92	4.8 ± 0.89	4.4 ± 1.00	4.6 ± 0.95	5.3 ± 1.11
Aug	5.6 ± 1.05	5.7 ± 0.84	5.7 ± 0.92	4.2 ± 1.05	4.1 ± 0.97	4.2 ± 1.01	5.2 ± 1.21
Sept	6.3 ± 0.74	5.8 ± 0.67	5.9 ± 0.73	4.8 ± 1.10	4.2 ± 1.13	4.6 ± 1.14	5.6 ± 1.04
Oct	5.6 ± 1.06	4.0 ± 1.02	5.4 ± 1.18	4.8 ± 1.20	4.1 ± 0.57	4.5 ± 1.00	4.9 ± 1.19
Nov	5.5 ± 1.12	4.7 ± 0.90	5.2 ± 1.11	4.8 ± 1.02	4.1 ± 0.65	4.6 ± 0.97	5.1 ± 1.11
Dec	5.2 ± 1.21	4.7 ± 0.97	5.0 ± 1.15	4.6 ± 0.81	4.2 ± 0.73	4.4 ± 0.80	4.8 ± 1.05

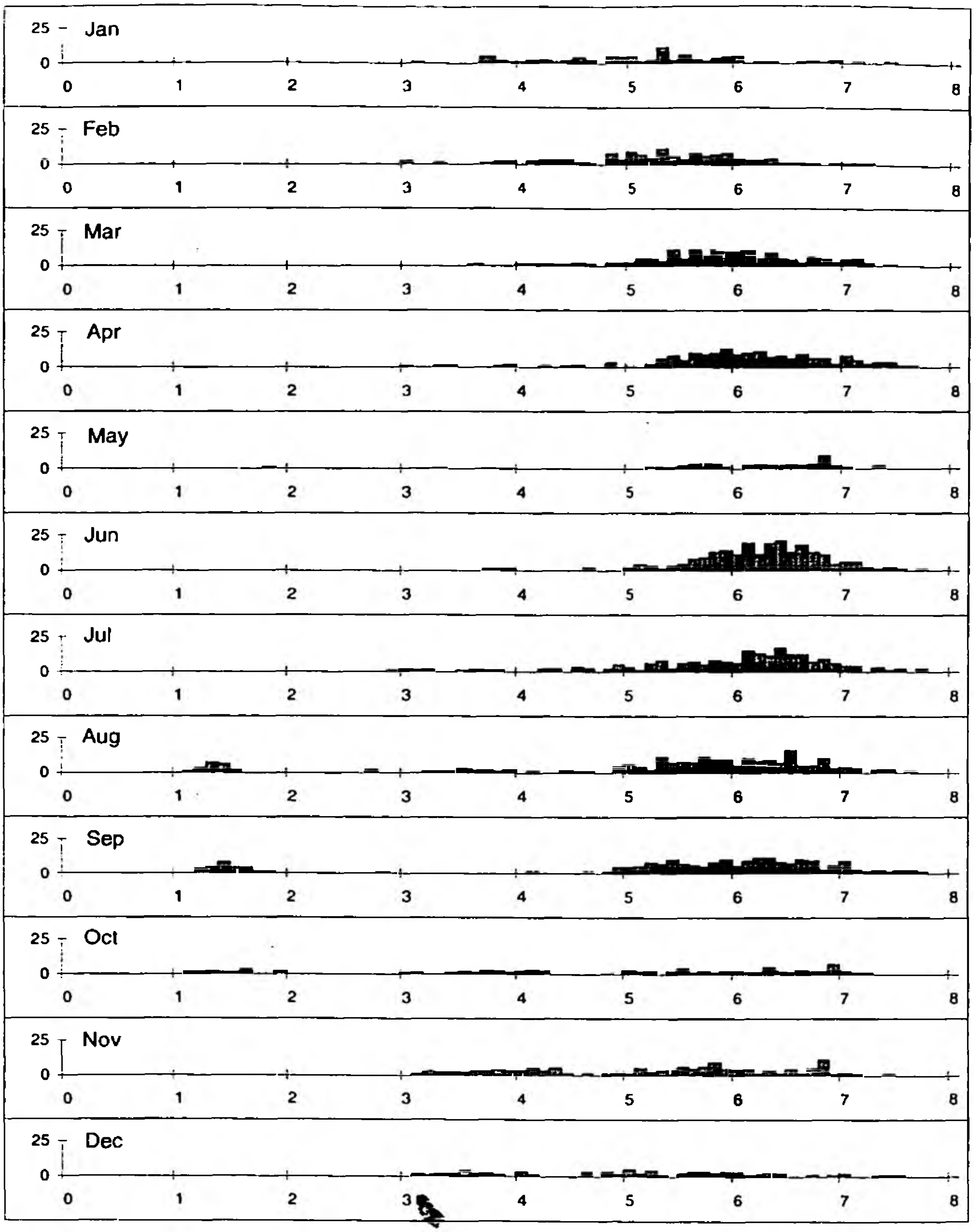


Figure 8.1a **Length frequency histograms of all signal crayfish captured by traps and kick sampling in an unexploited reach of the River Thame.**

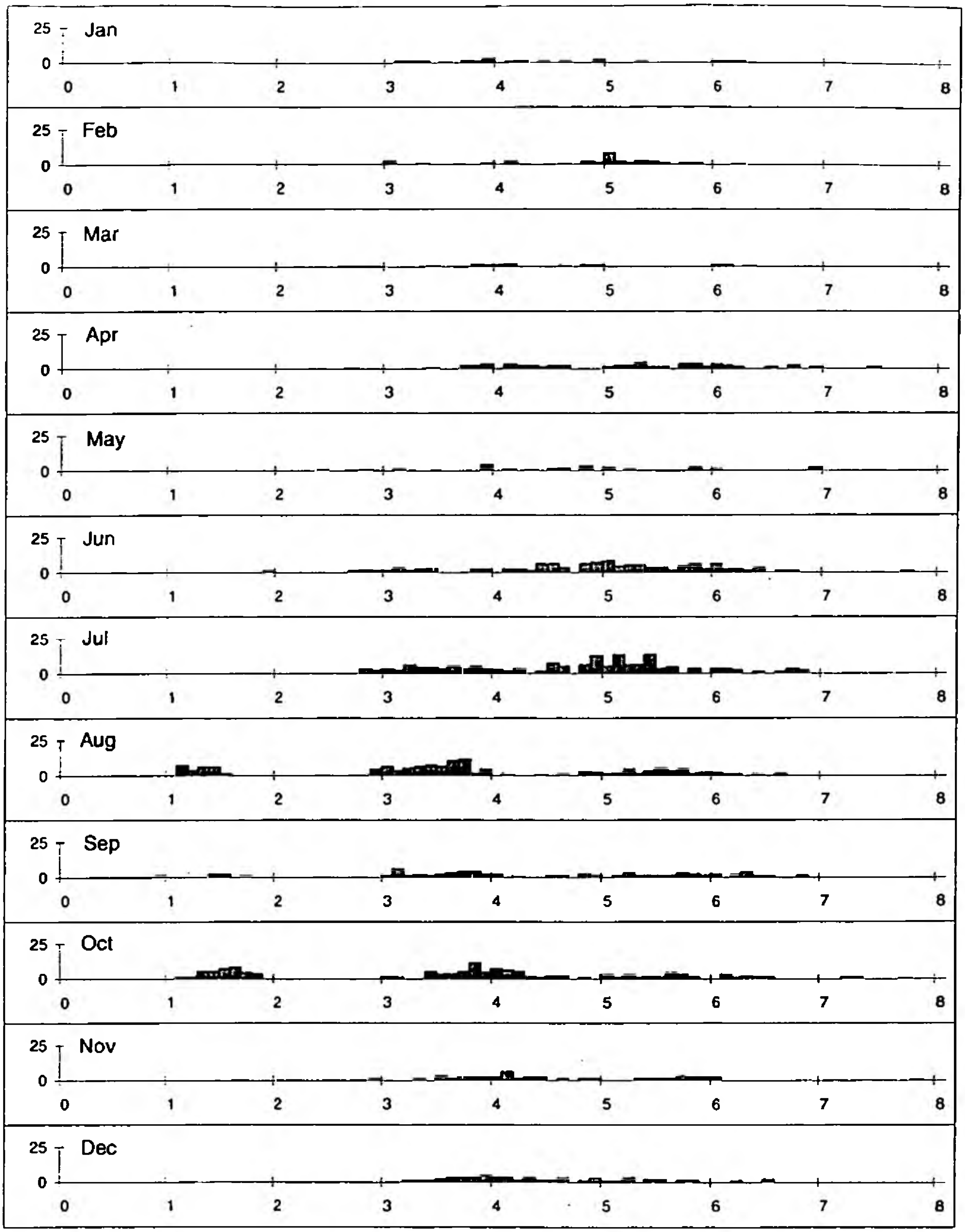


Figure 8.1b **Length frequency histograms of all signal crayfish captured by traps and kick sampling in an exploited reach of the River Thame.**

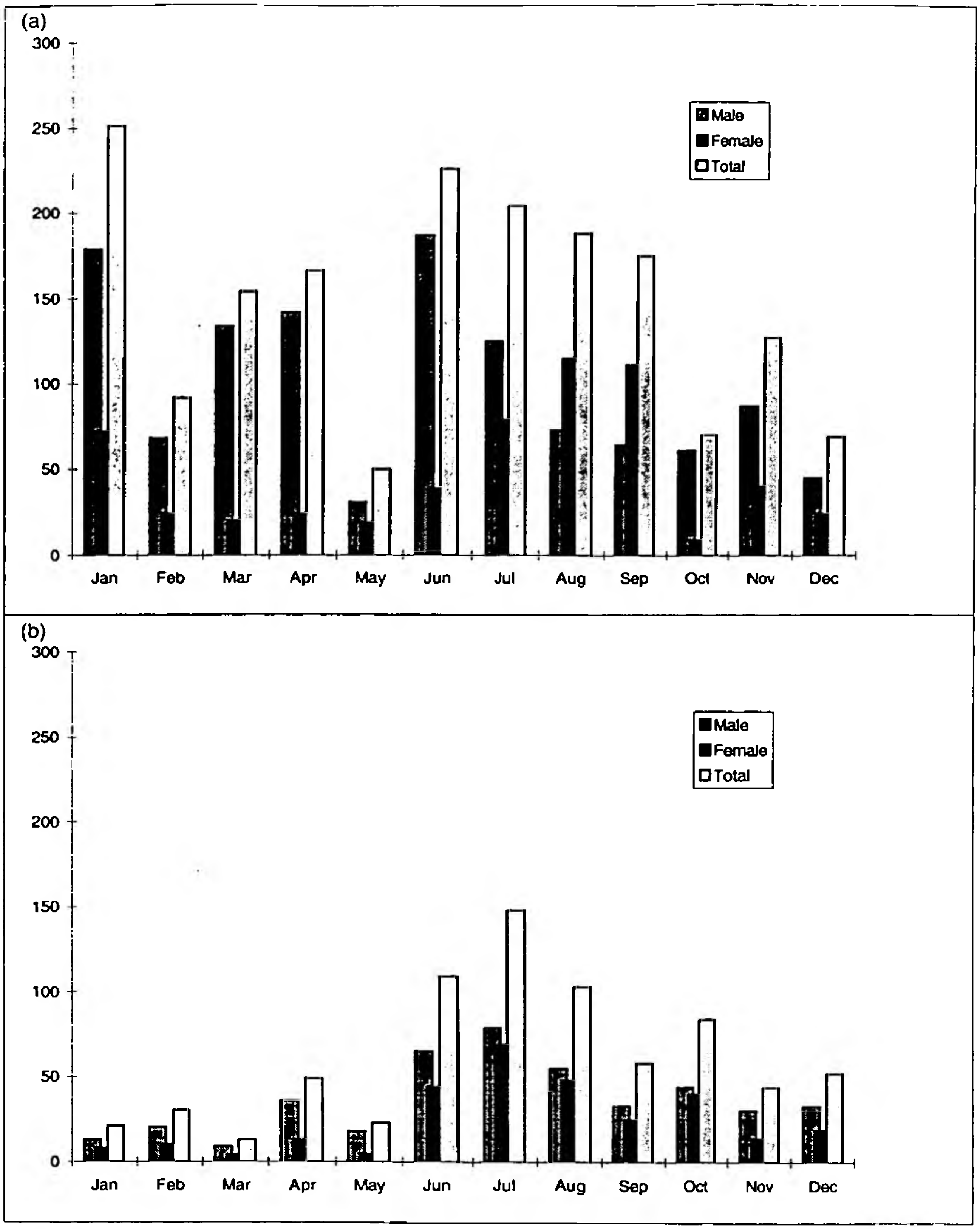


Figure 8.2 The numbers of males, females and combined sexes of crayfish captured in (a) an unexploited reach and (b) an exploited reach of the River Thame.

Table 8.2 Tag numbers, sex and date, size and site of original tagging of crayfish recaptured by commercial fisherman at Shabbington Island in 1996 up to 8 August.

Tag number	Month of original capture	Site of original Capture (U=unexploited reach; E=exploited reach)	Size at tagging (cm) (CL)	Sex
113	1	E	6.1	M
156	1	U	5.1	F
95	2	E	5.2	M
84	2	E	5.7	M
48	2	U	5.0	M
82	2	E	5.4	M
277	3	U	5.4	M
307	3	E	3.8	F
230	3	U	5.7	M
335	4	U	6.5	M
418	4	E	6.1	M
411	4	U	5.6	M
412	4	E	5.9	M
386	4	U	5.8	M
422	4	E	4.6	M
482	5	E	4.7	M
555	6	U	6.2	M
502	6	U	6.1	M
801	6	E	6.1	M
597	6	E	5.8	F
819	6	E	4.7	F
520	6	U	6.3	M
583	6	E	5.8	M
588	6	E	5.7	M
439	6	U	6.3	M
831	6	E	5.2	M
594	6	E	7.6	M
596	6	E	6.3	M
586	6	E	4.1	M
544	6	U	6.3	M
819	6	E	4.7	F
680	7	E	4.8	M
701	7	E	5.3	M
684	7	E	5.3	M
707	7	E	5.3	M
681	7	E	5.0	M
708	7	E	4.8	M
710	7	E	5.3	F
714	7	E	4.9	F
603	7	U	5.5	F
605	7	U	4.6	M
700	7	E	4.8	F

8.3 Results

8.3.1 Comparison of the population structure between the unexploited and exploited reaches

Both the numbers and size of the crayfish captured in the exploited reach was consistently lower than in the unexploited reach (Table 8.1; Fig. 8.1a,b).

Total numbers of crayfish over the complete year captured by the routine trapping programme were only 735 in the exploited reach compared to 1,783 in the unexploited reach (Appendix D). There were less of both male and female crayfish, in the exploited reach, with 300 females and 435 males compared with 579 females and 1,204 males captured in the unexploited reach (Appendix D).

Sex ratios between reaches were substantially different with the captured population of females comprising 41% in the exploited reach and only 32% in the unexploited reach.

Monthly mean sizes ranged from 4.2 to 5.1cm (CL) in the exploited reach and from 5.0 to 6.1 cm (CL) in the unexploited reach (Table 8.1).

Both captured females and males were smaller in the exploited reach with mean monthly size of females ranging from 3.8 to 4.7 cm (CL) and males from 4.2 to5.3 cm (CL), compared with ranges of 4.0 to 5.9 cm (CL) for females and 5.2 to 6.3 cm (CL) for males in the unexploited reach (Table 8.1).

With the exception of August and September the monthly catches always had a higher proportion of males than females in both the exploited and unexploited reaches. In those two months there were still more males than females captured in the exploited reach, but more females than males were captured in the unexploited reach (Fig. 8.2).

8.3.2 Monitoring of commercial fisherman's catches

Monitoring of the catches on both the 3 and 19 September reaped very few worthwhile results. During the visit of 3 September, it was estimated that 29 kg of crayfish were taken. Not enough tagged crayfish were captured to perform any estimates of population size. Indeed the only tagged crayfish was tag number 22, which was a male tagged in February in the unexploited reach.

On the 19 September, it was estimated that catches were 39 kg. Of these only three were previously tagged, all in the exploited reach.

8.3.3 Estimates of commercial catches at Shabbington Island

From the rates of tag loss (Fig. 5.1) $\lambda_f = \lambda - \lambda_c$ equates to 0.98 - 0.39 = 0.59 per month; ie the population removal rate by the commercial fisherman is 59% per month. The estimated mean monthly population of crayfish N in the exploited reach was 818. Therefore the mean annual removal is 480 crayfish per month, equivalent to 5,800 y^{-1}, in a 600 m length of river.

The total estimated length of river channel at Shabbington Island is 1.2 km which means that the estimated catches for that part of the River Thame fishery were 11,600 crayfish. However the list of 42 tagged recaptures given by the commercial fisherman (Table 8.4) included 14 from the unexploited reach. This means that the crayfish at Shabbington Island are being constantly replaced from surrounding reaches as they are removed by the commercial fisherman.

There is not sufficient data to estimate accurately what contribution this migration makes to the commercial catches at Shabbington Island. However it is possible to make some very broad estimate by adjusting the proportion of tagged recaptures from the unexploited reach, that appeared in the catches (14), with the number of tagged crayfish in that reach at the time the numbered tags were reported by the commercial fisherman (567). Assuming that the 28 out of 176 tagged crayfish taken from the exploited reach represented the proportion of the catches, then the percentage increase to the crayfish catches by the fishery can be estimated as 100x(14/567)/(28/176) or 15.5% from the 600 m of unexploited reach contributed an additional 15.5% to the commercial catches at Shabbington Island.

Taking account of length of river between the exploited reach and the unexploited reach and that this will contribute a similar number of crayfish by migration to the exploited reach, and that the river upstream of the exploited reach also contributes, then the estimate of catches at Shabbington Island in 1996 should be increased by approximately 110% to take account of migration to that reach from neighbouring reaches. This gives a final estimate of commercial catches at Shabbington Island in 1996 of 24,400 crayfish equivalent to 1.46 tonnes.

8.4 Discussion

8.4.1 Impacts of commercial fishery on signal crayfish population structure

All comparisons between the exploited and unexploited reaches were made from baited trap catches over the period of one year. This method of capture will bias both the sizes of crayfish captured as well as the sex ratio of the catches (Stuecheli, 1991). It is important to realise that the reported catches do not represent accurately the size distribution of the crayfish in the population, nor the sex ratio of the population. Stuecheli (1991) reports on a study where seining for crayfish found equal numbers of each sex, whilst trapping caught significantly more males which could lead to the conclusion that the population contains more males than females. This may not be the case. Furthermore the size of trap used influences both the size distribution of crayfish captured as well as the sex ratio (Stuecheli, 1991).

Even so, identical methods of capture were used in both the exploited and unexploited reaches and had the populations in both reaches been identical, it would have been expected that the trap catches would have been very similar. However, this was not the case and trap catches in the two reaches were substantially different, with the crayfish in the exploited reach being consistently smaller and the proportion of females captured being consistently higher.

This suggests that trap size alone does not determine the size of crayfish captured (Fig. 8.3). In catches of marron crayfish, using baited nets, Morrisey & Caputi (1981) found that the probability of capture for any one crayfish was related to its relative position in the size distribution of the population. In other words if it was the largest crayfish in the population it would have a high probability of capture regardless of its absolute size.

This variation in probability of capture with size relative to other crayfish may also explain the domination of males in catches, since these grow faster and are larger than the females.

In the present study two different trap sizes were used throughout the year in both sites, but bearing in mind the evidence of other authors the absolute values for numbers, size and sex of crayfish captured in each reach should not be taken to be representative of the population itself..

The impact of commercial fisheries on crayfish population structure is usually the same. The traps preferentially remove the largest crayfish which are mostly male (Miller & Van Hyning, 1970; Bills & Marking, 1988; Rach & Bills, 1989; Skurdal & Taugbol, 1994). As exploitation increases in intensity the proportion of females and smaller crayfish in the catches increases (Bills & Marking, 1988). This explains the difference between the catches of the exploited and unexploited reaches in the present study. The considerable exploitation exerted on the population at Shabbington Island has reduced the average size of the crayfish there and resulted in a greater proportion of females in the catches. It is suggested that the only large males captured from that reach are ones that have migrated in from neighbouring unfished reaches.

The present study was not detailed enough to detect any impacts that the commercial fishery had on population dynamics. Skurdal & Taugbol (1994), showed that a noble crayfish population responded to exploitation by increasing growth rate, but there was no detectable increases in the relationship between fecundity and size of females. Momot (1988, 1991) studied the exploitation of *Orconectes virilis* and concluded that this species responded to exploitation with increases in natural survival rates of smaller size groups and a lowering of the age at maturity.

Records of overexploitation of crayfish populations are rare. The collapse of the narrow-clawed crayfishery in Turkey was partly blamed on un-regulated over-exploitation (Koksal, 1988. However, Momot (1988, 1991) found that *O. virilis* populations were very resilient to exploitation and that they could withstand exploitation rates of 50-70 %. Other authors have found control of nuisance populations of crayfish with traps difficult (Bills & Marking, 1988; Rach & Bills, 1989) suggesting that over exploitation with traps may not be a serious concern in crayfisheries.

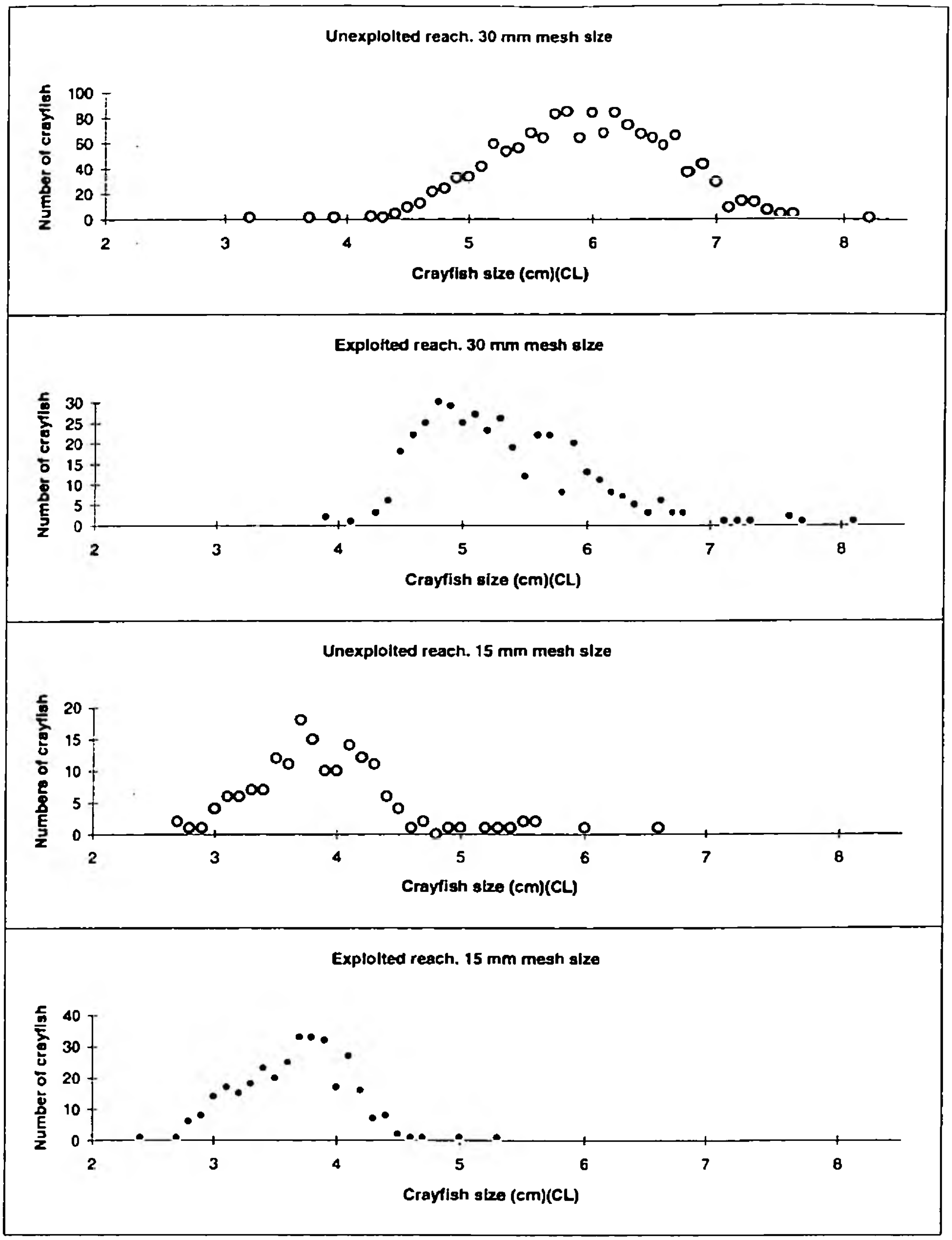


Figure 8.3 Length frequency distribution for signal crayfish captured in two different sized traps in an exploited and unexploited reach.

In the present study, exploitation rates were estimated to be 59%, which is well within the 50-70% estimated by Momot (1988, 1991). Furthermore the area of exploitation on the River Thame is relatively small in comparison to the distribution of crayfish. Thus there seems little probability that the current rate of exploitation on this river is any threat to the survival of the signal crayfish population.

8.4.2 Impacts of commercial fishery on conservation and neighbouring reaches

It is not known whether the commercial fishery at Shabbington Island increases survival of juveniles and recruitment locally, but if the experiences of Momot (1988, 1991) with other populations is similar then it probably will. The impacts of this for the whole of the River Thame and its conservation are not known, because the level of recruitment increases have not been quantified. Further it is not known where the effects of the increased recruitment is felt.

It is certain, that locally, the numbers of large crayfish are reduced both at the point of the fishery and from neighbouring reaches as crayfish migrate into the fishery area. In other words the fishery acts like a sink, pulling crayfish in from neighbouring reaches. However, the adults are known to exert influence by consuming macrophytes whereas juveniles consume invertebrates (see Chapter 7).

Local reductions in the number of adult crayfish will result in increased recruitment of juvenile crayfish, locally, but migration rates of crayfish can be quite high (see Chapter 5) and it is possible that this increased recruitment adds to populations in other parts of the river; increases the rate of colonisation of areas without signal crayfish and adds to the pressure on conservation interests. To date, there is not sufficient data to confirm or refute these potential impacts of the fishery.

It is likely that the intensity of the fishery or fisheries in the River Thame will determine the impacts of the crayfish, and that there will be an optimum level of exploitation which will minimise the conservation impacts. Knowledge of this level would increase significantly the potential for management of these populations and allow for informed regulation of a currently unregulated fishery.

8.4.3 Cray fishery regulation

Currently crayfisheries in the UK are largely unregulated. If the management of these alien populations for conservational interests is to take place efficiently, then this has to change. Additionally, the established populations now constitute a significant freshwater resource with a high commercial value.

Currently, regulatory authorities do not receive any financial benefit from these commercial fisheries unlike other forms of resource exploitation where substantial licence fees are collected. The sum value of these fisheries would probably stand quite a high licence charge, which would recover some of the costs of management. Decisions on whether the number of licences should be restricted, need to take account of the impact of the commercial fisheries and the objectives for managing the populations. Miller & Van Hyning (1970) found that the catches of crayfish were linearly related to the number of licences issued. Essentially this suggests that as licences are issued there is a proportional increase in exploitation rate.

An estimation of the annual value of the crayfisheries could be used to set licence fees, by comparison to fees charged to other types of commercial fisheries.

9. FUTURE WORK

Some of the results from this report were presented at a project board meeting on 20 January 1997. The ensuing discussions highlighted a number of topics where it was thought future work was needed and this chapter briefly describes these. In general they are divided into two issues; the first being impact of the alien crayfish population on native flora and fauna either directly or indirectly; and the second concerning management of crayfish.

9.1 Impact of alien crayfish on native flora and fauna

An opportunity to study the impacts of invading signal crayfish on the upper reaches of the Thame is presented by the baseline knowledge gained for the reach without signal crayfish at Long Crendon. A monitoring and experimental research programme is recommended for this reach.

- Monitoring should include the collection of quantitative information on a broad range of component floral and faunal groups at that site, together with levels of organic detritus. Amongst the groups that may be studied are periphyton, macrophytes, macro-invertebrates, including crayfish, and fish. This study would benefit from more than one year's study since the impacts are likely to increase as the population builds.

- Experimental studies should involve replicated caged trials, with and without crayfish, to investigate the impact of differential densities of crayfish on periphyton, macrophyte and macro-invertebrate assemblages. Such an experimental approach although difficult to complete is the only way in which the impacts can be truely quantified without the problem of 'alternative explanation' for observed phenomena that one would have for a monitoring study.

The evidence that signal crayfish are having an important impact on the taxon richness of macro-invertebrate assemblages is based on evidence from a single reach of river upstream of existing crayfish populations. The signal crayfish distribution in the Thame is discontinuous with an apparent gap downstream of the Cuddesdon Brook and no populations present downstream of Drayton St Leonard (Ibbotson *et al.*, 1995, 1996).

- Macro-invertebrate sampling of these reaches, which may be even more similar than Reach 3 to the character of Reaches 1 and 2 may provide data which is consistent with the hypothesis that crayfish have an impact on macro-invertebrate assemblages.

A single standard, RIVPACS-style sample taken from Shabbington Island, within Reach 2 of the current study, as part of the 1990 River Quality Survey has since been identified to species (Blackburn *et al.*, 1995). It contained seventeen taxa, including seven gastropods, three leeches, three beetles and four caddis now apparently scarce or absent from Reach 2 but present in Reach 3 (Table 7.3).

- A retrospective examination of the macro-invertebrate data held by the Environment Agency, Thames Region is recommended. This may give an indication of the rate of impact of signal crayfish populations upon the taxa identified in the present study. It may also highlight taxa which are vulnerable to elimination and those that take advantage of ecological changes resulting from the invasion of the large omnivore.

Whilst it is possible to measure local impacts of crayfish on flora and macro-invertebrates either by the use of monitoring or controlled experiment, or preferably both; it is much harder to quantify the impact on larger, more mobile animals such as fish, particularly at the population level. However, such a large omnivore could easily impact on fish populations either by direct predation on fish eggs or indirectly by reducing spawning area for plant spawners.

- Egg loss for key fish species could be studied in situ with planted eggs in replicated protected and unprotected areas. This could be done for a gravel spawner, chub, as well as a vegetation spawner, roach or perch.

Preliminary crayfish feeding studies in the River Thame has produced some data very specific to timing.

- More detailed studies are recommended using crayfish taken directly from the environment, rather than from traps, and over different seasons to take account of the seasonal appearance of some food items such as fish eggs, plants and invertebrate groups.

9.2 Management of crayfish populations

The gradual upstream movement of signal crayfish in the River Thame (Ibbotson *et al.*, 1996) presents a serious management problem for the whole of the Thames catchment as well as other catchments containing signal crayfish. Although it is known that these animals will migrate within river systems, very little is known about the migration patterns of individual crayfish. It is known in the Thame that despite their being in the river for more than 20 years their distribution is still very discontinuous (Ibbotson *et al.*, 1996), suggesting that there may be some factors limiting migration and/or distribution. Although it was outside the terms of reference of the current study some information on migration has been gathered and it clearly demonstrated that individual migration was highly variable. However, high tag loss resulted in low recapture rates and a poor estimate of migration in the present study.

A better knowledge of migration patterns would aid the assessment of potential for limiting crayfish movement. This is particularly pertinent at the moment because there is currently considerable investment being made on reintroducing native crayfish to catchments, in some cases upstream of established signal crayfish populations.

- It is recommended that another study specific to crayfish migration is instigated, utilising an alternative tagging technique, such as PIT tags. Migration could be assessed in relation to habitat, season, potential barriers dredging patterns and commercial fishery activities.

- Such a migration study could be combined with an assessment of techniques for limiting migration with the experimental creation of barrier zones i.e. bands of unsuitable habitat across the river.

There are already areas of the River Thame where commercial fishing exist and some of the impacts of these fisheries are dealt with in the present study. The commercial fishermen like to give the impression that such removal contributes to the conservation of the river by suppressing the invading species population. However, these fisheries only impact on the older age groups of crayfish and do not affect the younger groups directly. Removal of the older groups may benefit the younger age classes and increase recruitment to the adult stages, through a reduction in intra-specific predation and competition. Whilst the population abundance of the adult stages may remain suppressed in the commercially fished reach, the increased recruitment may increase the rate of colonisation and population levels in neighbouring unfished reaches. In addition, juvenile crayfish will have a different ecological impact than adult crayfish, by way of differences in diet and behaviour and increases in the lower age groups may only result in differing impacts not alleviation of them. A better understanding of the effects of the commercial fisheries on crayfish populations is required.

- More intense studies on the population dynamics of crayfish in areas, with and without commercial fisheries combined with information on the migration of all size groups of crayfish would facilitate informed management of commercial fisheries and direct these activities towards conservational interests. Such studies may need to be completed with controlled manipulation on crayfish populations in some of the tributaries, rather than by monitoring current commercial fisheries.

- Related to this study would be an appraisal of current techniques for removing crayfish populations, combined with experimental testing of novel approaches. A brain storming session may be required following the assessment of current techniques.

One of the biggest threats that signal crayfish present is to the native crayfish, either through the transfer of disease or competitive exclusion. However there are also a number of other threats to this species. Many native crayfish populations are in upstream rivers that are subject to high levels of water abstraction, but they are rarely, if ever, considered in questions related to minimum ecological flow level requirements, which is surprising when their conservational status is considered.

- The current trend in deciding instream flow issues is to use computer models that predict inventories of habitat type and quantity, such as PHabSim. In most cases in this country the use of these models have concentrated on the habitat requirements for fish populations, but it is just as valid to use them for other groups of animals and activities. Habitat suitability curves for use in these models could be generated for both native and signal crayfish to help answer questions related to flow requirements as well as the outcome of competitive interactions.

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APPENDIX A

MODIFIED RIVER HABITAT SURVEY FORM

BACKGROUND MAP-BASED INFORMATION

Altitude(m)
Solid geology code
Distance from source (km)
Height of source (m)

Slope (m/km)
Drift geology code
Significant tributary ?
Water Quality Class

Flow category (1-10)
Planform category
Navigation ?

FIELD SURVEY DETAILS

Reference network site number:

Mid-site grid reference of network site if different from designated location:

Grid Reference: River:

Date ..../..../1996 Time: .... Surveyor name . . . .

Accredited Surveyor? No ☐ Yes ☐ *If yes, state number* . . . .

Adverse conditions affecting survey? No ☐ Yes ☐ *If yes, state* . . . .

Bed of river visible? No ☐ partially ☐ entirely ☐ *(tick one box)*

Duplicate photographs: general character? No ☐ Yes ☐ *(tick one box)*

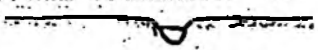
Site surveyed from: left bank ☐ right bank ☐ channel ☐ *(tick as appropriate)*

PREDOMINANT VALLEY FORM *(tick one box only)*

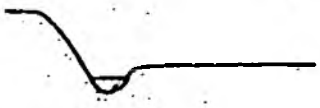
 ☐ shallow vee

 ☐ concave/bowl *(If U-shaped glacial valley - add "U")*

 ☐ deep vee

 ☐ symmetrical floodplain

 ☐ gorge

 ☐ asymmetrical floodplain

---

Terraced valley floor? No ☐ Yes ☐

NUMBER OF RIFFLES, POOLS AND POINT BARS *(indicate total number)*

Riffles
Unvegetated point bars

Pools
Vegetated point bars

END COMPLETED FORM TO HUGH DAWSON, IFE, RIVER LABORATORY, EAST STOKE, WAREHAM, BH20 6BB

Spot check 1 is at: upstream end ☐ downstream end ☐ of site (tick one box)

E PHYSICAL ATTRIBUTES (to be assessed across channel within a 1m wide transect)

' = one entry only REACH/SITE/TRAP POSITION										
LEFT BANK										
Material ' NV,BE,BO,CO,GS,EA,PE,CL,CC,SP,WP,GA,BR,RR,BW										
Bank modification(s) NK,NO,RS,RI,PC,BM,EM										
Bank feature(s) NV,NO,EC,SC,PB,VP,SB,VS										
CHANNEL [FOR SUBSTRATE USE :	DOMINANT % OTHERS OVER 10% (USE %s) ✓ PRESENT									
Channel substrate ' NV,BE,BO,CO,GP,SA,SI,CL,PE,AR	%									
Flow type ' FF,CH,BW,UW,CF,RP,UP,SM,NP,NO										
Channel modification(s) NK,NO,CV,RS,RI,DA,FO										
Channel feature(s) NV,NO,RO,MB,VB,MI,TR										
RIGHT BANK										
Material ' NV,BE,BO,CO,GS,EA,PE,CL,CC,SP,SW,GA,BR,RR,BW										
Bank modification(s) NK,NO,RS,RI,PC,BM,EM										
Bank feature(s) NV,NO,EC,SC,PB,VP,SB,VS										

F BANKTOP LAND USE AND VEGETATION STRUCTURE (to be assessed over a 10m wide transect)

Land use: choose one from BL, CP, OR, MH, SC, TH, RP, IG, TL, WL, OW, SU

LAND USE WITHIN 5m OF BANKTOP (L)										
LEFT BANK-TOP (*structure within 1m*) B/U/S/C										
LEFT BANK FACE (*structure*) B/U/S/C										
RIGHT BANK FACE (*structure*) B/U/S/C										
RIGHT BANK-TOP (*structure within 1m*) B/U/S/C										
LAND USE WITHIN 5m OF BANK-TOP (R)										

G CHANNEL VEGETATION TYPES (assessed over a 10m wide transect; use E (≥ 33% area) or ✓ (present))

USE A % FOR COVER

NONE											
Liverworts/mosses/lichens											
Emergent broad-leaved herbs											
Emergent reeds/sedges/rushes											
Floating-leaved (rooted)											
Free-floating											
Amphibious											
Submerged broad-leaved											
Submerged fine/linear-leaved											
Filamentous algae											

Use end 'catch-all' column for types not occurring in spot checks as well as overall assessment over 500m (use E or ✓) †

SITE NO. | 1996 RIVER HABITAT SURVEY: 500m SWEEP-UP

Water depth 0.25 from bank			Main channel width		
ater depth middle channel					
Water depth 0.75 from bank			Aspect	LB	RB
ooking down stream)					

BANK PROFILES: Use E (≥33% bank length) or ✓ (present) DRAW SUBMERGED BANK PROFILE IN BOX (EST.°)

atural/unmodified	L	R	Artificial/modified	L	R
ertical/undercut			Resectioned		
ertical + toe			Reinforced - whole bank		
eep (>45°)			Reinforced - top only		
entle			Reinforced - toe only		
mposite			Artificial two-stage		
10m wide transect)			Poached		
			Embanked		
			Set-back embankments		

EXTENT OF TREES AND ASSOCIATED FEATURES

Estimate % whole channel shaded, % overhung by boughs. Indicate > < 0.5m above water (10m wide transect) At each trap point.

TREES (*tick one box per bank*)

	Left	Right
None	☐	☐
Isolated/scattered	☐	☐
Regularly spaced, single	☐	☐
Occasional clumps	☐	☐
Semi-continuous	☐	☐
Continuous	☐	☐

ASSOCIATED FEATURES (*tick one box per feature*)

	None	Present	E (≥33%)
✳ Shading of channel	☐	☐	☐
✳ Overhanging boughs	☐	☐	☐
Exposed bankside roots	☐	☐	☐
Underwater tree roots	☐	☐	☐
Fallen trees	☐	☐	☐
Coarse woody debris	☐	☐	☐

✳

EXTENT OF CHANNEL FEATURES (*tick one box per feature*)

	None	Present	E
Waterfall(s)	☐	☐	☐
Cascades(s)	☐	☐	☐
Rapid(s)	☐	☐	☐
Riffle(s)	☐	☐	☐
Run(s)	☐	☐	☐
Boil(s)	☐	☐	☐
Glide(s)	☐	☐	☐
Pool(s)	☐	☐	☐

	None	Present	E (≥33%)
Marginal deadwater	☐	☐	☐
Exposed bedrock	☐	☐	☐
Exposed boulders	☐	☐	☐
Unvegetated mid-channel bar(s)	☐	☐	☐
Vegetated mid-channel bar(s)	☐	☐	☐
Mature island(s)	☐	☐	☐
Unvegetated side bar(s)	☐	☐	☐
Vegetated side bar(s)	☐	☐	☐

In cate predominant flow sequence (*select up to three features*):

L CHANNEL DIMENSIONS *(to be measured at one site on a straight uniform section, preferably across a riffle)*

LEFT BANK		Banktop width (m)		RIGHT BANK	
Banktop height (m)		Water width (m)		Banktop height (m)	
Embanked height (m)		Water depth (m)		*Embanked height (m)*	

If trashline lower than banktop break in slope, indicate: height (m) = width(m) =

Bed material at site is: consolidated (compact) ☐ unconsolidated (loose) ☐ unknown ☐

Location of measurement is: riffle ☐ run or glide ☐ other ☐ *(tick one box)*

M ARTIFICIAL FEATURES *(indicate total number or tick appropriate box)*

None ☐ Number of Culverts= Weirs= Outfalls= Fords =
Footbridges = Roadbridges = Other=

Is water impounded by weir/dam? No ☐ Yes, <33% of site ☐ >33% of site ☐

N EVIDENCE OF RECENT MANAGEMENT *(tick appropriate box(es))*

None ☐ Dredging ☐ Mowing ☐ Weed-cutting ☐
Enhancement ☐ Other ? State . . . .

O FEATURES OF SPECIAL INTEREST *(tick appropriate box(es))*

None ☐

Waterfalls > 5m high ☐ Artificial open water ☐ Bog ☐ Other (state) . . . . . .
Braided/side channels ☐ Natural open water ☐ Carr ☐
Debris dams ☐ Water meadow ☐ Marsh ☐
Leafy debris ☐ Fen ☐ Flush ☐

P CHOKED CHANNEL *(tick one box)*

Is 33% or more of the channel choked with vegetation? NO ☐ YES ☐

Q NOTABLE NUISANCE PLANT SPECIES *(Use ✓ or E (≥ 33% banklength))*

None ☐ Giant Hogweed ☐ Himalayan Balsam ☐ Japanese Knotweed ☐ Other? State . . . . .

R OVERALL CHARACTERISTICS *(Circle appropriate words, add others as necessary)*

Major impacts: landfill - tipping - litter - sewage - pollution - drought - abstraction - mill - dam - road - rail -industry -housing mining - quarrying - overdeepening - afforestation - fisheries management - silting

Land Management: set-aside - buffer strip - headland - abandoned land - parkland - MoD

Animals: otter - mink - water vole - kingfisher - dipper - grey wagtail - sand martin - heron - dragonflies/damselflies

Other significant observations:

S ALDERS *(tick appropriate box(es))*

Alders? None ☐ Present ☐ Extensive ☐ Diseased Alders? None ☐ Present ☐ Extensive ☐

APPENDIX B

CRAYFISH TRAPPING ENVIRONMENTAL DATA RECORDING FORM

CRAYFISH TRAPPING ENVIRONMENTAL DATA RECORDING FORM

REACH: SITE: TRANSECT: MONTH:

DISTANCE FROM NEAREST BANK

0m ☐ 1m ☐ 2m ☐ 3m ☐

4m ☐ ≥5m ☐

DEPTH

0-9cm ☐ 10-19cm ☐ 20-49cm ☐

50-99cm ☐ 1-<2m ☐ ≥2m ☐

DOMINANT SUBSTRATUM

BOULDERS/COBBLES ☐ PEBBLES/GRAVEL ☐

SAND ☐ SILT/CLAY ☐

NOT VISIBLE ☐

DISTANCE TO NEAREST PATCH OF..>50cm x 50cm

BOULDERS	0-<2m ☐	2-<5m ☐	5-<10m ☐	10-<25m ☐	25-<50m ☐	≥50m ☐
PEBBLES	0-<2m ☐	2-<5m ☐	5-<10m ☐	10-<25m ☐	25-<50m ☐	≥50m ☐
SAND	0-<2m ☐	2-<5m ☐	5-<10m ☐	10-<25m ☐	25-<50m ☐	≥50m ☐
SILT/CLAY	0-<2m ☐	2-<5m ☐	5-<10m ☐	10-<25m ☐	25-<50m ☐	≥50m ☐
PLANTS	0-<2m ☐	2-<5m ☐	5-<10m ☐	10-<25m ☐	25-<50m ☐	≥50m ☐

BOULDER/COBBLES = <64 mm (2.5") PEBBLES/GRAVEL = >2 - 64mm

APPENDIX C

PHYSICAL HABITAT VARIABLES AND THEIR RELATIONSHIP WITH SIGNAL CRAYFISH

List of the environmental variables. The 15 selected variables for the analysis with crayfish populations are listed before with their respective abbreviations.

1. Percentage shading of the river channel	SHADING
2. Left bank profile type	L-PROFILE
3. Left bank degrees slope	L-SLOPE
4. Aspect of the right bank	R-ASPECT
5. Right bank profile type	R-PROFILE
6. Right bank degrees slope	R-SLOPE
7. Flow type	FLOW
8. Water depth at one quarter from the river bank	DEPTH
9. Channel width	WIDTH
10. Mean percentage substrate cover of gravel and pebbles	%GRAPE
11. Total percentage cover of macrophytes in spring	%sCOVMA
12. Total percentage cover of macrophytes in autumn	%aCOVMA
13. Total number of macrophyte types	N.MAC.T
14. Change in total macrophyte cover between autumn and spring	CH.MACR
15. Distance of the traps to the river bank	BANK.D

16. Channel re-sectioned
17. Channel re-inforced
18. Channel with un-vegetated mid-channel bar
19. Channel with vegetated mid-channel bar
20. Percentage of overhanging boughs (less than 0.5 m above water)
21. Percentage of overhanging boughs (greater than 0.5 m above water)
22. Left bankside of crumbly earth
23. Left bank re-sectioned
24. Left bank poached
25. Left bank embanked
26. Left bank eroding earth cliff
27. Left bank stable earth cliff
28. Left bank with vegetated side bar
29. Left bank with isolated or scattered trees
30. Left bank with regularly spaced single trees
31. Left bank with occasional clumps of trees
32. Aspect of the left bank
33. Right bank re-sectioned
34. Right bank poached
35. Right bank berm
36. Right bank embanked
37. Right bank eroding earth cliff
38. Right bank stable earth cliff

39. Right bank with un-vegetated sided bar
40. Right bank with vegetated side bar
41. Right bank with isolated or scattered trees
42. Right bank with regularly spaced single trees
43. Right bank with occasional clumps of trees
44. Water depth at the medium channel
45. Water depth at three quarters from the bank
46. Channel dominant substrate
47. Channel subdominant substrate
48. Percentage cover of liverworts-mosses-lichens in spring
49. Percentage cover of emergent broad-leaved herbs in spring
50. Percentage cover of emergent reeds-sedges-rushes in spring
51. Percentage cover of floating-leaved rooted vegetation in spring
52. Percentage cover of free floating vegetation in spring
53. Percentage cover of amphibious vegetation in spring
54. Percentage cover of submerged broad-leaved vegetation in spring
55. Percentage cover of submerged fine-linear leaved vegetation in spring
56. Percentage cover of filamentous algae in spring
57. Percentage cover of liverworts-mosses-lichens in autumn
58. Percentage cover of emergent broad-leaved herbs in autumn
59. Percentage cover of emergent reeds-sedges-rushes in autumn
60. Percentage cover of floating-leaved rooted vegetation in autumn
61. Percentage cover of free floating vegetation in autumn
62. Percentage cover of amphibious vegetation in autumn
63. Percentage cover of submerged broad-leaved vegetation in autumn
64. Percentage cover of submerged fine-linear leaved vegetation in autumn
65. Percentage cover of filamentous algae in autumn

Correlation matrix of the 14 selected environmental variables in Reach 1 (significant correlations at the 0.05 level are in bold).

	SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFILE	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	N.MAC.T	%sCOVMA	%aCOVMA
L-PROFILE	-0.130												
L-SLOPE	0.187	**-0.795**											
R-ASPECT	0.221	-0.351	0.179										
R-PROFILE	-0.082	-0.085	**0.382**	0.288									
R-SLOPE	-0.037	0.239	-0.427	**-0.469**	**-0.899**								
FLOW	-0.051	0.226	-0.015	-0.245	0.302	-0.104							
DEPTH	-0.172	-0.004	0.105	**-0.520**	-0.056	0.252	0.337						
WIDTH	-0.260	0.083	0.196	**-0.677**	0.036	0.097	0.338	**0.625**					
%GRA.PE	0.046	**0.415**	-0.315	-0.275	-0.303	0.351	0.074	-0.126	0.090				
N.MAC.T	0.010	-0.295	0.022	**0.538**	0.088	-0.277	-0.039	**-0.494**	**-0.385**	-0.078			
%sCOVMA	0.037	-0.346	0.008	**0.723**	0.124	-0.311	**-0.392**	**-0.595**	**-0.698**	**-0.462**	**0.658**		
%aCOVMA	0.330	-0.228	0.285	0.156	0.351	-0.297	0.256	0.305	-0.042	**-0.661**	-0.156	0.144	
CH.MACR	0.196	0.131	0.189	**-0.493**	0.138	0.054	**0.502**	**0.705**	**0.552**	-0.070	**-0.655**	**-0.733**	**0.568**

Correlation matrix of the 14 selected environmental variables in Reach 2 (significant correlations at the 0.05 level are in bold).

	SHADING	L-PROFI	L-SLOPE	R-ASPEC	R-PROFI	R-SLOPE	FLOW	DEPTH	WIDTH	%sGRAPE	N.MACR.	%sCOVMA	%aCOVMA
L-PROFI	0.305												
L-SLOPE	-0.276	**-0.475**											
R-ASPEC	0.098	-0.112	-0.181										
R-PROFI	**0.366**	**0.469**	**-0.301**	-0.114									
R-SLOPE	-0.290	**-0.381**	**0.397**	-0.037	**-0.854**								
FLOW	0.247	0.101	0.129	-0.180	0.360	-0.250							
DEPTH	**-0.530**	-0.305	**0.378**	**-0.384**	**-0.442**	**0.564**	0.027						
WIDTH	-0.027	0.094	-0.165	0.317	-0.062	-0.001	-0.223	-0.294					
%sGRAPE	**-0.500**	-0.316	**0.510**	**-0.414**	**-0.604**	**0.684**	-0.238	**0.777**	-0.303				
N.MACR.	-0.322	-0.342	0.143	0.198	**-0.566**	**0.618**	**-0.368**	0.201	0.225	0.357			
%sCOVMA	-0.023	0.018	-0.177	0.344	-0.138	0.170	-0.261	**-0.404**	**0.446**	-0.234	**0.526**		
%aCOVMA	0.132	-0.012	**-0.435**	0.327	-0.343	0.330	0.033	-0.062	0.073	-0.087	0.259	**0.454**	
CH.MACR	0.120	-0.028	-0.119	-0.142	-0.096	0.052	0.310	**0.397**	**-0.436**	0.194	**-0.389**	**-0.767**	0.223

Correlation matrix of the 14 selected environmental variables in both reaches (significant correlations at the 0.05 level are in bold). (*: significant correlation for both reaches separately and together. #: significant correlation for both reahes but with different sign)

	SHADING	L-PROFI	L-SLOPE	R-ASPEC	R-PROFI	R-SLOPE	FLOW	DEPTH	WIDTH	%sGRA.P	N.MACR.	%sCOVMA	%aCOVMA
L-PROFI	0.071												
L-SLOPE	0.021	***-0.688**											
R-ASPEC	0.198	-0.262	0.109										
R-PROFI	0.094	0.110	0.135	0.096									
R-SLOPE	-0.127	-0.022	-0.075	-0.213	***-0.875**								
FLOW	0.118	0.169	0.042	-0.200	0.314	-0.170							
DEPTH	-0.290	-0.139	0.253	-0.271	-0.296	**0.475**	0.140						
WIDTH	-0.034	0.075	0.162	-0.196	-0.083	0.159	0.112	0.327					
%sGRA.P	**-0.380**	-0.041	0.090	-0.352	-0.361	**0.451**	-0.140	**0.403**	-0.231				
N.MACR.	-0.238	-0.266	-0.026	0.199	-0.062	0.015	-0.183	-0.270	**-0.378**	0.307			
%sCOVMA	-0.065	-0.209	-0.101	**0.438**	0.100	-0.188	-0.312	***-0.541**	**#-0.485**	-0.132	***0.674**		
%aCOVMA	0.127	-0.151	0.034	0.072	0.205	-0.157	0.143	-0.063	-0.218	-0.115	0.204	0.351	
CH.MACR	0.160	0.087	0.124	**-0.369**	0.059	0.062	**0.411**	***0.476**	0.303	0.040	***-0.497**	***-0.7**	**0.423**

Table of the regression values for the numbers of crayfish during the first four months of the year in Reach 1.
(G = gravid females; NG = non-gravid females)

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFIL	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	%osCOVMA	%osCOVMA	N.MAC.T.	CH.MACR
TOTAL	t-ratio				-50.3		2.02		4.82	4.16		-3.80		-4.14	3.75
	p				0.000		0.053		0.000	0.000		0.001		0.000	0.001
	Rsq				45.6		9.6		43.4	36		31.6		35.7	31
MALE	t-ratio				-5.15				4.71	4.85		-4.03		-3.64	3.58
	p				0.000				0.000	0.000		0.000		0.001	0.001
	Rsq				46.8				42.2	43.7		34.4		29.7	28.9
FEMALE	t-ratio				-2.70		2.32		2.97			-1.92		-3.59	2.66
	p				0.012		0.028		0.006			0.065		0.001	0.013
	Rsq				17.8		13.1		21.2			8.5		29	17.3
G.FEMAL	t-ratio				-2.05		2.18		3.29			-2.03			3.08
	p				0.049		0.037		0.003			0.052			0.005
	Rsq				10		11.5		25.2			9.7			22.6
NG.FEMA	t-ratio													-3.18	
	p													0.004	
	Rsq													24	

Table of the regression values for the average size of crayfish during the first four months of the year in Reach 1.

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFIL	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	%osCOVMA	%osCOVMA	N.MAC.T.	CH.MACR
Av.size total	t-ratio	2.07				-2.19									
	p	0.048				0.037									
	Rsq	10.2				11.5									
Av.size male	t-ratio	2.70													
	p	0.012													
	Rsq	17.8													
Av.size female	t-ratio	2.48													
	p	0.020													
	Rsq	16													
Av.size g.female	t-ratio											2.89		2.01	-2.46
	p											0.009		0.058	0.024
	Rsq											26.9		13.3	20.1
Av.size ng.female	t-ratio														
	p														
	Rsq														

Table of the regression values of the total numbers of crayfish in Reach 1 through the year.

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFILE	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	%sCOVMA	%aCOVMA	N.MAC.T.	CH.MACR	BANK.D
JAN	t-ratio								2.59					-2.29	2.34	
	p								0.05					0.03	0.027	
	Rsq %								16.4					12.8	13.4	
FEB	t-ratio				-4.69				2.61	4.16		-2.81		-2.33		
	p				0.000				0.014	0.000		0.009		0.027		
	Rsq %				42				16.7	36		19.3		13.2		
MAR	t-ratio				-3.14				3.83	3.07		-2.97		-3.23	2.55	
	p				0.004				0.001	0.005		0.006		0.003	0.016	
	Rsq %				23.4				32	22.6		21.3		24.6	16	
APR	t-ratio				-2.26			2.16				-2.26				
	p				0.031			0.039				0.032				
	Rsq %				12.5			11.3				12.4				
MAY	t-ratio															
	p															
	Rsq %															
JUN	t-ratio						-2.05	-3.00								
	p						0.050	0.006								
	Rsq %						9.9	21.6								
JUL	t-ratio															
	p															
	Rsq %															
AUG	t-ratio															
	p															
	Rsq %															
SEP	t-ratio															
	p															
	Rsq %															
OCT	t-ratio															
	p															
	Rsq %															
NOV	t-ratio															
	p															
	Rsq %															
DEC	t-ratio															
	p															
	Rsq %															

Table of the regression values of the numbers of males in Reach 1 through the year.

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFILE	R-SLOPE	FLOW	DEPTH	WIDTH	%GRAPE	%sCOVMA	%aCOVMA	N.MAC.T.	CH.MACR	BANK.D
JAN	t-ratio								2.35						2.2	
	p								0.026						0.036	
	Rsq %								13.5						11.7	
FEB	t-ratio				-4.33				2.61	3.28		-2.4		-2.11		
	p				0.000				0.014	0.003		0.023		0.044		
	Rsq %				37.9				16.7	25.1		14.1		10.7		
MAR	t-ratio				-2.94				4.39	3.65		-3.24		-3.59	3.05	
	p				0.007				0.000	0.001		0.003		0.001	0.005	
	Rsq %				20.8				38.6	29.8		24.6		29	22.3	
APR	t-ratio				-2.34			2.19				2.28				
	p				0.026			0.037				0.031				
	Rsq %				13.4			11.5				12.6				
MAY	t-ratio															
	p															
	Rsq %															
JUN	t-ratio															
	p															
	Rsq %															
JUL	t-ratio															
	p															
	Rsq %															
AUG	t-ratio												2.08			
	p												0.047			
	Rsq %												10.3			
SEP	t-ratio															
	p															
	Rsq %															
OCT	t-ratio															
	p															
	Rsq %															
NOV	t-ratio															
	p															
	Rsq %															
DEC	t-ratio															
	p															
	Rsq %															

Table of the regression values of the numbers of females in Reach 1 through the year.

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFILE	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	%sCOVMA	%aCOVMA	N.MAC.T.	CH.MACR	BANK.D
JAN	t-ratio													-2.57		
	p													0.016		
	Rsq %													16.2		
FEB	t-ratio				-3.00				3.38	4.34		-2.64			2.92	
	p				0.006				0.002	0.000		0.014			0.007	
	Rsq %				21.7				26.4	31.8		17			20.7	
MAR	t-ratio															
	p															
	Rsq %															
APR	t-ratio										2.40					
	p										0.023					
	Rsq %										14.1					
MAY	t-ratio				-2.63											
	p				0.014											
	Rsq %				17											
JUN	t-ratio				2.30			-3.60	-2.62	-2.67		3.00				
	p				0.029			0.001	0.014	0.012		0.006				
	Rsq %				12.9			29.2	16.8	17.5		21.6				
JUL	t-ratio															
	p															
	Rsq %															
AUG	t-ratio															
	p															
	Rsq %															
SEP	t-ratio															
	p															
	Rsq %															
OCT	t-ratio															
	p															
	Rsq %															
NOV	t-ratio															
	p															
	Rsq %															
DEC	t-ratio								2.07				2.19		2.64	
	p								0.048				0.037		0.014	
	Rsq %								10.2				11.6		17	

Table of the regression values of the numbers of gravid females in Reach 1 through the year.

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFILE	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	%sCOVMA	%aCOVMA	N.MAC.T.	CH.MACR	BANK.D
JAN	t-ratio														2.18	
	p														0.038	
	Rsq %														11.5	
FEB	t-ratio				-3.18		2.37		4.17	3.26				-2.23		
	p				0.004		0.025		0.000	0.003				0.034		
	Rsq %				24		13.8		36.1	25				12		
MAR	t-ratio															
	p															
	Rsq %															
APR	t-ratio															
	p															
	Rsq %															
MAY	t-ratio						2.50									
	p						0.018									
	Rsq %						15.4									
JUN	t-ratio															
	p															
	Rsq %															
JUL	t-ratio															
	p															
	Rsq %															
AUG	t-ratio															
	p															
	Rsq %															
SEP	t-ratio															
	p															
	Rsq %															
OCT	t-ratio															
	p															
	Rsq %															
NOV	t-ratio															
	p															
	Rsq %															
DEC	t-ratio															
	p															
	Rsq %															

Table of the regression values of the numbers of non gravid females in Reach 1 through the year.

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFILE	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	%sCOVMA	%aCOVMA	N.MAC.T.	CH.MACR	BANK.D
JAN	t-ratio													-2.52		
	p													0.018		
	Rsq %													15.6		
FEB	t-ratio															
	p															
	Rsq %															
MAR	t-ratio				-2.38											
	p				0.024											
	Rsq %				13.9											
APR	t-ratio										2.19					
	p										0.037					
	Rsq %										11.6					
MAY	t-ratio															
	p															
	Rsq %															
JUN	t-ratio				2.30			-3.60	-2.62	-2.67		3.00				
	p				0.029			0.001	0.014	0.012		0.006				
	Rsq %				12.9			29.2	16.8	17.5		21.6				
JUL	t-ratio															
	p															
	Rsq %															
AUG	t-ratio															
	p															
	Rsq %															
SEP	t-ratio															
	p															
	Rsq %															
OCT	t-ratio															
	p															
	Rsq %															
NOV	t-ratio				2.34	2.52						2.68				
	p				0.027	0.018						0.012				
	Rsq %				13.3	15.6						17.6				
DEC	t-ratio							2.05					4.42		3.37	
	p							0.050					0.000		0.002	
	Rsq %							9.9					39		26.3	

Table of the regression values of the total numbers of crayfish in Reach 2 through the year.

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFILE	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	%sCOVMA	%aCOVMA	N.MAC.T.	CH.MACR	BANK.D
	t-ratio					-2.52										
JAN	p					0.018										
	Rsq %					15.5										
	t-ratio	-2.28			2.70	-3.50	3.02									
FEB	p	0.030			0.012	0.002	0.005									
	Rsq %	12.7			17.8	28	21.9									
	t-ratio			-2.08												
MAR	p			0.046												
	Rsq %			10.3												
	t-ratio													3.02		
APR	p													0.005		
	Rsq %													21.9		
	t-ratio					5.07	-3.60		-2.36		-4.46			-3.20		
MAY	p					0.000	0.001		0.026		0.000			0.003		
	Rsq %					46	29.2		13.6		39.4			24.1		
	t-ratio				-2.56				2.55			-2.79				
JUN	p				0.016				0.017			0.009				
	Rsq %				16.1				15.9			19				
	t-ratio															
JUL	p															
	Rsq %															
	t-ratio	-2.17			-2.70				2.41							
AUG	p	0.039			0.012				0.023							
	Rsq %	11.3			17.9				14.2							
	t-ratio		2.06								-2.49					
SEP	p		0.049								0.019					
	Rsq %		10.1								15.1					
	t-ratio					2.06	-2.20	2.47			-3.18					
OCT	p					0.049	0.037	0.020			0.004					
	Rsq %					10.1	11.6	14.9			23.8					
	t-ratio															
NOV	p															
	Rsq %															
	t-ratio						-2.76				-2.83			-2.57		
DEC	p						0.010				0.009			0.016		
	Rsq %						18.5				19.5			16.2		

Table of the regression values of the numbers of males in Reach 2 through the year.

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFILE	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	%sCOVMA	%aCOVMA	N.MAC.T.	CH.MACR	BANK.D
JAN	t-ratio					-2.49										
	p					0.019										
	Rsq %					15.2										
FEB	t-ratio					-3.30	2.81									
	p					0.003	0.009									
	Rsq %					25.4	19.2									
MAR	t-ratio			-2.37							-1.97					
	p			0.025							0.058					
	Rsq %			13.7							9.1					
APR	t-ratio													2.52		
	p													0.018		
	Rsq %													15.6		
MAY	t-ratio					4.65	-3.26				-2.97			-3.44		
	p					0.000	0.003				0.006			0.002		
	Rsq %					41.6	25				21.3			15.6		
JUN	t-ratio				-2.67				2.44			-2.24				
	p				0.012				0.021			0.033				
	Rsq %				17.5				14.6			12.2				
JUL	t-ratio								2.38							
	p								0.025							
	Rsq %								13.8							
AUG	t-ratio		2.20													
	p		0.036													
	Rsq %		11.7													
SEP	t-ratio									2.08						
	p									0.047						
	Rsq %									10.3						
OCT	t-ratio															
	p															
	Rsq %															
NOV	t-ratio															
	p															
	Rsq %															
DEC	t-ratio										-2.23			-2.68		
	p										0.034			0.012		
	Rsq %										12			17.6		

Table of the regression values of the numbers of females in Reach 2 through the year.

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFILE	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	%sCOVMA	%aCOVMA	N.MAC.T.	CH.MACR	BANK.D
JAN	t-ratio											-2.13				
	p											0.042				
	Rsq %											10.9				
FEB	t-ratio															
	p															
	Rsq %															
MAR	t-ratio															
	p															
	Rsq %															
APR	t-ratio															
	p															
	Rsq %															
MAY	t-ratio	2.19		-2.50					-2.92		-3.97		2.20			
	p	0.037		0.019					0.007		0.000		0.036			
	Rsq %	11.5		15.3					20.5		33.7		11.7			
JUN	t-ratio											-2.56				
	p											0.016				
	Rsq %											16				
JUL	t-ratio															
	p															
	Rsq %															
AUG	t-ratio			2.25	-2.11				2.52	-2.40	2.24					
	p			0.033	0.044				0.018	0.023	0.033					
	Rsq %			12.3	10.7				15.6	14.1	12.2					
SEP	t-ratio						-2.68		-2.44		-3.02					
	p						0.012		0.021		0.005					
	Rsq %						17.5		14.6		21.8					
OCT	t-ratio										-2.72					
	p										0.011					
	Rsq %										18					
NOV	t-ratio															
	p															
	Rsq %															
DEC	t-ratio					2.32	-2.76				-2.63					
	p					0.028	0.010				0.014					
	Rsq %					13.1	18.6				17					

Table of the regression values of the numbers of gravid females in Reach 2 through the year.

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFILE	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	%sCOVMA	%aCOVMA	N.MAC.T.	CH.MACR	BANK.D
JAN	t-ratio															
	p															
	Rsq %															
FEB	t-ratio												2.21			
	p												0.036			
	Rsq %												11.8			
MAR	t-ratio															
	p															
	Rsq %															
APR	t-ratio														2.05	
	p														0.050	
	Rsq %														9.9	
MAY	t-ratio															
	p															
	Rsq %															
JUN	t-ratio															
	p															
	Rsq %															
JUL	t-ratio															
	p															
	Rsq %															
AUG	t-ratio															
	p															
	Rsq %															
SEP	t-ratio															
	p															
	Rsq %															
OCT	t-ratio															
	p															
	Rsq %															
NOV	t-ratio															
	p															
	Rsq %															
DEC	t-ratio															
	p															
	Rsq %															

Table of the regression values of the numbers of non gravid females in Reach 2 through the year.

		SHADING	L-PROFILE	L-SLOPE	R-ASPECT	R-PROFILE	R-SLOPE	FLOW	DEPTH	WIDTH	%GRA.PE	%sCOVMA	%aCOVMA	N.MAC.T.	CH.MACR	BANK.D
	t-ratio											-2.13				
JAN	p											0.042				
	Rsq %											10.9				
	t-ratio															
FEB	p															
	Rsq %															
	t-ratio															
MAR	p															
	Rsq %															
	t-ratio															
APR	p															
	Rsq %															
	t-ratio	2.19		-2.50					-2.92		-3.97		2.20			
MAY	p	0.037		0.019					0.007		0.000		0.036			
	Rsq %	11.5		15.3					20.5		33.7		11.7			
	t-ratio											-2.56				
JUN	p											0.016				
	Rsq %											16				
	t-ratio															
JUL	p															
	Rsq %															
	t-ratio			2.25	-2.11				2.52	-2.40	2.24					
AUG	p			0.033	0.044				0.018	0.023	0.033					
	Rsq %			12.3	10.7				15.6	14.1	12.2					
	t-ratio						-2.68		-2.44		-3.02					
SEP	p						0.012		0.021		0.005					
	Rsq %						17.5		14.6		21.8					
	t-ratio										-2.72					
OCT	p										0.011					
	Rsq %										18					
	t-ratio															
NOV	p															
	Rsq %															
	t-ratio					2.44	-3.08		-1.82	1.80	-2.72					
DEC	p					0.022	0.005		0.079	0.083	0.011					
	Rsq %					14.5	22.6		7.4	7.1	18.1					

APPENDIX D

MONTHLY SIGNAL CRAYFISH TRAP CATCHES

THE NUMBER OF MALE AND FEMALE SIGNAL CRAYFISH, TOGETHER WITH THEIR RATIOS CAPTURED IN EACH MONTH FROM AN UNEXPLOITED REACH OF THE RIVER THAME

		TOTAL	MALE	Gravid Females	Non-gravid females	%Male/Female
JAN	Site 1	99	75	13	11	71 % male 29 % female
	Site 2	96	66	13	17	
	Site 3	56	38	8	10	
	TOTAL	251	179	34	38	
FEB	Site 1	46	35	6	5	74 % male 26 % female
	Site 2	38	26	9	3	
	Site 3	8	7	0	1	
	TOTAL	92	68	15	9	
MAR	Site 1	55	49	0	6	87 % male 13 % female
	Site 2	71	63	5	3	
	Site 3	28	22	4	2	
	TOTAL	154	134	9	11	
APR	Site 1	64	56	2	6	86 % male 14 % female
	Site 2	66	57	3	6	
	Site 3	44	36	2	6	
	TOTAL	174	149	7	18	
MAY	Site 1	21	12	2	7	62 % male 38 % female
	Site 2	20	13	1	6	
	Site 3	11	7	1	3	
	TOTAL	52	32	4	16	
JUN	Site 1	75	71	0	4	83 % male 17 % female
	Site 2	65	56	0	9	
	Site 3	86	60	0	26	
	TOTAL	226	187	0	39	
JUL	Site 1	69	42	0	27	61 % male 39 % female
	Site 2	63	39	0	24	
	Site 3	72	44	0	28	
	TOTAL	204	125	0	79	
AUG	Site 1	54	20	0	34	39 % male 61 % female
	Site 2	71	31	0	40	
	Site 3	63	22	0	41	
	TOTAL	188	73	0	115	
SEP	Site 1	60	23	0	37	36 % male 64 % female
	Site 2	66	24	0	42	
	Site 3	50	17	0	33	
	TOTAL	176	64	0	112	
OCT	Site 1	12	10	0	2	87 % male 13 % female
	Site 2	35	30	0	5	
	Site 3	23	21	0	2	
	TOTAL	70	61	0	9	
NOV	Site 1	34	26	4	4	69 % male 31 % female
	Site 2	48	34	5	9	
	Site 3	45	27	6	12	
	TOTAL	127	87	15	25	
DEC	Site 1	20	12	5	3	65 % male 35 % female
	Site 2	30	17	4	9	
	Site 3	19	16	0	3	
	TOTAL	69	45	9	15	

THE NUMBER OF MALE AND FEMALE SIGNAL CRAYFISH, TOGETHER WITH THEIR RATIOS CAPTURED IN EACH MONTH FROM AN EXPLOITED REACH OF THE RIVER THAME

		TOTAL	MALE	Gravid females	Non-gravid females	%Male/Female
	Site 1	5	2	0	3	62 % male
JAN	Site 2	12	9	0	3	38 % female
	Site 3	4	2	0	2	
	TOTAL	21	13	0	8	
	Site 1	4	4	0	0	67 % male
FEB	Site 2	21	13	5	3	33 % female
	Site 3	5	3	0	2	
	TOTAL	30	20	5	5	
	Site 1	0	0	0	0	69 % male
MAR	Site 2	4	3	0	1	31 % female
	Site 3	9	6	0	3	
	TOTAL	13	9	0	4	
	Site 1	11	10	0	1	73 % male
APR	Site 2	21	15	0	6	27 % female
	Site 3	17	11	1	5	
	TOTAL	49	36	1	12	
	Site 1	6	6	0	0	78 % male
MAY	Site 2	0	0	0	0	22 % female
	Site 3	17	12	0	5	
	TOTAL	23	18	0	5	
	Site 1	60	37	0	23	60 % male
JUN	Site 2	28	17	0	11	40 % female
	Site 3	21	11	0	10	
	TOTAL	109	65	0	44	
	Site 1	59	29	0	30	53 % male
JUL	Site 2	46	27	0	19	47 % female
	Site 3	43	23	0	20	
	TOTAL	148	79	0	69	
	Site 1	46	22	0	24	53 % male
AUG	Site 2	31	15	0	16	47 % female
	Site 3	26	18	0	8	
	TOTAL	103	55	0	48	
	Site 1	15	11	0	4	56 % male
SEP	Site 2	13	7	0	6	44 % female
	Site 3	31	15	0	16	
	TOTAL	59	33	0	26	
	Site 1	22	13	0	9	52 % male
OCT	Site 2	20	9	0	11	48 % female
	Site 3	42	22	0	20	
	TOTAL	84	44	0	40	
	Site 1	16	12	0	4	68 % male
NOV	Site 2	10	5	0	5	32 % female
	Site 3	18	13	0	5	
	TOTAL	44	30	0	14	
	Site 1	14	12	0	2	63 % male
DEC	Site 2	7	3	2	2	37 % female
	Site 3	31	18	1	12	
	TOTAL	52	33	3	16	

APPENDIX E

RECAPTURES OF INDIVIDUALLY TAGGED CRAYFISH

Tag number	Sex	Recapture Month	Tagging Month	Tagging Size (CL) (cm)	Recapture Size (CL) (cm)	Distance migrated (m)
72	M	3	2	5.3	5.3	-20
228	M	4	3	5.5	5.5	0
265	M	4	3	6.7	6.7	0
271	M	4	3	5.7	5.7	-20
308	M	4	3	5.9	5.9	-20
407	M	5	4	6.7	6.7	0
28	M	6	2	5.5	5.7	+40
32	M	6	2	5.7	6.3	+20
405	M	6	4	5.5	6.0	-100
364	M	6	4	6.2	6.6	-80
335	M	6	4	6.5	6.8	-20
282	M	6	3	5.3	6.1	0
214	M	7	3	5.5	6.3	-100
51	M	7	2	6.0	6.5	-20
370	M	7	4	4.4	4.9	-340
507	M	7	6	6.0	6.0	-20
287	F	7	3	5.6	6.1	-20
95	M	7	2	5.2	5.7	0
397	M	7	4	6.8	7.3	+60
50	M	7	2	6.1	6.4	+180
205	M	7	3	6.2	6.2	-180
61	M	7	2	6.9	7.2	+240
404	M	7	4	5.6	5.6	-160
321	F	7	7	5.7	5.7	0
384	M	7	4	6.2	6.8	+140
469	M	7	5	5.6	6.1	+60
148	M	7	1	4.7	5.3	0
153	M	7	1	4.7	5.3	0
26	M	7	2	5.2	5.6	-40
247	M	7	3	6.6	7.1	+280
104	M	8	1	5.2	5.7	+800
385	F	8	4	6.1	6.4	+120
616	F	8	7	6.4	6.4	-340
493	F	8	6	6.0	6.4	+200
318	F	9	7	6.5	6.5	-40
715	F	9	8	6.4	6.4	-80
364*	M	9	4	6.2	6.6	-140
61	M	9	2	6.9	7.4	-340
618	F	9	7	5.4	5.8	+20
183	M	9	1	4.4	5.5	-420
612	M	9	7	6.2	6.4	+120
716	M	9	8	6.3	6.3	-80
385*	F	9	4	6.1	6.4	+50
21	F	9	2	6.4	7.0	-40
782	M	9	8	6.3	6.3	+400

Tag number	Sex	Recapture Month	Tagging Month	Tagging Size (CL) (cm)	Recapture Size (CL) (cm)	Distance migrated (m)
579	M	9	6	7.0	7.0	+20
280	M	10	3	5.6	6.9	-80
761	M	10	8	6.7	6.7	-540
936	M	10	9	4.7	4.7	+10
924	M	10	9	6.3	6.3	-70
217	M	10	3	5.1	6.0	0
999	M	10	9	6.9	6.9	+50
370	M	11	4	4.4	5.4	-480
108	M	11	1	5.4	6.6	0
874	M	11	8	5.5	5.5	-40
433	M	11	6	6.2	6.7	+730
946	F	11	9	6.3	6.3	-130
164	M	11	1	5.2	6.5	0
280*	M	12	3	5.6	6.9	-80
49	M	12	2	4.2	5.2	+40

* Second recapture.

APPENDIX F

MACRO-INVERTEBRATE SPECIES LISTS AND BMWP INDEX VALUES FOR EACH SAMPLE

R. Thame - Crayfish project species listings

Reach 1 Site 1 Spring (21 May 1996)

Taxon code	Taxon name
16110101	Theodoxus fluviatilis (L.)
20000000	Oligochaeta
36110101	Asellus aquaticus (L.)
37130101	Crangonyx pseudogracilis Bousfield
37140206	Gammarus pulex (L.)
40120201	Centroptilum luteolum (Muller)
40320103	Ephemera vulgata L.
4051020Z	Caenis luctuosa group
42140101	Calopteryx splendens (Harris)
48240103	Cyrnus trimaculatus (Curtis)
48410104	Athripsodes cinereus (Curtis)
48410401	Mystacides azurea (L.)
50360387	Simulium (Simulium) posticatum Meigen
50400000	Chironomidae

BMWP score	:	**69**
Number of taxa	:	**12**
ASPT	:	**5.75**

Reach 1 Site 1 Autumn (10 September 1996)

17130100	Sphaerium sp.
17130200	Pisidium sp.
20000000	Oligochaeta
36110101	Asellus aquaticus (L.)
37130101	Crangonyx pseudogracilis Bousfield
37140206	Gammarus pulex (L.)
4012011Z	Baetis scambus group
40120201	Centroptilum luteolum (Muller)
40120401	Procloeon bifidum Bengtsson
40320103	Ephemera vulgata L.
4051020Z	Caenis luctuosa group
42110101	Platycnemis pennipes (Pallas)
46110102	Sialis lutaria (L.)
48240103	Cyrnus trimaculatus (Curtis)
5036034Z	Simulium (Eusimulium) aureum group
50400000	Chironomidae

BMWP score	:	**58**
Number of taxa	:	**12**
ASPT	:	**4.83**

R. Thame - Crayfish project species listings

Reach 1 Site 2 Spring (21 May 1996)

16140301	Potamopyrgus jenkinsi (Smith)
16240101	Ancylus fluviatilis Muller
20000000	Oligochaeta
24000000	Hydracarina
37140206	Gammarus pulex (L.)
40120111	Baetis vernus Curtis
4012011Z	Baetis scambus group
40320103	Ephemera vulgata L.
40410101	Ephemerella ignita (Poda)
4051020Z	Caenis luctuosa group
42120201	Ischnura elegans (Van der Linden)
42140101	Calopteryx splendens (Harris)
48130300	Hydroptila sp.
48250207	Hydropsyche pellucidula (Curtis)
48410104	Athripsodes cinereus (Curtis)
48410403	Mystacides nigra (L.)
50350000	Ceratopogonidae
50360350	Simulium (Wilhelmia) sp.
50360361	Simulium (Boophthora) erythrocephalum (de Geer)
50360387	Simulium (Simulium) posticatum Meigen
50400000	Chironomidae

BMWP score	:	**89**
Number of taxa	:	**15**
ASPT	:	**5.93**

Reach 1 Site 2 Autumn (10 September 1996)

17130100	Sphaerium sp.
20000000	Oligochaeta
36110101	Asellus aquaticus (L.)
37130101	Crangonyx pseudogracilis Bousfield
37140206	Gammarus pulex (L.)
40120201	Centroptilum luteolum (Muller)
40320103	Ephemera vulgata L.
42110101	Platycnemis pennipes (Pallas)
42140101	Calopteryx splendens (Harris)
46110102	Sialis lutaria (L.)
48250207	Hydropsyche pellucidula (Curtis)
50360361	Simulium (Boophthora) erythrocephalum (de Geer)
50400000	Chironomidae

BMWP score	:	**57**
Number of taxa	:	**12**
ASPT	:	**4.75**

R. Thame - Crayfish project species listings

Reach 1 Site 3 Spring (21 May 1996)

16240101	Ancylus fluviatilis Muller
16250101	Acroloxus lacustris (L.)
20000000	Oligochaeta
36110101	Asellus aquaticus (L.)
37140206	Gammarus pulex (L.)
40120111	Baetis vernus Curtis
4012011Z	Baetis scambus group
40210301	Habrophlebia fusca (Curtis)
40320103	Ephemera vulgata L.
40410101	Ephemerella ignita (Poda)
4051020Z	Caenis luctuosa group
42140101	Calopteryx splendens (Harris)
48130300	Hydroptila sp.
50350000	Ceratopogonidae
50360361	Simulium (Boophthora) erythrocephalum (de Geer)
50360387	Simulium (Simulium) posticatum Meigen
50400000	Chironomidae
50710000	Empididae

BMWP score	**:**	**78**
Number of taxa	**:**	**13**
ASPT	**:**	**6.00**

Reach 1 Site 3 Autumn (10 September 1996)

16240101	Ancylus fluviatilis Muller
17130200	Pisidium sp.
20000000	Oligochaeta
36110101	Asellus aquaticus (L.)
37130101	Crangonyx pseudogracilis Bousfield
37140206	Gammarus pulex (L.)
40120111	Baetis vernus Curtis
4012011Z	Baetis scambus group
40120201	Centroptilum luteolum (Muller)
40120301	Cloeon dipterum (L.)
40120401	Procloeon bifidum Bengtsson
40320103	Ephemera vulgata L.
4051020Z	Caenis luctuosa group
42110101	Platycnemis pennipes (Pallas)
42120201	Ischnura elegans (Van der Linden)
42140101	Calopteryx splendens (Harris)
45150401	Orectochilus villosus (Muller)
46110102	Sialis lutaria (L.)
48240103	Cyrnus trimaculatus (Curtis)
48250207	Hydropsyche pellucidula (Curtis)
48410400	Mystacides sp.
50360361	Simulium (Boophthora) erythrocephalum (de Geer)
50400000	Chironomidae

BMWP score	**:**	**98**
Number of taxa	**:**	**18**
ASPT	**:**	**5.44**

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Reach 2 Site 1 Spring (22 May 1996)

20000000	Oligochaeta
36110101	Asellus aquaticus (L.)
37130101	Crangonyx pseudogracilis Bousfield
37140206	Gammarus pulex (L.)
40120201	Centroptilum luteolum (Muller)
40210301	Habrophlebia fusca (Curtis)
40320103	Ephemera vulgata L.
4051020Z	Caenis luctuosa group
42120201	Ischnura elegans (Van der Linden)
42140101	Calopteryx splendens (Harris)
43610910	Sigara (Sigara) sp.
43610922	Sigara (Subsigara) falleni (Fieber)
46110102	Sialis lutaria (L.)
50350000	Ceratopogonidae
50360387	Simulium (Simulium) posticatum Meigen
50400000	Chironomidae
50830400	Hydrellia sp.

BMWP score	:	**71**
Number of taxa	:	**13**
ASPT	:	**5.46**

Reach 2 Site 1 Autumn (10 September 1996)

16140301	Potamopyrgus jenkinsi (Smith)
17120200	Anodonta sp.
17130200	Pisidium sp.
20000000	Oligochaeta
37140206	Gammarus pulex (L.)
40320103	Ephemera vulgata L.
4051020Z	Caenis luctuosa group
45150401	Orectochilus villosus (Muller)
45630600	Oulimnius sp.
46110102	Sialis lutaria (L.)
48240103	Cyrnus trimaculatus (Curtis)
48410403	Mystacides nigra (L.)
50400000	Chironomidae

BMWP score	:	**69**
Number of taxa	:	**13**
ASPT	:	**5.31**

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Reach 2 Site 2 Spring (22 May 1996)

16140301	Potamopyrgus jenkinsi (Smith)
16240101	Ancylus fluviatilis Muller
20000000	Oligochaeta
24000000	Hydracarina
37130101	Crangonyx pseudogracilis Bousfield
37140206	Gammarus pulex (L.)
40120107	Baetis rhodani (Pictet)
40120111	Baetis vernus Curtis
4012011Z	Baetis scambus group
40320103	Ephemera vulgata L.
40410101	Ephemerella ignita (Poda)
4051020Z	Caenis luctuosa group
42140101	Calopteryx splendens (Harris)
48130300	Hydroptila sp.
48220408	Tinodes waeneri (L.)
48250207	Hydropsyche pellucidula (Curtis)
48410104	Athripsodes cinereus (Curtis)
50350000	Ceratopogonidae
50360350	Simulium (Wilhelmia) sp.
50360361	Simulium (Boophthora) erythrocephalum (de Geer)
50360387	Simulium (Simulium) posticatum Meigen
50400000	Chironomidae

BMWP score	:	**91**
Number of taxa	:	**15**
ASPT	:	**6.07**

Reach 2 Site 2 Autumn (10 September 1996)

16110101	Theodoxus fluviatilis (L.)
16140301	Potamopyrgus jenkinsi (Smith)
16240101	Ancylus fluviatilis Muller
17130200	Pisidium sp.
20000000	Oligochaeta
36110101	Asellus aquaticus (L.)
37130101	Crangonyx pseudogracilis Bousfield
37140206	Gammarus pulex (L.)
40120111	Baetis vernus Curtis
4012011Z	Baetis scambus group
40120401	Procloeon bifidum Bengtsson
40320103	Ephemera vulgata L.
42140101	Calopteryx splendens (Harris)
48130300	Hydroptila sp.
48220408	Tinodes waeneri (L.)
48250207	Hydropsyche pellucidula (Curtis)
50400000	Chironomidae

BMWP score	:	**71**
Number of taxa	:	**14**
ASPT	:	**5.07**

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Reach 2 Site 3 Spring (22 May 1996)

16250101	Acroloxus lacustris (L.)
17130100	Sphaerium sp.
20000000	Oligochaeta
36110101	Asellus aquaticus (L.)
37130101	Crangonyx pseudogracilis Bousfield
37140206	Gammarus pulex (L.)
40120301	Cloeon dipterum (L.)
4051020Z	Caenis luctuosa group
42120201	Ischnura elegans (Van der Linden)
43610922	Sigara (Subsigara) falleni (Fieber)
46110102	Sialis lutaria (L.)
48130300	Hydroptila sp.
48410403	Mystacides nigra (L.)
50350000	Ceratopogonidae
50400000	Chironomidae
50710000	Empididae

BMWP score	:	**63**
Number of taxa	:	**13**
ASPT	:	**4.85**

Reach 2 Site 3 Autumn (10 September 1996)

17130200	Pisidium sp.
20000000	Oligochaeta
36110101	Asellus aquaticus (L.)
37130101	Crangonyx pseudogracilis Bousfield
40120201	Centroptilum luteolum (Muller)
40120301	Cloeon dipterum (L.)
42120201	Ischnura elegans (Van der Linden)
43230100	Gerris sp.
43610922	Sigara (Subsigara) falleni (Fieber)
46110102	Sialis lutaria (L.)
48410403	Mystacides nigra (L.)
50400000	Chironomidae

BMWP score	:	**49**
Number of taxa	:	**11**
ASPT	:	**4.46**

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Reach 3 Site 1 Spring (22 May 1996)

16130103	Valvata piscinalis (Muller)
16140301	Potamopyrgus jenkinsi (Smith)
16160102	Bithynia tentaculata (L.)
16220104	Lymnaea peregra (Muller)
16230202	Anisus vortex (L.)
16230402	Gyraulus albus (Muller)
16250101	Acroloxus lacustris (L.)
17130100	Sphaerium sp.
17130200	Pisidium sp.
20000000	Oligochaeta
22310101	Erpobdella octoculata (L.)
36110101	Asellus aquaticus (L.)
40120201	Centroptilum luteolum (Muller)
40320103	Ephemera vulgata L.
4051020Z	Caenis luctuosa group
42110101	Platycnemis pennipes (Pallas)
42120201	Ischnura elegans (Van der Linden)
42140101	Calopteryx splendens (Harris)
43610910	Sigara (Sigara) sp.
45110304	Haliplus fluviatilis Aube
45141303	Potamonectes depressus (Fabricius)
46110102	Sialis lutaria (L.)
48130300	Hydroptila sp.
48240501	Polycentropus flavomaculatus (Pictet)
48341719	Limnephilus lunatus Curtis
50350000	Ceratopogonidae
50400000	Chironomidae

BMWP score	:	**110**
Number of taxa	:	**23**
ASPT	:	**4.78**

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Reach 3 Site 1 Autumn (9 September 1996)

16140301	Potamopyrgus jenkinsi (Smith)
16160102	Bithynia tentaculata (L.)
16220104	Lymnaea peregra (Muller)
16230202	Anisus vortex (L.)
16230402	Gyraulus albus (Muller)
16230501	Armiger crista (L.)
16240101	Ancylus fluviatilis Muller
16250101	Acroloxus lacustris (L.)
17130200	Pisidium sp.
20000000	Oligochaeta
20420401	Eiseniella tetraedra (Savigny)
22120401	Glossiphonia complanata (L.)
22310101	Erpobdella octoculata (L.)
4012011Z	Baetis scambus group
40120201	Centroptilum luteolum (Muller)
40320103	Ephemera vulgata L.
40410101	Ephemerella ignita (Poda)
4051020Z	Caenis luctuosa group
42110101	Platycnemis pennipes (Pallas)
42140101	Calopteryx splendens (Harris)
45150401	Orectochilus villosus (Muller)
45630101	Elmis aenea (Muller)
45630600	Oulimnius sp.
46110102	Sialis lutaria (L.)
48130300	Hydroptila sp.
48220408	Tinodes waeneri (L.)
48250207	Hydropsyche pellucidula (Curtis)
48410104	Athripsodes cinereus (Curtis)
48410403	Mystacides nigra (L.)
5036034Z	Simulium (Eusimulium) aureum group
50360361	Simulium (Boophthora) erythrocephalum (de Geer)
50400000	Chironomidae

BMWP score	:	**120**
Number of taxa	:	**23**
ASPT	:	**5.22**

R. Thame - Crayfish project species listings

Reach 3 Site 2 Spring (22 May 1996)

16120101	Viviparus contectus (Millet)
16160102	Bithynia tentaculata (L.)
16220105	Lymnaea stagnalis (L.)
16230402	Gyraulus albus (Muller)
16230501	Armiger crista (L.)
16240101	Ancylus fluviatilis Muller
16250101	Acroloxus lacustris (L.)
17130100	Sphaerium sp.
17130200	Pisidium sp.
20000000	Oligochaeta
22120401	Glossiphonia complanata (L.)
22310101	Erpobdella octoculata (L.)
22310302	Trocheta subviridis Dutrochet
24000000	Hydracarina
36110101	Asellus aquaticus (L.)
37130101	Crangonyx pseudogracilis Bousfield
40320103	Ephemera vulgata L.
4051020Z	Caenis luctuosa group
42110101	Platycnemis pennipes (Pallas)
42120201	Ischnura elegans (Van der Linden)
42140101	Calopteryx splendens (Harris)
45630604	Oulimnius tuberculatus (Muller)
46110102	Sialis lutaria (L.)
48130300	Hydroptila sp.
48220100	Lype sp.
48220408	Tinodes waeneri (L.)
48340602	Halesus radiatus (Curtis)
48341401	Anabolia nervosa (Curtis)
48341719	Limnephilus lunatus Curtis
48410104	Athripsodes cinereus (Curtis)
48410403	Mystacides nigra (L.)
50400000	Chironomidae

BMWP score	:	**119**
Number of taxa	:	**23**
ASPT	:	**5.17**

R. Thame - Crayfish project species listings

Reach 3 Site 2 Autumn (9 September 1996)

16160102	Bithynia tentaculata (L.)
16220104	Lymnaea peregra (Muller)
17130100	Sphaerium sp.
17130200	Pisidium sp.
20000000	Oligochaeta
22120401	Glossiphonia complanata (L.)
22310101	Erpobdella octoculata (L.)
36110101	Asellus aquaticus (L.)
40320103	Ephemera vulgata L.
42110101	Platycnemis pennipes (Pallas)
42140101	Calopteryx splendens (Harris)
43610910	Sigara (Sigara) sp.
46110102	Sialis lutaria (L.)
48220100	Lype sp.
48250207	Hydropsyche pellucidula (Curtis)
48410403	Mystacides nigra (L.)
50330000	Culicidae
50400000	Chironomidae

BMWP score	:	**77**
Number of taxa	:	**16**
ASPT	:	**4.81**

R. Thame - Crayfish project species listings

Reach 3 Site 3 Spring (22 May 1996)

16140301	Potamopyrgus jenkinsi (Smith)
16160102	Bithynia tentaculata (L.)
16230202	Anisus vortex (L.)
16230402	Gyraulus albus (Muller)
16230501	Armiger crista (L.)
16240101	Ancylus fluviatilis Muller
16250101	Acroloxus lacustris (L.)
17120202	Anodonta cygnea (L.)
17130100	Sphaerium sp.
17130200	Pisidium sp.
20000000	Oligochaeta
22120301	Hemiclepsis marginata (Muller)
22310101	Erpobdella octoculata (L.)
37140206	Gammarus pulex (L.)
4012011Z	Baetis scambus group
40320103	Ephemera vulgata L.
40410101	Ephemerella ignita (Poda)
4051020Z	Caenis luctuosa group
42120201	Ischnura elegans (Van der Linden)
42140101	Calopteryx splendens (Harris)
45150401	Orectochilus villosus (Muller)
45630101	Elmis aenea (Muller)
45630600	Oulimnius sp.
48130300	Hydroptila sp.
48220408	Tinodes waeneri (L.)
48250207	Hydropsyche pellucidula (Curtis)
48250209	Hydropsyche siltalai Dohler
48340602	Halesus radiatus (Curtis)
48341719	Limnephilus lunatus Curtis
48390101	Molanna angustata Curtis
48410104	Athripsodes cinereus (Curtis)
50350000	Ceratopogonidae
50360350	Simulium (Wilhelmia) sp.
50360361	Simulium (Boophthora) erythrocephalum (de Geer)
50360387	Simulium (Simulium) posticatum Meigen
50400000	Chironomidae

BMWP score	:	**142**
Number of taxa	:	**25**
ASPT	:	**5.68**

R. Thame - Crayfish project species listings

Reach 3 Site 3 Autumn (9 September 1996)

16130103	Valvata piscinalis (Muller)
16140301	Potamopyrgus jenkinsi (Smith)
16160102	Bithynia tentaculata (L.)
16220104	Lymnaea peregra (Muller)
16220105	Lymnaea stagnalis (L.)
16230101	Planorbis carinatus Muller
16230202	Anisus vortex (L.)
16230501	Armiger crista (L.)
16250101	Acroloxus lacustris (L.)
17130200	Pisidium sp.
20000000	Oligochaeta
22120401	Glossiphonia complanata (L.)
22310101	Erpobdella octoculata (L.)
36110101	Asellus aquaticus (L.)
37130101	Crangonyx pseudogracilis Bousfield
40120201	Centroptilum luteolum (Muller)
40120301	Cloeon dipterum (L.)
40320103	Ephemera vulgata L.
42110101	Platycnemis pennipes (Pallas)
42120201	Ischnura elegans (Van der Linden)
4212040Z	Coenagrion puella group
42140101	Calopteryx splendens (Harris)
43610910	Sigara (Sigara) sp.
45110304	Haliplus fluviatilis Aube
45110308	Haliplus immaculatus Gerhardt
46110102	Sialis lutaria (L.)
48220100	Lype sp.
48310500	Phryganea sp.
48390101	Molanna angustata Curtis
48410403	Mystacides nigra (L.)
50400000	Chironomidae

BMWP score	:	**125**
Number of taxa	:	**24**
ASPT	:	**5.21**