Assessment of Spatial and Temporal Variation in Puerulus Settlement of the Southern Rock Lobster

FINAL REPORT TO THE FISHERIES RESEARCH AND DEVELOPMENT CORPORATION

by R B Kennedy

Department of Primary Industry and Fisheries Tasmania

February 1994

TABLE OF CONTENTS

LIST OF FIGURES

Figure No.

SUMMARY

The overall goal of the present project was to establish a long term puerulus settlement monitoring program for the southern rock lobster *(Jasus edwardsii)* in Tasmania. Exploratory sampling was conducted throughout much of the Tasmanian coastline to determine key sites suitable for long term monitoring. Experiments were also conducted to determine guidelines for the use of collectors and to determine whether individual sampling stations could provide a representative indication of inter-annual variation in settlement throughout a larger area.

Exploratory sampling around Tasmania found both small and large scale spatial variation in settlement levels. In general settlement rates obtained on the west coast were considerably lower than on the east. Distinct seasonality of settlement was also observed and differences existed in the timing of settlement between areas. Two peaks in settlement occurred each year on the east coast, these being winter (June to September) and summer (November/December). The timing of peaks on the south coast were similar to the east coast except that the summer settlement often occurred one to two months later. On the west coast, the primary period of settlement appeared to be from January to April.

Because of differences in the timing of settlement between the east, south and west coasts, it was considered important that long term monitoring be conducted within each of these regions. A total of 8 sites were established for long term monitoring. This comprised 4 sites on the east coast (Bicheno area), 1 site in the south east (South Arm), 2 sites in the south (Recherche Bay) and 1 site on the west coast (King Island). The number of collectors currently in use will allow inter-annual settlement declines of between 30 and 50 percent to be detected as being significant on the east, south east and south coasts, but on the west coast, declines would need to be nearly 100% to be detected as being significant. The number of collectors required to detect changes was highly dependant on catch rates with lower numbers of collectors being required at sites with high catch rates.

Significant inter-annual variation in settlement has already been detected. There was a significant decline in settlement on the east coast (Bicheno) between the 1991/92 and 1992/93 settlement seasons (a settlement season being defined as 1 May to 30 April) and it appears likely that settlement will again decline for the 1993/94 settlement season. Declines from 1991/92 to 1992/93 were also evident on the south coast, but not on the west coast.

Experiments found that conditioning of collectors and height of collectors above the substrate had a significant effect on catch rates. It was recommended that well conditioned collectors (at least one year of submergence) be used when replacements are required and that when this is not possible, that analyses exclude results from collectors with less than 120 days of

conditioning. It was also recommended that the height of collectors be maintained between 0.2 and 0.8 metres above the substrate.

Catch rates did not appear to be influenced by the alignment of collectors or by the degree of sand deposition. There was a possible relationship between catch rates and water movements in which sites with the highest flow rates tended to have low catch rates. However, analysis of the relationship was hindered by gaps in the time-series and any relationship was overshadowed by the fact that it proved impossible to reliably sample sites with high exposure to water movement.

An important result was that individual sampling sites appeared to provide a representative indication of temporal changes in settlement over a wider region. Hence, it should be possible to make inferences regarding inter-annual settlement trends for a region by monitoring a limited number of sites within that region.

1. GENERAL INTRODUCTION

The southern rock lobster (*Jasus edwardsii*) occurs throughout southern Australia with highest abundance off South Australia, Tasmania and Victoria. The fisheries for this species produces an annual catch of approximately 4,500 tonnes and is one of the most valuable fisheries in Australia.

The southern rock lobster fisheries have previously been monitored through a combination of catch sampling studies and commercial catch and effort data. These are the basic monitoring tools used by most fisheries throughout the world and they also provide the fundamental ingredients required by many stock assessments. This includes general CPUE trends, fishing mortality, size and sex composition, size at maturity and spawning stock index. Despite the obvious importance of catch sampling studies and commercial catch data, the time lag between settlement and recruitment to the fishable population means that neither method provides managers with real-time information concerning the status of the resource.

The puerulus larva of *J. edwardsii* is a transitional settling stage between the planktonic phyllosoma larva and the benthic juvenile. A knowledge of annual variation in puerulus settlement rates would provide information concerning fluctuations in the resource at an earlier time than is achieved through other methods of fishery monitoring. This assumes that reproductive output and pre-settlement processes acting upon the planktonic stages are dominant variables influencing recruitment to the fishery, while post-settlement processes are relatively small. Hence, large inter-annual fluctuations in puerulus settlement levels should later be observed as fluctuations in recruitment to the fishery.

In order to provide timely advice to management, it is important to monitor the fishery at the earliest possible stage, so the development of a puerulus monitoring program is considered to be a high priority. Monitoring of puerulus settlement has proved useful in fisheries management by enabling forecasting of recruitment trends (Phillips, 1986) and to aid in monitoring the health of a fishery (Booth and Bowring, 1988).

In Tasmania, slow growth rates in some areas and the large variation in growth rates around the state will hinder the development of an accurate catch prediction model. Nevertheless, knowledge of annual variation in puerulus settlement would provide an important early warning system of potential declines in the fishery. Furthermore, knowledge of the timing and patterns of settlement is an important first step towards developing an understanding of larval recruitment in the rock lobster fishery.

A one year pilot study into larval recruitment (FIRDC 88/41) identified a suitable design of puerulus collector and that puerulus could be successfully collected in Tasmania. The overall purpose of the present study was to identify and establish key sites suitable for long term sampling of puerulus settlement levels for the purpose of monitoring the status of the rock lobster resource. The specific individual objectives were as follows:

(a) Quantify localised variations in puerulus settlement, and:
- Assess the impact of environmental variables including exposure to water movement (rate and direction), collector conditioning, sand deposition, and depth.
- Determine whether individual stations are representative of an area on an inter-annual basis (i.e. whether inter-annual variability in settlement levels is consistent between stations).

(b) Assess large scale spatial variations in the levels of puerulus settlement around Tasmania.
(c) Using (a) and (b), establish key sites suitable for long term monitoring of puerulus settlement levels.
(d) Use settlement information to aid understanding of larval recruitment processes.

Results of objectives "a" to "c" are presented in chapters 3 to 5 respectively. Chapter 6 provides a brief discussion on the use of settlement information to aid in understanding of larval recruitment processes. It does not present results because the time-series of data obtained during this study is, as stated in the initial project submission, far too short to obtain meaningful information on larval recruitment processes.

2. GENERAL METHODOLOGY

Monitoring of puerulus settlement was conducted using collectors which act as artificial habitats for settling puerulus. A crevice-type of puerulus collector (Figure 1) similar to that described by Booth and Tarring (1986) was used for all sampling. A comparison of collector types (Kennedy et. al., 1991) identified the crevice collector as being the most suitable for Tasmanian sampling. The collector consists of seven wedge shaped crevices that provide shelter for puerulus. The crevices were formed by eight plywood sheets (400 x 400 mm, CCA treated structural ply, 9 mm thick) which were secured in a galvanised steel frame. The crevices were formed by conduit spacers placed at alternating opposite ends of the plywood sheets. A sleeve welded to the bottom frame allowed the collector to be placed onto the mooring stand. A pin secured the collector head on the stand.

Wherever possible, collectors were deployed on a sand substrate in order to minimise confounding effects arising from possible migration of puerulus between the collectors and the reef fauna. Sampling sites were established using groups of 3, 6 or 12 collectors with a distance of 3 metres between collectors. Sampling was conducted throughout much of the Tasmanian coastline (Figure 2) and the layout of specific sites is described further in the relevant sections. All collectors (unless otherwise specified) were initially moored 680 mm above the sea floor in depths ranging between 3.5 to 12 metres. The height above the sea floor varied with movement of sand, so this distance was recorded each month on the data sheets. An attempt was made to keep the heights between 0.2 m and 0.8 m above the sea floor by adding or removing extensions from the mooring stand.

Each collector was labelled in two ways. The first was a label which referred to the position of a collector within a site. This enabled collectors to be repositioned to their original sampling location after being serviced. The second label was a unique identification number for the collector. This enabled a separate history to be kept for each collector. The history contains details of the construction date, and the dates and location of each deployment and removal or retrieval of each collector. This enables factors such as degree conditioning to be assessed for use in later analysis.

Collectors were serviced on a monthly basis. Divers placed a mesh bag (knotless nylon, 6 mm mesh) around a collector head to prevent loss of puerulus during movement of the collector. The collector was then hauled into a boat, where the collector and mesh bag was inspected for puerulus. All specimens were removed, counted and staged according to the criteria of Booth (1979). The collector position label and the amount of algal growth on the collector was also recorded. Specimens with a carapace length of more than 16 mm in length were considered to be juveniles and have been excluded from the results presented within this report. Prior to returning a collector to the water, algal and encrusting growth was removed using a saw blade, paint scraper and wire brush. This practise was conducted to decrease habitat variation between consecutive sampling periods.

Samples of puerulus obtained from collectors were returned to the sea well away from any sampling sites, or provided to other organisations (including the University of Tasmania and the University of Melbourne) where they were used in further research.

3. ASSESSMENT OF LOCALISED VARIATIONS IN SETTLEMENT

3.1. INTRODUCTION

A pilot study into larval recruitment and genetic variation of the southern rock lobster (FRDC 88/41) demonstrated that significant differences could occur in settlement levels between neighbouring sites over a small spatial scale (< 1 km). The current project devoted significant effort to quantifying within-site variability of settlement. This was considered to be an essential prerequisite for subsequent long-term monitoring of settlement levels.

Two aspects of localised variability were considered. The first was an examination of possible factors that might influence settlement rates. The purpose of this was to enable development of appropriate controls and guide-lines for the use, fine scale positioning and alignment of collectors. These factors are discussed in sections 3.2.a. to 3.2.e. The second and most important aspect was to determine whether individual stations could provide a representative indication of changes in settlement throughout a larger area over time. If this was not possible, then the number of sites required to monitor settlement would be so large as to preclude long term monitoring. This aspect is discussed in section 3.2.f.

3.2. METHODS and RESULTS

Sampling to assess localised variations in settlement was conducted on the east coast of Tasmania at Bicheno (Figure 2). Twelve sites, labelled "B01" to "B12" were established for this purpose. The locations of these sites are shown in Figure 3. Sampling was also conducted at two sites which were established during the previously mentioned pilot study (labelled "BDWB" and "BSWB" in Figure 3).

Sites BDWB and BSWB contained three collectors per site and the collectors were separated by approximately 3 metres.

Sites B01 to B12 were established during October and November 1990. Twelve collectors were deployed at each of these sites using a standard "cross" alignment of collectors as shown in Figure 4. The collectors were new (not conditioned) when deployed. The cross contained four arms (labelled A to D), with each arm containing 3 collectors. Arms A and C were aligned parallel to the predominant direction of swell, with arm A pointing into the swell. Arms B and D were aligned perpendicular to the predominant direction of swell. Analyses of the effects of collector alignment are presented in section 3.2.c.

Five of the twelve sites were established for specific experiments. Sites B11 and B12 were established to test the effects of collector conditioning. This is detailed further in section 3.2.a. Sites B01, B02 and B03 were established to test the effect of height of collectors above the substrate. This is detailed further in section 3.2.b. With the exception of site B01, data from the experimental sites were used solely in analyses of their respective experiments and monitoring at these sites concluded at the end of the experiments. Site B01 was monitored throughout the entire project. Data obtained from this site were used in both the collector height experiment and in comparisons involving the remaining sites.

The remaining sites (B04 to B10) were deployed in a variety of depths (Figure 3) and at locations which provided contrast in the degree of exposure to water movements. Electronic flow counters and sediment traps were deployed at the centre of each of these sites and at sites B01 and BDWB. Settlement results for these sites (B04 to B10, B01 and in some cases BDWB and BSWB) were used to examine the effects of collector alignment, exposure to water movement, sand deposition and for testing whether temporal variability in settlement was uniform between sites.

3.2.a. Collector conditioning

Within this report, collector conditioning refers to the length of time a collector had been submerged prior to its use for sampling puerulus settlement. Two experimental sites (labelled B11 and B12 in Figure 3) were established at Bicheno in a depth of 8 metres during October 1990 to test the effects of collector conditioning. Three experiments were conducted at these sites.

The first experiment was a test for any site specific differences in settlement at the chosen experimental sites. Collectors for both sites were new when deployed in October 1990. The first sampling of these sites (November 1990) was during the spring settlement peak and the data was used to test for site differences. The average catch per collector was 1.25 and 1.75 for B11 and B12 respectively, with standard errors of 0.305 and 0.372 for the same respective sites. A one-way ANOVA using square root transformed catches found no evidence for differences between the sites ($df=1,22$, $F=0.7617$, $p>0.39$).

The second experiment was a trial to determine whether the catch rate of new collectors differed from collectors with one month of previous conditioning. Comparisons of catch rates were obtained each month from December 1990 to September 1991. Every second month, all collectors at one site would be replaced with new collectors, while collectors at the other site would remain in place. Hence, during one month, site B11 might contain new collectors and B12 would have 1 month old collectors, while in the next month, this would be reversed. This sampling design is not optimal in that site specific differences in settlement would add to the variation in the data and thus result in reduced power to detect differences in catch rates between degrees of collector conditioning. A more powerful design would have been to have 6 new and 6 one month old collectors at each site each month. However, the final choice of design was made for practical reasons. It was found to be more efficient (in terms of time in the field) to replace one site of 12 collectors than replacing 6 collectors in each of two sites. Also, divers can become disorientated while under water and errors are more likely to occur in replacing collectors if two ages of collectors exist in the same site (i.e. the diver has to choose which of the six collectors must be replaced in each site).

Results of the collector conditioning experiment are shown in Figure 5. It is clear that new collectors had a lower catch rate than did collectors with one month of previous conditioning. This is confirmed by a two-way ANOVA using square root transformed catches (Table 1) in which condition of collector had a very highly significant effect on catches. A very highly significant month effect was also obtained (due to distinct Seasonality of settlement) as well as an interaction between month and collector condition. The interaction is clearly seen in Figure 5. In months of low catches, few specimens are caught and there is no noticeable effect of collector conditioning. It is in months of high catches that an effect of collector conditioning becomes noticeable.

Table 1: Two-way ANOVA to test the effect of one month of collector conditioning.

Source of Variation	S.S.	D.F.	M.S.	F	p
Collector Condition	10.64	1	10.64	30.24	<0.001
Month	129.00	9	14.33	40.75	<0.001
Collector Condition * Month	8.95	9	0.99	2.83	<0.01
Error	77.38	220	0.35		

A third trial was conducted to determine whether differences could be detected between collectors with 1 and 2 months of conditioning, 2 and 3 months, 3 and 4 months, and 4 and 5 months of conditioning. The same sites (B11 and B12) were used as in the previous collector conditioning experiment. Six 1 month old collectors (i.e. 1 month of previous conditioning) and six 2 month old collectors were placed at each site during September 1991. These collectors were monitored for the next four months. The results of this trial and catches from site B10 during the same period are shown in Figure 6.

Examination of Figure 6 (ignoring results for site B10) indicates slight differences between the catch rates of collectors conditioned for 1 and 2 months and between collectors conditioned for 2 and 3 months. However, there were no noticeable differences between collectors conditioned for 3 and 4 months and between collectors conditioned for 4 and 5 months. This suggests that one month of extra conditioning may have a slight effect if the collectors have had less than 3 months of conditioning, but no effect after this. However, analyses of variance using square root transformed catches revealed no significant differences for any of these collector conditioning comparisons (Table 2).

Table 2: Summarised results of tests to determine whether differences existed in the catch rates between collectors with 1 and 2 months of conditioning, 2 and 3 months, 3 and 4 months, and 4 and 5 months of conditioning.

Comparison	D.F.	F	p
1 vrs 2 months of conditioning	1,20	1.94	>0.17
2 vrs 3 months of conditioning	1,22	1.70	>0.20
3 vrs 4 months of conditioning	1,22	0.007	>0.93
4 vrs 5 months of conditioning	1,22	0.004	>0.95

The above results provide no indication as to whether well conditioned collectors catch more puerulus than collectors with just a few months of conditioning. It may require one or more years submergence before a collector becomes fully conditioned. Results from site B10 may provide an indication of the effects of a longer period of conditioning. During the period in question (Oct. 91 to Jan. 92), this site contained collectors which had been conditioned for 11 to 14 months. Site B10 is also positioned physically between sites B11 and B12 (see Figure 3) and hence differences in catch rates due to position should be minimal. Furthermore, a comparison of a single months catches for all three sites when all had new collectors (November 1990, the spring settlement peak) revealed no significant differences ($df=2,33$, $F=0.71$, $p>0.49$) between the catch rates which averaged 1.25, 1.25 and 1.75 per collector for sites B10, B11 and B12 respectively.

Figure 6 shows that the well conditioned collectors at site B10 always caught as many puerulus (usually more) as did the "newer" collectors from sites B11 and B12. This might suggest that collectors require quite long periods of conditioning. However, the differences were not significant and the differences in catch rates between collector ages were not consistent through time.

3.2.b. Height of collectors above the substrate

Three experimental sites were established at the same location during November 1990 to test the effect of height of collectors above the substrate on catch rates. The experiment contained three height categories (labelled B01, B02 and B03 in Figure 3), with the heights averaging 43, 162 and 282 centimetres above the substrate. The depth of the site was 9 metres. Twelve collectors were deployed at each height and the layout of collectors is shown in Figure 7. All collectors were unconditioned when initially deployed. Catches of collectors at each height were monitored each month from December 1990 to February 1992. At the end of this time, the two heighest levels (B02 and B03) were removed and sampling continued at the lowest level (B01).

Figure 8 shows the average monthly catch per collector for each height category. Catch rates were low during the first 6 months, which is probably a partial reflection of the lack of conditioning of the collectors (see section 3.2.a). It is clear that higher catches were consistently obtained from those collectors nearest the sea floor (B01) and that lowest catches were consistently obtained from the heighest collectors (B03).

A repeated measures ANOVA was conducted to determine whether significant differences existed in the catches between the three heights of collectors. Each month of sampling was treated as a repeated measure. Catches from two individual collectors (one from B01 and one from B03) were excluded from the analysis since these were missing data for some of the months. The analysis used a square root transformation of catches. Table 3 shows the results of this analysis.

Table 3: Repeated measures ANOVA to test the effect of collector heights.

Source of Variation	S.S.	D.F.	M.S.	F	p
Between collectors					
Height category	146.99	2	73.50	84.29	<0.01
Error	27.03	31	0.87		
Between times within collectors					
Month	436.71	14	31.19	63.36	<0.01
Month * Height category	79.75	28	2.85	5.79	<0.01
Error	213.67	434	0.49		

The results show that height of collectors had a highly significant effect on catches. An effect due to months was expected due to distinct seasonality of settlement. However, there was also a highly significant interaction between months and height of collectors. Figure 8a shows that the difference in catch rate between heights was not constant through time. The differences in catch rates between heights was larger in months with high catches than it was in months with low catches.

At the conclusion of the above experiment, a standard practise was adopted in which an attempt was made to keep the distance from the sea floor to the base of a collector between 0.2 and 0.8 metres. It was not possible to maintain a fixed height because of movement of sand and submergence of collectors on the sea floor. For example, a height of 0.5 metres might become 0.2 metres after sand deposition. When an 0.3m extension is then placed on the mooring to return the height to 0.5 metres, a period of sand erosion could result in a height of 0.8 metres. In order to assess whether minor fluctuations in height of collectors may have effected catches, the distance between the substrate and the bottom of each collector was measured to the nearest centimetre at each sampling period. An analysis of covariance was then conducted (with height as the covariate). The analysis was restricted to standard sites with the most continuous time series of data (i.e. B01, B04, B08, B09 and B10) and to months with high catches (7/92, 8/92, 9/92, 11/92, 12/92, 7/93, 8/93) and was conducted with square root transformed catches. The analysis found no significant influence of collector height after removing the effects of months and sites.

Table 4 shows the range of collector heights which occurred for the above sites and months. The overall range of collector heights is quite large (nearly 1 metre), but there is only minor variation within each site during each month. Of the 34 site*month combinations, 25 (74%) had a range of heights of 20 cm or less and 32 (94%) had a range of 30 cm or less. Hence, while this minor variation of collector heights has not had a significant effect on the results, it does not rule out the possibility of a relationship between catch rate and height of collectors where there is a difference of at least 30 cm between heights.

Table 4: Heights of collectors (cm) above the substrate in different sites and months. Each cell contains the minimum and maximum height of collectors within each site and month combination.

	Sampling Sites					
Month	B01	B04	B08	B09	B010	ALL
07/92	35-51	61-68	69-74	34-55	52-67	34-74
08/92	30-58	58-64	63-72	48-65	55-62	30-72
09/92	30-50	60-80	39-55	43-55	50-80	30-80
11/92	29-51	57-65	49-60	47-60	55-71	29-71
12/92	25-50	53-63	35-117	51-65	60-74	25-117
07/93	23-45	61-66	31-55	38-51	31-39	23-66
08/93	34-46	60-67	20-58	38-55	-	20-67
ALL	23-58	53-80	20-117	34-65	31-80	20-117

3.2.c. Collector alignment

As previously mentioned, collectors were deployed at sites around Bicheno using a standard cross layout of collectors. The cross contained four arms (labelled A to D), with each arm containing 3 collectors. Arms A and C were aligned parallel to the predominant direction of swell, with arm A pointing into the swell. Arms B and D were aligned perpendicular to the predominant direction of swell.

Data from sites monitored during the period from March 1991 to June 1993 (B01, B04, B05, B06, B07, B08, B09 and B10) were used to assess whether alignment of collectors with respect to swell direction had any effect on catch rates. An average catch per collector was calculated (from the monthly averages) for each arm and site. These averages are shown in Table 5. To facilitate comparisons of averages between arms of a site, some data has been excluded. Data was excluded for collectors with less than 120 days of conditioning (as can occur when collectors require replacement), and for individual sites, the data for any month in which one or more of the arms was not sampled.

Table 5: Average catch of puerulus and post puerulus per collector according to site and alignment of collectors during the period from March 1991 to June 1993. The method by which averages were obtained is described in the text.

	Parallel		Perpendicular	
Site	Arm A	Arm C	Arm B	Arm D
B01	4.0	4.1	5.6	5.8
B04	4.8	3.8	3.4	3.9
B05	2.6	2.1	1.8	2.1
B06	5.2	4.8	4.9	4.3
B07	1.9	1.6	1.8	2.1
B08	3.6	2.6	3.7	4.0
B09	4.8	5.0	5.0	5.1
B10	3.6	3.0	2.9	4.1
Overall Average	3.8	3.4	3.6	3.9

Perusal of table 5 provides no indication of consistent trends over sites in catch rates between individual arms or between arms which are parallel and those which are perpendicular to the predominant direction of swell. Hence, alignment of collectors with respect to the predominant direction of swell does not appear to have a noticeable effect on catch rates. However, it is possible that alignment of collectors with respect to other factors that vary between sites could be important. To examine this possibility, Figure 9 provides the average catch per collector for each arm and site through time. It could be suggested that the "perpendicular arms" (B and D) provide the highest peaks for site B01 and that arm A provides the highest peaks for B04, but this is not convincing and it is even more difficult to identify any consistent differences between the arms at the other sites.

The analysis above was restricted to comparisons of catch rates between "arms" of the standard cross arrangement of collectors. However, the cross arrangement of collectors can also be thought of as comprising three rings of collectors, these being an inner ring made up of the four innermost collectors, a middle ring of four collectors and an outer ring of four collectors. Collectors in the inner ring are surrounded by more collectors and at closer average distances between collectors than are collectors in the middle ring (Figure 4). Similarly, collectors in the middle ring are surrounded by more collectors and at closer average distances between collectors than collectors in the outer ring. It is possible that neighbouring collectors compete for the available catch of puerulus. If so, then catch rates are likely to be lower for collectors which are positioned too closely together (i.e. within the fishing radius of another collector) and for collectors which are positioned inside an assemblage of other collectors (due to filtering effects etc.). A comparison of the catch rates between the three rings of collectors was conducted in order to assess whether any competitive interference was occurring between collectors in the present study. If such interference was occurring, then lowest catch rates should occur for the inner ring of collectors.

Table 6 shows the average catch rates for each the three rings at 8 different sites over the period from March 1991 to June 1993. Calculation of averages and restriction of data followed the same method as that described for the analysis of collector alignment. There are no consistent trends over sites in catch rates between the three rings of collectors. Overall, the inner ring of collectors had a marginally higher catch rate than did the other rings, so there is no evidence to suggest that there was any competitive interference between collectors.

Table 6: Average catch of puerulus and post puerulus per collector according to site and position of collectors during the period from March 1991 to June 1993. The method by which averages were obtained is described in the text.

Site	Inner Collectors	Middle Collectors	Outer Collectors
B01	5.0	4.5	5.1
B04	4.5	3.8	3.6
B05	2.3	1.9	2.0
B06	4.0	5.1	4.6
B07	1.9	1.4	2.1
B08	3.9	3.7	2.8
B09	5.1	5.5	4.3
B10	3.7	3.2	3.3
Overall Average	3.8	3.6	3.5

Figure 10 provides the average catch per collector for each ring of collectors and site through time. In none of the individual sites is there any evidence which suggests that inner ring or middle rings have a lower catch rates than does the outer ring of collectors.

3.2.d. Exposure to water movement

Exposure to different degrees of water movement has the potential to influence the catch rate of puerulus collectors. This could be through altering the volume of water filtered by collectors or by producing conditions which might be unfavourable for puerulus settlement or retention. Quantification of such effects might assist in choosing future locations for monitoring puerulus settlement and possibly for calibrating catches during months or years in which the degree of water movement differed from the norm.

Sites at Bicheno were chosen to provide contrast in the degree of exposure to water movement. Sites B05 and B07 were the most exposed sites. Sites B06 and B08 had intermediate exposure, whereas sites B01, B04, B09 and B10 were fairly sheltered in comparison. Site BDWB (a continuation from the pilot study) was also fairly sheltered.

Initially, monthly quantification of exposure to water movement at each site was attempted through the use of plaster balls. This technique relied on plaster dissolving as a function of flow past the balls so that the weight loss of the balls could be used to provide an estimate of the flow. To be useful for the current study, the balls needed to last in the field for periods exceeding thirty days (the time between consecutive samplings). A number of experimental trials with different ball sizes and plaster/water mix ratios demonstrated that an additive would be required to obtain the required life span of balls. Following the work of Gerard and Mann (1979) further trials were conducted, incorporating latex into the mixture. These trials indicated that a 100 mm diameter sphere with a latex resin (Kemitex brand):water mixture of 1:5 and a casting plaster (BORAL brand):liquid mixture of 5:4 would be suitable for the current study. A standard procedure was adopted whereby the mixtures were thoroughly stirred with an electric paint stirrer, then poured into moulds. The moulds were left standing on a shaking table to remove any air bubbles, then dried at 45°C for at least 96 hours until a stable mass was achieved. The resultant balls were deployed in a cross arrangement of PVC tubes (Figure 11) so that some directional flow information could be obtained. The cross arrangement of tubes contained 3 replicates for both directions in order to assess the reliability of the technique. Attempts to quantify flow using these techniques were conducted from March 1991 to July 1991 The results obtained were highly variable and generally showed greater variation between replicates at a single site than between sites. Some of the variation appeared to be caused by the latex additive. Occasionally, the latex would form a hard crust near the edge of the sphere instead of mixing throughout, and when this occurred, the sphere was resistant to being dissolved. No solution was identified for solving this problem although there was a suspicion that variation in temperatures when mixing the solution may have contributed to variations in "crustiness". Variability was also caused by Octopus using the tubes as "homes", changing water temperatures (affecting the dissolving rate) and inherent variability of the plaster ball technique. It was concluded that continued use of the technique would not be profitable.

An alternative technique for quantifying flow was identified. This involved the development and construction of low cost (less than $100) electronic flow counters. Figure 12 provides details of the flow counter and its components. Calibrations of the counter were conducted in a towing tank at the Australian Maritime College. A meter was repeatedly towed over a distance of 25.66 metres at speeds ranging from 4.3 to 48.5 centimetres per second. Figure 13 shows the results of the calibration runs. It can be seen that at speeds of 9 cm/sec or more, the total number of propeller revolutions was fairly constant over the towing distance. Hence, at such speeds, the flow counter should provide accurate information. At lower speeds, the total number of revolutions for the distance was lower, indicating that these speeds (4 cm/sec)were approaching the threshold level for turning the propeller. However, when the data is scaled for tow duration to provide the number of revolutions per minute, the results appear close to linear for speeds ranging from 4 to 49 cm/sec (Figure 14). Speeds lower than 4 cm/sec are likely to be sufficiently small as to have little impact on puerulus settlement and can probably be ignored. Flow monitoring in site "BDWB" at Bicheno every hour from June to December 1991 with a Sensordata SD-2000 flow meter did not reveal any flow rates exceeding 20 cm/sec and this is well within the range of speeds in which the flow counter was tested.

The electronic flow counters were deployed at the centre of each of the Bicheno puerulus monitoring sites during September 1991. A number of problems were experienced in the operation of the flow counters. The most frequent problem was fouling of the propeller by drifting kelp or algal growth. In general, the results were discarded when this occurred. In order to reduce algal growth, a spray-on anti fouling paint (International's "Interspeed 2000") was tested. However, this had no noticeable effect on the algal growth and was discontinued. The best solution for reducing algal growth was found to be a replacement of the propellers each month or a thorough scrubbing of the propellers at times when sufficient replacements were not available. Other problems included damage to the counters or propellers in rough conditions, or even loss of the entire flow counting unit. The latter was a frequent problem at rough sites where heavy swells would also cause the loss of puerulus collectors.

Due to the above problems, there are many gaps in the time series of flow rate data. However, sufficient data is available to provide an approximate ranked order of exposure for the puerulus sampling sites. The flow rate data for each site over time is shown in Figure 15. Results obtained from fouled propellers have been excluded from these graphs except for sites in which there was little other data available (these cases are marked with an arrow). The average catch rate of puerulus and post puerulus per collector over the time period is shown in the top right hand corner of the graph for each site. In order to facilitate comparisons between sites, these averages excludes months in which no catch data was available for one or more sites (12/91, 2/92, 4/92, 5/92, 6/92 and 7/92). Furthermore, the average catch rates exclude data from any collectors which had less than 120 days of previous conditioning.

Perusal of Figure 15 suggests that lowest catch rates were obtained from the calmest site (BDWB) and the three most exposed sites (B05, B07 and B08). However, site BDWB contained only 3 collectors since it was a continuation of monitoring from the pilot study. Furthermore, the flow rates at BDWB were not much lower than at sites with higher catch rates. Hence, it does not appear to be valid to attribute the lower catch rates at this site to low flow rates. Flow rates at the three most exposed sites (B05, B07 and B08) were substantially higher than at all remaining sites with the possible exception of B06. Furthermore, the highest flow rates for these three sites are not available because months of high seas usually resulted in the loss of flow counters from these particular sites. It is thus possible that the low catches at these sites may be related to unfavourable conditions caused by their high degree of exposure.

In addition to having low catch rates, sites with the highest flow rates were the most difficult to service and had the highest proportion of missing data. The missing data was caused both by loss of collectors due to wave action and by adverse conditions which prevented divers from retrieving the collectors. Table 7 provides an indication of the reliability of the sites over the period in which flow rates were monitored (October 1991 to June 1993). It can be seen that beyond a certain flow rate, sites with increasing flow rates had a reduced percentage of collector checks (more missing data). Site B06 was an exception to this rule because it was situated near a moving sand bank and collectors at this site were often buried when the sand bank shifted.

Table 7: Number of successful collector checks conducted per site and the maximum number of possible collector checks per site (when sampling once per month) during the period October 1991 to June 1993. Sites are ordered in approximate ranked order of exposure to water movements as indicated in Figure 15.

Site	Actual Number of Collector Checks	Theoretical Maximum Number of Collector Checks	Percentage of Maximum
BDWB	63	63	100
B10	252	252	100
B04	252	252	100
B01	252	252	100
B09	252	252	100
B06	181	252	71.8
B08	251	252	99.6
B07	213	252	84.5
B05	169	252	67.1

3.2.e. Sand deposition

In the current study, collectors were always deployed on sandy substrates. Being in sandy areas, there could be varied levels of sand transportation and deposition which might affect levels of puerulus settlement. This was investigated with the aid of sediment traps.

Sediment traps were constructed according to the design shown in Figure 16 and were deployed in the centre of each of the Bicheno puerulus monitoring sites during November 1991. Monitoring of sand deposition was conducted on a monthly basis till April 1993.

Analysis of the sediment samples involved rinsing of the samples through a 63 μm sieve. The resultant samples were then oven dried at 100^0C to remove all moisture. The drying procedure lasted up to three days, after which the total mass of each sample was weighed. The samples were then subjected to an acid treatment in order to remove any organic matter. This was considered important as the amount of organic material may vary between sites and could provide misleading results in relation to sand deposition. The acid treatment involved rinsing samples with a 10% solution of Hydrochloric acid and leaving the samples in the solution overnight. The resultant samples were then rinsed and subjected to the same drying and weighing procedures as mentioned above. Fractional analysis for sediment sizes was also conducted, but the results are not reported here due to lack of any positive findings.

The full analysis of samples mentioned above was conducted from December 1991 to April 1992. The results over this period revealed a reasonably close relationship between the total sample mass and the mass after acid treatment (Figure 17). Due to time restraints and the close relationship, sample preparation from May 1992 and onwards was restricted to the acid treatment (i.e. the sample were rinsed, then acid treated without the preliminary total mass drying and weighing).

Figure 18 shows the sedimentation results for each site over time (December 1991 to April 1993). Gaps in the time series were caused by technical difficulties which included loss or damage to equipment in periods of high seas. The average catch rate of puerulus and post puerulus per collector over the time period is shown in the top right hand corner of the graph for each site. In order to facilitate comparisons between sites, these averages excludes months in which no catch data was available for one or more sites (12/91, 2/92, 4/92, 5/92, 6/92 and 7/92). The average catch rates also exclude data from any collectors which had less than 120 days of previous conditioning.

There was no apparent relationship between the average catch rate of puerulus and post puerulus to the levels of sedimentation at different sites. Sedimentation appeared to be related to distance from shore. The three sites with the least sedimentation (B01, BDWB and B10) were the furthest offshore (Figure 3). Site B04 had the next most sedimentation. This site was close to shore, but was in a sheltered location. The degree of sedimentation in the remaining sites was consistent with the distance of these sites from shore.

3.2.f. Uniformity of temporal variability in settlement

A long term puerulus settlement monitoring program will involve repeated sampling of a limited number of locations with a limited number of collectors in each location. The strategy of the monitoring program will be to use this restricted sampling to make inferences about temporal changes (either intra-annual or inter-annual) in settlement over a wider geographical scale. However, for this strategy to be valid it must be demonstrated that temporal changes in settlement at individual sites can provide a representative indication of temporal changes in settlement over a wider area.

A comparison of temporal trends between individual sampling sites at Bicheno was conducted in order to determine whether the trends were the same for each site and thus whether an individual site could provide a representative indication of temporal changes throughout a wider area.

Figure 19 shows the average catch rates per month at each of the sampling sites around Bicheno. In order to reduce confounding effects due to differences in collector conditioning, the averages exclude collectors with less than 120 days of conditioning.

It can be seen that all sites (with the possible exception of B05) show distinct biannual-annual peaks in settlement, with one peak from July to September and the other from November to December. Results for B05 can be slightly misleading because collectors at this site were often destroyed or lost due to high turbulence which results in reduced sample sizes. For example the average catches at B05 during July and August 1991 were based on 1 and 4 collectors respectively, so little confidence can be placed in these averages.

In addition to similar intra-annual trends, most sites also showed similar inter-annual trends in settlement levels. It can be seen that there was a clear decrease in settlement from 1991 to 1992 and again from 1992 to 1993. The only exceptions to this rule were sites BDWB and BSWB. These sites were established in a previous pilot study and hence only contained 3 collectors per site. The low sample sizes of these two sites in conjunction with their low catch rates limits both the resolution and accuracy of their results.

Table 8 shows the average catch rate for these sites for the period 1 May 1991 to 30 April 1993. Sites B05 and B07 were excluded from the table because these were often missing data and thus comparisons involving these sites would have involved the exclusion of too many months of data.

Table 8: Average catch rates of puerulus and post puerulus per month and collector in sites at Bicheno. The catch rates exclude data from February and June of each year since sites B06 and B08 were missing data in one or both of these months. Also excluded are catches from collectors with less than 120 days of conditioning.

Site	Average Catch Rate 1/5/91 to 30/4/92	Average Catch Rate 1/5/92 to 30/4/93	Change in Catch Rate	Percentage Change
B01	8.8	3.6	-5.2	59.1
B04	6.1	3.3	-2.8	45.9
B06	5.6	4.2	-1.4	25.0
B08	5.7	3.5	-2.2	38.6
B09	8.0	4.8	-3.2	40.0
B10	5.4	3.4	-2.0	37.0
BSWB	2.1	1.9	-0.2	9.5
BDWB	1.4	2.1	+0.7	50.0

It can be seen that all sites with the exception of BSWB and BDWB showed a large (25% to 59%) decline in catch rates between the 1991/92 and 1992/93 seasons. The two exceptions were the sites which contained only three collectors. Analysis of the data using log-linear models revealed that there was not a significant difference between seasons for these two sites. The remaining sites showed highly significant differences between seasons with the exception of B06 in which the significance was marginal (p=0.05). This site frequently had a reduced sample size (number of collectors) due to burial by a moving sand bank (see table 7). Site B01 showed the largest reduction in catch rates between seasons. However, this site was altered between the two seasons by removing 24 collectors from 2 higher levels (see section 3.2.b.). The two higher levels may have acted as "antennas" for collecting puerulus which then moved to the lower level (site B01). If so, the removal of the higher levels would have contributed to the large reduction seen at this site.

From the above, it is apparent that individual sites at Bicheno are capable of providing a representative indication of temporal changes in settlement throughout the region. This is conditional on an adequate sample size (number of collectors) and a controlled sampling regime. If results are restricted to sites without a reduced sample size (i.e. excluding B06, BSWB and BDWB), the reduction in settlement between seasons ranged from 37 to 59 percent. If results are further restricted to eliminate sites which were altered between seasons (i.e. B01), the range of reductions is reduced to between 37 and 46 percent.

3.3. SUMMARY and DISCUSSION

Results demonstrate that collectors require a period of immersion in sea water before they can be regarded as being conditioned for catching puerulus. The only significant results were those which compared new collectors (1 month old when sampled) to collectors which had one month of previous submersion (2 months old when sampled). However, this was the only experiment with complete replication through time. Other experiments indicated that longer periods of conditioning might be required. A possibility exists whereby a difference of one month of conditioning is noticeable between collectors with less than 3 months of previous conditioning (4 months when sampled). The data also suggests that noticeable differences might exist between well conditioned collectors (over a year) to collectors with up to 5 months of previous conditioning (longer periods were not examined). Further experiments would be required to test these possibilities. It must also be mentioned that other factors such as temperature and settlement and growth rate of fouling organisms might influence the time required to condition collectors. Hence, differences in the time and location of deployment might influence the time required to condition collectors. Until such factors can be quantified, it is advisable to use well conditioned collectors (over a year of immersion) when installing new sites and replacing old collectors. It is also advisable to keep a database of individual collector ages and histories so that future analyses can adjust for differences in collector ages. In order to reduce confounding effects caused by collector conditioning, the current study eliminated collectors with less than 120 days of immersion (at the time of sampling) when comparing results where differences in the degree of conditioning might occur. However, in cases where a long time series of data exist, it would be advisable to restrict analyses to collectors which had over 1 year of previous immersion.

Height of collectors above the sea floor was found to have a significant effect on catch rates of puerulus and post puerulus. Collectors with an average height of 0.4 m above the sea floor caught more than those with an average height of 1.6 m, which in turn caught more than those with an average height of 2.8 m. No investigations were conducted to determine the reasons for the differences. It could be that puerulus tend to settle near the sea floor, or that they will initially settle at all heights, but soon afterwards, move towards the sea floor. As a consequence of the collector height experiment, a standard practise was adopted in which an attempt was made to keep all collectors at heights ranging from 0.2 to 0.8 m above the sea floor (movement of sand meant that it was not possible to maintain a fixed height of collectors). Slight variations that existed in these heights were not found to have a significant influence on catch rates.

No evidence was found for differences in catch rates according to alignment of collectors with respect to direction of the predominant direction of the swell. Hence, it does not appear important to align collectors in any particular orientation.

Little is known about the minimum spacing required between collectors so that one collector does not affect the catches of others (Phillips and Booth, in press). The general puerulus settlement literature tends to discuss possible adverse effects (competitive catching) on catch rates of placing a number of collectors in nearby proximity. The present study does not shed light on any specific distance, but results from the study provides an interesting twist to the general train of thought regarding adverse effects. Instead of adverse effects on catch rates, it might be possible that increasing the number of collectors in a region could have a positive effect on catch rates. The present study does not provide any solid evidence of this occurring, but rather, provides a few pointers towards this possibility which suggests that further study would be worthwhile. The first pointer was that inner rings of collectors had a fractionally overall higher catch rate than middle and outer rings of collectors (Table 6). The opposite would be expected if competitive catching was occurring between collectors. Secondly, the two sites with only 3 collectors per site (BSWB and BDWB) usually had much lower catch rates per collector than did the remaining sites which had 12 collectors (Figure 19). Yet, there is no reason to expect lower catch rates due to any features associated with the location of these two sites. Furthermore, on some occasions when another site caught fewer puerulus than these two sites, it was found that the other site had a reduced number of collectors. For example, site B05 had low catches during July and August 1991 and there were only 1 and 4 collectors present at this site at these respective times. Finally, site B01 showed a larger reduction in catch rates between the 1991/92 and 1992/93 seasons than did the other sites (Table 9 and Figure 19). This large reduction corresponds to the removal of 24 nearby collectors prior to the 1992/93 season.

The above pointers are not sufficient to provide compelling evidence of an enhancement effect. Further study of the effects on catch rate of increasing the number of collectors in a small region is desirable. Knowledge of such an effect could have implications on the likely mode by which puerulus locate settlement habitats. For instance, assuming that a large number of collectors causes more disturbance in the water than a small number of collectors, it might suggest that puerulus were capable of locating habitats from a distance and actively swimming towards the habitat rather than locating habitats by passive, chance encounters.

Interpretation of the effects on catch rates of exposure to water movement and degree of sedimentation were hindered by gaps in the time series of both flow rate and sediment data. No relationship was evident between the degree of sedimentation at individual sites and the average catch rate at those sites. There was a possible relationship between catch rates and water movement in which the sites with the highest flow rates tended to have low catch rates. However, equally important was the fact that it was not possible to maintain a controlled sampling regime at the sites with the highest flow rates. Collectors were often lost and it was occasionally impossible to sample these sites due to extreme conditions. A puerulus monitoring program requires a controlled sampling regime, not only to prevent gaps in the time series of settlement data, but also to reduce confounding effects caused by changing factors such as varied degree of conditioning of replacement collectors and any impact of collector numbers on catch rates. Clearly sites in which a controlled sampling regime cannot be maintained are unsuitable for a puerulus monitoring program.

An important result from the study was that individual sites at Bicheno provide a representative indication of temporal changes in settlement throughout the region (Figure 19). This was dependant of sites having an adequate number of collectors, which is to be expected.

4. ASSESSMENT OF LARGE SCALE SPATIAL VARIATIONS IN SETTLEMENT

4.1. INTRODUCTION

A long term monitoring program requires that puerulus be caught in sufficient numbers to ensure that observed temporal fluctuations in settlement are meaningful. Therefore, identifying sites which produce the greatest catch rates is crucial. Not only does this allow for improved power in statistical analysis, but it also minimises the effort involved in monitoring (i.e. fewer collectors to service) and thus makes a long term monitoring project more cost effective and viable.

In addition to a requirement for sites which yield a high catch rate of puerulus, there is a need to conduct sampling in a number of representative locations around Tasmania. The Tasmanian fishing grounds are located at the confluence of several water masses (including: the sub-tropical Pacific Ocean waters of the East Australian Current, the sub-Antarctic waters of the Southern Ocean, and the intermittent influence of sub-tropical waters of the Leeuwin Current). Furthermore, the larval stages of the southern rock lobster are planktonic and could spend in the order of 8 to 16 months at sea prior to settling onto coastal reefs (Kennedy, 1990). Given the long larval phase together with the diversity of oceanic influences, it is possible that different processes could be influencing settlement at different locations around Tasmania. Such processes might vary on a temporal basis, producing different settlement seasons in different locations and causing different locations to show different trends in the magnitude of settlement through time.

The principal purpose of this part of the project was to locate sites with high catch rates which were representative of the major regions surrounding the Tasmanian coast.

4.2. METHODS

It was logistically impossible to conduct large scale sampling concurrently in a number of different regions around Tasmania, or to sample many regions for a long period in time.

Hence, to achieve the greatest coverage of regions, collectors were deployed so that monitoring would be underway when peak settlement periods were expected to occur. These periods were defined by the pilot study and subsequent ongoing monitoring. At the conclusion of settlement peaks, sampling was often discontinued to free resources for exploratory sampling in other locations. Collectors were monitored on a longer term only if they caught puerulus in quantities equivalent to the established collector sites at Bicheno and Recherche Bay or, if the timing of settlement varied from the established sites.

Sampling sites were restricted to those locations in which vehicle or speedboat access was feasible, or where suitable people were available to conduct the sampling in otherwise non-accessible locations. These restrictions prevent sampling off the south west coast. Extended sampling was not planned nor conducted on the north coast because results from the pilot study, diving observations and knowledge of the low net flow of water through Bass Strait all indicated that there would be low settlement in this region. Sampling for the north-east coast was given a low priority due to low catch rates obtained for this region during the pilot study. Although sampling was planned for the north-east coast, extra effort was required to establish and monitor the higher priority west coast sites which prevented the north east coast from being sampled during this project.

Collectors were deployed at six sites on the south coast at Recherche Bay (labelled RB1 to RB6 in Figure 20) during October 1990 in anticipation of a November to February settlement period. One other site was monitored at Recherche Bay (RBFP in Figure 20). This site was a continuation of sampling which commenced during the pilot study.

Collectors were deployed in seven general locations on the east coast from February to May 1991 so as to be ready for an anticipated July/August settlement peak. These general locations were (from north to south) Little Swanport and Maria Island (Figure 21a), and Pirates Bay, Port Arthur, South Arm and North Bruny Island (Figure 21b). As indicated in Figures 21a and 21b, most of these general locations were usually subdivided into two or more sites. The sites at South Arm and North Bruny Island were deployed during February 1991 and collectors at the other sites were deployed during April or early May 1991. Another site (Howden, Figure 21b) was established in November 1992 in response to claims by salmon farmers that puerulus were settling on ropes which anchored the salmon cages. However, sampling at this site was abandoned in September 1993 after only one puerulus had been caught for the entire period. This site is not considered further.

On the west coast, collectors were deployed at four sites at King Island, three sites at Couta Rocks (Figure 22b) and one site in McGuinness Gut (Figure 22c). Of the King Island sites, only one was regularly monitored (Currie Harbour, Figure 22a), so the others are not mentioned further. The west coast sites were deployed during September 1991 with the exception of Currie Harbour which was deployed in June 1991. The west coast sites were monitored for a minimum of 12 months since no prior knowledge of peak settlement times was available.

Collector layout and monthly servicing of the collectors at each site was similar to that outlined in chapter 2. The use of fully conditioned collectors would have been preferable to unconditioned collectors in order to obtain the best catch rates and to reduce bias according to the differences in the degree of conditioning between collectors (see section 3.2.a.). However, the number of collectors involved and logistics of large scale sampling in both time and space, meant that it was not possible to use fully conditioned collectors. Instead, where possible, the collectors used for large scale sampling were taken from stockpiles which had been used elsewhere (such as in conditioning experiments or in previous exploratory sampling). Most of these collectors had "dried out" while on land, so are unlikely to perform as well as conditioned collectors. Table 9 provides a summary of the number of collectors at each of the sites (excluding Bicheno sites) including details of the average degree of conditioning of collectors when they were first deployed at these sites.

Table 9: Mean time in which collectors had been previously submerged and the time they had spent on land prior to deployment at the specified site. Dates of deployment are mentioned in the text. Site "RBFP" was established over one year prior to the other Recherche Bay sites. However, the submergence details for collectors at this site are presented as if it were deployed at the same time as the other sites.

Location	Site	Initial Number of Collectors	Average number of days of previous submergence	Average number of days on land prior to deployment
Little Swanport	SWAN	6	57	44
Maria Is.	MI1	6	64	71
	MI2	6	59	52
Pirates Bay	PB1	6	63	79
	PB2	6	64	65
Port Arthur	PA1	6	35	142
	PA2	6	49	110
South Arm	SA1	3	64	72
	SA2	3	64	72
	SA3	3	35	100
North Bruny Is.	NB1	3	64	72
	NB2	3	64	72
Howden	HOW	6	455	14
Recherche Bay	RBFP	3	526	0
	RB1	3	0	0
	RB2	3	0	0
	RB3	3	0	0
	RB4	3	0	0
	RB5	12	404	0
	RB6	3	525	1
McGuinness Gut	MG	12	62	123
Couta Rocks	CR1	6	63	107
	CR2	6	57	86
	CR3	6	56	170
Currie Harbour	CH	6	0	0

4.3. RESULTS

The seven sites at Recherche Bay showed substantial differences in the magnitude of the catch, but the timing of settlement peaks was fairly consistent between sites (Figure 23). The highest catch rates were obtained from sites RB5, RBFP and RB1 and sampling at these sites has been continued.

A comparison of pooled catch trends at Recherche Bay and Bicheno regions is shown in figure 24. The data used in the comparisons has been restricted to sites which have been continued for long term monitoring (see Chapter 5). These comprise RB1, RB5 and RBFP from Recherche Bay and B01, B04, B08 and B09 from Bicheno. However, site B01 was excluded from the comparison because the number of collectors at this location changed during the period being compared and the change may have affected catch rates (see section 3.2.f.).

Within each year there were two major settlement peaks at Bicheno, a winter peak from July to September followed by a spring peak in November and December. The summer peak in 1990 for Bicheno and Recherche Bay seemed to coincide, but during 1991 and 1992, the summer peaks at Recherche Bay occurred one to two months later than at Bicheno. The winter peaks occurred at the same time for both locations, although this may have been slightly later at Recherche Bay during 1993. In both locations there has been a gradual decline in settlement from 1991 to 1993 inclusive.

Sampling at exploratory east coast sites (Little Swanport, Maria Island, Pirates Bay and Port Arthur) was conducted from May to September 1991 in order to assess catch rates during the expected winter settlement peak. The catch rates obtained (Figure 25) were not sufficiently high to justify continued sampling at these sites. However, simultaneous sampling and sampling over a longer period was conducted at two nearby locations (South Arm and North Bruny Island). The extended sampling period was possible because South Arm and North Bruny Island were located near the Taroona Marine Research Laboratories and could thus be easily sampled in a single day. Results for the five sites at these locations are shown in Figure 26. Catch rates and trends in settlement through time were similar at all sites, but catch rates were less than half that of Bicheno sites. A winter peak in settlement was evident each year, but spring/summer peaks were haphazard and less distinct. Sampling at all locations continued till February 1993, after which collectors at SA2, SA3, NB1 and NB2 were moved to the best site (SA1) where sampling continues.

Sampling on the west coast produced very few puerulus with the site at King Island (CH) yielding the highest catch rates (Figure 27). The main period of settlement of puerulus at King Island appeared to be in late summer from January to April. This is distinctly different from the east coast sites which had low settlement through much of this period. Other locations on the west coast (Couta Rocks and McGuinness Gut) may have a similar main settlement period as King Island, but it is difficult to state this with certainty due to the low catch rates at Couta Rocks and McGuinness Gut. Sampling at Couta Rocks and McGuinness Gut was discontinued after 14 months of sampling (November 1992) since the catch rates were too low to be of any use. Catches at King Island were slightly better, so sampling at this location has continued.

4.4. DISCUSSION

Considerable differences existed in the catch rates of sites in nearby locations for the east and south coast sites. This provided scope for selecting long term monitoring sites which yielded the highest catch rates. The timing of settlement was relatively consistent at nearby locations and only differed slightly along the length of the east coast. A winter peak in settlement occurred in all east and south coast locations between June and September. Spring/summer peaks usually occurred between November and February, with the timing often being in the later half of this period towards the south of Tasmania.

Settlement results for west coast sites were quite different from east and south coast sites. Overall settlement rates were substantially lower on the west than on the east and south coasts, and the main settlement period on the west coast (January to April) occurred at a different time from the east and south coasts.

It is not yet possible to provide an explanation for the generally low settlement on the west coast. It might be due to low puerulus densities off the west coast. If so, this could be related to low egg per recruit (<15%) off the north west coast of Tasmania (R.B. Kennedy, unpublished data). Low settlement rates on the west coast could also be due to poor site selection since the exposed and isolated nature of this coast meant that few areas could be sampled. Finally, given the exposed nature of the west coast, it is possible that puerulus might settle further from shore than on the east coast. In order to examine this possibility, trials and design modifications of deep water collectors (which can be hauled from a boat) have been underway for 18 months. However, to date, no success has been achieved in obtaining a collector which will survive west coast conditions. The main problems have been fouling of the buoy line by kelp and movement of collectors over the bottom. It is possible that a remote or timer released line and buoy may solve some of these problems.

The difference in timing of peaks in settlement between the west and east coasts is not surprising since the two coasts have different oceanic influences. Given the difference in timing and oceanic influence, it is possible that the two coasts will show different trends in the magnitude of settlement on an inter-annual basis. Hence it is important that monitoring of settlement be conducted on both coasts. The only site on the west coast with high enough catches to indicate timing of settlement was "CH" at King Island, so monitoring should continue at this location. However, even at this site, the low catch rates mean that it will not be possible to reliably detect small inter-annual changes in settlement.

5. ESTABLISHMENT OF THE LONG TERM MONITORING PROGRAM

5.1. INTRODUCTION

The overall objective of the present three year study was to establish a long term puerulus settlement monitoring program in Tasmania. Provision of funds by FRDC was conditional upon Tasmania embarking on a long term monitoring program given a successful conclusion to the three year study.

The three year study has been successful as it has determined key areas to be sampled (as identified by differences in the timing of settlement), located sites which will supply an adequate number of puerulus and demonstrated that individual sites are capable of providing a representative indication of temporal changes in settlement over a wider region.

The three year study officially concluded in June 1993, and long term monitoring at key areas is now underway. This chapter outlines the progress made in establishing the long term monitoring program and the scope of that program.

5.2. ESTABLISHMENT OF LONG TERM MONITORING SITES

Establishment of long term monitoring sites requires selection of suitable sites, use of an appropriate number of collectors with a suitable sampling procedure, maintaining a stockpile of conditioned collectors for replacement purposes and mechanisms for collection of any required environmental data. These aspects are discussed in section 5.2.a to 5.2.e.

5.2.a. Site selection

Selection of sites for the long term monitoring program has been partially discussed in previous chapters. Sampling revealed three different patterns of settlement around Tasmania. The east coast had settlement peaks during winter (June to September) and spring/summer (November to December). The south coast was similar to the east, except the summer settlement usually occurred 1 or 2 months later. Finally, the west coast had only one obvious peak period of settlement, this being between January and April.

Because of the different timing of settlement between the three areas, it was considered important that each of these areas be monitored over the long term. This is because factors that influence the timing of settlement between areas might also lead to different inter-annual trends in the magnitude of settlement between areas.

Only one site on the west coast was selected for long term monitoring, this being "CH" in Currie Harbour on King Island (Figure 22a). No other sites on the west coast provided sufficient puerulus to justify continued sampling. However, additional west coast sites are desirable and continued trials with boat hauled collectors for deep water use are underway in the hope that these could be used to locate sites with higher catch rates.

Two sites on the south coast have been selected for long term monitoring, these being "RB1" and "RB5" at Recherche Bay (Figure 20). Site "RB5" had the highest catch rates of sites in this area and is thus considered to be the primary long term monitoring site. The additional site ("RB1") is being monitored for comparison purposes and as a safety measure in case weather conditions cause a gap in the time-series of data for the primary site. It could be argued that "RBFP" would be a better long-term monitoring site than "RB1" due to slightly higher catch rates at "RBFP". However, only three collectors were deployed at "RBFP" as opposed to 12 at "RB1" and increasing the number of collectors at "RBFP" to a suitable number may change the catch rate and thus be inconsistent with the existing time-series of data for this site. Nevertheless, sampling at "RBFP" is continuing on a temporary basis while a decision is made as to whether to increase the number of collectors so as to maintain three long term monitoring sites on the south coast.

Four sites on the east coast have been selected for long term monitoring, these being "B01", "B04", "B08" and "B09" at Bicheno (Figure 3). These specific sites were selected for a variety of reasons including: catch rates; contrast in terms of degree of exposure to water movement and actual position; reliability of the site in terms of survival of collectors and ability to sample the site in most weather conditions. As with the south coast, multiple sites are being maintained at Bicheno for comparison purposes and as a safety measure in case weather conditions cause a gap in the time-series of data for some of the sites.

One additional long term monitoring site has been established in another area, this being "SA1" at South Arm on the south east coast (Figure 21b). A site was established on the south east to provide a midway point between the east and south coasts, and because this area is close to the Marine Research Laboratories and thus requires little time or cost to sample. Site "SA1" had the highest catch rate of the five sites ("SA1" to "SA3", "NB1" to "NB2") sampled near the laboratories.

5.2.b. Number of collectors per site

The number of collectors sampled at each site is highly important in relation to the ability to detect inter-annual changes in settlement levels. A power analysis was conducted in order to assess the affect of the number of collectors on the ability to detect changes in settlement levels. For the purpose of this analysis a settlement season was defined as the twelve months of settlement commencing on 1 May. This time period was chosen because it starts and finishes outside the peak settlement periods at all monitoring sites. Thus, the same annual settlement season can be used for all sites. With one exception, the settlement season commencing May

1992 was used in the power analysis because it is the most recent complete season and this season contains the most highly conditioned collectors.

The power analysis assumed that later analyses for detecting inter-annual changes in settlement levels at each site would involve a one-way ANOVA with two treatments (two years). It also assumed that the ANOVA would use square root transformations of the total catch of each collector for a settlement season.

The objective of the power analysis was to determine the number of collectors required to provide an 80% power of detecting different levels of declines (20,30,40,50 and 100%) in settlement as being significant ($p<0.05$). The results are provided in Table 10. The percentage declines listed in the table refer to a percentage decline in the average catch per collector on the original scale of measurement. Thus, if the average annual catch per collector was 50 specimens, a 20% decline means an average decrease of 10 specimens per collector. Similarly a 20% decline when the average catch is 5 specimens per collector means an absolute decline of only 1 specimen per collector. It is thus not surprising to find that sites with a low catch rate generally require a larger number of collectors than sites with a high catch rate.

Table 10: Number of collectors required to provide an 80 percent power of detecting the specified percentage decline in settlement as being significant at the 95% confidence level. The puerulus sampling season used in the analysis refers to the twelve months of data commencing 1 May on the specified year (except for "*" which was only based on the first 8 months of data). The number of collectors currently in use at each site are shown in parentheses.

	Data used in the analysis			**Number of collectors required to detect a decline in settlement of:**				
Site	Puerulus Sampling Season	Number Of Collectors	Average Annual Catch Per Collector	20%	30%	40%	50%	100%
B01	1992	12 (12)	37.2	30	13	8	5	2
B04	1992	12 (12)	37.3	22	10	6	4	2
B08	1992	12 (12)	36.4	42	18	10	7	2
B09	1992	12 (12)	50.5	21	10	6	4	2
SA1	1992	3 (16)	24.0	30	13	8	5	2
	1993*	15 (16)	6.5	64	28	15	10	3
RB1	1992	12 (12)	2.7	66	28	16	10	3
RB5	1992	11 (12)	17.1	39	17	10	7	2
CH	1992	6 (8)	10.7	101	43	23	14	3

The number of collectors currently being used at each site are shown in parentheses in Table 10. Perusal of this table indicates that the current number of collectors are capable of detecting declines in settlement of around 30-40% at Bicheno, 30-40% at South Arm, 40-50% at Recherche Bay and 100% at King Island. Due to the number of collectors required and the associated sampling effort, there are no sites at which it would be realistic to attempt to resolve declines in settlement as low as 20%. Hence, detection of declines in the order of 30% are the best that can be realistically achieved, so the current number of collectors currently at Bicheno and South Arm are considered to be adequate. The number of collectors at Recherche Bay and King Island are not sufficient to 30% declines in settlement. It is feasible to increase the number of collectors at one of the Recherche Bay site ("RB5") to obtain a 30% resolution, but at King Island, the best resolution that would be achievable is 50%. Both possibilities are currently under consideration.

For the same species in New Zealand, the goal of settlement monitoring has been to discriminate 100% differences in levels of annual puerulus settlement for each site at the 95% confidence level (Phillips and Booth, in press). Furthermore, in New Zealand, good correlation has also been found between levels of settlement and juvenile abundance (Breen and Booth, 1989). Hence, given the New Zealand experience, the current number of collectors at each Tasmanian site can be considered as being suitable.

5.2.c. Sampling procedure and layout of collectors

The sampling procedure (including the type of equipment) for the long term monitoring program follows that described in Chapter 2. It is important to note that a controlled sampling regime is extremely important to the success of a long term monitoring program. Catch rates could be influenced by changes in factors such as condition of collectors (through use of replacements), minor design modifications of collectors, the cleaning regime of collectors, the number of collectors in a site and the frequency of sampling (e.g. monthly versus fortnightly) etc. Changes in such factors could thus cause difficulties in the interpretation of settlement results and are best avoided.

With the exception of "RB5" at Recherche Bay and "KICH" at King Island, the layout of collectors within the long term monitoring sites is according to the standard cross alignment of collectors as described in section 3.2. This standard layout has proved to have practical benefits particularly in relation to location of collectors in times of poor visibility. The two cases where the cross alignment has not been used was because such an alignment would have interfered with popular anchorage's.

5.2.d. Conditioning of collectors

During the long term monitoring program, there will be times when collectors require replacement due to loss, damage, or general wear and tear. However, it has been demonstrated (section 3.2.a) that conditioning of collectors has an effect on catch rates and thus replacement of collectors could result in lower catch rates being observed. Unfortunately, the results of section 3.2.a were not sufficiently precise to state the number of months of conditioning required before a collector becomes fully conditioned.

In order to reduce problems caused by condition of replacement collectors, a number of conditioning sites have been established. The purpose of conditioning sites is to provide a stockpile of well conditioned collectors (at least one year of conditioning) which can be used for replacement purposes. This currently comprises 11 collectors at Bicheno, 7 collectors at South Arm and 5 collectors at Recherche Bay. A conditioning site has yet to be established at King Island (due to transportation difficulties), but there are plans to do so and to increase the number of collectors at all existing conditioning sites.

Despite the use of conditioning sites, there will be occasions where data exists for collectors which have had little conditioning. This occurs in the existing data set and could occur in the future when new sites are established. In such cases, it is recommended that analyses which seek to quantify inter-annual trends in settlement exclude collectors with less than 120 days of conditioning (at the time of sampling). Furthermore, it would be advisable to verify conclusions of such analysis by repeating the analysis with more restrictive conditions on the age of collectors.

5.2.e. Environmental parameters

Variations in environmental conditions have sometimes been found to influence the levels or patterns of puerulus settlement (e.g. Phillips and Booth, in press). A long time-series of environmental data may prove to be highly valuable in assisting to understand variations in settlement and collection of such data should thus be considered to be an integral part of a puerulus settlement monitoring program.

However, collection of environmental data can be expensive in terms of both equipment and labour, and without foreknowledge of the "critical" parameters, it is only practical for a monitoring project to obtain relatively simple and inexpensive information. For the present monitoring program, mechanisms have been put in place for collection of the following information: Hourly readings of bottom water temperature at each of the general sampling locations (using remote data loggers); total monthly water flow measurements at each site except King Island (using the flow counter described in Figure 12); and at most locations, a variety of synoptic data provided by the Bureau of Meteorology (including wind speed and direction, swell height and direction, rainfall, and atmospheric pressure etc).

5.3. INFORMATION STORAGE AND RETRIEVAL

By definition, a long term monitoring program will collect a long time-series of data. Furthermore, the longer the time-series, the more useful the data becomes. Hence, it is not acceptable for this type of data to be stored in a spreadsheet or add-hoc database on the principal researcher's desktop computer. The possibility of data loss through staff changes, hard disk failures, accident, or theft etc. would be too high.

To overcome the above problems and to obtain high quality integrity checking and flexible data retrieval, a centralised relational database has been developed for the puerulus monitoring program. The database contains all raw puerulus sampling data, a complete history and inventory of all individual collectors, plus all the environmental data mentioned in section 5.2.e. The database was developed in "Oracle" and is located on the Marine Research Laboratories mini-computer which has nightly tape backup and off-site storage of tapes. A user friendly data entry and query interface to the Oracle database has been developed with "Omnis 7" so that users can easily access the database through their desktop computers.

6. SETTLEMENT INFORMATION AS AN AID TO UNDERSTANDING LARVAL RECRUITMENT PROCESSES

6.1. DISCUSSION

Genetic studies have indicated that there is some larval dispersal throughout the southern rock lobster populations of Australasia (Ovenden et. al., 1992). This is not surprising when considering the long larval life-span (>8 months). However, it is possible that genetic homogeneity is maintained by small numbers of dispersing larvae, in which case several functionally independent breeding populations or important semi-discrete sources of larvae might exist. Furthermore, there is a large geographic variation in egg production around the southern rock lobster fishery. For example, egg production ranges from less than 15% of that of the virgin biomass in the north west of Tasmania to nearly 100% in the south of Tasmania (Kennedy, R.B. unpublished data). Hence, the pattern of larval recruitment is immensely important in relation to the sustainability and optimal management of the resource.

Unfortunately, there is no single project which is likely to provide a complete understanding of larval recruitment processes. The Southern Rock Lobster Research Group (SRLRG) recommended that as a first step, fishery-wide puerulus settlement patterns be used in conjunction with oceanic data to suggest hypotheses about larval recruitment mechanisms (SRLRG, 1992). An objective of the present project was to begin the collection of a time-series of puerulus settlement data for this purpose. Collection of this data has commenced (as discussed in chapters 3 to 5), but development of hypotheses is a long term objective requiring a longer time-series of data.

It is currently envisaged that future work will follow two broad lines of attack.

The first line of attack would be to develop an understanding of the relationship between puerulus settlement and the offshore distribution of phyllosoma larvae. This could be accomplished by continued settlement monitoring in conjunction with a short term (~3 year) larval trawling program. The first step in this program would be a pilot study to determine suitable methodology (gear type and required sample sizes). This would be accomplished by offshore trawling adjacent to puerulus monitoring sites prior to peak periods in settlement. This is a period when the largest quantities of phyllosomes would be expected. Supplemental data could be obtained by extracting information from existing offshore larval samples (such as held by CSIRO Division of Fisheries, Hobart). Once a suitable methodology has been determined, the trawling program would determine the monthly abundance and developmental stages of phyllosomes in waters adjacent to puerulus monitoring sites. Within a region, it would seek to determine whether:

(a) there are "transient" populations of phyllosomes for which the monthly abundance of phyllosomes relates to the monthly abundance of puerulus on collectors;

or (b) there are "resident" populations of phyllosomes and peaks in puerulus settlement are associated with periods when phyllosomes become fully developed or to periods in which conditions facilitate on-shore movement of puerulus.

In the case of "a", retention of larvae within general regions may be unlikely and further work would be reliant on developing suitable hypotheses from the second line of attack (see later). In the case of "b", there is the possibility of larval retention within general regions, so follow up work should seek to determine whether there is a relationship between abundance of phyllosomes and egg production between regions. Alternatively, abundance of phyllosomes may be more closely linked to the presence of certain oceanic features which enhance larval retention within a region.

The second line of attack requires a long time-series of fishery wide puerulus settlement data. This approach involves examination of the time-series in conjunction with environmental data in order to determine factors which appear to influence settlement rates. Furthermore, given the large geographical range of current settlement monitoring for the southern rock lobster (South Australia, Tasmania and New Zealand), it is conceivable that shared climatic events (such as ENSO) could have different influences on settlement depending on area (e.g. decreased settlement off South Australia and western Tasmania, and increased settlement off New Zealand etc). Such contrasts would further assist development of hypotheses regarding larval recruitment processes. Testing or support of any hypotheses would probably be obtained through a targeted larval trawling program.

ACKNOWLEDGEMENTS

The success of the project is largely due to the excellent organisational skills of D. Tarbath and R. Pearn who were in charge of field and laboratory operations. Special thanks to R. Pearn, D. Tarbath, P. Terry and R. Green who conducted the vast majority of sampling and did so with a high degree of dedication. Thanks go to those who have assisted with the sampling, including I. Gibson, B. Hislop, A. Cawthorn, C. Waterworth, J. Marshall, B. Hodgson, J. Mauric, T. Fox, A. Schaap, S. Frusher and the others who are too numerous to mention.

Assistance given by S. Frusher, R. Pearn and A. Cawthorn in preparing this report is gratefully appreciated as is the support of the Shellfish Branch Manager (A. Schaap) throughout the duration of the project.

REFERENCES

Booth, J.D. (1979). Settlement of the rock lobster *Jasus edwardsii* (Decapoda: Palinuridae), at Castlepoint, New Zealand. N.Z. J. Mar. Freshw. Res. **13(3):** 395-406.

Booth, J.D. and Bowring, L.D. (1988) Decreased abundance of the puerulus stage of the rock lobster *Jasus edwardsii*, at Kaikoura, New Zealand. N.Z. J. mar. Freshw. Res. **22:** 613-616.

Booth, J.D. and Tarring, S.C. (1986). Settlement of the red rock lobster, *Jasus edwardsii*, near Gisborne, New Zealand. N.Z. J. Mar. Freshw. Res. **20:** 291-297.

Breen, P.A. and Booth, J.D. (1989). Puerulus and juvenile abundance in the rock lobster *Jasus edwardsii* at Stewart Island, New Zealand. N.Z. J. mar. Freshw. Res. **23:** 519-523.

Kennedy, R.B. (1990). Juvenile crays: Where do they settle and when? Fishing Today **3(6):** 22-23.

Kennedy, R.B., Wallner, B. and Phillips, B.F. (1991). Preliminary investigations of puerulus settlement of the rock lobster *Jasus novaehollandiae* in southern Australia. Revista De Investigaciones Marinas **12(1-3):** 76-82.

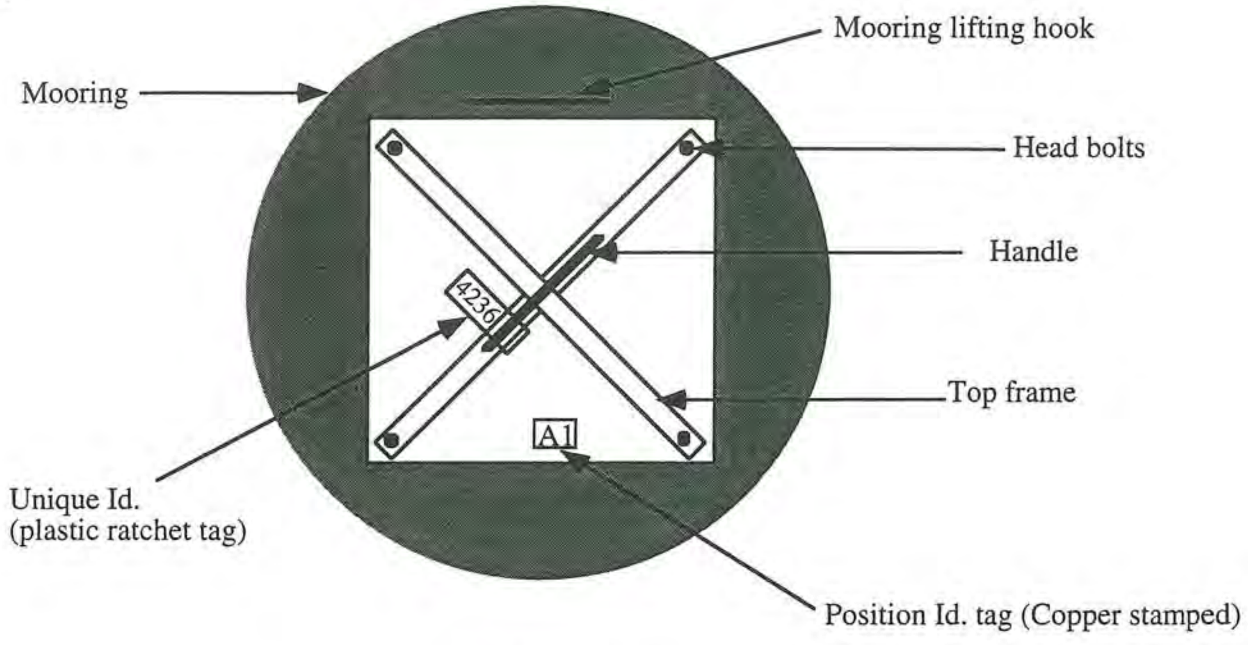
Ovenden, J.R., Brasher, D.J. and White, R.W.G. (1992). Mitochondrial DNA analyses of the red rock lobster *Jasus edwardsii* supports an apparent lack of population subdivision throughout Australasia. Mar. Biol. **112:** 319-326.

Phillips, B.F. (1986) Prediction of commercial catches of the western rock lobster *Panulirus cygnus*. Can. J. Fish. Aquat. Sci. **43:** 2126-2130.

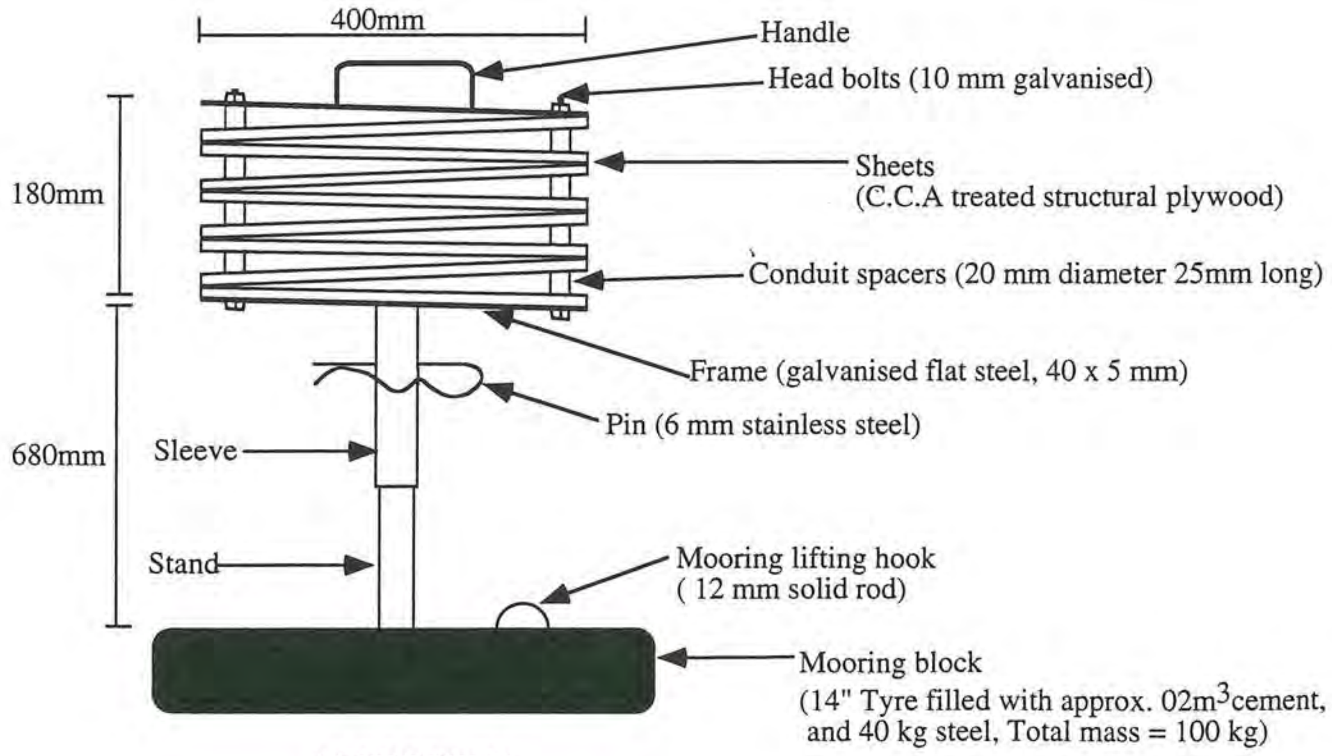
Phillips, B.F. and Booth, J.D. (in press). Design, use, and effectiveness of collectors for catching the puerulus stage of spiny lobsters. Reviews in Fisheries Science.

Southern Rock Lobster Research Group (1992). Strategic Research Plan: For the southern rock lobster fishery *Jasus edwardsii* fisheries in Australia. 8p.

Figure 1: Diagram of a crevice collector collector. a) showing view from above, b) showing side view.



a) TOP VIEW



b) SIDE VIEW

Figure 2: Tasmania showing locations mentioned in the text. Solid squares represent sampling locations from a pilot study (FIRDC 88/41) and solid circles refer to locations sampled in the current study.

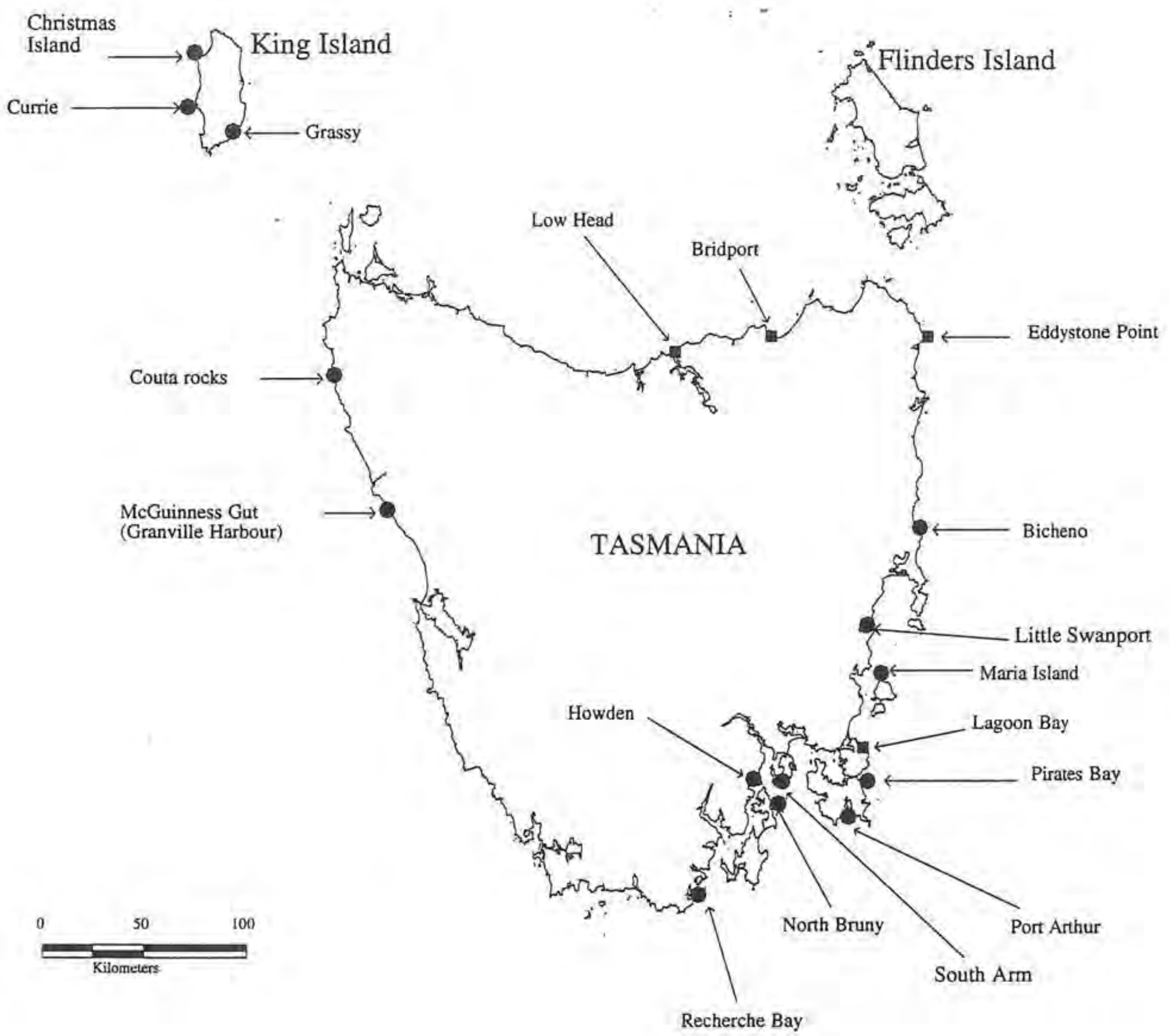


Figure 3: Location of puerulus sampling sites at Bicheno. Sites are labelled B01 to B12, BDWB and BSWB. Twelve collectors were positioned at each site from B01 to B12. Sites BDWB and BSWB were a continuation from the pilot study and only contained 3 collectors per site. Sites B01, B02 and B03 were established to test the effect height of collectors above the substrate. These sites shared a common location, the difference being in the vertical position of the collectors. Sites B11 and B12 were used to test the effects of collector conditioning.

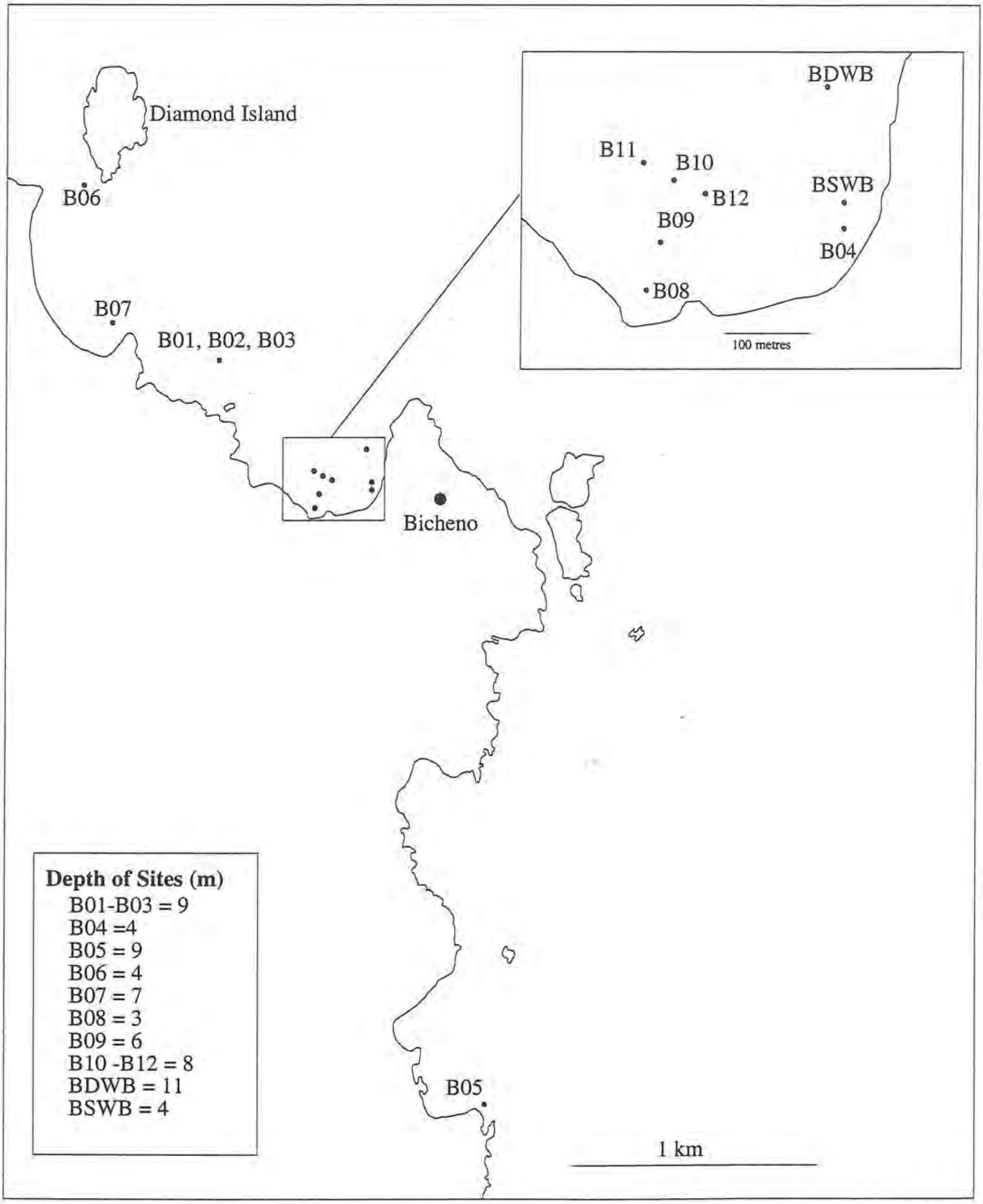
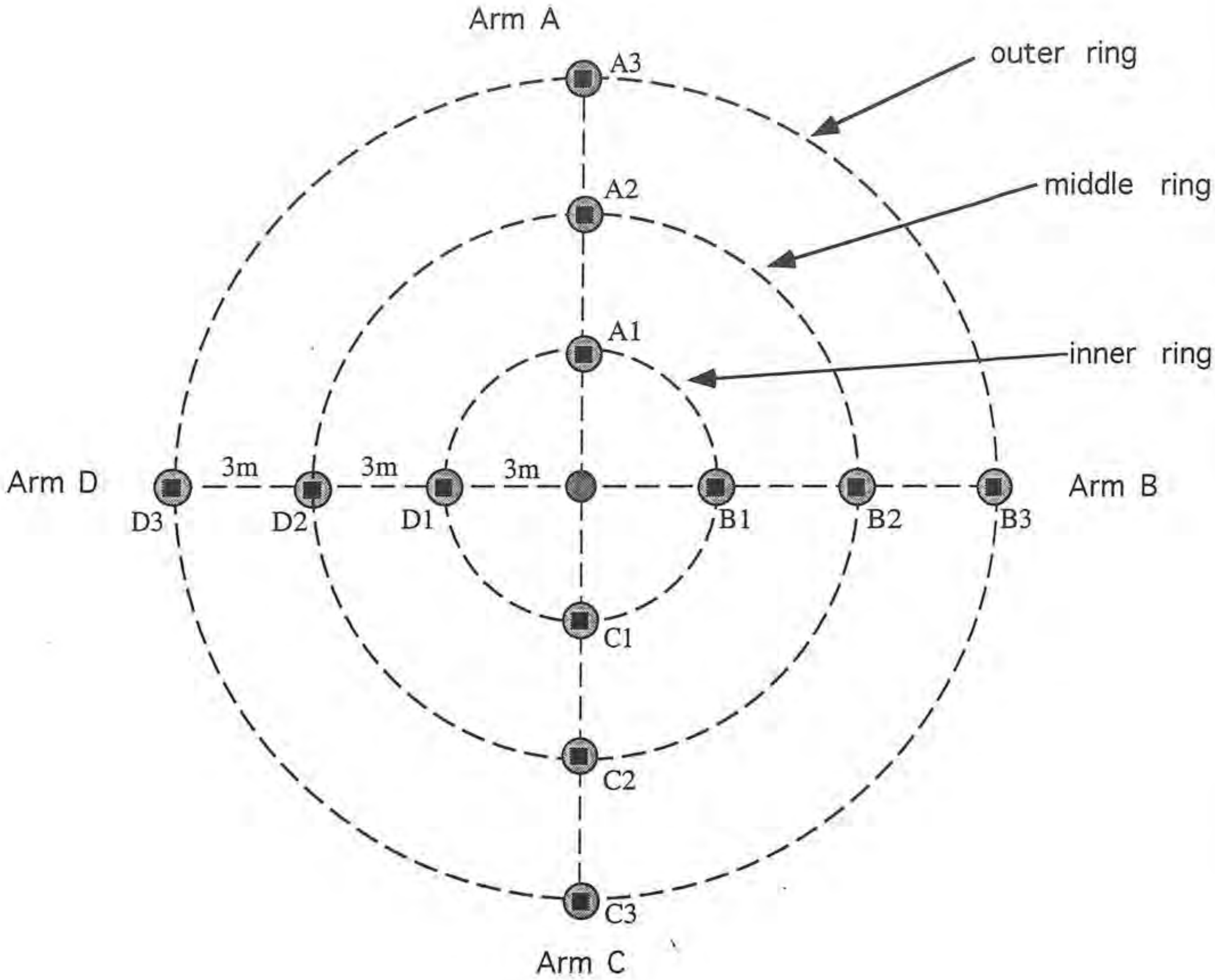


Figure 4: Standard collector layout for sites of 12 collectors



KEY

individual crevice collector

The centre mooring contains the sediment trap, flow counter and marker buoy.

Figure 5: Catch rates of puerulus and post puerulus on new collectors and collectors with one month of prior conditioning. Error bars show the standard error around each average. Each average is based on a sample of 12 collectors.

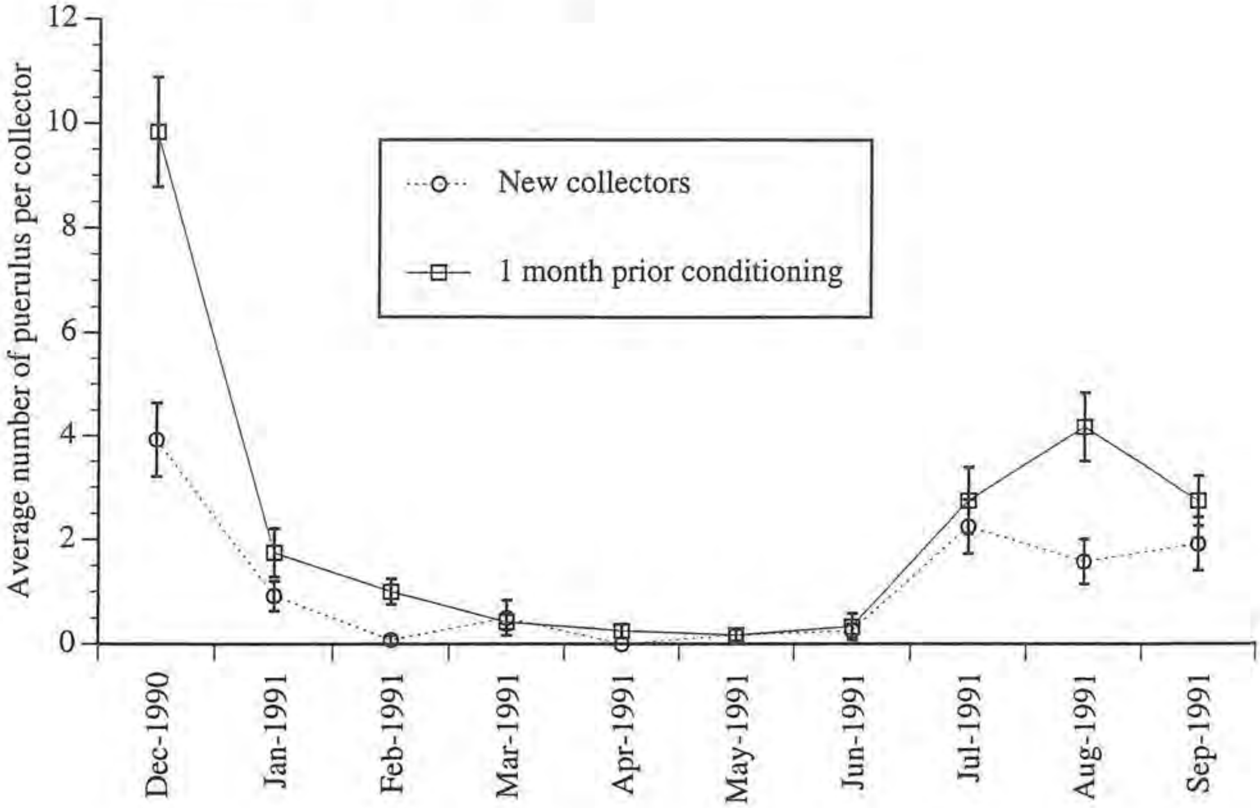


Figure 6: Catch rates of puerulus and post puerulus on collectors with increasing conditioning through time. There is 1 month difference in conditioning between the lines for "less" and "more" conditioned. Numbers on the graph indicate the number of months of conditioning prior to the month sampled. Error bars show the standard error around each average. Each Average is based on a sample of 10 or 12 collectors.

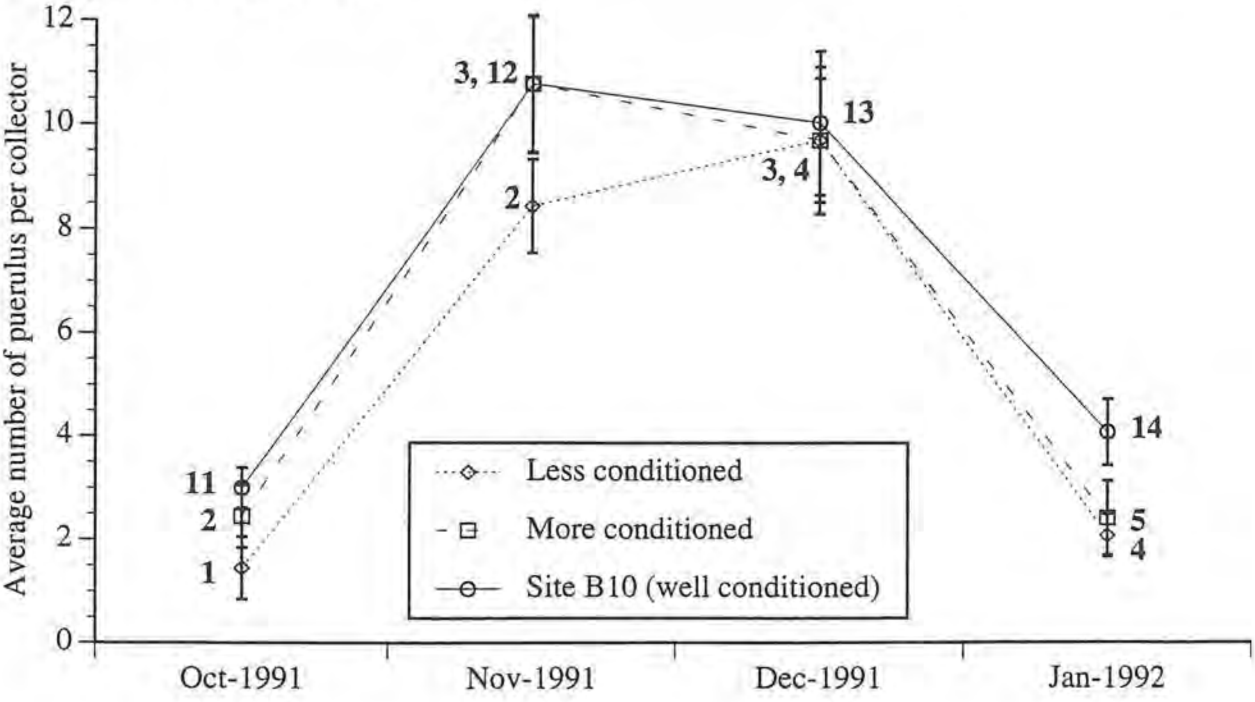


Figure 7 : Layout of collectors for collector height experiment.

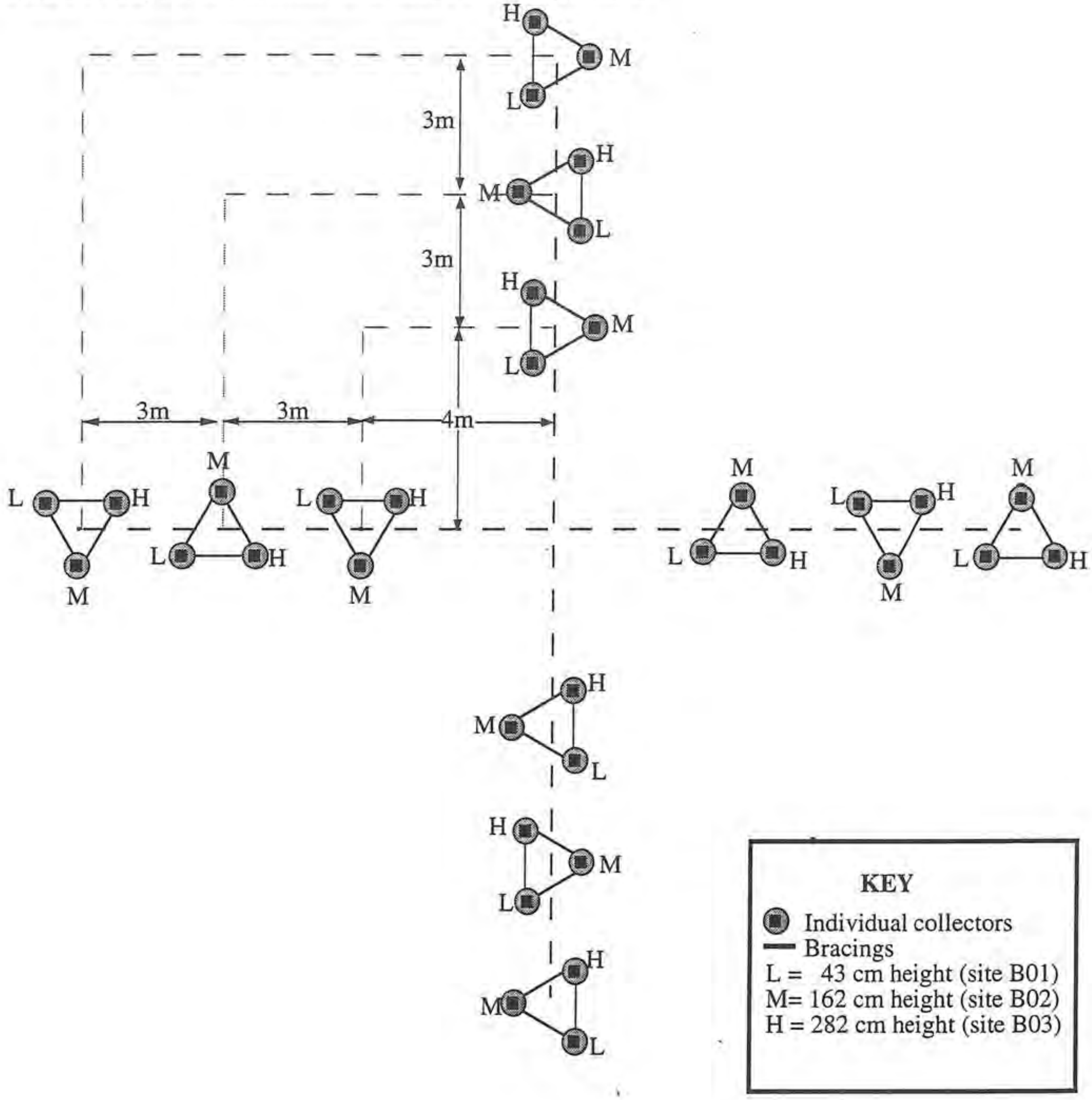


Figure 7a: Side profile showing mooring bracing

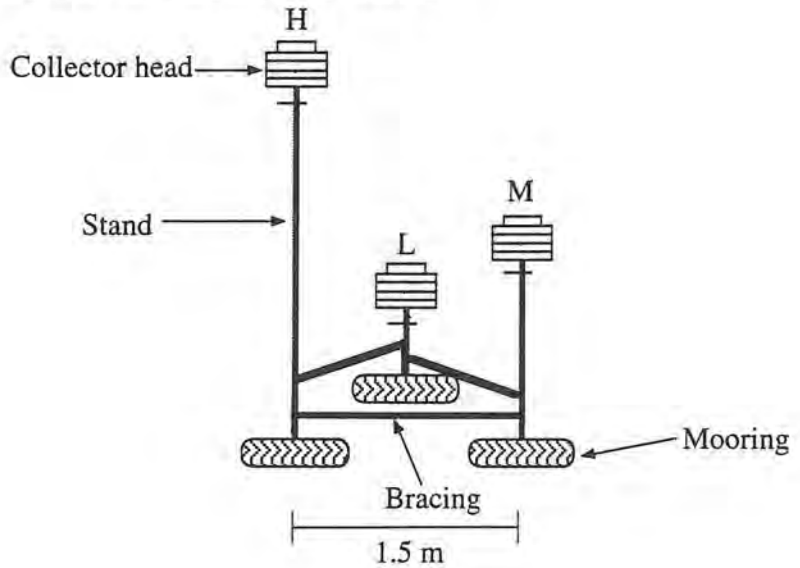


Figure 8: Catch rates of puerulus and post puerulus on collectors positioned at three different heights above the sea floor. The three levels averaged 43, 162 and 282 cm's above the sea floor. Error bars show the standard error around each average. Each average is based on a sample of 11 or 12 collectors.

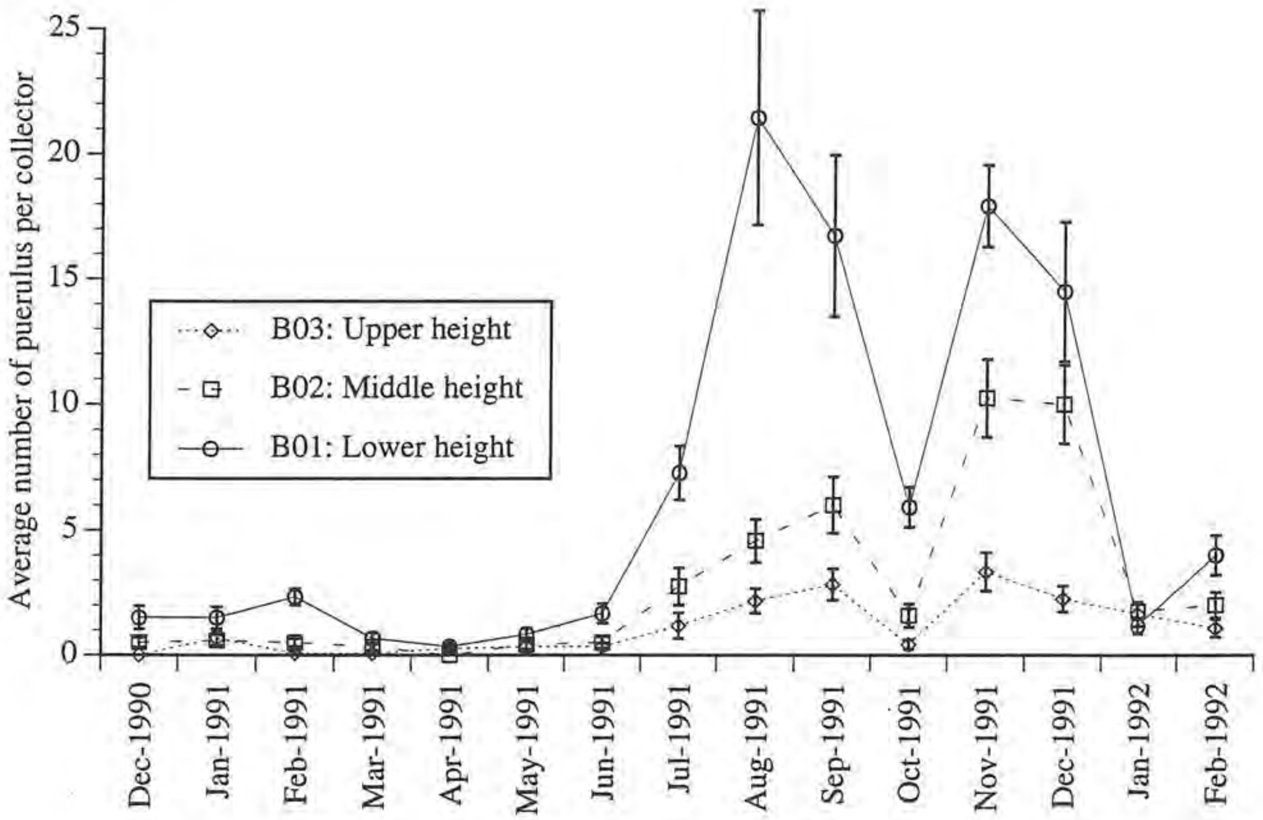


Figure 9: Average catch rates of puerulus and post puerulus on each arm of the standard cross alignment of collectors within a site. Arms A and C are parallel to the most frequent direction of the swell, with Arm A pointing into the swell. Arm B and D are perpendicular to the swell. Averages are usually based on 3 collectors, but occasionally represent the catch of one or two collectors. Lines connect the sample points except for cases in which a sampling period has been missed. Catches from collectors with less than 120 days of conditioning have been excluded from the results.

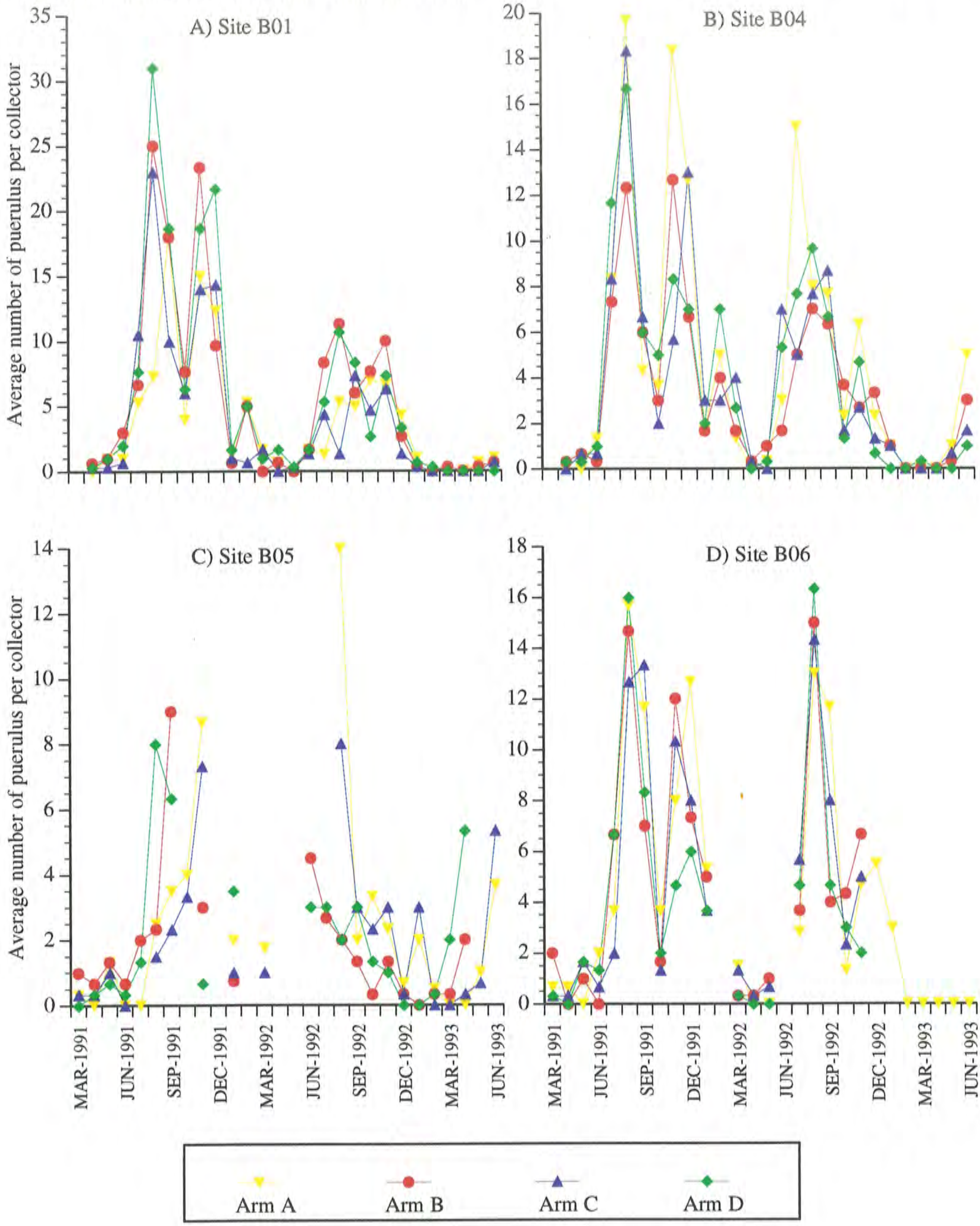


Figure 9: Continued.

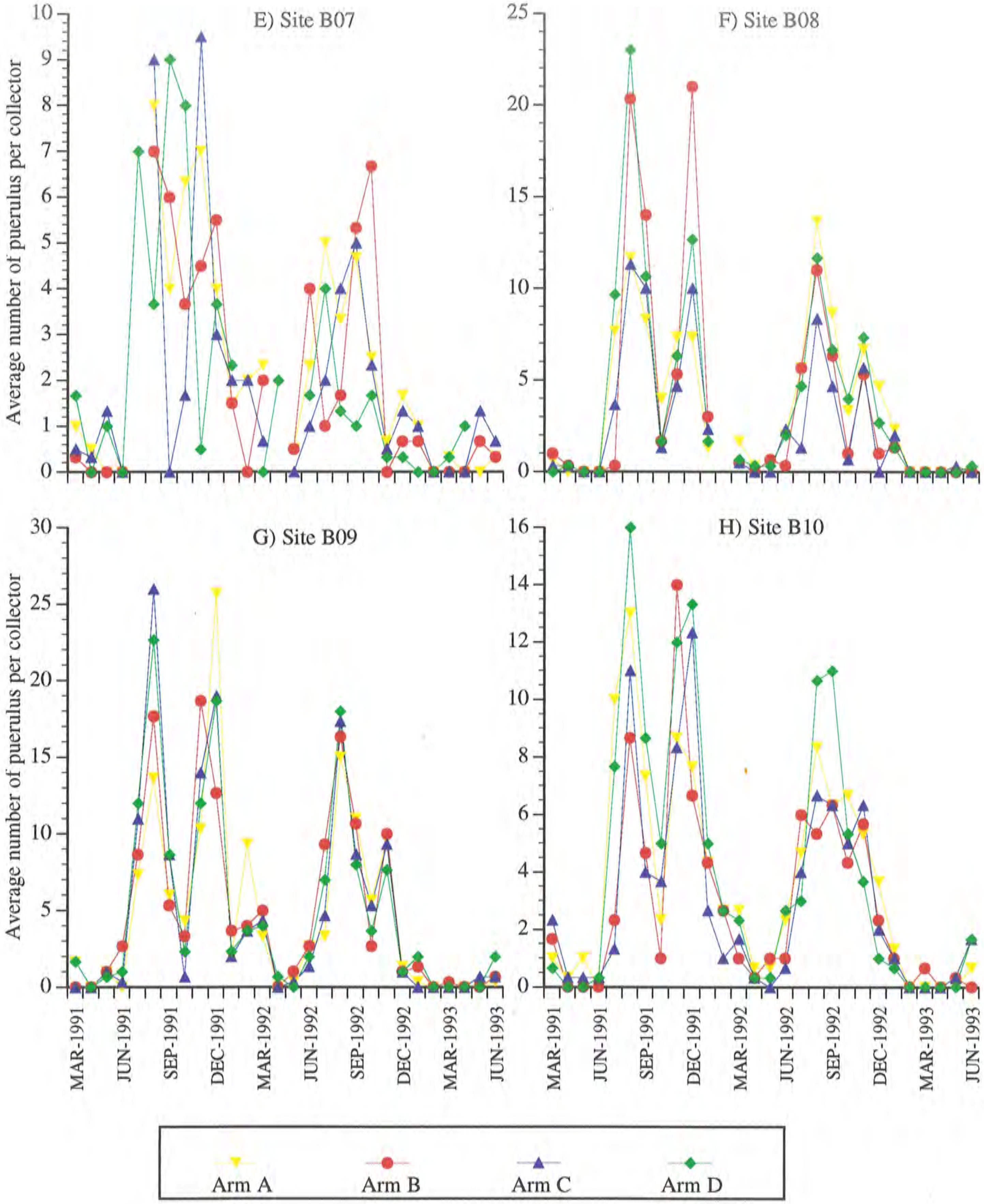


Figure 10: Average catch rates of puerulus and post puerulus on collectors at the inner, middle and outer positions within the standard cross alignment of collectors. Averages are usually based on 4 collectors, but occasionally represent the catch from one to three collectors. Lines connect the sample points except for cases in which a sampling period has been missed. Catches from collectors with less than 120 days of conditioning have been excluded from the results.

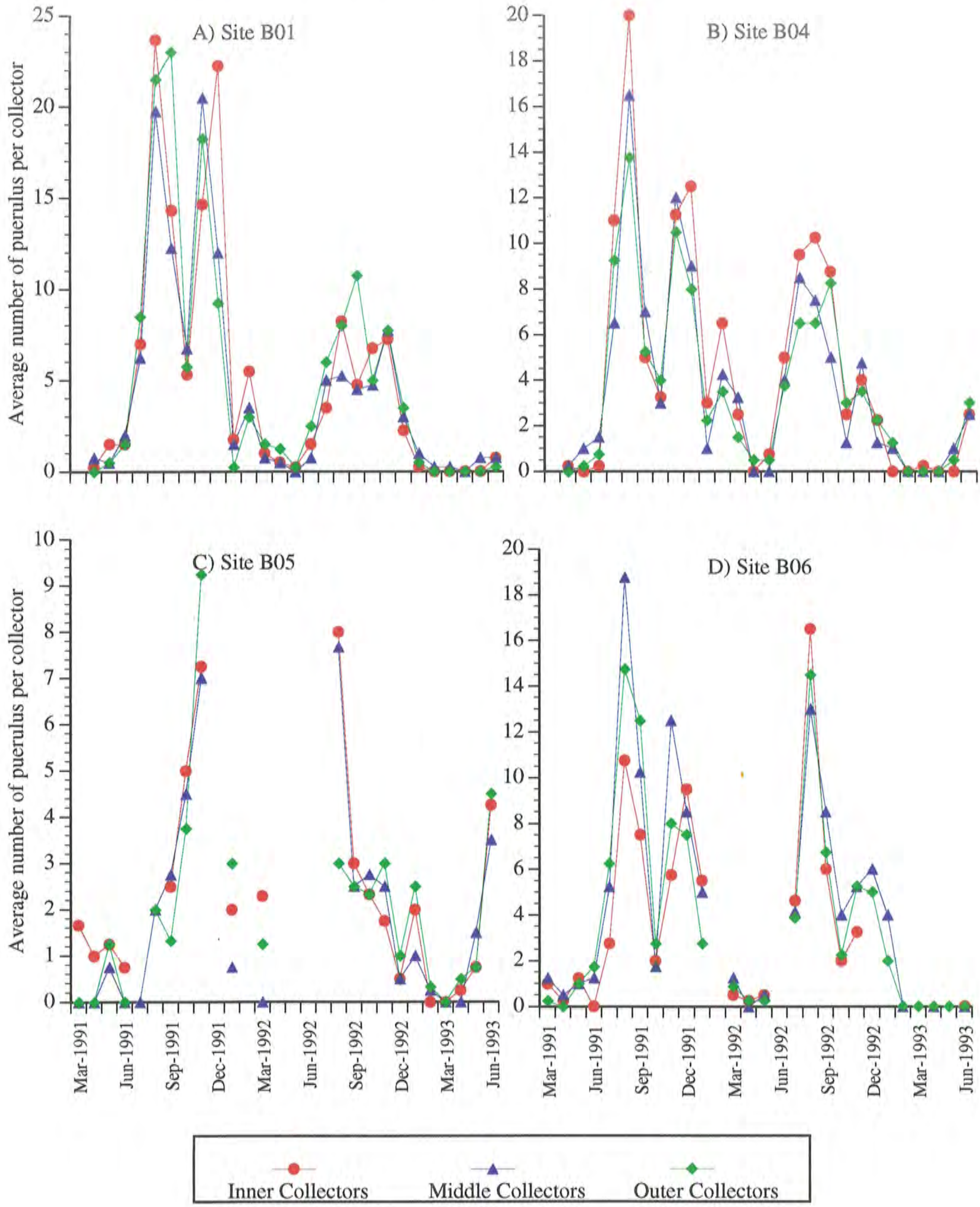


Figure 10: Continued.

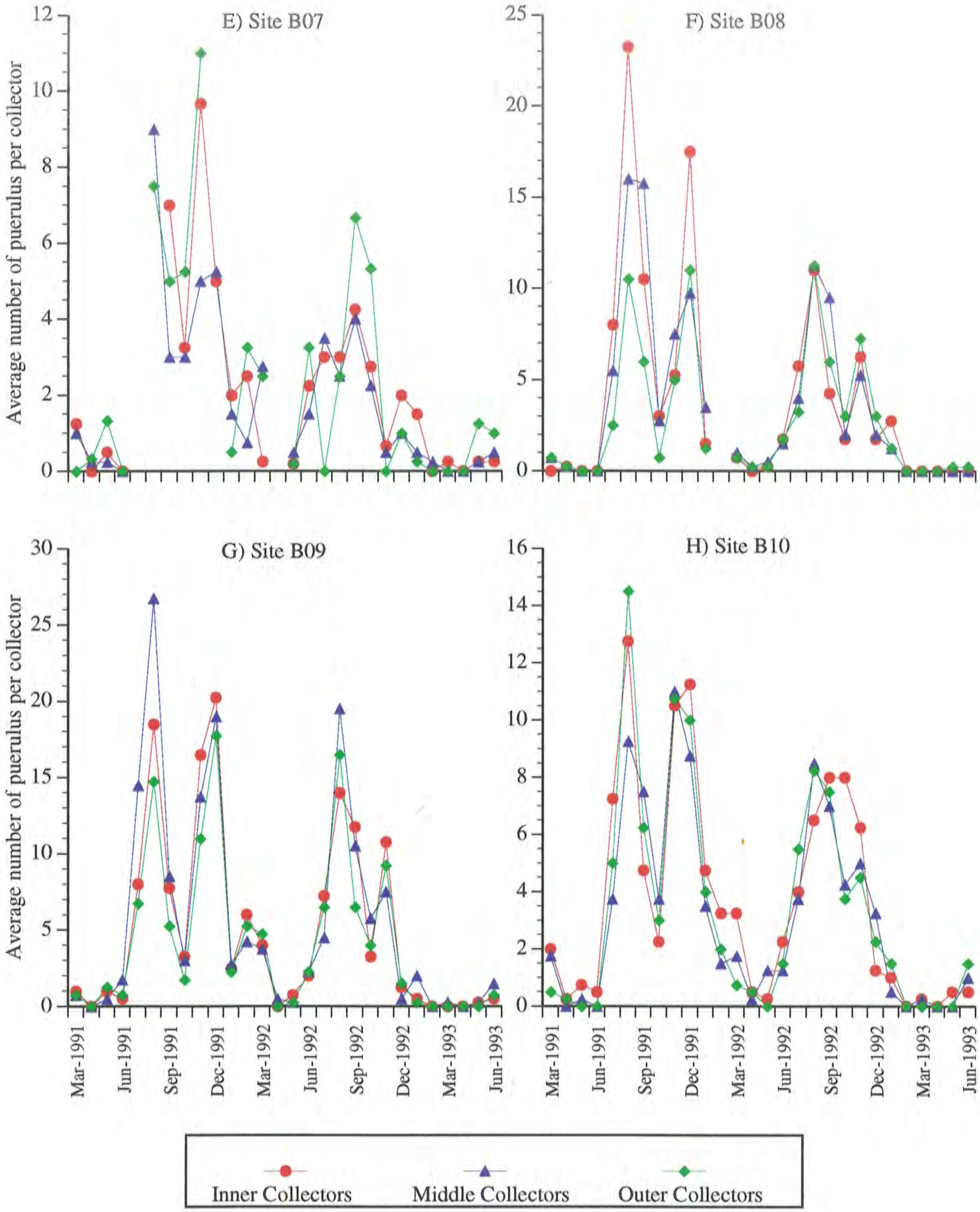


Figure 11: Diagram of PVC tube assembly used for deployment of plaster balls. a) Holes in frame to allow for the fastening down of pipes, using stretch rubber straps. b) Galvanised steel mounting frame to hold two layers of PVC pipes. c) Upper three PVC pipes set at 90 degrees to lower pipes. d) Nylon hex nuts locking plaster ball in place. e) 10mm nylon threaded rod. Rod is imbedded through plaster ball and held in place by a hex nut on bottom. f) 160mm PVC pipe. g) 100mm plaster ball. h) Nylon hex nut to suit 10mm threaded rod. i) Mooring post. j) Mooring base (as used with crevice collectors).

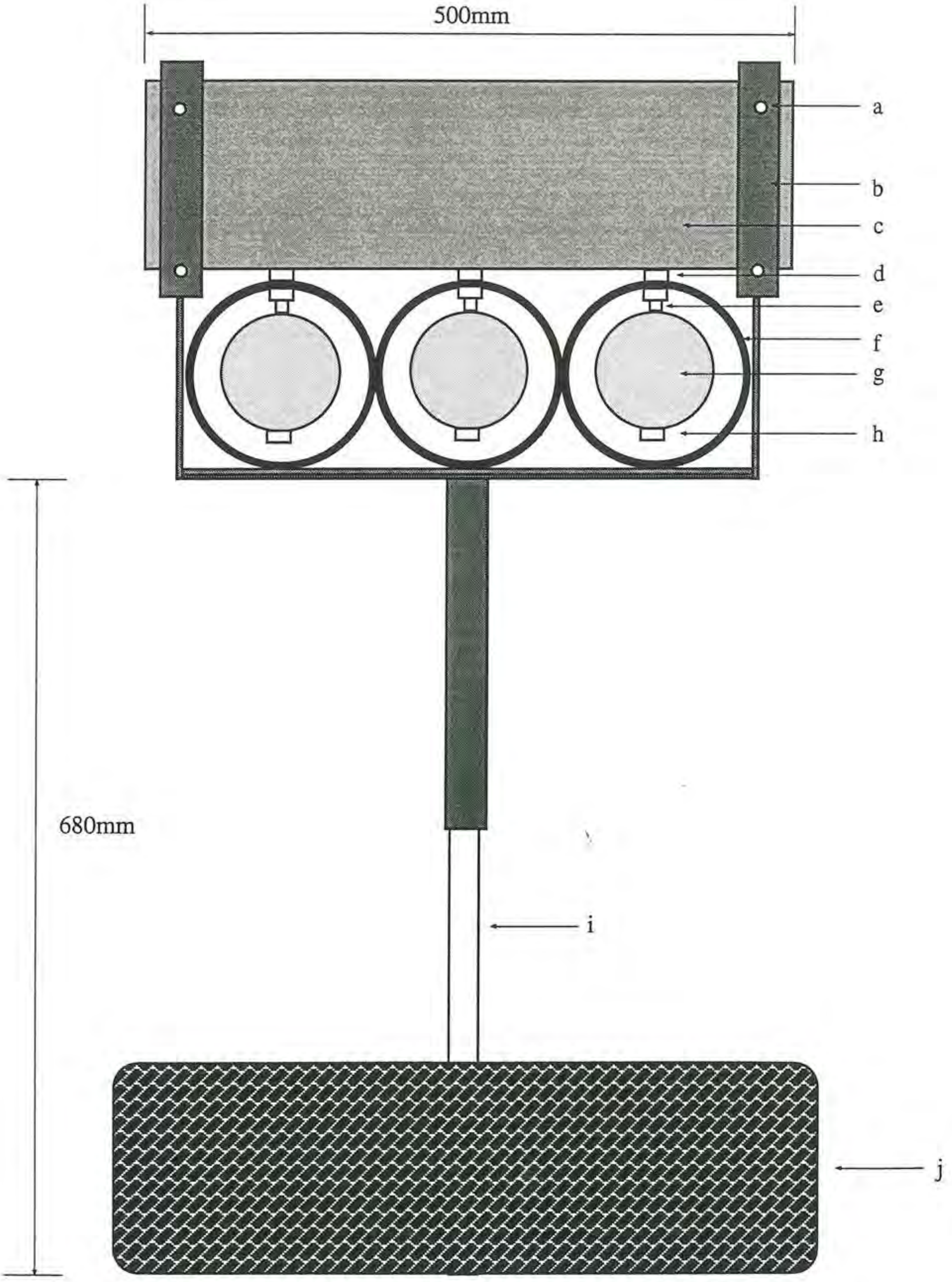


Figure 12: Diagram of electronic flow counter. a) Eye ring for attachment of 15cm styrene bouy. b) 6mm stainless steel shaft. c) PVC end cap for housing. d) Sealed 50mm PVC pipe and Perspex housing. e) Nuts welded to stainless steel shaft to fix height on shaft. Also allows housing to swivel on shaft. f) Magnetic reed switch for reseting counter. g) Kirby fan blade (Thorgren valparisio 5.56 -25ccw) available from C.I.G. h) Eye ring for attachment to mooring. i) Magnetic reed switch for counting propeller revolutions. j) Electronic counter (RS component stock number 341-519, add only counter) with ten year battery life. The low speed counting circuit of the counter was used. k) Ferrite Magnets (aussie magnets 15mm*4mm disc magnet) glued to a recess in the propeller base using 24 hour araldite. Sufficient araldite was used to fill recess leaving a smooth surface. These magnets were used to trigger the counting reed switch. l) Twin stainless steel nuts and washer on threaded 3mm stainless steel rod to hold on propeller.

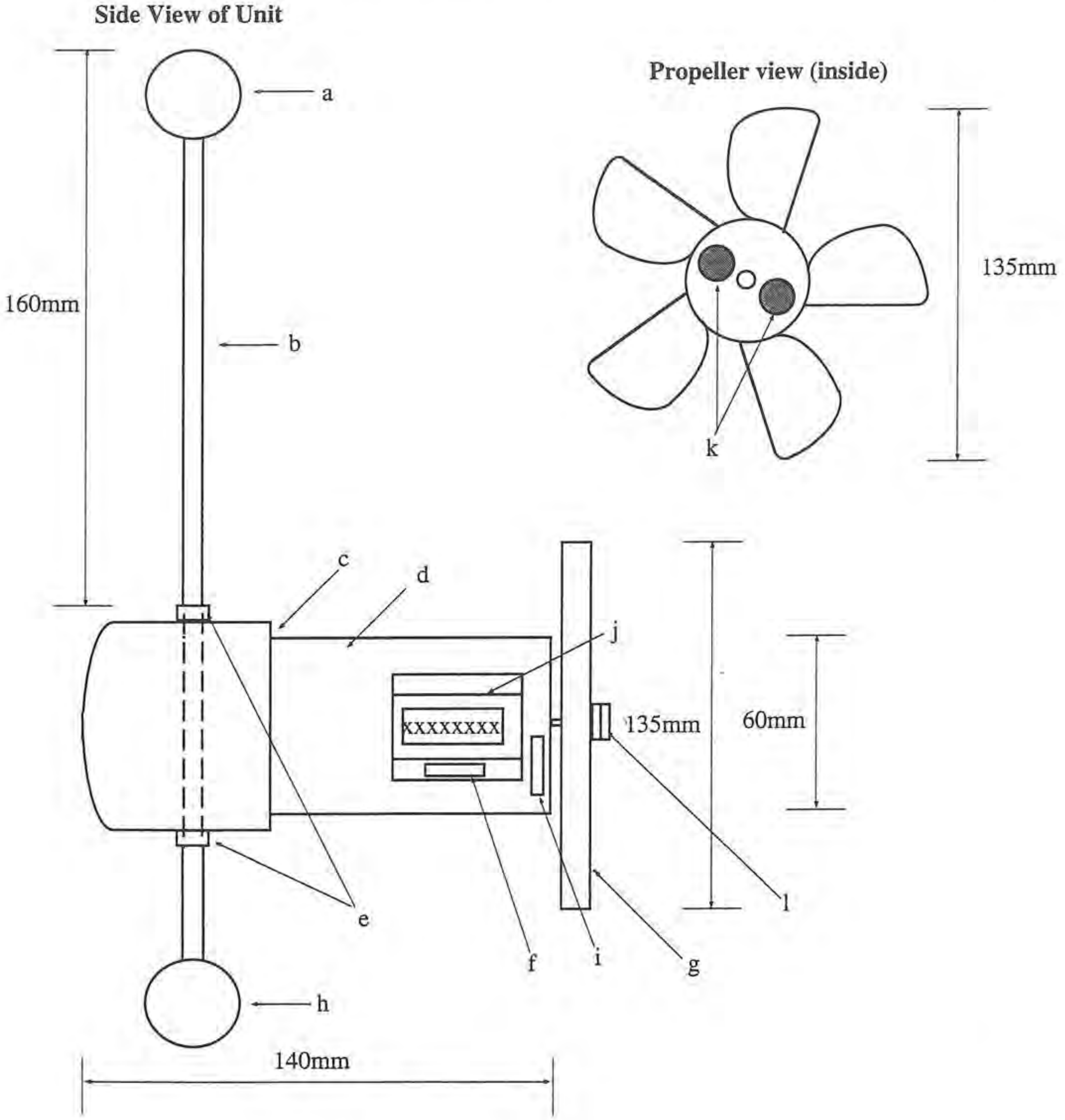


Figure 13: Calibration results of electronic flow counter. Total number of propeller revolutions in a fixed distance tow for a variety of towing speeds.

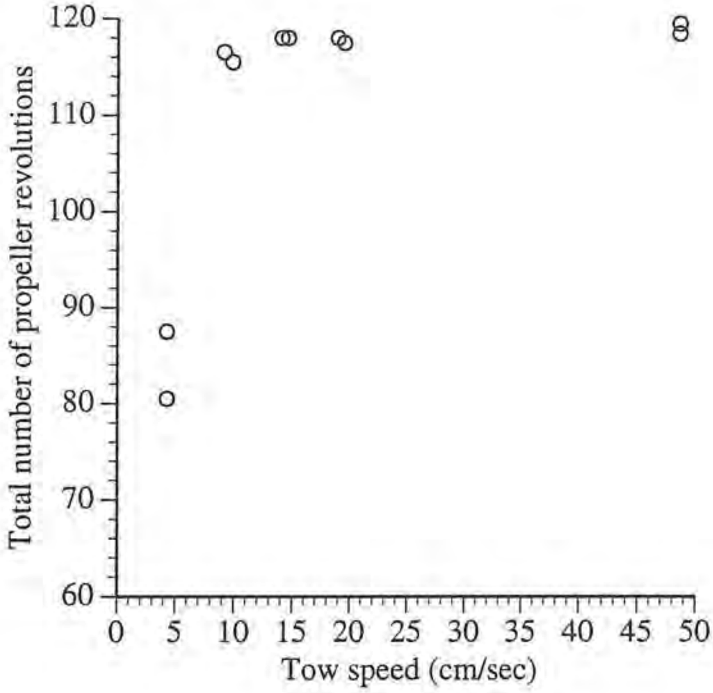


Figure 14: Calibration results of electronic flow counter. Number of propeller revolutions per minute against tow speed.

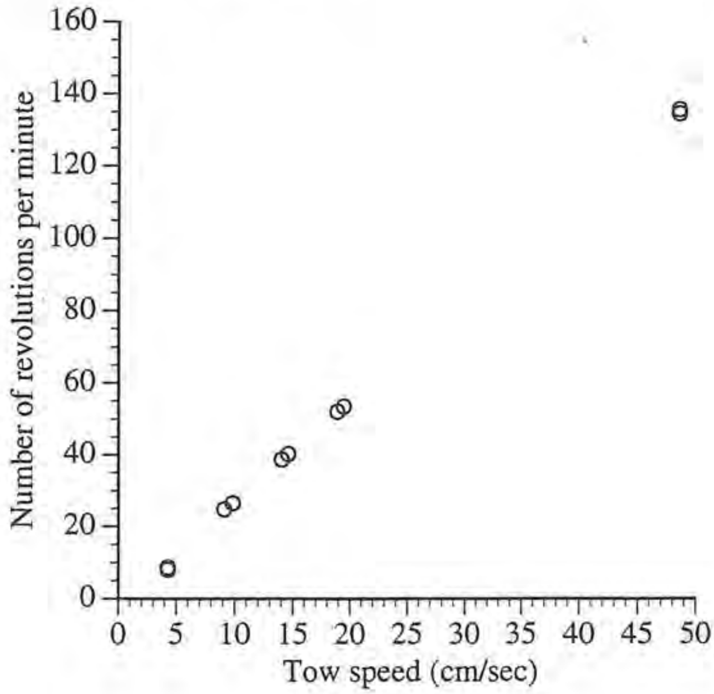


Figure 15: Flow rates (propeller revolutions per minute) obtained from electronic flow counters at each site. Graphs are arranged in approximate ranked order of exposure of the sites, with the calmest site on top and the most exposed at the bottom. Arrows indicate flow rates which were under estimated due to fouling of the propeller. The average catch rate of puerulus and post puerulus per collector for the period is shown in the top right hand corner of the graph for each site. The displayed catch rates exclude catches for 12/91, 2/92 and 4/92 to 7/92 inclusive. This is because some sites were missing catch data for these months.

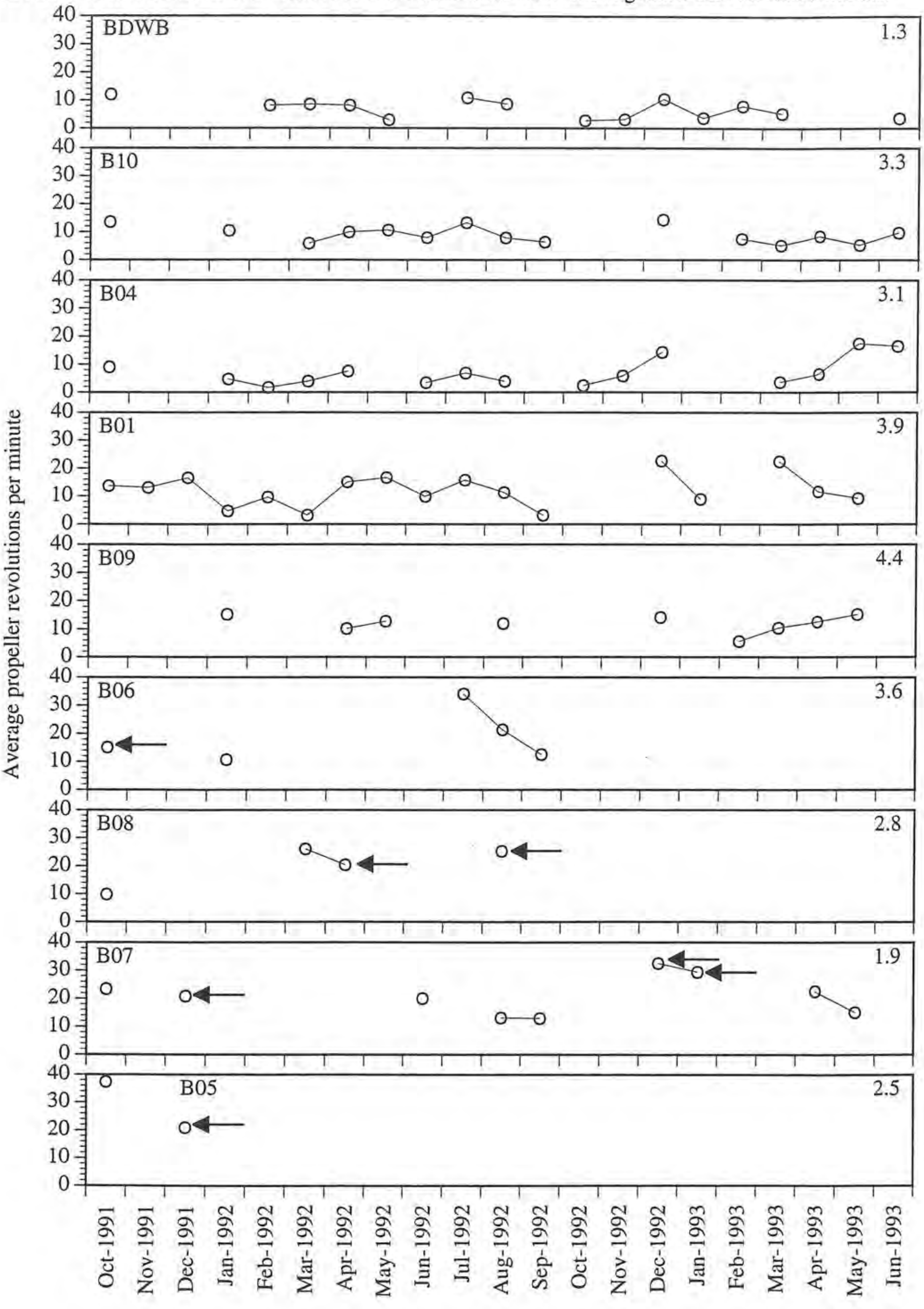


Figure 16: Diagram of sediment trap. a) Threaded cap 90mm. This is only used when retrieving and transporting the trap. It is left off when the trap is sampling. b) Access coupling 90mm. c) Funnel in mouth of trap to retard loss of sediment. d) PVC pipe 90mm which acts as the sediment store. e) Mounting bracket. f) Grub screw to allow for height adjustment. g) Wing nut to allow easy removal and deployment. h) Stopped end cap 90mm. Glued to bottom of PVC pipe. i) Mooring pole. j) Mooring base as used in crevice collector.

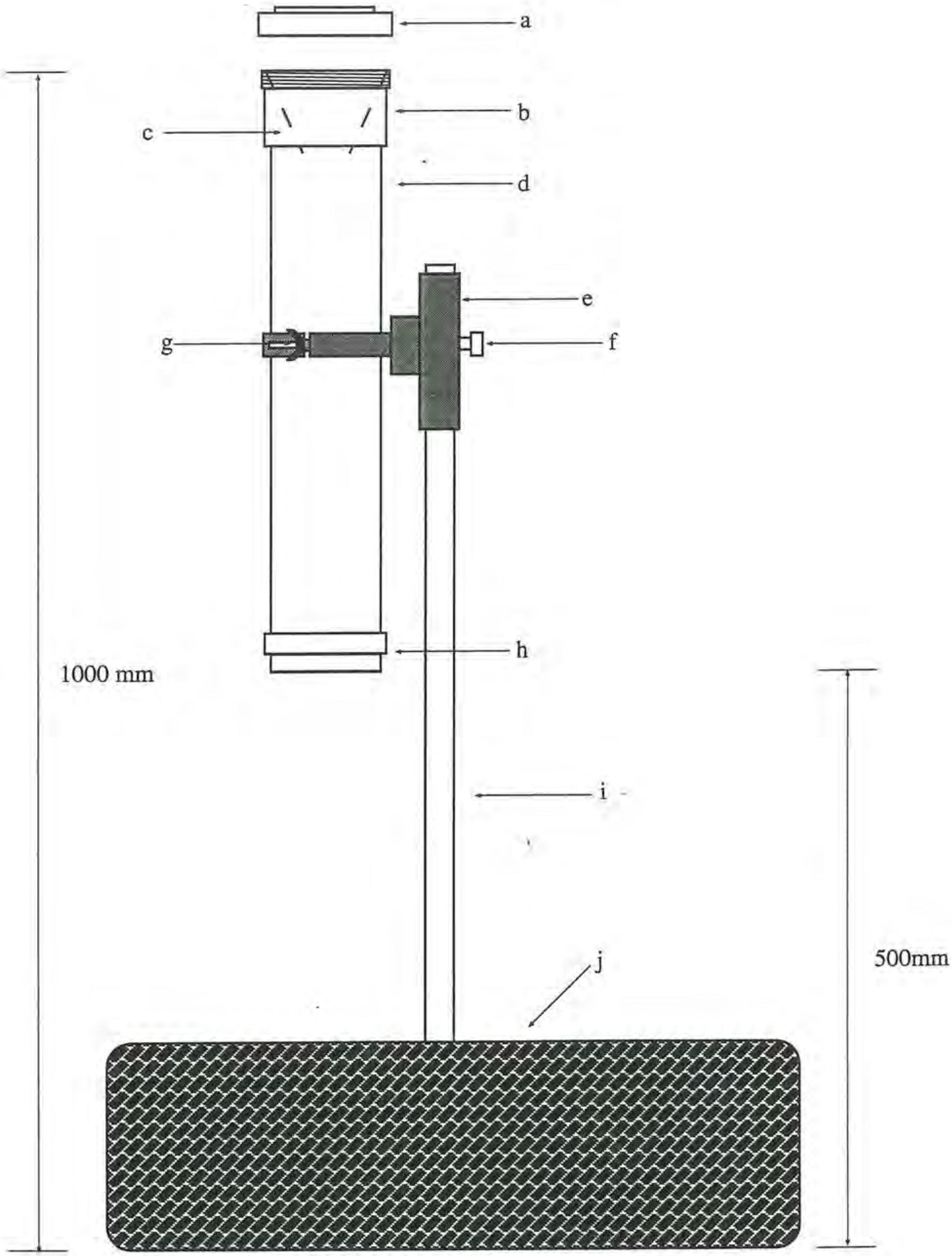


Figure 17: Acid washed mass versus entire sample mass from sediment traps. Axes are drawn in a logarithmic scale.

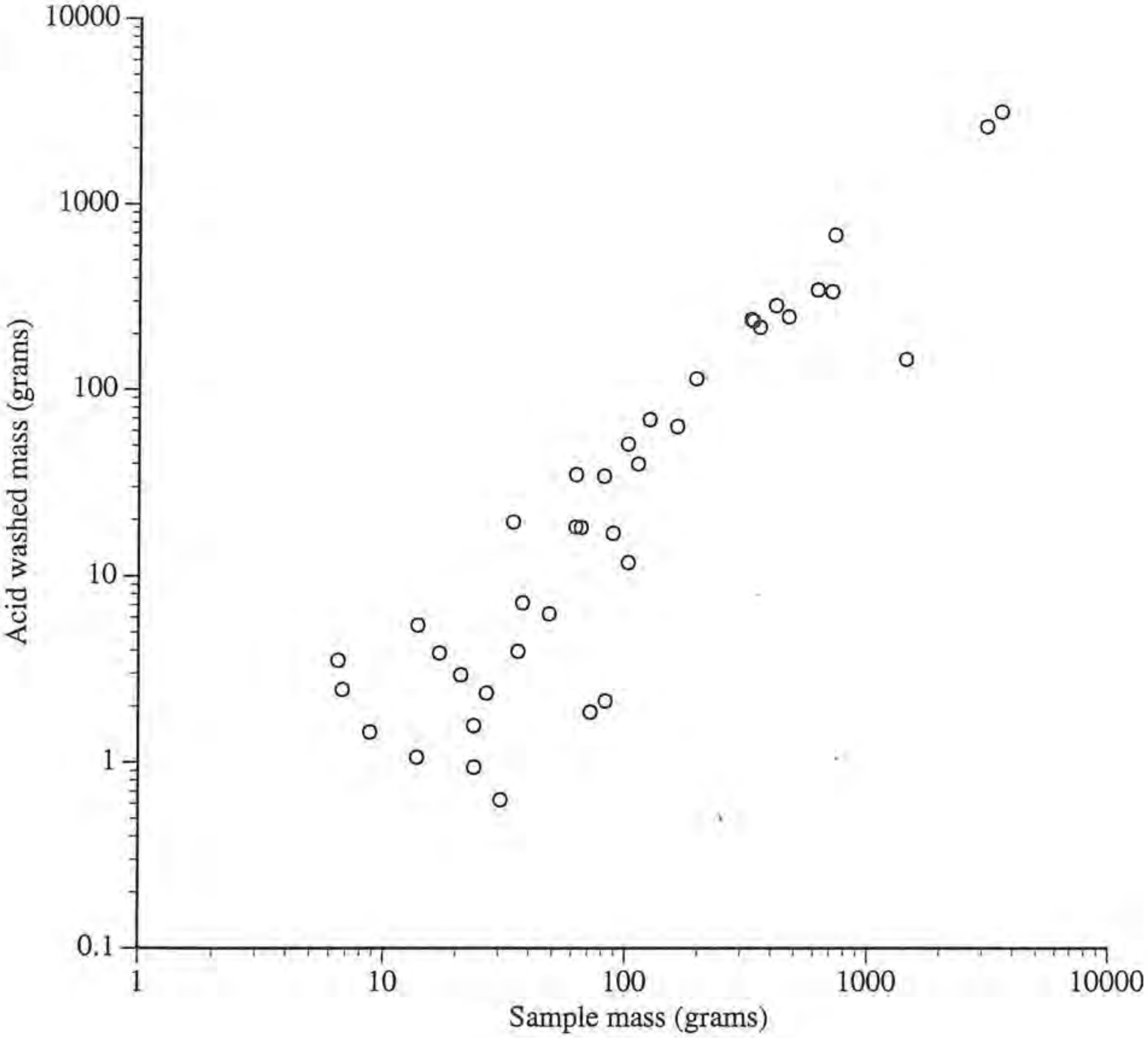


Figure 18: Weight of sediments (after acid treatment) collected from sediment traps at each site. Graphs are arranged in approximate ranked order of degree of sedimentation. The average catch rate of puerulus and post puerulus per collector is shown in the top right hand corner of the graph for each site. The displayed catch rates exclude catches for 12/91, 2/92 and 4/92 to 7/92 inclusive. This is because some sites were missing catch data for these months.

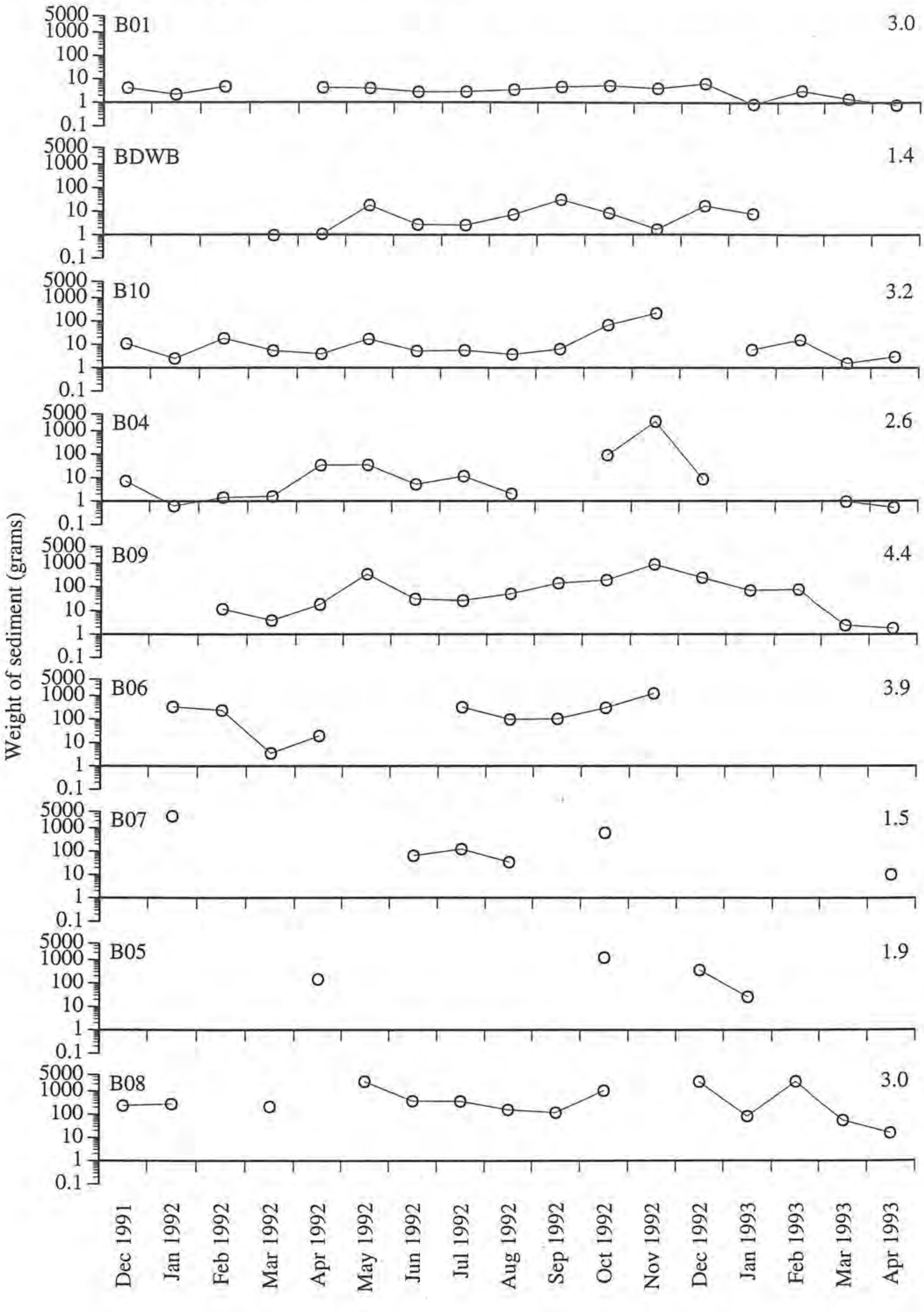


Figure 19: Average catch rates of puerulus and post puerulus at each Bicheno site through time. Lines connect sample except when samples were missing. Catches from collectors with less than 120 days of conditioning have been excluded from the results.

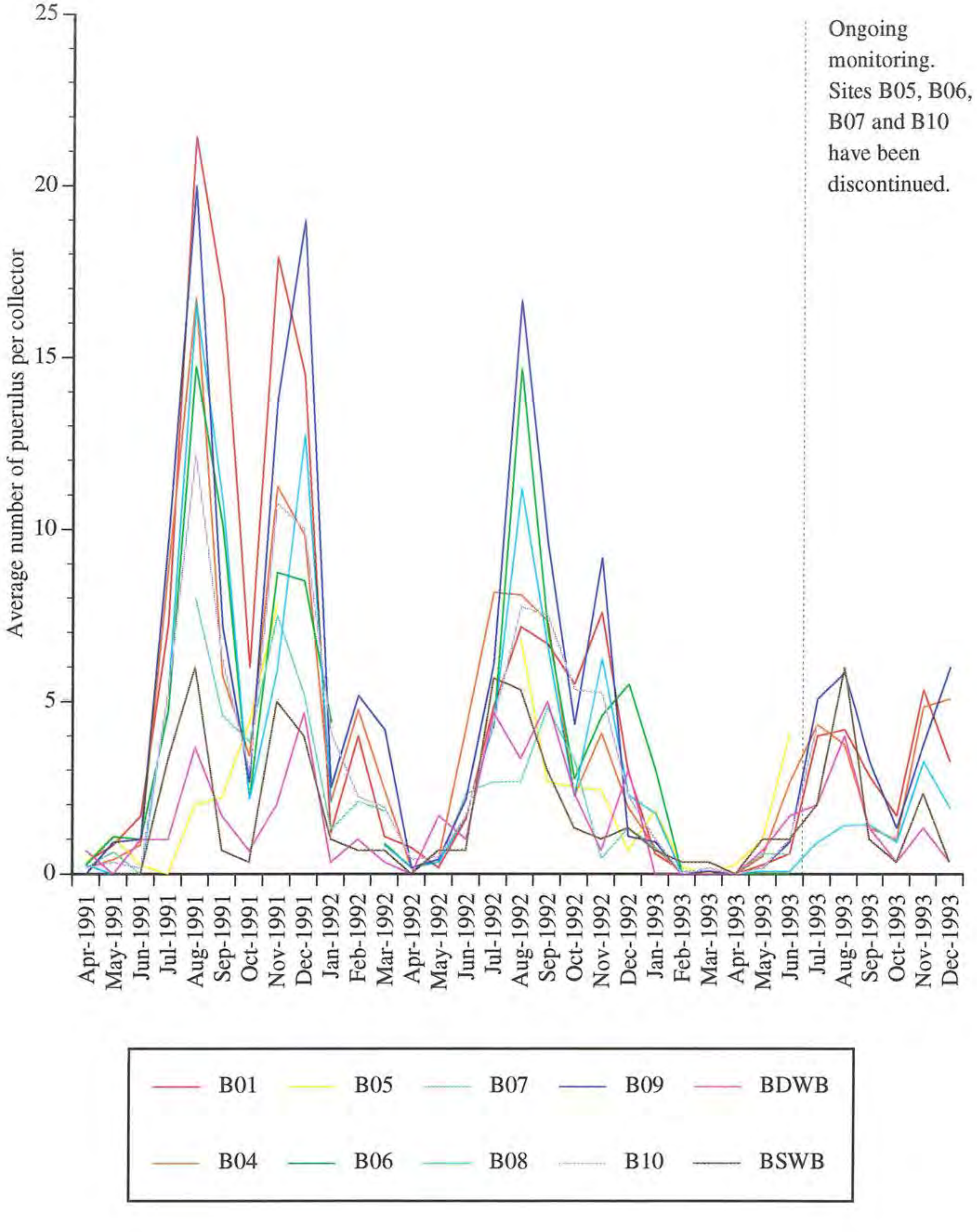
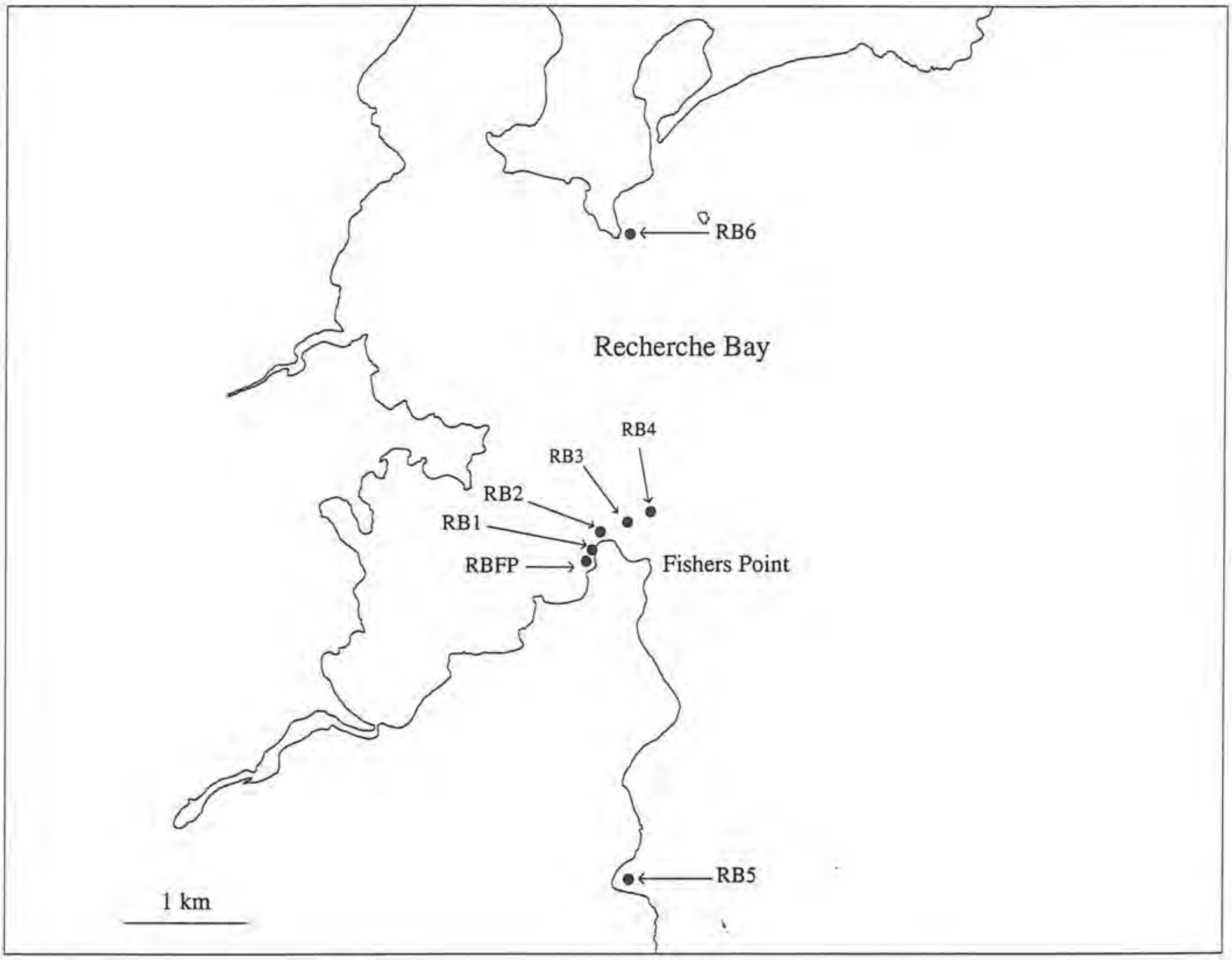


Figure 20: Location of puerulus sampling sites at Recherche Bay.



Depth Of Sites (m)

RBFP = 3
RB1 = 4
RB2 = 6
RB3 = 7
RB4 = 9
RB5 = 8
RB6 = 6

Figure 21a: Location of east coast puerulus sampling sites (Maria Island and Little Swanport). Depth of sites are SWAN (6m), MI1 (4m) and MI2 (6m).

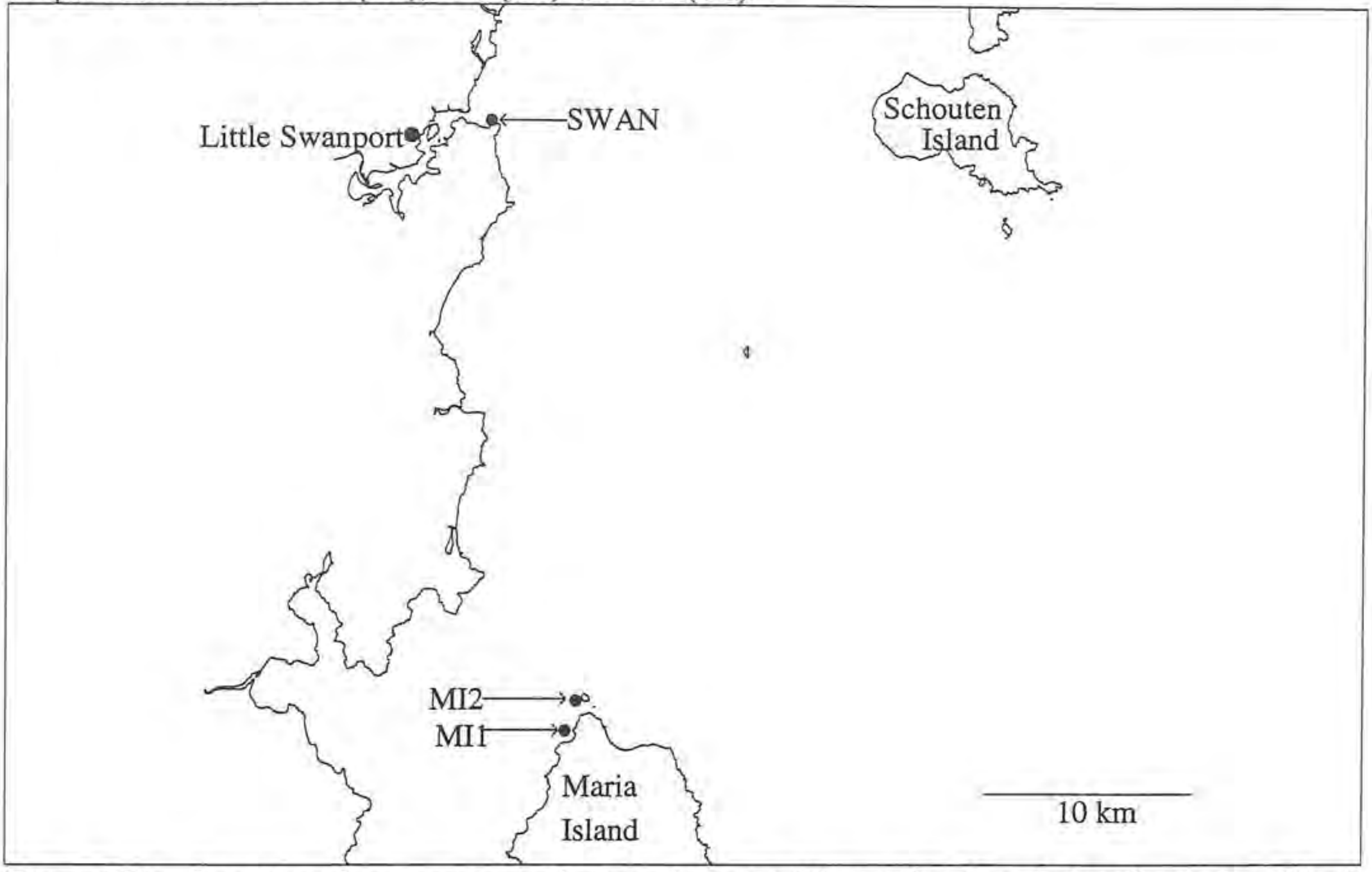


Figure 21b: Location of east coast puerulus sampling sites (Pirates Bay, Port Arthur, South Arm, North Bruny Island and Howden. Depth of sites are PB1 (4m), PB2 (5m), PA1 (4m) , PA2 (7m), SA1 (7m), SA2 (5m), SA3 (3m), NB1 (6m), NB2 (5m) and HOW (6m).

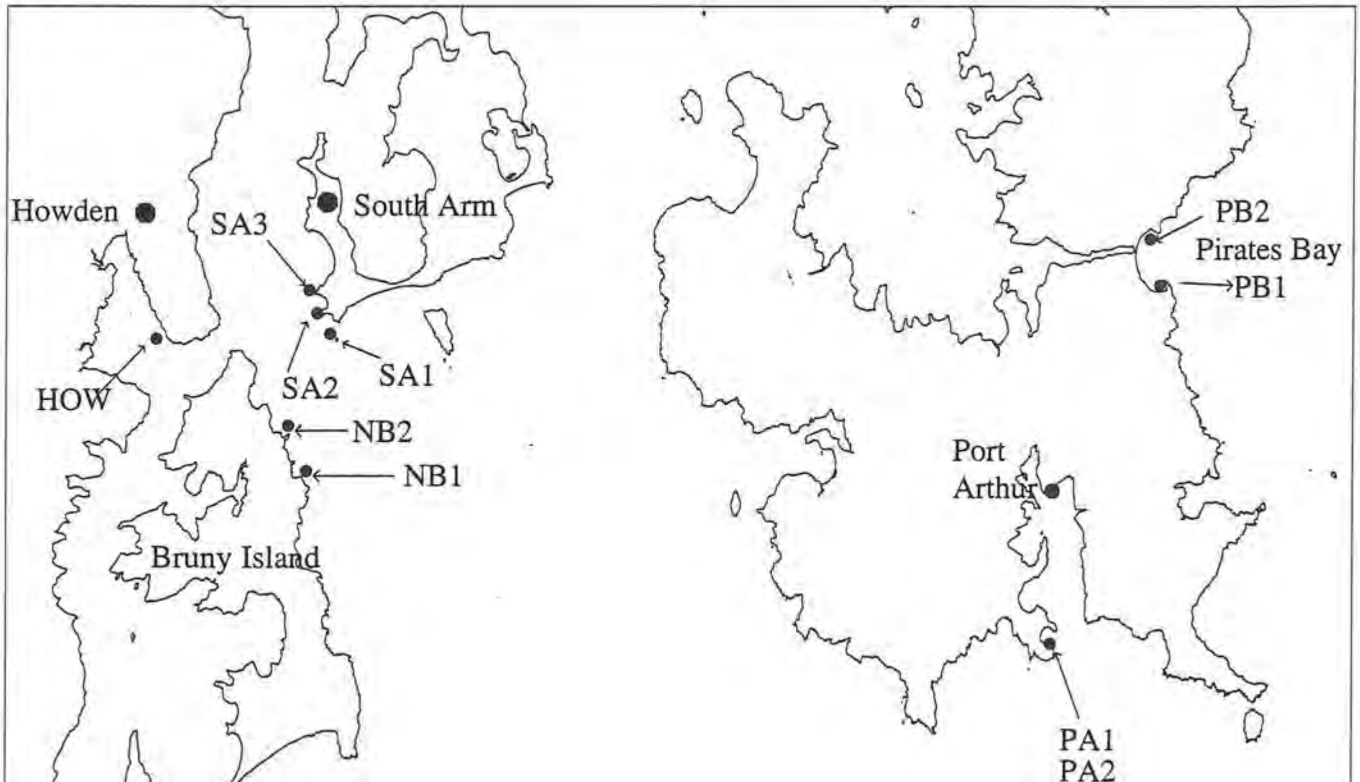


Figure 22: Location of west coast puerulus sampling sites. Depth of sites are CH (4m), CR1 (2m), CR2 (3m), CR3 (5m) and MG (2 to 5m).

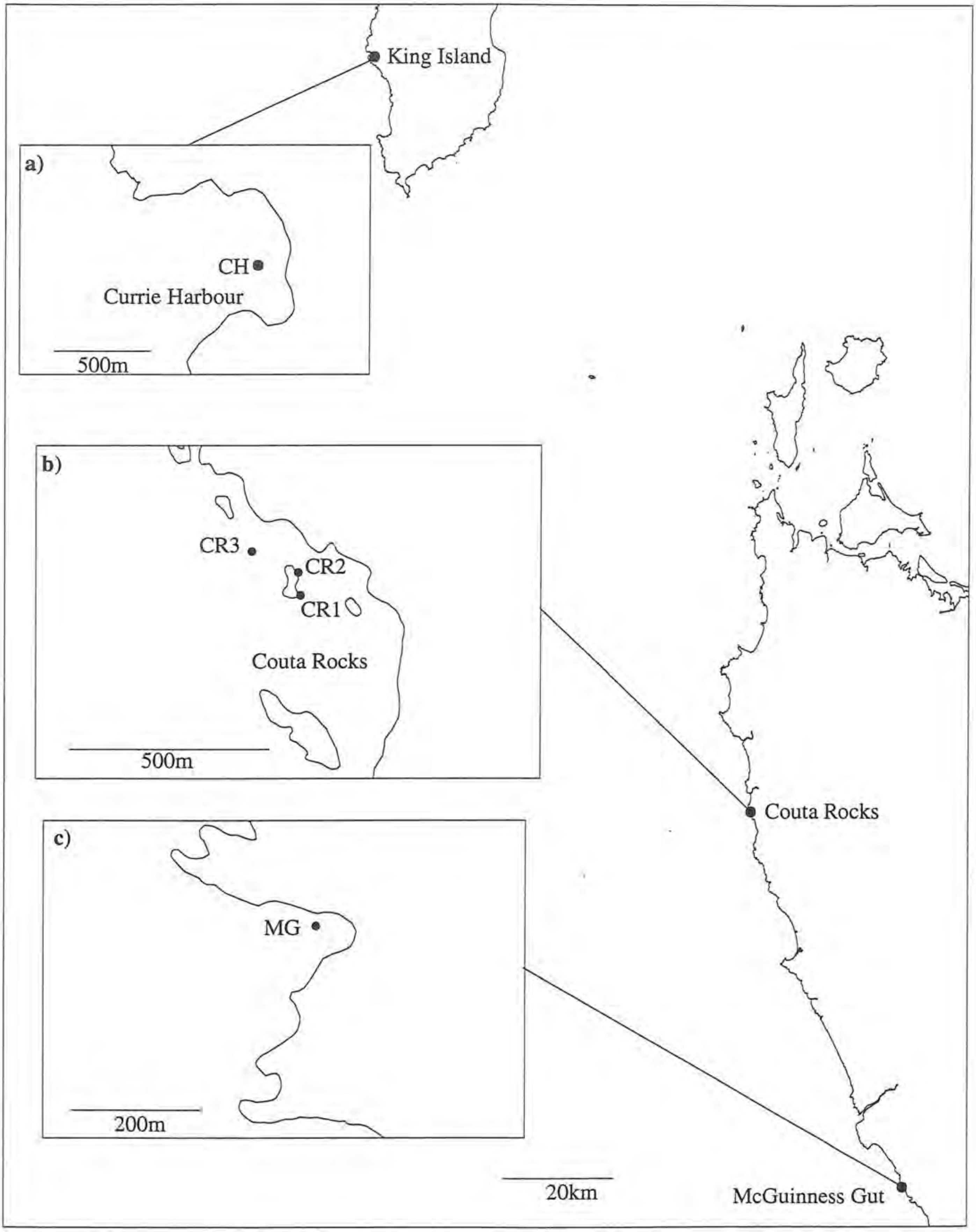


Figure 23: Average catch rates of puerulus and post puerulus at Recherche Bay. Site labels are shown in the top left hand corner of each graph. Periods in which data was not available and the cessation of sampling at sites is indicated by gaps in the horizontal axes.

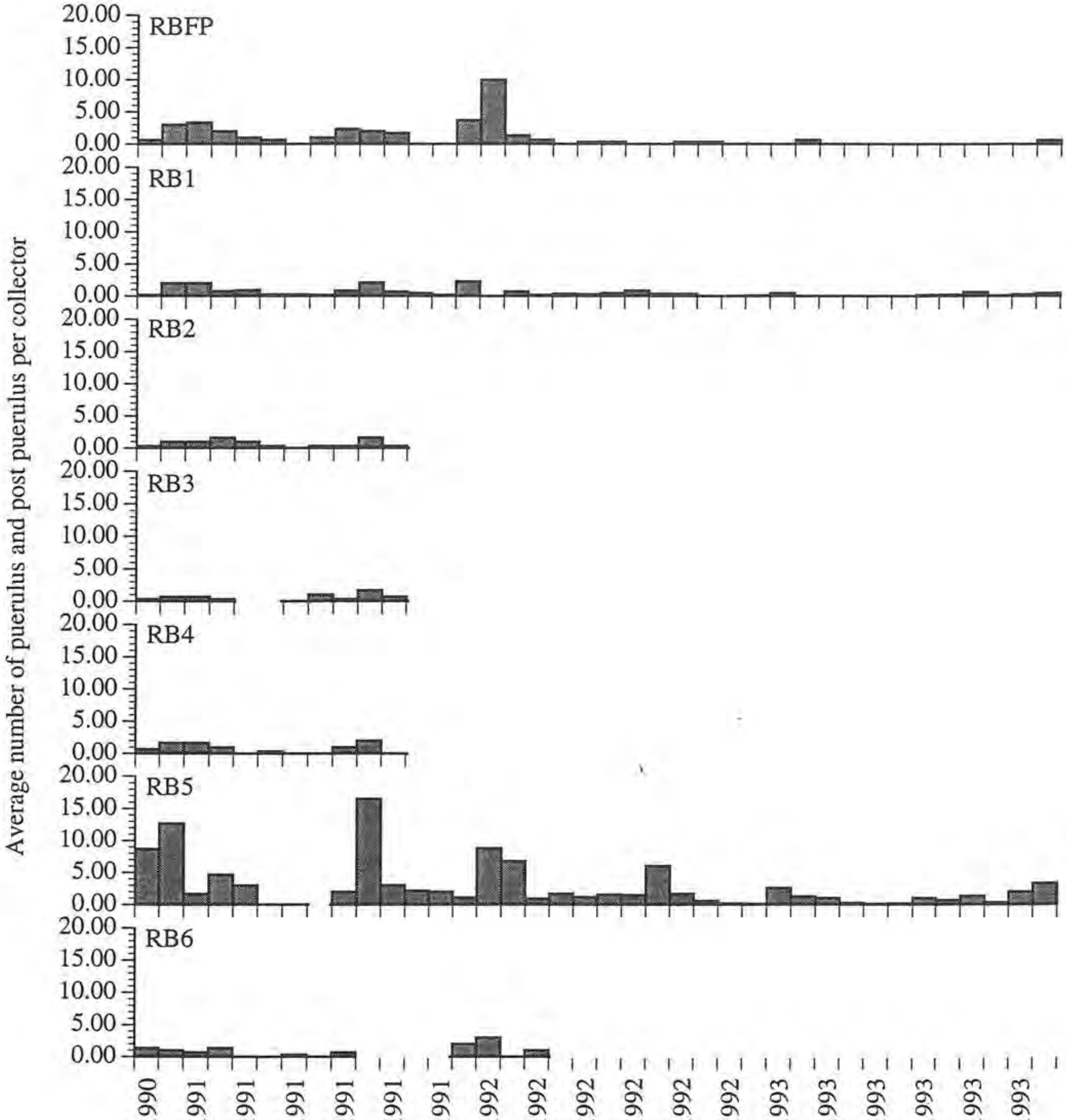


Figure 24: Average catch rates of puerulus and post puerulus pooled over sites at Bicheno and Recherche Bay. Sites B4, B8 and B9 where used for Bicheno and sites RBFP, RB1 and RB5 where used for Recherche Bay. Solid and dashed arrows connect winter and spring/summer settlement peaks between the two locations respectively.

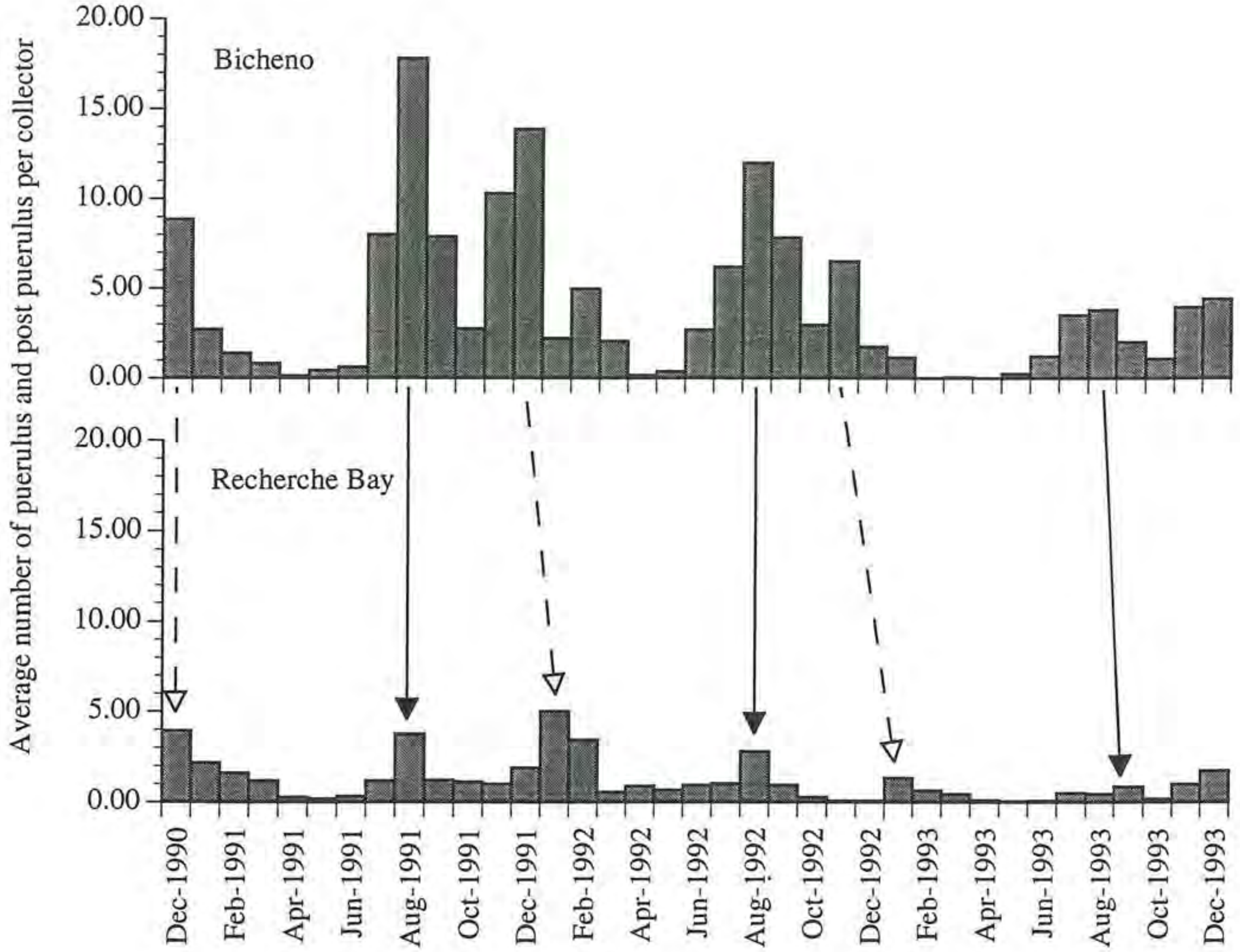


Figure 25: Average catch rates of puerulus and post puerulus for exploratory east coast sites (Little Swanport, Maria Island, Pirates Bay and Port Arthur). Site labels are shown in the upper left hand corner of each graph. Pooled results from Bicheno (using sites B4, B8 and B9) are provided for comparison. Periods in which data was not available is indicated by gaps in the horizontal axes.

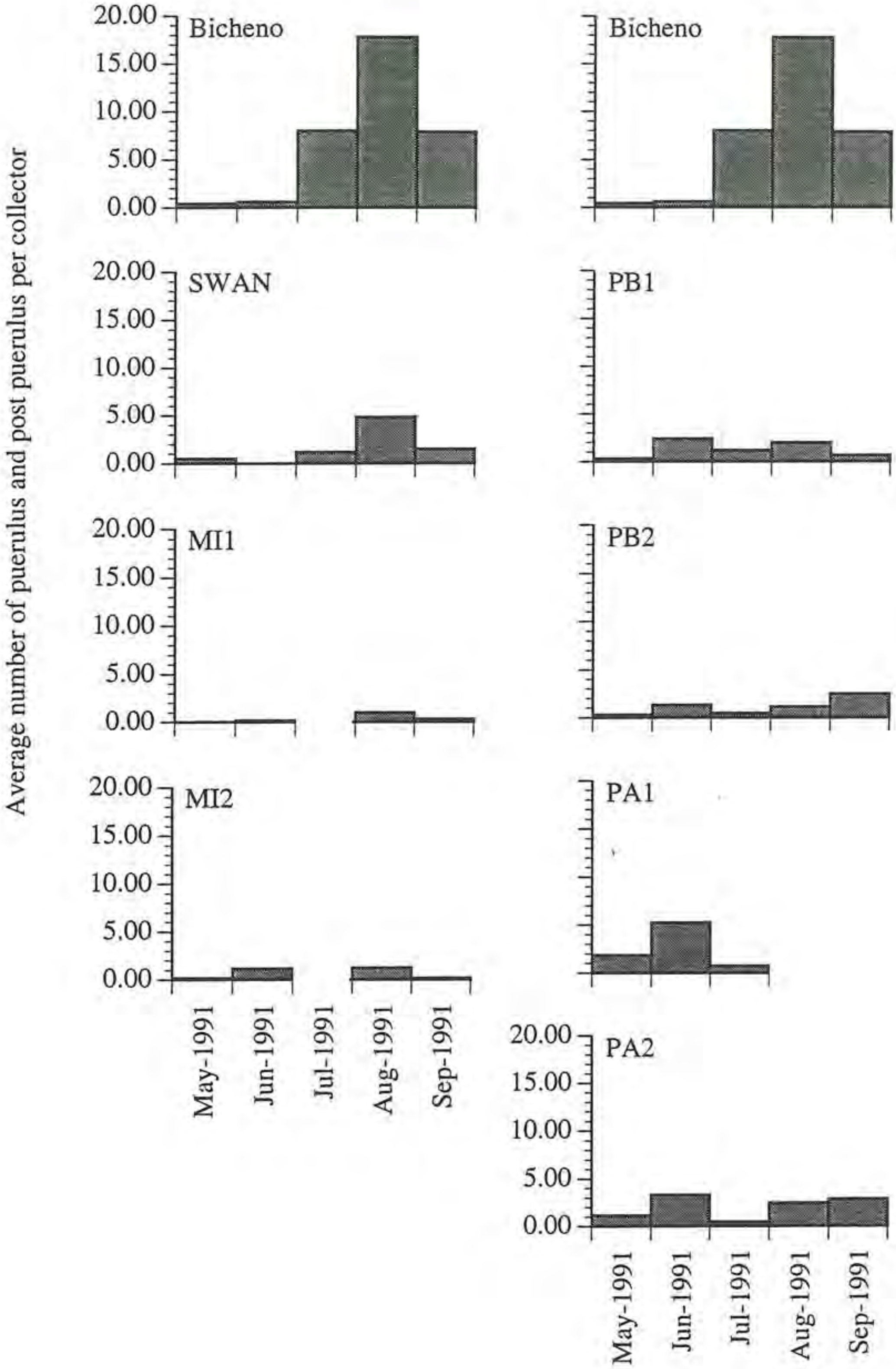


Figure 26: Average catch rates of puerulus and post puerulus at South Arm and North Bruny Island. Site labels are shown in the upper left hand corner of each graph. Pooled results from Bicheno (using sites B4, B8 and B9) are provided for comparison. Periods in which data was not available and the cessation of sampling at sites is indicated by gaps in the horizontal axes.

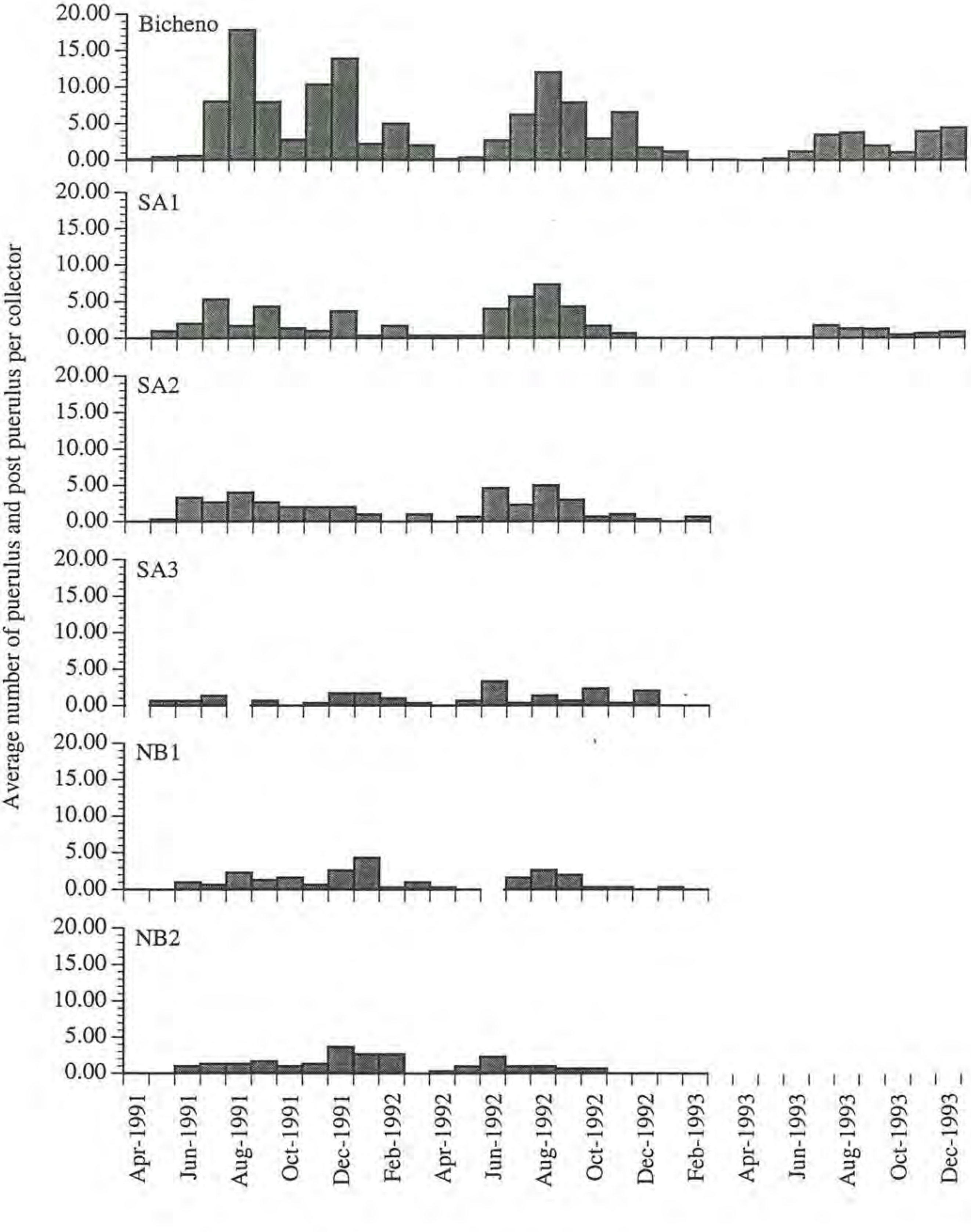


Figure 27: Average catch rates of puerulus and post puerulus for west coast sites (King Island, Couta Rocks and McGuinness Gut). Site labels are shown in the upper left hand corner of each graph. Pooled results from Bicheno (using sites B4, B8 and B9) are provided for comparison. Periods in which data was not available and the cessation of sampling at sites is indicated by gaps in the horizontal axes. No graph is provided for site "CR3" since this site failed to catch puerulus.