## 4.3 Results

### 4.3.1 Comparison of "fished" v "unfished" areas in the Wooli and Corindi estuaries

**Abundance**

A total of 2026 crabs was caught between July 2000 and April 2002 in the Wooli and Corindi estuaries. Pooling months at each site, there were significantly more crabs caught at the unfished Sanctuary Zone (Site 1 (U) – 647 crabs and Site 2 (U) – 490 crabs) than the fished Recreation Zone (Site 3 (F) – 166 crabs) at Wooli ($F_{2,8} = 32.56$ , $P = 0.0006$). Variation between sites also occurred in the unfished Sanctuary Zone with more crabs caught at Site 1 than Site 2 (Figure 4.4). At Corindi, the mean number of crabs was significantly higher in the Sanctuary Zone (Site 1 (U) – 320 crabs and Site 2 (U) – 351 crabs) than the fished Recreation Zone where very few crabs were caught over the sampling period (Site 3 (F) – 52 crabs) ($F_{2,8} = 33.43$ , $P = 0.0006$) (Figure 4.4).

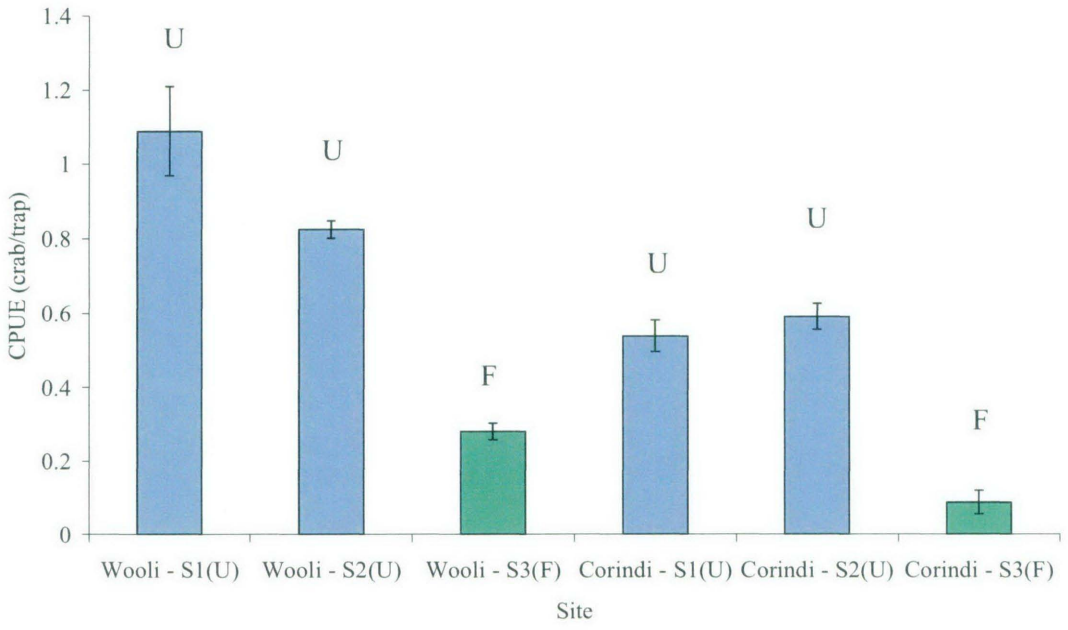


**Figure 4.4.** Mean CPUE of crabs (± SE) caught in unfished (U) and fished (F) sites (S1 - S3) in the Wooli and Corindi estuaries between July 2000 and April 2002. (Catch per unit effort based on 594 trapping nights).

Due to the highly significant ((Fished v Unfished) x Estuary x Month) interaction found in the constructed ANOVA (Table 4.8) and the lack of ability to pool to higher order terms, monthly ANOVAs were used to detect any differences among Sites in each estuary. There was large variation in CPUE between months in each estuary (Figures 4.5 - 4.6). Higher catches of mud crabs occurred in the Sanctuary Zone sites in most months (Site 1 and 2). No difference in CPUE between sites occurred during August 2000, November 2000 and May 2001 at Wooli and July 2000, September 2000, May 2001 and December 2001 at Corindi (Table 4.9). Of the 19 months in which there was a difference among sites at Wooli, 13 had both Sanctuary Zone sites with significantly more crabs than the fished Site 3. There were two months where there was a difference between Sanctuary Zone sites as well as them both having more crabs than the fished site while the remaining 4 months had at least one of the Sanctuary Zone sites with significantly more crabs than the fished site (Table 4.9). At Corindi a similar pattern occurred. In the 18 months where there was a difference between sites, 15 of these had both Sanctuary Zone sites containing significantly more crabs than the fished site, while the other three sites had at least one Sanctuary Zone site with significantly more crabs than the fished site (Table 4.9)

Monthly variation in captures was more evident at Corindi than Wooli with smaller catches occurring during winter/spring between July 2000 and October 2000 and then again between May 2001 and July 2001 (Figure 4.6). At Wooli there was no distinct seasonal pattern in monthly variation in the Sanctuary Zone sites with each having similar CPUE in most months (Figure 4.5, Table 4.9). The two fished sites in each estuary showed different patterns of CPUE. At Wooli captures increased in periods leading up to high fishing pressure events such as school holidays which occurred in January, April, July, and October each year. Captures then declined during these periods. This is particularly evident during October 2000, January - February 2001, July 2001, and February 2002 (Figure 4.5). CPUE always increased after these periods in fished areas (Figure 4.5).

At Corindi, a different scenario occurred with an increase in crabs in the fished zone occurring only during the summer months, between November and February each year. Catches outside these periods were either small or non-existent. Captures of crabs during

this period peaked in February 2001 and December 2001. Captures after these peaks slowly declined until either no or few crabs were caught by April each year. CPUE increased considerably in December 2001 compared to previous months during the trial. This increase was not sustained but crabs were still being caught in April and May 2002 where only small catches were made in previous years (Figure 4.6).

In summary, the results indicate that Sanctuary zones provide protection to mud crabs causing an increase in abundance within those sites. There are also differences in the number of crabs occurring and when they occurred in the fished sites between estuaries, with higher overall CPUE at Wooli. Catches peaked during winter and prior to holiday periods at Wooli, while at Corindi, crabs were captured during summer only.

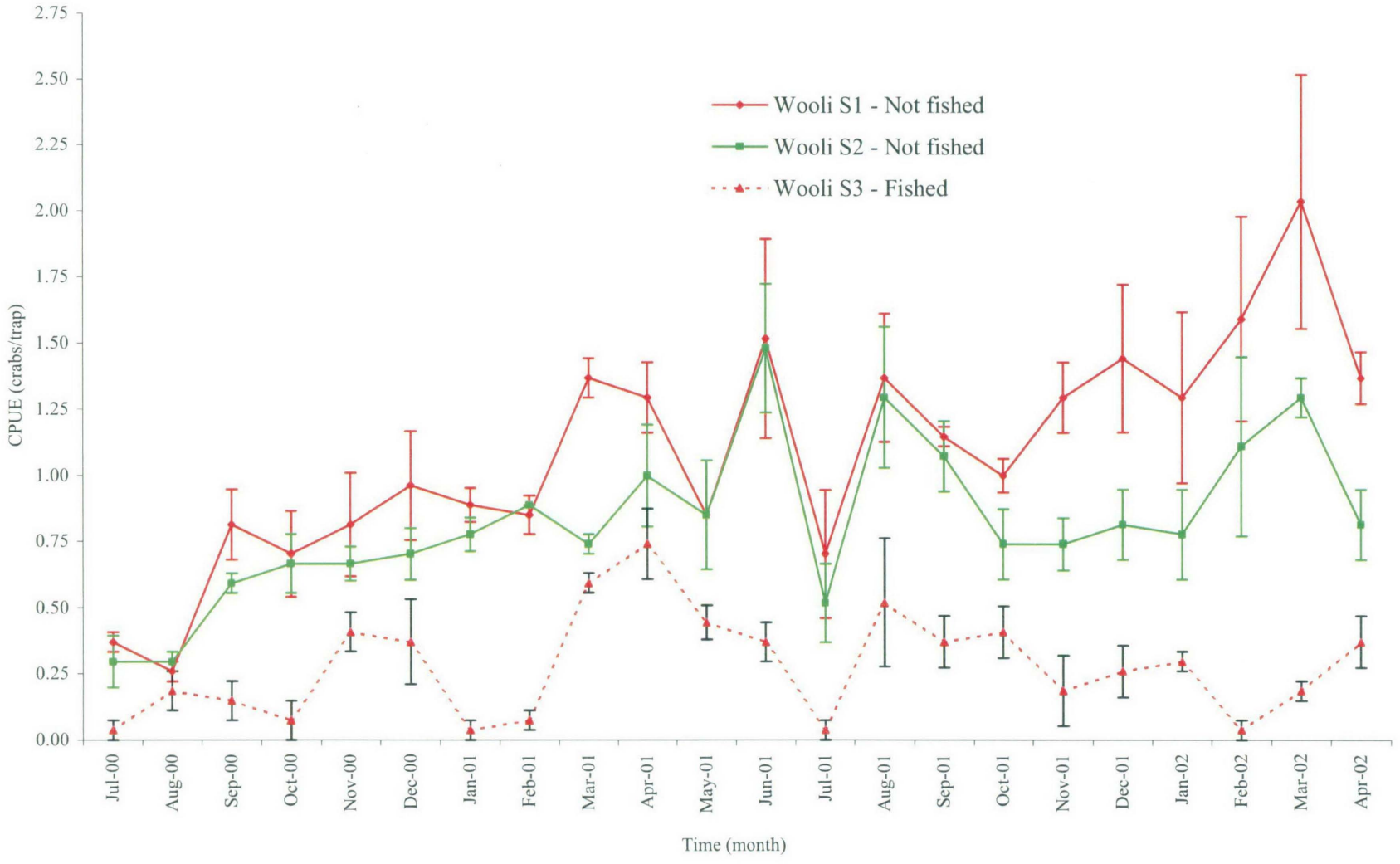


**Figure 4.5.** Temporal and spatial variation in mean (± SE) catch per unit effort (CPUE) of crabs in fished and unfished sites in the Wooli Estuary between July 2000 and April 2002.

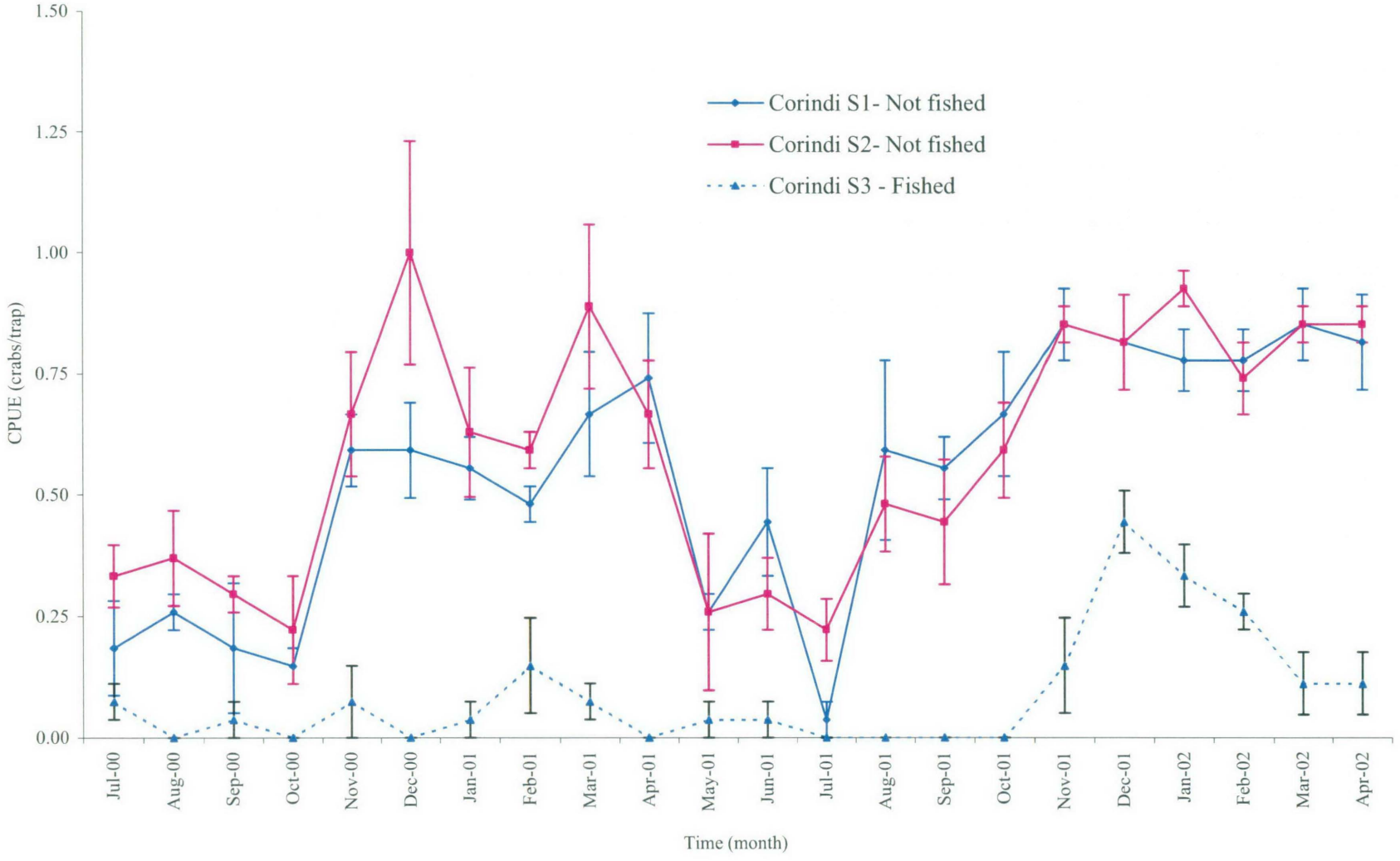


**Figure 4.6.** Temporal and spatial variation in mean (± SE) CPUE of crabs in fished and unfished sites in the Corindi Estuary between July 2000 and April 2002.

**Table 4.8**. Summary of ANOVA of mean differences in crab abundance between Fished (F) v Unfished (U) sites in the Wooli and Corindi estuaries over 21 months between July 2000 and April 2002. Where the F-ratio was non-significant (plain text) at p = 0.25, the sums of squares and DF were pooled (pld) with the residual otherwise it was deemed as not significant (ns) at p = 0.05.

| | DF | SS | MS | F-ratio | P |
|---|---|---|---|---|---|
| **Fished v Unfished – FvU** | **1** | **135.86** | **135.86** | - | |
| **Estuary - E** | **1** | **37.22** | **37.23** | - | |
| **E x FvU** | **1** | **0.19** | **0.19** | - | |
| **Sites (ExU) - S(U)** | **2** | **3.20** | **1.60** | **1.69** | **ns** |
| **Areas (S(ExU)) - A(S(U))** | **8** | **7.56** | **0.94** | **5.41** | **0.0000** |
| **Area (ExF) - A(F)** | **4** | **2.12** | **0.53** | **3.03** | **0.0167** |
| **Month - M** | **21** | **54.46** | **2.59** | **3.65** | **0.0000** |
| **FvU x M** | **21** | **10.78** | **0.51** | **0.95** | **ns** |
| **E x M** | **21** | **14.91** | **0.71** | **4.06** | **0.0000** |
| **FvU x E x M** | **21** | **11.37** | **0.54** | **3.10** | **0.0000** |
| S(U) x M | 42 | 5.49 | 0.13 | pld | |
| A(S(U)) x M | 168 | 24.32 | 0.14 | pld | |
| A(F) x M | 84 | 8.78 | 0.10 | pld | |
| **Residual** | 792 | 151.31 | 0.1911 | | |
| | **1086(pld)** | **189.90(pld)** | **0.1749 (pld)** | | |
| **Total** | **1187** | | | | |

**Table 4.9.** Comparison of F-ratios comparing monthly abundances between 'unfished (U)' (Site 1 and Site 2) and 'fished (F)' (Site 3) sites in the Wooli and Corindi Estuaries. Tukey's comparison of means tests were conducted when F-ratios were significant.

| Wooli | Source of variation | | | | *Post hoc* test – Tukey's | | |
|---|---|---|---|---|---|---|---|
| | DF | MS | F-ratio | P | S1 – U | S2-U | S3 - F |
| July 00 | 2,18 | 0.97 | 8.40 | 0.0182 | **A** | **A** | **B** |
| Aug 00 | 2,18 | 0.09 | 1.00 | 0.4220 | - | - | - |
| Sept 00 | 2,18 | 1.97 | 13.25 | 0.0063 | **A** | **A** | **B** |
| Oct 00 | 2,18 | 2.34 | 10.96 | 0.0099 | **A** | **A** | **B** |
| Nov 00 | 2,18 | 0.51 | 3.42 | 0.1021 | - | - | - |
| Dec 00 | 2,18 | 1.17 | 5.48 | 0.0442 | **A** | **AB** | **B** |
| Jan 01 | 2,18 | 3.95 | 108.54 | 0.0001 | **A** | **A** | **B** |
| Feb 01 | 2,18 | 3.54 | 101.19 | 0.0001 | **A** | **A** | **B** |
| Mar 01 | 2,18 | 0.87 | 61.67 | 0.0001 | **A** | **B** | **B** |
| Apr 01 | 2,18 | 0.64 | 6.64 | 0.0301 | **A** | **AB** | **B** |
| May 01 | 2,24 | 0.35 | 1.60 | 0.2221 | - | - | - |
| June 01 | 2,18 | 2.23 | 6.27 | 0.0339 | **A** | **A** | **B** |
| July 01 | 2,18 | 2.05 | 5.14 | 0.0500 | **A** | **A** | **B** |
| Aug 01 | 2,18 | 1.60 | 4.27 | 0.0701 | **A** | **A** | **B** |
| Sept 01 | 2,18 | 1.89 | 17.31 | 0.0032 | **A** | **A** | **B** |
| Oct 01 | 2,18 | 0.78 | 5.29 | 0.0473 | **A** | **AB** | **B** |
| Nov 01 | 2,18 | 2.91 | 9.75 | 0.0130 | **A** | **B** | **C** |
| Dec 01 | 2,18 | 2.83 | 13.29 | 0.0062 | **A** | **B** | **C** |
| Jan 02 | 2,18 | 1.94 | 7.34 | 0.0244 | **A** | **A** | **B** |
| Feb 02 | 2,18 | 5.57 | 12.04 | 0.0079 | **A** | **A** | **B** |
| Mar 02 | 2,18 | 5.79 | 35.28 | 0.0004 | **A** | **A** | **B** |
| Apr 02 | 2,18 | 1.89 | 13.35 | 0.0062 | **A** | **A** | **B** |
| **Corindi** | **Source of variation** | | | | ***Post hoc* test – Tukey's** | | |
| | **DF** | **MS** | **F-ratio** | **P** | **S1 – U** | **S2-U** | **S3 - F** |
| July 00 | 2,18 | 0.41 | 3.22 | 0.1120 | - | - | - |
| Aug 00 | 2,18 | 0.97 | 10.51 | 0.0109 | **A** | **A** | **B** |
| Sept 00 | 2,24 | 0.44 | 2.31 | 0.1213 | - | - | - |
| Oct 00 | 2,24 | 0.43 | 3.48 | 0.0470 | **AB** | **A** | **B** |
| Nov 00 | 2,18 | 2.05 | 10.88 | 0.0101 | **A** | **A** | **B** |
| Dec 00 | 2,18 | 4.08 | 39.45 | 0.0004 | **A** | **A** | **B** |
| Jan 01 | 2,18 | 2.41 | 33.10 | 0.0006 | **A** | **A** | **B** |
| Feb 01 | 2,18 | 1.19 | 11.48 | 0.0089 | **AB** | **A** | **B** |
| Mar 01 | 2,18 | 2.89 | 18.86 | 0.0026 | **A** | **A** | **B** |
| Apr 01 | 2,18 | 3.49 | 30.91 | 0.0007 | **A** | **A** | **B** |
| May 01 | 2,24 | 0.47 | 2.74 | 0.0847 | - | - | - |
| June 01 | 2,18 | 1.17 | 7.53 | 0.0231 | **A** | **A** | **B** |
| July 01 | 2,18 | 0.55 | 7.75 | 0.0217 | **B** | **A** | **B** |
| Aug 01 | 2,18 | 2.30 | 8.17 | 0.0194 | **A** | **A** | **B** |
| Sept 01 | 2,18 | 2.03 | 16.01 | 0.0039 | **A** | **A** | **B** |
| Oct 01 | 2,18 | 3.14 | 39.06 | 0.0004 | **A** | **A** | **B** |
| Nov 01 | 2,18 | 2.79 | 26.62 | 0.0010 | **A** | **A** | **B** |
| Dec 01 | 2,24 | 0.54 | 2.80 | 0.0806 | - | - | - |
| Jan 02 | 2,18 | 1.30 | 23.66 | 0.0014 | **A** | **A** | **B** |
| Feb 02 | 2,18 | 1.14 | 16.06 | 0.0039 | **A** | **A** | **B** |
| Mar 02 | 2,18 | 3.06 | 45.26 | 0.0002 | **A** | **A** | **B** |
| Apr 02 | 2,18 | 2.97 | 37.73 | 0.0004 | **A** | **A** | **B** |

**Size class**

Size class distributions did not differ between fished and unfished areas within estuaries (Figure 4.7). Between estuaries, Site 1 (U) at Wooli was significantly different (with a higher proportion of 135 - 155 mm crabs) from the unfished Site 2 at Corindi which was dominated by 125 mm crabs (KS = 0.21, P = 0.025) (Table 4.10).

As distributions among sites were similar, the mean abundance of crabs in each size class would indicate where differences occur between sites. The majority of crabs at all sites were caught in the 125 mm and 135 mm size classes (Figure 4.8). At Wooli, large numbers of crabs were caught at the unfished Site 1 and Site 2 between the 125 - 155 mm size class. The fished Site 3 was dominated by 115 - 135 mm crabs. At Corindi, catches were dominated by 125 - 135 mm crabs in the unfished sites while the fished Site 3 had only few crabs in all size classes but most in the 125 mm category. ANOVA was used to compare each size class between sites within each estuary in the range from 105 - 175 mm only because of the small captures in size classes outside these (Table 4.11). At Wooli, at least one of the two unfished sites had significantly more crabs than the fished sites in each size class category between 115 - 155 mm and 175 mm. The 165 mm category was the only size class where there was no difference between any site. At Wooli, differences occurred between Sanctuary Zone sites in the 115 mm size class where Site 1 supported significantly more crabs than Site 2 (U) and Site 3 (F). Differences also occurred in the 155 mm size class, where the unfished Site 1 had significantly more crabs than the unfished Site 2, which was also greater than the fished Site 3. In all analyses where there was a difference at Corindi (115 - 155 mm), the two Sanctuary Zone sites had more crabs than the fished site while there was no difference among sites in the 165 - 175 mm categories (Table 4.11)

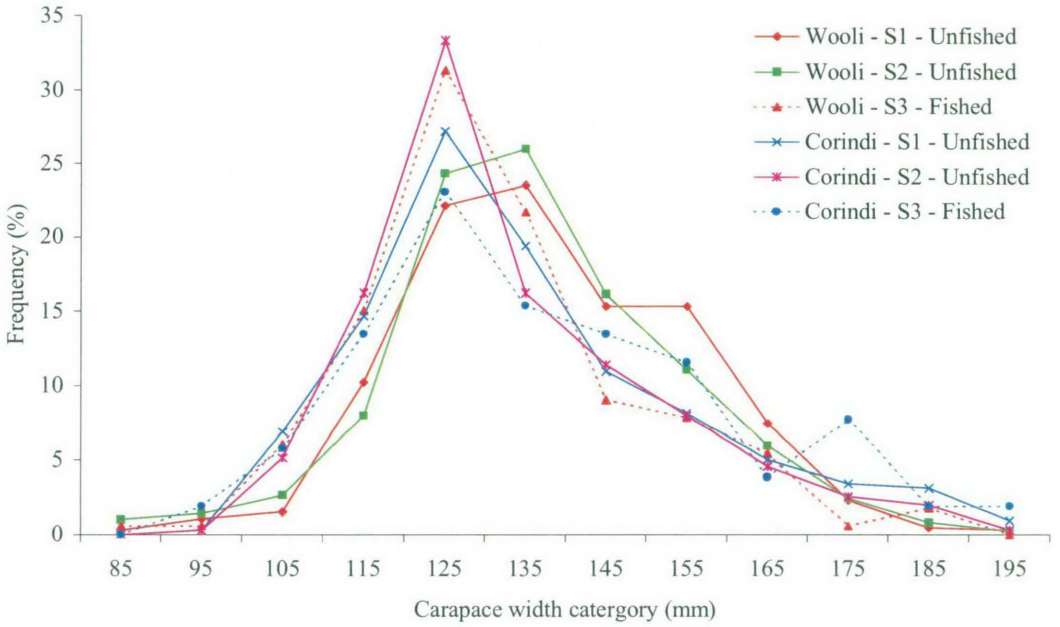


**Figure 4.7** Proportional distributions of size classes for mud crabs tagged at Wooli (Site 1 – Unfished (n = 647), Site 2 – Unfished (n = 490) and Site 3 - Fished (n = 166)) and Corindi (Site 1 - Unfished (n = 320), Site 2 – Unfished (n = 351) and Site 3 - Fished (n = 52)) estuaries between July 2000 and April 2002.

**Table 4.10.** Probability values using the Kolmogorov-Smirnov goodness of fit test comparing width cohorts for mud crabs at each site within and between estuaries. Bracketed numbers are the number of crabs used in the analysis for each site.

| | Site | | | | | |
|---|---|---|---|---|---|---|
| **Site** | **1** | **2** | **3** | **4** | **5** | **6** |
| **1 -Site 1 - Wooli (U) (647)** | | 1.000 | 0.056 | 0.303 | **0.025** | 0.815 |
| **2- Site 2 - Wooli (U) (490)** | | | 0.111 | 0.486 | 0.053 | 0.981 |
| **3- Site 3 - Wooli (F) (166)** | | | | 1.000 | 1.000 | 0.206 |
| **4- Site 1 - Corindi (U) (320)** | | | | | 1.000 | 1.000 |
| **5- Site 2 - Corindi (U) (351)** | | | | | | 0.472 |
| **6- Site 3 - Corindi (F) (52)** | | | | | | |

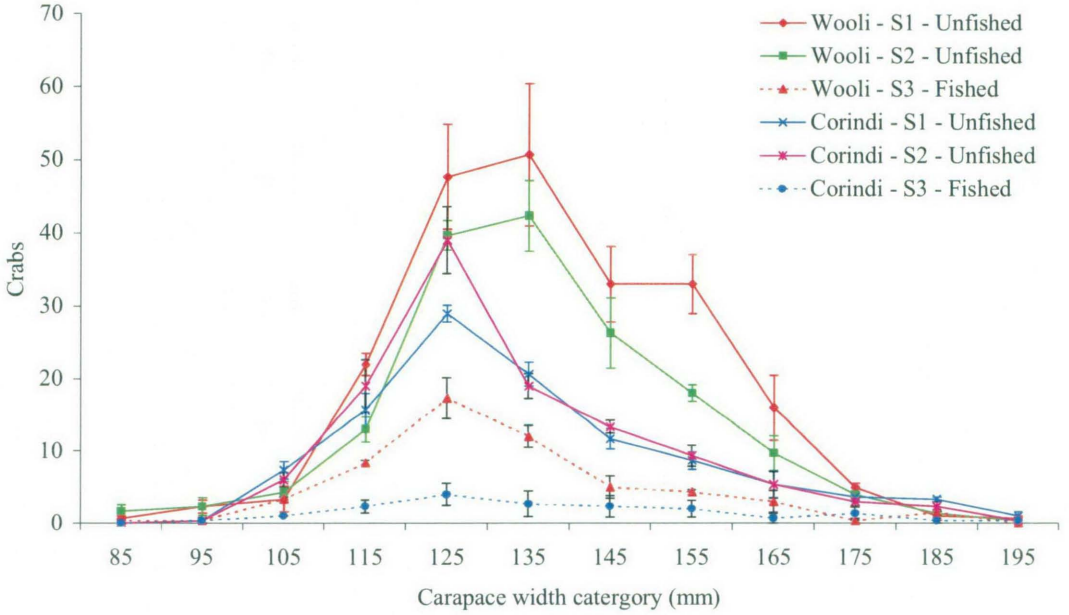


**Figure 4.8**. Mean abundance (±SE) by size class for crabs tagged at Wooli (Site 1 - Unfished (n = 647), Site 2 - Unfished (n = 490) and Site 3 - Fished (n = 166)) and Corindi (Site 1 - Unfished (n = 320), Site 2 - Unfished (n = 351) and Site 3 - Fished (n = 52)) estuaries between July 2000 and April 2002.

**Table 4.11.** ANOVA comparison of differences in the mean number of crabs in each size class between sites. Totals are pooled totals of crabs caught between July 2000 and April 2002. Tukey's comparison of means tests were conducted when F-ratios were significant.

| Size class (mm) | Estuary | Source of variation | | | | *Post hoc* test – Tukey's | | |
|---|---|---|---|---|---|---|---|---|
| | | DF | MS | F-ratio | P | Site 1 *'U'* | Site2 *'U'* | Site 3 *'F'* |
| 105 | Wooli | 2,8 | 1.00 | 0.19 | 0.8337 | --- | --- | --- |
| | Corindi | 2,8 | 33.44 | 13.68 | 0.0058 | A | A | B |
| 115 | Wooli | 2,8 | 144.78 | 26.59 | 0.0010 | A | B | B |
| | Corindi | 2,8 | 233.33 | 12.14 | 0.0078 | A | A | B |
| 125 | Wooli | 2,8 | 741.44 | 11.77 | 0.0084 | A | A | B |
| | Corindi | 2,8 | 975.00 | 39.53 | 0.0004 | A | A | B |
| 135 | Wooli | 2,8 | 1242.33 | 10.36 | 0.0113 | A | A | B |
| | Corindi | 2,8 | 296.78 | 33.39 | 0.0006 | A | A | B |
| 145 | Wooli | 2,8 | 641.78 | 12.16 | 0.0077 | A | A | B |
| | Corindi | 2,8 | 105.44 | 21.09 | 0.0019 | A | A | B |
| 155 | Wooli | 2,8 | 616.78 | 35.36 | 0.0005 | A | B | C |
| | Corindi | 2,8 | 49.33 | 10.09 | 0.0120 | A | A | B |
| 165 | Wooli | 2,8 | 126.78 | 4.46 | 0.0651 | --- | --- | --- |
| | Corindi | 2,8 | 21.78 | 3.11 | 0.1183 | --- | --- | --- |
| 175 | Wooli | 2,8 | 18.11 | 40.75 | 0.0003 | A | A | B |
| | Corindi | 2,8 | 4.33 | 2.79 | 0.1394 | --- | --- | --- |

### 4.3.2 Opening areas to "fishing" in the Wooli and Corindi estuaries

**Abundance**

A total of 2706 crabs was caught between December 1998 and July 2002 at Wooli prior to the zoning change (Figures 4.9 and Figure 4.11). Site 1 (UU) and Site 3 (FF) were sampled between December 1998 and July 2002 (n = 1134 trapping nights) while Site 2 (U) was split three months before the zoning change (n = 1053 trapping nights) to form Site 4 (UF) and Site 5 (UU) (Figure 4.9). These months were not included in analysis of totals as only 43 (Site 4) and 39 (Site 5) crabs were caught over the three months. Significantly more crabs were caught per unit effort in the Sanctuary Zone sites (Site 1 – 1281 crabs and Site 2 – 937 crabs) than the fished Recreation Zone (Site 3 – 406) ($F_{2,6}$ = 41.43, P = 0.0003) (Figure 4.9). After the zoning change, 655 crabs were caught between August 2002 and August 2003 (n = 351 trapping nights). There were significantly more crabs caught in the Sanctuary Zone Site 1 (319 crabs) than Site 5 (179 crabs) but both of these sites yielded more crabs than the now fished Site 4 (57 crabs) and the control fished Site 3 (100 crabs) ($F_{2,8}$ = 58.93 , P = 0.0000) (Figure 4.9).

At Corindi, 798 crabs were caught between July 2000 and July 2002 prior to the zoning change (Figures 4.10 and 4.12). The mean number of crabs captured was significantly higher in the Sanctuary Zone sites (Site 1 (UF) – 354 crabs and Site 2 (UU) – 386 crabs) than the fished Recreation Zone (Site 3 (FF) – 58 crabs) ($F_{2,8}$ = 63.12 , P = 0.0001) (Figure 4.10) prior to the zoning change. After the zoning change, a total of 420 crabs was captured. The Sanctuary Zone Site 2 (UU) (227 crabs) yielded significantly more crabs than the now fished Site 1 (UF) (117 crabs), which was opened to fishing, and control Site 3 (FF) (76 crabs) ($F_{2,8}$ = 24.98, P = 0.0012) (Figure 4.10). Site 1 had been opened to fishing after previous protection prior to the zoning change.

Both Site 2 (Site 4) (Wooli) and Site 1 (Corindi) were opened to fishing during the zoning change. Prior to the change, there was no difference in yield between unfished sites while they were both significantly larger in crab numbers than the fished Site 3. After the zoning change both Site 4 and Site 1 yielded fewer crabs than the Sanctuary Zone sites but numbers were not different to the fished Site 3 in their respective estuaries (Figures 4.9 and 4.10).

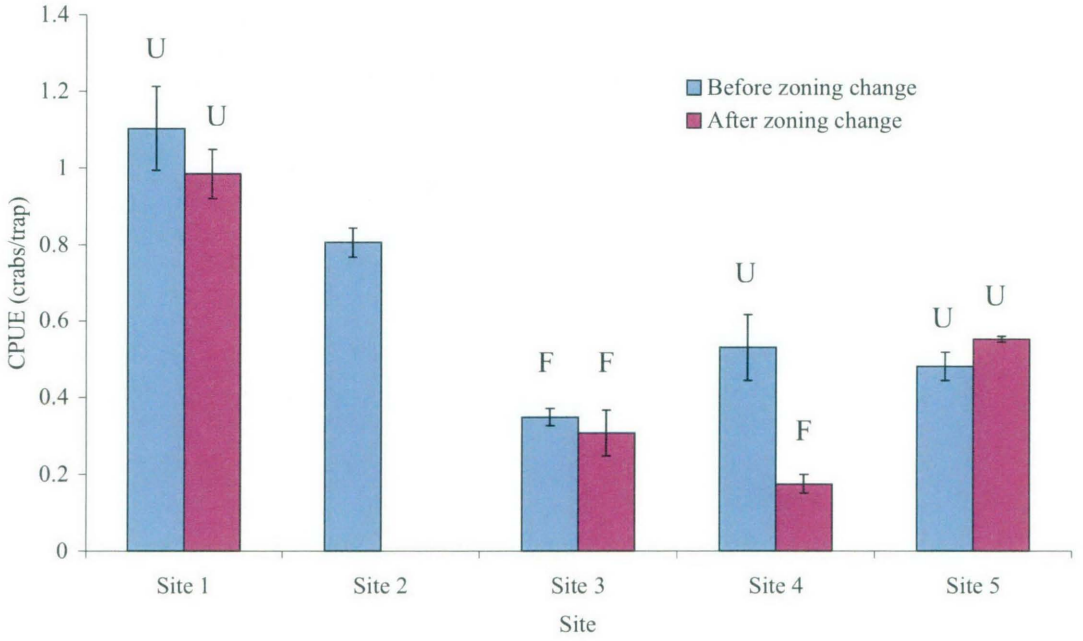


**Figure 4.9.** Average CPUE of crabs (± SE) caught in 'unfished' (U) and 'fished' (F) sites in the Wooli Estuary 'before' (December 1998 – July 2002 (Site 1 and 3), December 1998 – April 2002 (Site 2), May 2002 – July 2002 (Site 4 and 5)) and 'after' (August 2002 – August 2003) the change in zoning scheme. Note, site 2 became sites 4 and 5.

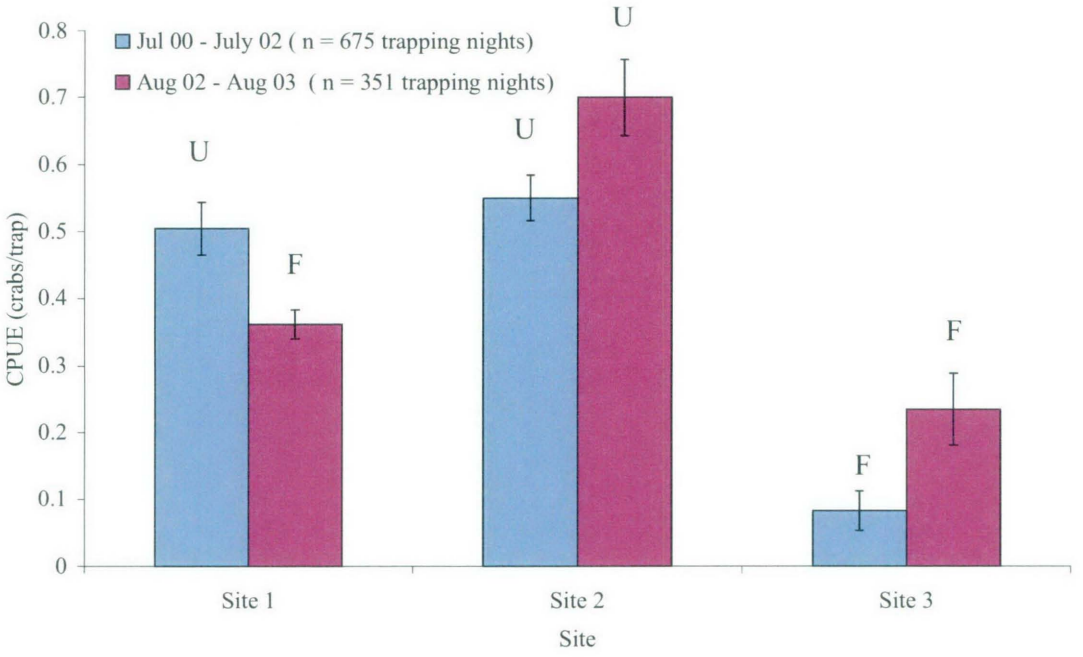


**Figure. 4.10**. Average CPUE of crabs (± SE) caught in 'unfished' (U) and 'fished' (F) sites in the Corindi Estuary 'before' (July 2000 - July 2002) and 'after' (August 2002 - August 2003) the change in zoning schemes.

The BACI analysis comparing the three months before against 13 months after the change found no detectable change comparing Site 4 (UF) against the other control fished (Site 3 - FF) and unfished sites (Site 1 - UU and Site 5 - UU) (Table 4.12). However, the repartitioned variances revealed changes between treatments among times before and after the zoning change. There were no significant differences in the trends between treatments before the change with all treatments having similar temporal variation. After the zoning change there was a significant difference among treatments (Table 4.12; Figure 4.11). This occurred between Site 4 (UF), which had been opened to fishing, and the two unfished sites (UU) ($P < 0.005$).

Analysis of individual months illustrated finer scale changes to CPUE (Figure 4.11, Table 4.14). In the Wooli Estuary prior to the zoning change, a total of 42 months were sampled. In 33 months, at least one of the two Sanctuary Zone sites yielded significantly greater catches than the fished site. In 22 of these months the two Sanctuary Zone sites were not different to each other but significantly different to the fished site, on 3 occasions there was significantly more crabs in the unfished sites than the fished sites but significantly more crabs in one of the unfished sites than the other while on 8 occasions at least one of the Sanctuary Zone sites was significantly different to the fished site. After the zoning change at Wooli, it was expected that this relationship would change because a previously protected site was reopened to fishing so it may take some time for this site to become fished down (Figure 4.11, Table 4.14). This did not occur and catches from the previously unfished site at Wooli (Site 4) quickly resembled those taken in the fished zone (Site 3) suggesting crabs were fished down within months of reopening that site. At Wooli the numbers of crabs at the newly opened Site 4 were the same as the fished site in all months after the change and had the lowest CPUE in 9 of the 13 months following the opening of the area to fishing.

At Corindi, the BACI analysis also showed no significant differences in trends after the impact occurred even though 25 months of before data were used in contrast to three for Wooli (Figure 4.11, Table 4.13). The repartitioned variance before and after the zoning change showed that prior to the zoning change, there was no difference between the two unfished (Site 1 - UF v Site 2 - UU) sites while there was a significant difference in the

trends of the Site 1 (UF) v Site 3 (FF), primarily because one site was unfished and there were few crabs caught in the control fished site during any month. After the change, while Site 1 (UF) contained fewer crabs than Site 2 (UU) it showed the same trend as the other treatments in each month. As the test used detects gradual changes in trends once the perturbation occurs, immediate changes in the catch after the impact would result in no detectable change between treatment trends (Underwood 1991). As Site 1 was opened to fishing in August 2002, it already yielded catches similar to the control fished Site 3, by the first sampling period in late August. As the change was immediate, it is impossible to detect the change in trends as all sites showed similar trend patterns even though the number of crabs was smaller now at the fished Site 1. The flood in February 2002 also masked any effect as all treatments behaved similarly each month once the estuary was in flood.

For 21 of the 25 months before the zoning changes at Corindi, the unfished sites yielded significantly more crabs than the fished site (Figure 4.12, Table 4.14). On 17 occasions, both unfished sites were different to the fished Site 3, in 3 months there was at least one Sanctuary Zone site different to the fished Site 3, and on one occasion there was a difference among all three sites.

At Corindi, the same trend occurred as at Wooli in the first 6 months following the opening of an unfished zone to fishing (Figure 4.12, Table 4.14). The previously protected Site 1 (UF) quickly resembled catches in the fished Site 3. In this 6 months, Site 1 was already significantly different to the unfished Site 2 one month after the zoning change and it was only in two months in the next 6 where there was no difference between the sites. Between February and August 2003, June was the only month where there was a difference in catch among sites. This period coincided with a major flooding event in the estuary and low salinity concentrations (Appendix 8).

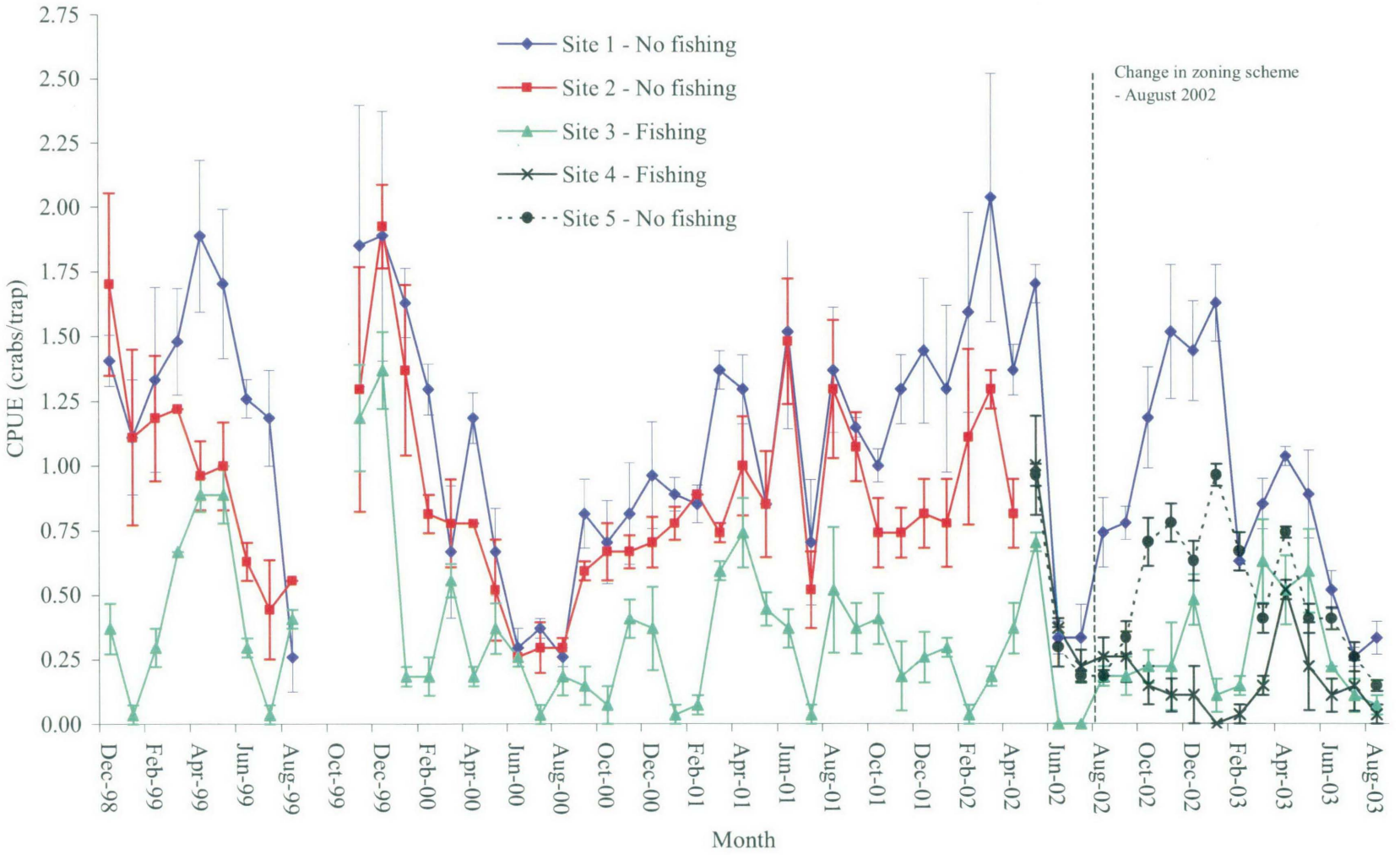


**Figure 4.11.** Temporal variation in mean (±SE) CPUE of mud crabs captured at each site in the Wooli Estuary 'before' and 'after' the zoning change in August 2002. *note:* Site 2 was split during August 2002 zoning change to form Site 4 (fished) and 5 (unfished) post zoning. Missing values in September and October 1999 indicate periods where no sampling was undertaken.

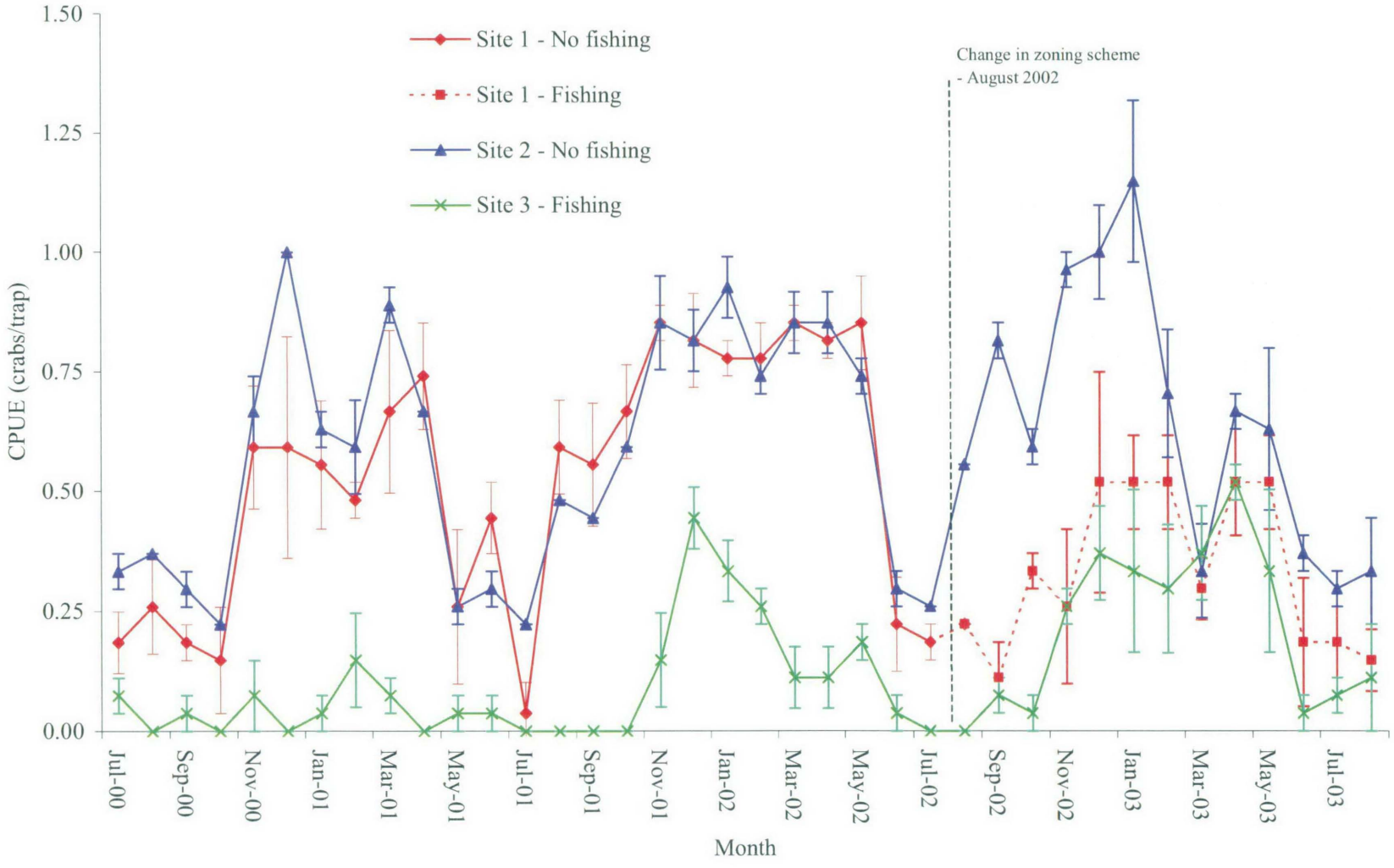


**Figure 4.12**. Temporal variation in mean (±SE) CPUE of mud crabs captured at each site in the Corindi Estuary 'before' and 'after' the zoning change in August 2002

**Table 4.12.** Summary of results of BACI ANOVA: replicated before/after sampling at four locations (three treatments), comparing the catches from three treatments (2 x UU, FF and UF) sampled before and after changes in zoning scheme at Wooli. (pld) indicates that the F-ratio was non significant at P<0.25, and the sums of squares and DF were pooled with the residual. (-) = incalculable F-ratio.

| Source of variation | DF | SS | MS | F-ratio | Sig. |
|---|---|---|---|---|---|
| **BvA** | **1** | **0.09** | **0.09** | - | |
| **Treatments** | **2** | **17.54** | **8.77** | - | |
| **BvA x Treatments** | **2** | **6.60** | **3.30** | - | |
| **Month (BvA)** | **14** | **44.72** | **3.19** | **14.81** | **<0.001** |
| **Month (BvA) x Treatments** | **28** | **17.61** | **0.63** | **0.50** | **ns** |
| ***Month (B) x Treatments** | **4** | **0.52** | **0.13** | **0.60** | **ns** |
| ***Month (B) x UFvUU** [1] | **2** | **0.43** | **0.22** | **1.01** | **ns** |
| ***Month (B) x UFvFF** [2] | **2** | **0.39** | **0.19** | **0.90** | **ns** |
| ***Month (A) x Treatments** | **24** | **17.09** | **0.71** | **3.30** | **<0.05** |
| ***Month (A) x UFvUU** [3] | **12** | **11.75** | **0.98** | **4.54** | **<0.05** |
| ***Month (A) x UFvFF** [4] | **12** | **3.20** | **0.27** | **1.24** | **ns** |
| **Area (U)** | **1** | **4.55** | **4.55** | - | |
| **Area (U) x BvA** | **1** | **0.13** | **0.13** | **0.60** | **ns** |
| **Area (U) x Month (BvA)** | 14 | **3.02** | **0.21** | **1.26** | **ns** |
| Site (A(U)) | 4 | 0.21 | 0.05 | 0.30 | **pld** |
| Site (A(U)) x BvA | 4 | 0.61 | 0.15 | 0.88 | **pld** |
| Site (A(U)) x Month (BvA) | 56 | 6.52 | 0.12 | 0.63 | **pld** |
| Site (F) | 2 | 0.28 | 0.14 | 0.80 | **pld** |
| Site (F) x BvA | 2 | 0.18 | 0.09 | 0.53 | **pld** |
| Site (F) x Month (BvA) | 28 | 3.58 | 0.13 | 0.69 | **pld** |
| **Site (UF)** | **2** | **0.69** | **0.35** | **2.01** | **ns** |
| Site (UF) x BvA | 2 | 0.17 | 0.08 | 0.48 | **pld** |
| Site (UF) x Month (BvA) | 28 | 4.58 | 0.16 | 0.88 | **pld** |
| **Residual** | 384 | 71.13 | 0.18 | | |
| | **510 (pld)** | **87.25 (pld)** | **0.17 (pld)** | | |
| **Total** | **575** | **182.22** | | | |

**F-ratios of interest**

| | F ratio | Significance | Critical values |
|---|---|---|---|
| **Month (B) x UFvUU / Month (A) x UFvUU** $= {}^{3}/_{1}$: | 4.5111 | Not Significant | (12,2) DF two-tailed = 39.4 |
| **Month (B) x UFvFF / Month (A) x UFvFF** $= {}^{4}/_{2}$: | 1.375 | Not Significant | (12,2) DF two-tailed = 39.4 |

* Repartitioned sources of variation

**Table 4.13.** Summary of results of BACI ANOVA: replicated before/after sampling at three locations comparing the catches from three treatments (UU, FF and UF) sampled before and after changes in zoning scheme at Corindi. (pld) indicates that the F ratio was non significant at P<0.25, and the sums of squares and DF were pooled with the residual. (-) = incalculable F-ratio.

| Source of variation | DF | SS | MS | F-ratio | Sig. |
|---|---|---|---|---|---|
| **BvA** | **1** | **0.09** | **0.09** | **0.05** | **0.8159** |
| **Treatments** | **2** | **60.41** | **30.21** | **-** | |
| **BvA x Treatments** | **2** | **8.32** | **4.16** | **15.25** | **<0.0001** |
| **Month (BvA)** | **36** | **60.23** | **1.67** | **8.17** | **<0.0001** |
| **Month (BvA) x Treatments** | **72** | **19.64** | **0.27** | **1.51** | **0.0048** |
| ***Month (B) x Treatments** | **48** | **13.104** | **0.27** | **1.56** | **<0.05** |
| ***Month (B) x UFvUU** [1] | **24** | **2.90** | **0.12** | **0.69** | **ns** |
| ***Month (B) x UFvFF** [2] | **24** | **9.97** | **0.41** | **2.37** | **<0.0005** |
| ***Month (A) x Treatments** | **24** | **6.54** | **0.27** | **1.55** | **<0.05** |
| ***Month (A) x UFvUU** [3] | **12** | **3.53** | **0.29** | **1.68** | **ns** |
| ***Month (A) x UFvFF** [4] | **12** | **1.70** | **0.14** | **0.81** | **ns** |
| **Sites(Treatments)** | **6** | **9.64** | **1.61** | **9.17** | **<0.0001** |
| Sites(Treatments) x BvA | 6 | 0.53 | 0.09 | pld | |
| Sites(Treatments) x Months(BvA) | 216 | 21.58 | 0.10 | pld | |
| **Residual** | 684 | 136.61 | 0.1997 | | |
| | **906(pld)** | **158.71(pld)** | **0.1752(pld)** | | |
| **Total** | **1025** | **317.04** | | | |

**F-ratios of interest**

| | F ratio | Significance | Critical values |
|---|---|---|---|
| Month (B) x UFvU / Month (A) x UFvUU $= {}^{3}/_{1}$: | 2.4372 | Not Significant | (12,2) DF two-tailed = 2.54 |
| Month (B) x UFvF / Month (A) x UFvFF $= {}^{4}/_{2}$: | 0.3412 | Not Significant | (12,2) DF two-tailed = 2.54 |

* Repartitioned sources of variation

**Table 4.14**. Comparison of F-ratios comparing monthly abundances between 'unfished' (Site 1 and Site 2) and 'fished' sites (Site 3) in the Wooli Estuary. Tukey's comparison of means tests were conducted when F-ratios were significant.

| **Before** | **Source of variation** | | | | ***Post hoc* test – Tukey's** | | |
|---|---|---|---|---|---|---|---|
| | **DF** | **MS** | **F-ratio** | **P** | **S1 - U** | **S2 - U** | **S3 - F** |
| Dec-98 | 2,18 | 3.16 | 13.58 | 0.0059 | **A** | **A** | **B** |
| Jan-99 | 2,18 | 4.77 | 12.68 | 0.007 | **A** | **A** | **B** |
| Feb-99 | 2,18 | 2.62 | 10.33 | 0.0114 | **A** | **A** | **B** |
| Mar-99 | 2,18 | 0.96 | 20.32 | 0.0021 | **A** | **A** | **B** |
| Apr-99 | 2,18 | 0.87 | 9.42 | 0.0141 | **A** | **B** | **B** |
| May-99 | 2,24 | 0.65 | 4.64 | 0.0198 | **A** | **AB** | **B** |
| Jun-99 | 2,18 | 1.86 | 45.33 | 0.0002 | **A** | **B** | **B** |
| Jul-99 | 2,18 | 4.47 | 16.31 | 0.0038 | **A** | **B** | **C** |
| Aug-99 | 2,18 | 0.60 | 3.51 | 0.0977 | - | - | - |
| Sep-99 | | no | sample | | | | |
| Oct-99 | | no | sample | | | | |
| Nov-99 | 2,18 | 0.31 | 0.55 | 0.6032 | - | - | - |
| Dec-99 | 2,18 | 0.23 | 0.98 | 0.4288 | - | - | - |
| Jan-00 | 2,18 | 5.17 | 42.09 | 0.0003 | **A** | **A** | **B** |
| Feb-00 | 2,18 | 3.38 | 24.06 | 0.0014 | **A** | **A** | **B** |
| Mar-00 | 2,18 | 0.11 | 0.29 | 0.7541 | - | - | - |
| Apr-00 | 2,18 | 2.91 | 111.57 | 0.0001 | **A** | **A** | **B** |
| May-00 | 2,18 | 0.32 | 0.99 | 0.4235 | - | - | - |
| Jun-00 | 2,18 | 0.03 | 0.50 | 0.6312 | - | - | - |
| ***July 00 to Apr 02*** | ▲ ▼ | ***See table 4.9 for results*** | | | S2 was split into S4 and S5 in May 2002 when it was revealed that S2 would be split into different zoning schemes at the August 2002 zoning change. | | |
| | | | | | | **S4 - U** | **S5 - U** |
| May 02 | 3,24 | 0.77 | 11.023 | 0.0033 | **A** | **B** | **B** | **B** |
| June 02 | 3,24 | 0.81 | 9.8582 | 0.0046 | **A** | **A** | **A** | **B** |
| July 02 | 3,24 | 0.59 | 4.458 | 0.0404 | **A** | **A** | **A** | **B** |
| **After** | **Source of variation** | | | | | | | |
| | **DF** | **MS** | **F-ratio** | **P** | **S1 - U** | **S4 - F** | **S5 - U** | **S3 - F** |
| Aug 02 | 3,24 | 0.95 | 9.48 | 0.0052 | **A** | **B** | **B** | **B** |
| Sept 02 | 3,24 | 0.83 | 4.50 | 0.0394 | **A** | **AB** | **AB** | **B** |
| Oct 02 | 3,24 | 2.48 | 17.08 | 0.0008 | **A** | **C** | **AB** | **BC** |
| Nov 02 | 3,24 | 3.86 | 13.09 | 0.0019 | **A** | **B** | **AB** | **B** |
| Dec 02 | 3,24 | 3.08 | 14.55 | 0.0013 | **A** | **B** | **A** | **AB** |
| Jan 03 | 3,24 | 6.24 | 95.11 | 0.0001 | **A** | **B** | **A** | **B** |
| Feb 03 | 3,24 | 2.12 | 28.22 | 0.0001 | **A** | **B** | **A** | **B** |
| Mar 03 | 3,24 | 1.21 | 10.46 | 0.0038 | **A** | **B** | **AB** | **A** |
| Apr 03 | 3,24 | 0.59 | 8.98 | 0.0061 | **A** | **B** | **AB** | **B** |
| May 03 | 3,24 | 1.26 | 3.92 | 0.0543 | - | - | - | - |
| June 03 | 3,24 | 0.72 | 7.11 | 0.0121 | **A** | **B** | **A** | **AB** |
| July 03 | 3,24 | 0.20 | 1.18 | 0.3755 | - | - | - | - |
| Aug 03 | 3,24 | 0.39 | 6.45 | 0.0157 | **A** | **B** | **AB** | **B** |

**Table 4.15.** Comparison of F-ratios comparing monthly abundances between 'unfished' (Site 1 and Site 2) and 'fished' sites (Site 3) in the Corindi Estuary. Tukey's comparison of means tests were conducted when F-ratios were significant.

| **Before** | **Source of variation** | | | | ***Post hoc* test – Tukey's** | | |
|---|---|---|---|---|---|---|---|
| | **DF** | **MS** | **F-ratio** | **P** | **S1 - U** | **S2 - U** | **S3 - F** |
| ***July 00 to April 02*** | ↕ | ***See table 4.9 for results*** | | | | | |
| May 02 | 2,18 | 1.96 | 43.183 | 0.0003 | **A** | **A** | **B** |
| June 02 | 2,24 | 0.55 | 3.7777 | 0.0375 | **AB** | **A** | **B** |
| July 02 | 2,18 | 0.61 | 11.979 | 0.0080 | **A** | **A** | **B** |
| **After** | **Source of variation** | | | | | | |
| | **DF** | **MS** | **F-ratio** | **P** | **S1 - F** | **S2 - U** | **S3 - F** |
| Aug 02 | 2,18 | 1.63 | 36.98 | 0.0004 | **B** | **A** | **C** |
| Sept 02 | 2,18 | 3.22 | 38.60 | 0.0004 | **B** | **A** | **B** |
| Oct 02 | 2,18 | 1.86 | 45.43 | 0.0002 | **A** | **A** | **B** |
| Nov 02 | 2,18 | 1.92 | 20.17 | 0.0022 | **B** | **A** | **B** |
| Dec 02 | 2,24 | 0.90 | 3.89 | 0.0345 | **AB** | **A** | **B** |
| Jan 03 | 2,18 | 1.80 | 8.04 | 0.0201 | **B** | **A** | **B** |
| Feb 03 | 2,18 | 0.69 | 3.59 | 0.0943 | ---------- | ---------- | ---------- |
| Mar 03 | 2,18 | 0.00 | 0.01 | 0.9847 | ---------- | ---------- | ---------- |
| Apr 03 | 2,18 | 0.10 | 1.07 | 0.3996 | ---------- | ---------- | ---------- |
| May 03 | 2,18 | 0.41 | 1.35 | 0.3285 | ---------- | ---------- | ---------- |
| June 03 | 2,18 | 0.69 | 3.95 | 0.0329 | **AB** | **A** | **B** |
| July 03 | 2,18 | 0.36 | 3.78 | 0.0865 | ---------- | ---------- | ---------- |
| Aug 03 | 2,18 | 0.55 | 2.26 | 0.1853 | ---------- | ---------- | ---------- |

**Size Class**

The size distributions of crabs sampled from each site were similar in each estuary whether they were fished or unfished (Table 4.16). There was no difference between sites before the zoning change at Wooli (Figure 4.13, Table 4.16a) and Corindi (Figure 4.15, Table 4.16b) and after the zoning change in Corindi (Figure 4.16, Table 4.16b). The only difference between distributions occurred at Wooli (Figure 4.14) where there was a significant difference between distributions. This occurred where unfished sites were skewed to larger crabs than the fished sites. Differences occurred between Site 1 (UU) and Site 3 (FF) ($KS = 0.31$, $P < 0.001$) and Site 1 (UU) and Site 4 (UF) ($KS = 0.25$, $P = 0.004$) and between Site 5 (UU) and Site 4 (UF) ($KS = 0.20$, $P = 0.045$). The distributions between Site 5 (UU) and Site 3 (FF) were not significant ($KS = 0.19$, $P = 0.055$) but the distributions at Site 5 were skewed to larger crabs.

There were two occasions where size class distributions were significantly higher at unfished sites among times at Wooli (Table 4.16a). This occurred between the fished Site 3 before the zoning change against the unfished Site 1 (UU) after the zoning change ($KS = 0.37$, $P < 0.001$) and Site 5 (UU) after zoning change ($KS = 0.25$, $P = 0.005$). At Corindi, there was a significant difference between distributions for Site 3 (FF) after zoning changed against Site 1 (UF) before ($KS = 0.21$, $P = 0.033$) and Site 2 (UU) before ($KS = 0.24$, $P = 0.014$). Distributions at Site 3 were skewed towards larger crabs (Figure 4.15, Figure 4.16).

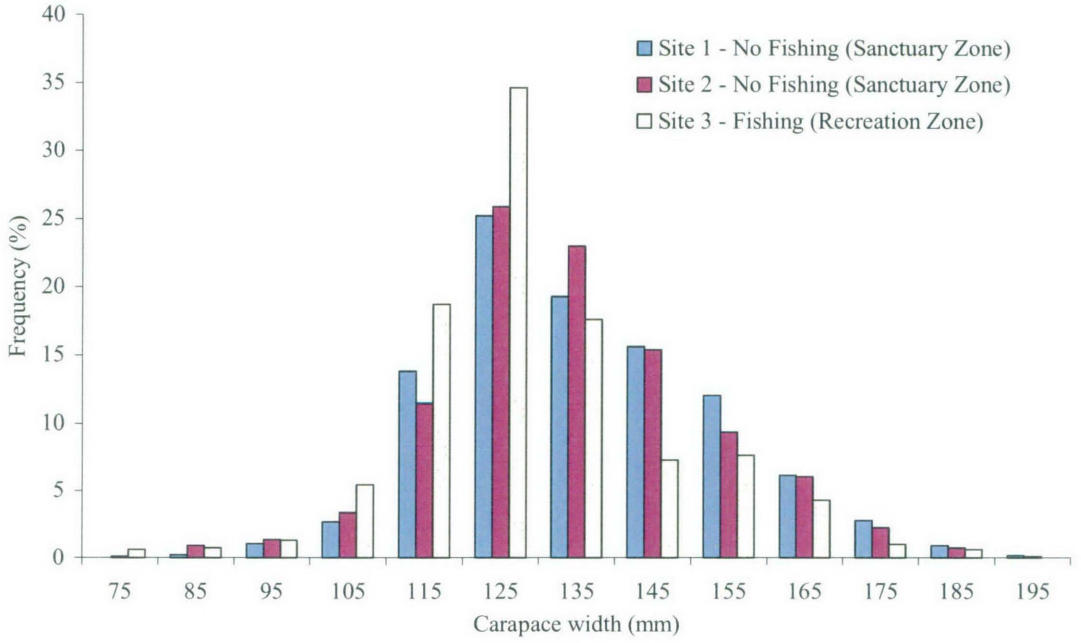


**Figure 4.13**. Size class proportion distribution for mud crabs captured at Site 1 – unfished (U) (n = 1281) or Site 2 – unfished (U) (n = 937), and Site 3 – fished (F) (n = 406) in the Wooli Estuary before the zoning change (December 1998 – April 2002).

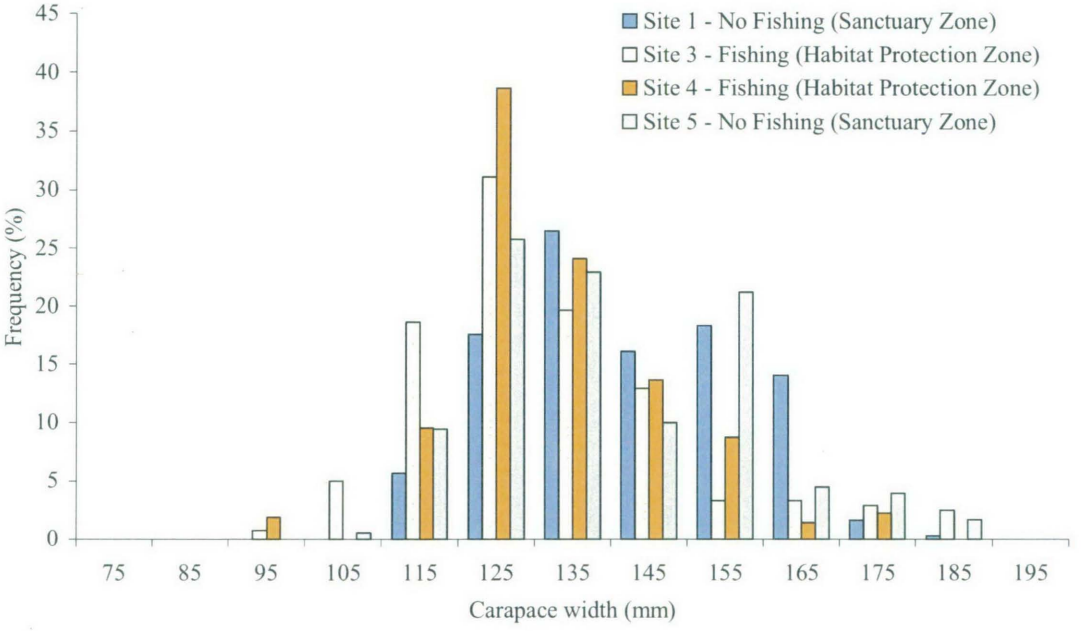


**Figure 4.14**. Size class proportion distribution for mud crabs captured at Site 1 - unfished (U) (n = 319) or Site 3 - fished (F) (n = 100), Site 4 - fished (F) (n = 57) and Site 5 - unfished (U) (n = 179) in the Wooli Estuary after the zoning change (August 2002 – August 2003).

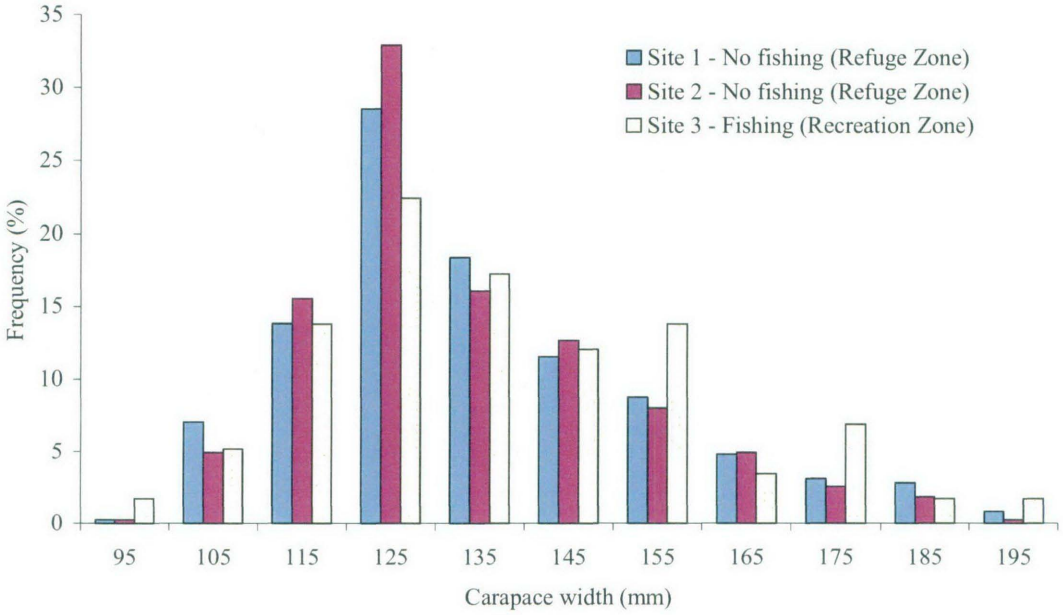


**Figure 4.15**. Size class proportion distribution for mud crabs captured at Site 1 – unfished (n = 354) or Site 2 - unfished (n = 386), and Site 3 – fished (n = 58) in the Corindi Estuary before the zoning change (July 2000- July 2002).

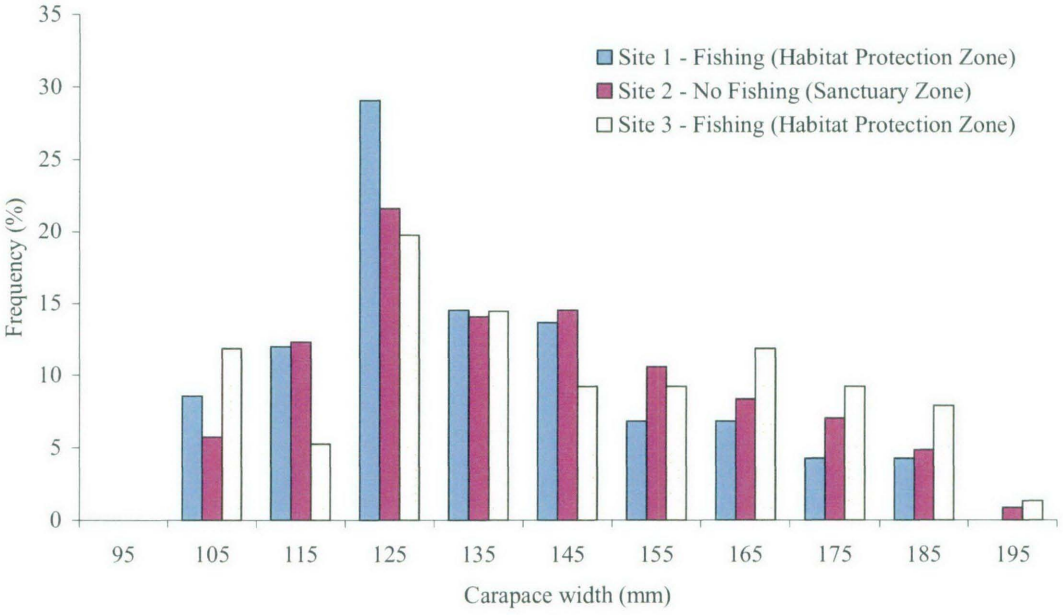


**Figure 4.16**. Size class proportion distribution for mud crabs captured at Site 1 – fished (n = 117) or Site 2 - unfished (n = 227), and Site 3 – fished (n = 76) in the Corindi Estuary after the zoning change (August 2002 – August 2003).

**Table 4.16.** Probability values using the Kolmorgorov-Smirnov goodness of fit test comparing width cohorts for mud crabs within and between treatments, before and after the change in zoning scheme in the (a) Wooli and (b) Corindi estuaries. Bracketed numbers are the number of crabs used in the analysis for each treatment.

**(a) - Wooli**

| **Treatment** | | | **Treatment** | | | |
|---|---|---|---|---|---|---|
| **(1-3 = Before, 4-7 After) – zone change** | **2** | **3** | **4** | **5** | **6** | **7** |
| **1 -Site 1 - Unfished (1281)** | 1.000 | 0.078 | 0.083 | 0.445 | 0.229 | 1.000 |
| **2- Site 2 - Unfished (935)** | | 0.078 | 0.083 | 0.652 | 0.653 | 0.463 |
| **3- Site 3 - Fished (406)** | | | **0.000** | 1.000 | 0.187 | **0.005** |
| **4- Site 1 - Unfished (319)** | | | | **0.000** | **0.004** | 0.559 |
| **5- Site 3 - Fished (100)** | | | | | 0.191 | 0.055 |
| **6- Site 4 - Fished (57)** | | | | | | **0.045** |
| **7- Site 5 - Unfished (179)** | | | | | | |

**(b) - Corindi**

| **Treatment** | | | **Treatment** | | |
|---|---|---|---|---|---|
| **(1-3 = Before, 4-6 After) – zoning change** | **2** | **3** | **4** | **5** | **6** |
| **1 -Site 1 - Unfished (354)** | 1.000 | 1.000 | 1.000 | 0.208 | **0.033** |
| **2- Site 2 - Unfished (386)** | | 0.690 | 1.000 | 0.151 | **0.014** |
| **3- Site 3 - Fished (58)** | | | 1.000 | 1.000 | 0.101 |
| **4- Site 1 - Fished (117)** | | | | 0.698 | 0.091 |
| **5- Site 2 - Unfished (227)** | | | | | 0.853 |
| **6- Site 3 - Fished (76)** | | | | | |

Prior to the zoning change, there were significantly more crabs in the size ranges from 135 – 155 mm at Wooli and 105 – 155 mm at Corindi in both unfished sites than the fished site (Figure 4.17, Figure 4.19, Table 4.17). Within the size classes of 105, 115 and 165 mm at Wooli, atleast one of the Sanctuary Zone sites had significantly more crabs than the fished site. There was no difference among sites for size classes 175 and 185 mm (Table 4.17a). At Corindi, the same trend followed where there was no difference in number of crabs in the larger size classes (165 and 175 mm) while few crabs were caught larger than 190 mm in each estuary (Table 4.17b).

After the zoning change, it was hypothesised that the newly opened sites to fishing at Wooli (Site 4) and Corindi (Site 1) would have larger crabs removed from their population leaving smaller undersized crabs (<125 mm crabs). After the zoning change at Wooli, Site 3 (fished), Site 4 (fished) and Site 5 (unfished) had similar size ranges of captures and were only

significantly different from each other in the 155 mm size class where Site 5 suggested more crabs (Figure 4.18; Table 4.17a). Site 1 (UU) had significantly more crabs in the size ranges between 135 - 165 mm while there was no difference between any sites in the size classes of 115, 125 and 175 mm. There were only few crabs above 175 mm in all sites (Table 4.17a).

At Corindi, a different trend occurred after the zoning change. Before the change, both Site 1 (UF) and Site 2 (UU) yielded similar captures of crabs in each size class but after the change the number of crabs diminished in Site 1, to levels similar to the fished Site 3 (Figure 4.20, Table 4.17b). There was no difference in captures among sites in the size classes of 105, 135, 165 - 175 mm, while in the 115 mm class the three sites were all significantly different to each other with Site 2 (UU) > Site 1 (UF) > Site 3 (FF) (Table 4.17b). In all other size classes where there was a difference (125, 145 and 155 mm), Site 2 (UU) had significantly more crabs than Site 3 in all sizes but only had more crabs than Site 1 in the 155 mm class.

These varied results suggest that previously protected crab stocks at Wooli (Site 4) and Corindi (Site 1) were depleted once fishing was permitted. These crabs were primarily in the legal size class ranges above 125 mm but also included undersize crabs in the 105 and 115 mm size categories. There may be some protection to larger size classes of crabs as there was no difference between captures in the larger size categories above 155 and 165 mm in both estuaries.

**Abundance by size class**

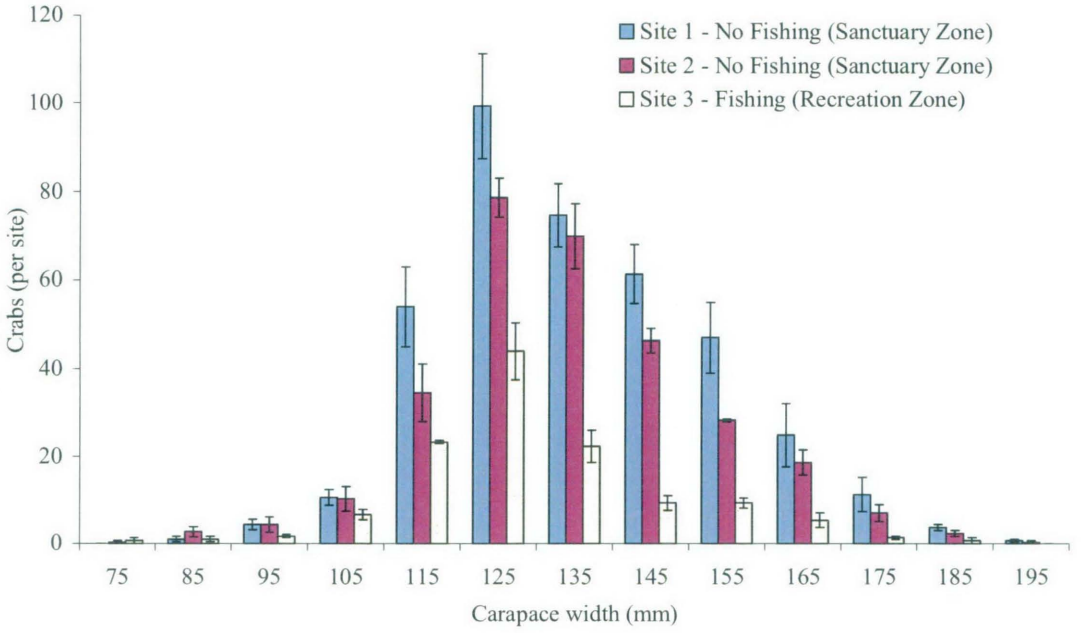


**Figure 4.17**. Mean abundance (± SE) by size class for crabs tagged at Wooli (Site 1 - Unfished (n = 1281), Site 2 – Unfished (n = 937) and Site 3 Fished (n = 406)) before the zoning change between December 1998 and April 2002.

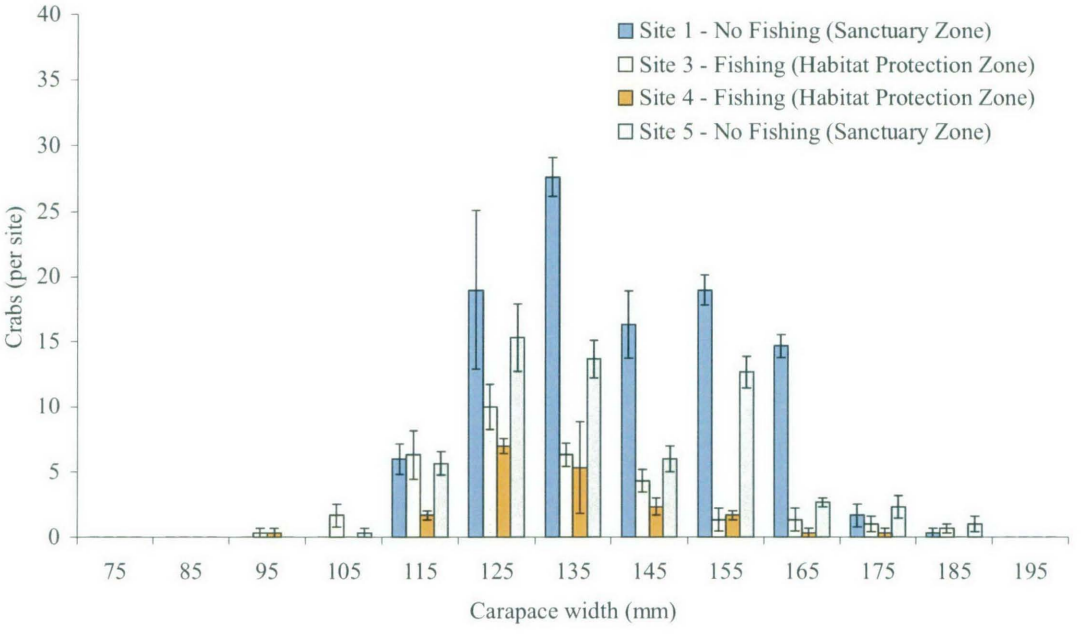


**Figure 4.18**. Mean abundance (± SE) by size class for crabs tagged at Wooli (Site 1 - Unfished (n = 319), Site 3 - Fished (n = 100), Site 4 - Fished (n = 57) and Site 5 - Fished (n = 175) after the change in zoning scheme between August 2002 and August 2003.

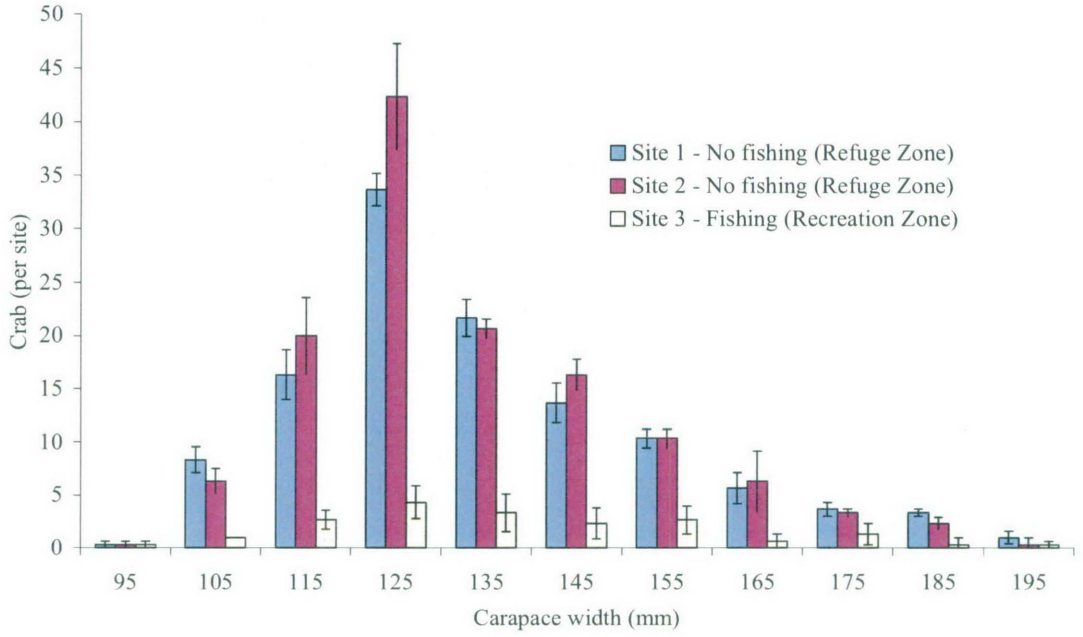


**Figure 4.19**. Mean abundance (± SE) by size class for crabs tagged at Corindi (Site 1 - Unfished (n = 354), Site 2 - Unfished (n = 386) and Site 3 - Fished (n = 58)) before the zoning change between July 2000 and July 2002.

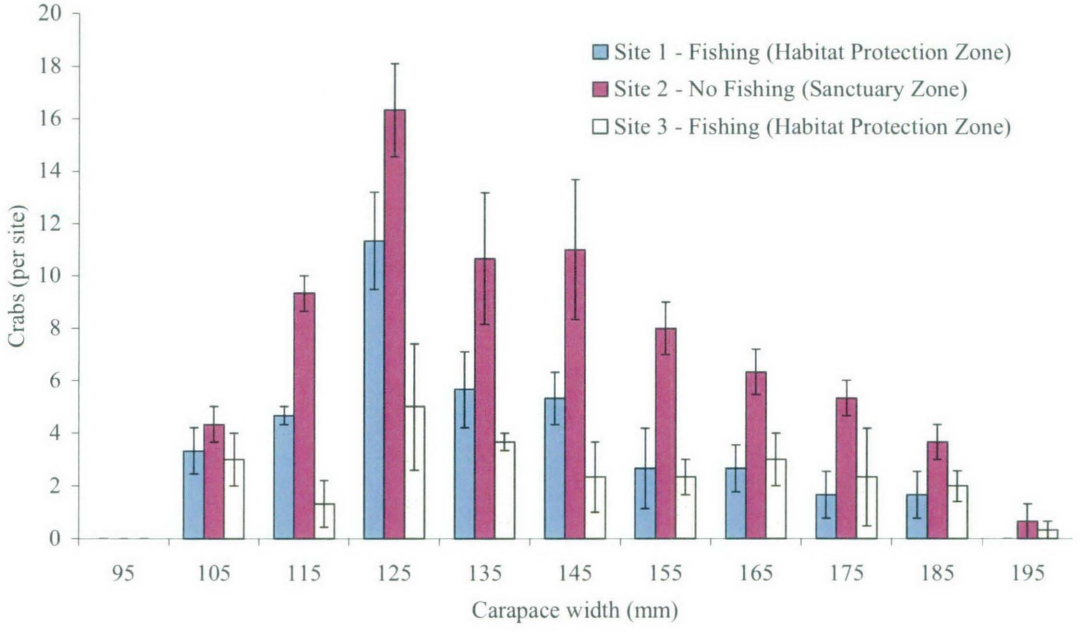


**Figure 4.20**. Mean abundance (± SE) by size class for crabs tagged at Corindi (Site 1 - fished (n = 117), Site 2 - Unfished (n = 227) and Site 3 - Fished (n = 76)) after the zoning change between August 2002 and August 2003

**Table 4.17**. Comparison size class between sites by ANOVA for individual months before and after the zoning change in the (a) Wooli and (b) Corindi estuaries. Tukey's comparison of means tests were conducted when F-ratios were significant.

**(a) Wooli**

| Size class | Zoning Period | Source of variation | | | | *Post hoc* test – Tukey's | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | DF | MS | F | P | Site 1 UU | Site 2 U | Site 3 FF | Site 4 UF | Site 5 UU |
| 95 | Before | 2,8 | 5.78 | 1.53 | 0.2910 | -------- | -------- | -------- | | |
| | After | ----- | ---------- | ---------- | ---------- | -------- | | -------- | -------- | -------- |
| 105 | Before | 2,8 | 20.33 | 1.58 | 0.2820 | -------- | -------- | -------- | | |
| | After | ----- | ---------- | ---------- | ---------- | -------- | | -------- | -------- | -------- |
| 115 | Before | 2,8 | 707.44 | 6.00 | 0.0370 | A | AB | B | | |
| | After | 2,8 | 15.11 | 3.49 | 0.0700 | -------- | | -------- | -------- | -------- |
| 125 | Before | 2,8 | 2668.78 | 12.14 | 0.0080 | A | AB | B | | |
| | After | 2,8 | 102.08 | 3.27 | 0.0802 | -------- | | -------- | -------- | -------- |
| 135 | Before | 2,8 | 2824.11 | 27.33 | 0.0010 | A | A | B | | |
| | After | 2,8 | 352.97 | 25.21 | 0.0002 | A | | B | B | B |
| 145 | Before | 2,8 | 2250.33 | 33.98 | 0.0000 | A | A | B | | |
| | After | 2,8 | 99.33 | 12.04 | 0.0025 | A | | B | B | B |
| 155 | Before | 2,8 | 1369.33 | 35.52 | 0.0000 | A | B | C | | |
| | After | 2,8 | 222.97 | 74.32 | 0.0000 | A | | C | C | B |
| 165 | Before | 2,8 | 577.44 | 6.78 | 0.0290 | A | AB | B | | |
| | After | 2,8 | 132.55 | 106.04 | 0.0000 | A | | B | B | B |
| 175 | Before | 2,8 | 75.00 | 3.21 | 0.1130 | -------- | -------- | -------- | | |
| | After | 2,8 | 2.97 | 1.49 | 0.2902 | -------- | | -------- | -------- | -------- |
| 185 | Before | 2,8 | 5.44 | 4.08 | 0.0760 | -------- | -------- | -------- | | |
| | After | ----- | ---------- | ---------- | ---------- | -------- | | -------- | -------- | -------- |

**(b) Corindi**

| Size class | Zoning Period | Source of variation | | | | *Post hoc* test – Tukey's | | |
|---|---|---|---|---|---|---|---|---|
| | | DF | MS | F | P | Site 1 UF | Site 2 UU | Site 3 FF |
| 95 | Before | ----- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| | After | ----- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |
| 105 | Before | 2,8 | 43.11 | 14.92 | 0.0047 | A | A | B |
| | After | 2,8 | 1.44 | 0.65 | 0.5552 | ---------- | ---------- | ---------- |
| 115 | Before | 2,8 | 250.33 | 11.80 | 0.0083 | A | A | B |
| | After | 2,8 | 48.44 | 36.33 | 0.0004 | B | A | C |
| 125 | Before | 2,8 | 1189.78 | 41.99 | 0.0003 | A | A | B |
| | After | 2,8 | 96.78 | 6.65 | 0.0301 | AB | A | B |
| 135 | Before | 2,8 | 318.78 | 34.15 | 0.0005 | A | A | B |
| | After | 2,8 | 39.00 | 4.03 | 0.0776 | ---------- | ---------- | ---------- |
| 145 | Before | 2,8 | 165.78 | 21.62 | 0.0018 | A | A | B |
| | After | 2,8 | 58.11 | 6.08 | 0.0361 | AB | A | B |
| 155 | Before | 2,8 | 58.78 | 17.63 | 0.0031 | A | A | B |
| | After | 2,8 | 30.33 | 9.41 | 0.0141 | B | A | B |
| 165 | Before | 2,8 | 28.78 | 2.70 | 0.1460 | ---------- | ---------- | ---------- |
| | After | 2,8 | 12.33 | 4.27 | 0.0703 | ---------- | ---------- | ---------- |
| 175 | Before | 2,8 | 4.78 | 3.58 | 0.0946 | ---------- | ---------- | ---------- |
| | After | 2,8 | 11.44 | 2.45 | 0.1666 | ---------- | ---------- | ---------- |
| 185 | Before | 2,8 | 7.00 | 10.50 | 0.0110 | A | AB | B |
| | After | ----- | ---------- | ---------- | ---------- | ---------- | ---------- | ---------- |

## Monthly size classes among treatments

### Wooli

The average size of crabs at Wooli was significantly larger in the unfished Site 1 (UU) (136 mm) and Site 2 (UF) (134 mm) compared to the fished Site 3 (FF) (130 mm) before the zoning change ($F_{2,6}$ = 19.16 , P = 0.0025) (Figure 4.21). After the zoning change, crabs caught at the unfished Site 1 (141 mm) and Site 5 (UU) (138 mm) were significantly larger than the fished Site 3 (132 mm) and Site 4 (UF) (130 mm) ($F_{3,8}$ = 13.64 , P = 0.0016). In most months, the average sizes of crabs in the protected areas were larger than the legal size limit (Figure 4.21). Prior to the zoning change, the average carapace width of crabs at the fished Site 3 was under the legal size in 45% of months while the average carapace width was only under the legal size limit in 19% of months at the unfished Site 1 and 21% of months at Site 2 (Figure 4.21). The average size of crabs varied temporally for the two unfished sites while Site 3 usually had larger crabs during November to February but even these months varied each year. After the zoning change in August 2002, once fishing was introduced to Site 4, there was a sharp decline in the average carapace width by October while larger sizes of crabs were being caught at both Site 1 and Site 5 (unfished) and Site 3 (fished) (Figure 4.21).

### Corindi

At Corindi there was no significant difference in the average size of crabs among the unfished Site 1 (UF) (134 mm), Site 2 (UU) (133 mm) and fished Site 3 (137 mm) before the zoning change ($F_{2,6}$ = 3.53, P = 0.0967) (Figure 4.22). After the zoning change, Site 3 (143 mm) had significantly larger crabs than Site 1 (136 mm), but not Site 2 (140 mm) ($F_{2,6}$ = 6.92, P = 0.0277) (Figure 4.22). Before and after the zoning change, crabs from the fished Site 3 had the largest average carapace width than those at any other site even though it had been fished and other sites had been protected from fishing. As was the case at Wooli, differences among sites varied each month. Site 1 showed a seasonal trend with higher average sizes during summer while the unfished Site 2 averaged slightly above the legal size limit of 128 mm from July 2000 to December 2001 before showing some seasonal trend similar to Site 1 thereafter. There was large monthly variation within Site 3. Crabs in this site were usually larger crabs than at the two protected sites.

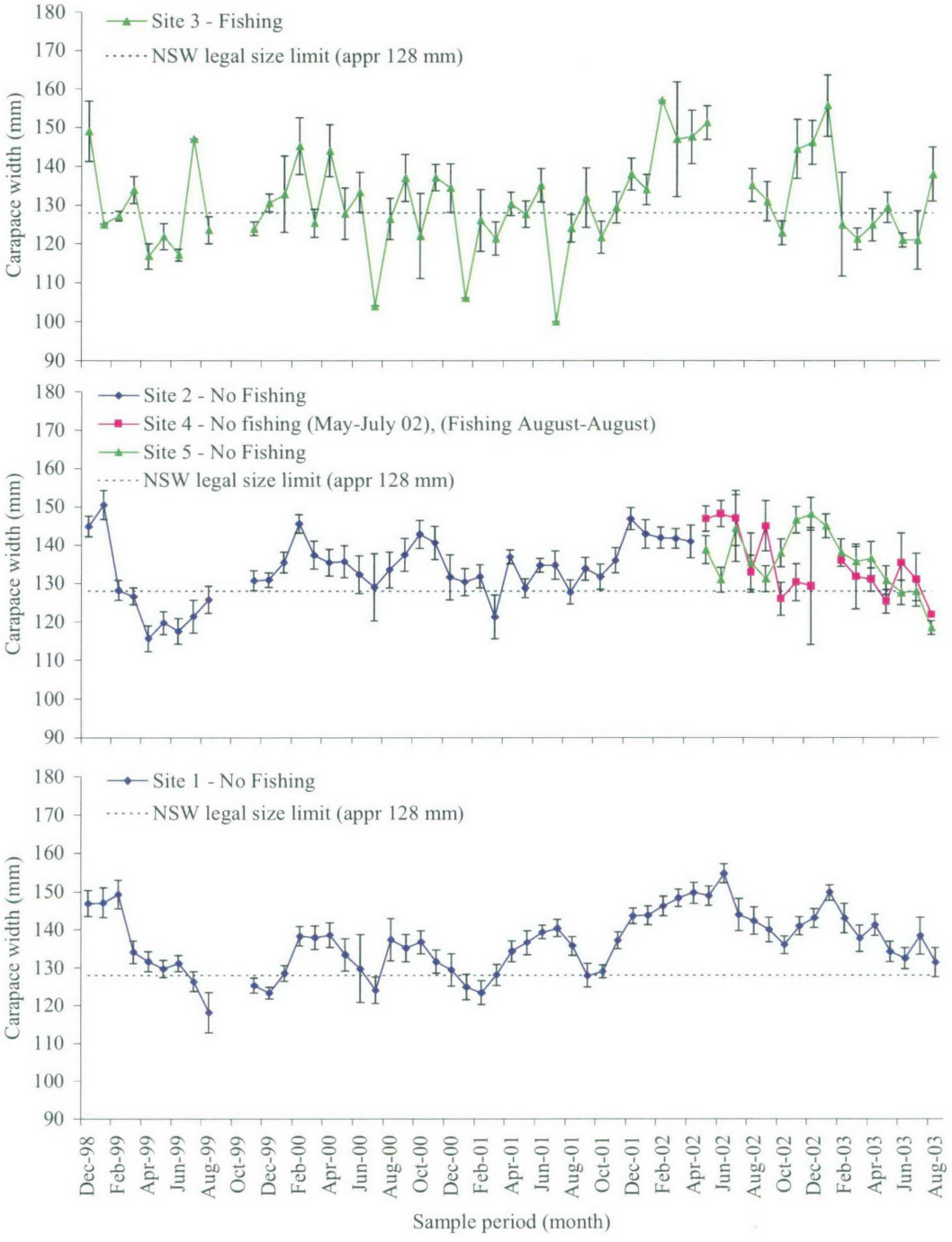


**Figure 4.21.** Comparison of the average (±SE) carapace width (mm) of mud crabs caught each month in fished and unfished areas of the Wooli Estuary.

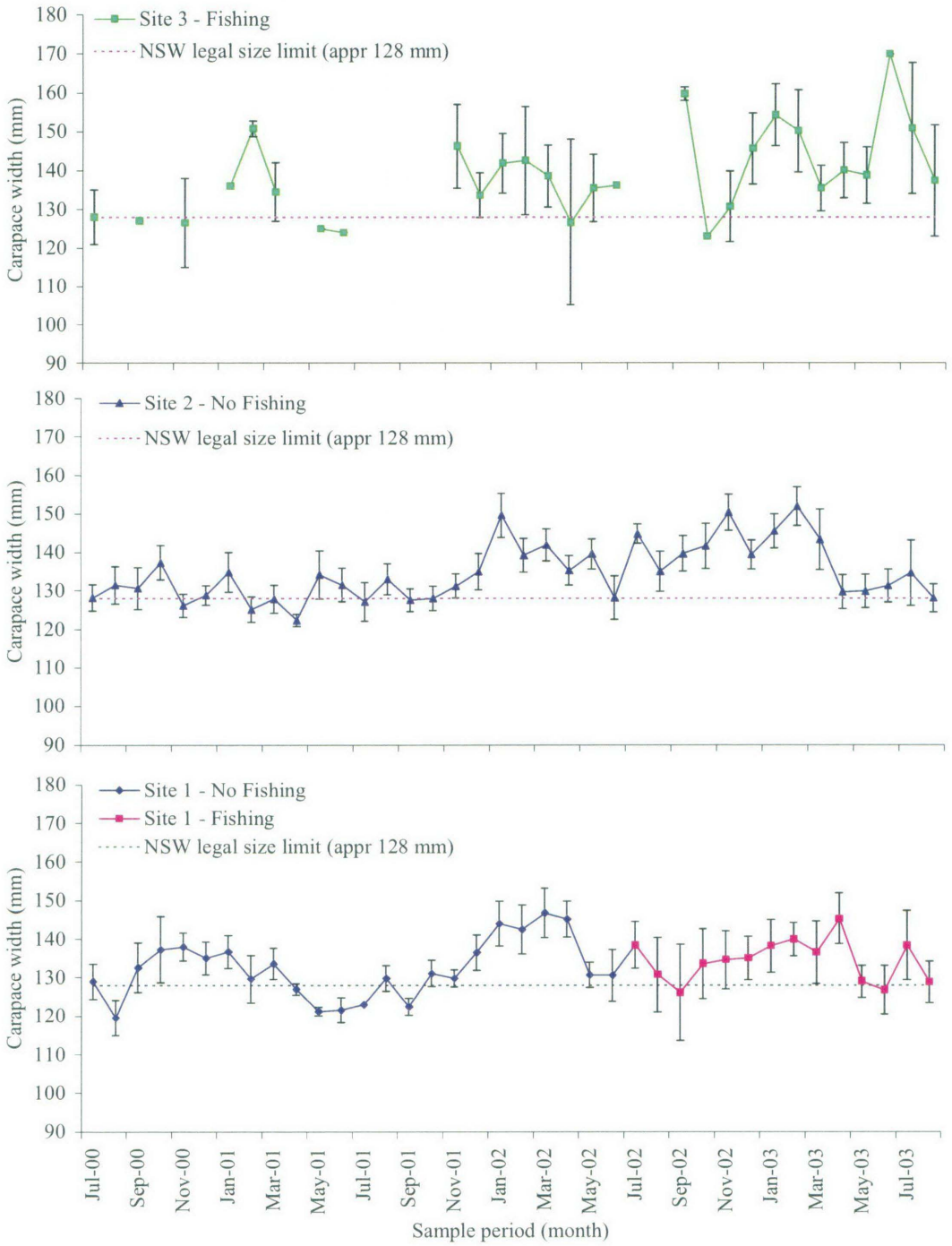


**Figure 4.22**. Comparison of the average (±SE) carapace width (mm) of mud crabs caught each month in fished and unfished areas of the Corindi Estuary.

**Gender**

During the study, 2215 male and 1143 female crabs were caught at Wooli and 781 male and 437 female crabs were caught at Corindi. Prior to the zoning change, 1770 males and 933 female crabs were caught at Wooli and 480 males and 318 female crabs were caught at Corindi (Figures 4.23a and Figure 4.24a). There was an association between site and gender at Wooli ($\chi^2$ 54.17, df 2, P = 0.0000). At the fished Site 3, the number of males to females was almost 1:1, while on average, more males were caught than females at the protected sites with sex ratios of 1.88 at Site 1 and 2.49 at Site 2. There was no association between site and gender at Corindi ($\chi^2$ 5.33, df 2, P = 0.0698). Trends still suggested that it was more likely that male crabs would be caught in the protected Site 1 (1.49 males:females) and Site 2 (1.66) than the fished Site 3 (0.87) where more females than male crabs were caught before the zoning change (Figure 4.24a).

After the zoning change, 445 males and 210 female crabs were caught at Wooli and 301 males and 119 female crabs were caught at Corindi (Figures 4.23b and Figure 4.24b). There was no association between area and gender at Wooli ($\chi^2$ 2.01, df 2, P = 0.5698) or Corindi ($\chi^2$ 2.80 ,df 2, P = 0.2471). Although no association was found, the number of male and female crabs caught in different sites showed that there were more male crabs in the unfished sites than fished sites either side of the zoning change. There was an increase in males after the zoning change in all sites except Site 4 at Wooli. The most notable change was in the fished Site 3 at Wooli and Corindi which changed from almost equal numbers of males and females caught prior to the zoning change to nearly two males for every female after the zoning change (Figures 4.23b and Figure 4.24b).

**Sex ratio**

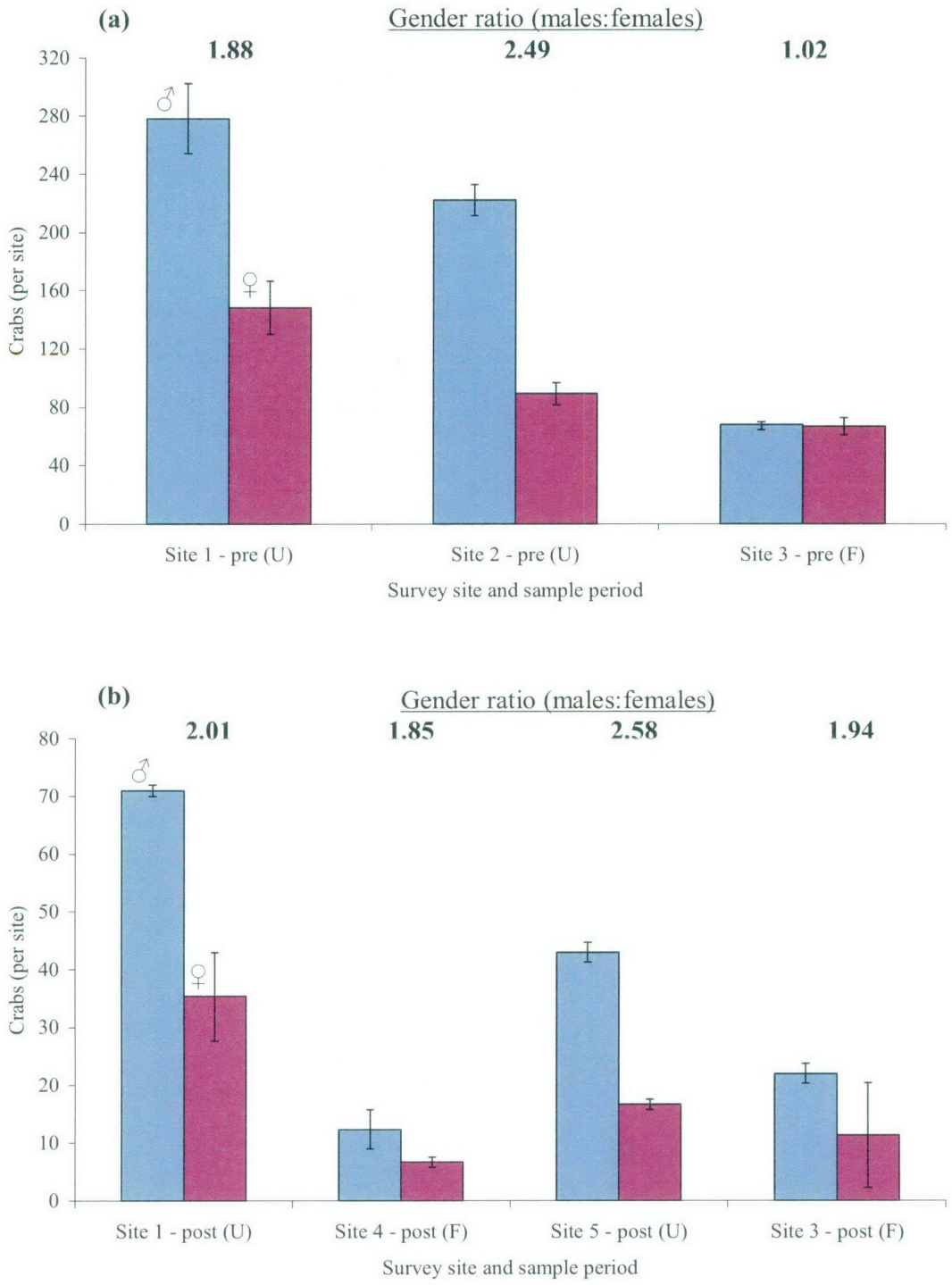


**Figure 4.23.** Average (± SE) number of male and female crabs caught at each site in the Wooli estuary, 'before' (a) and 'after' (b) the change in zoning in August 2002.

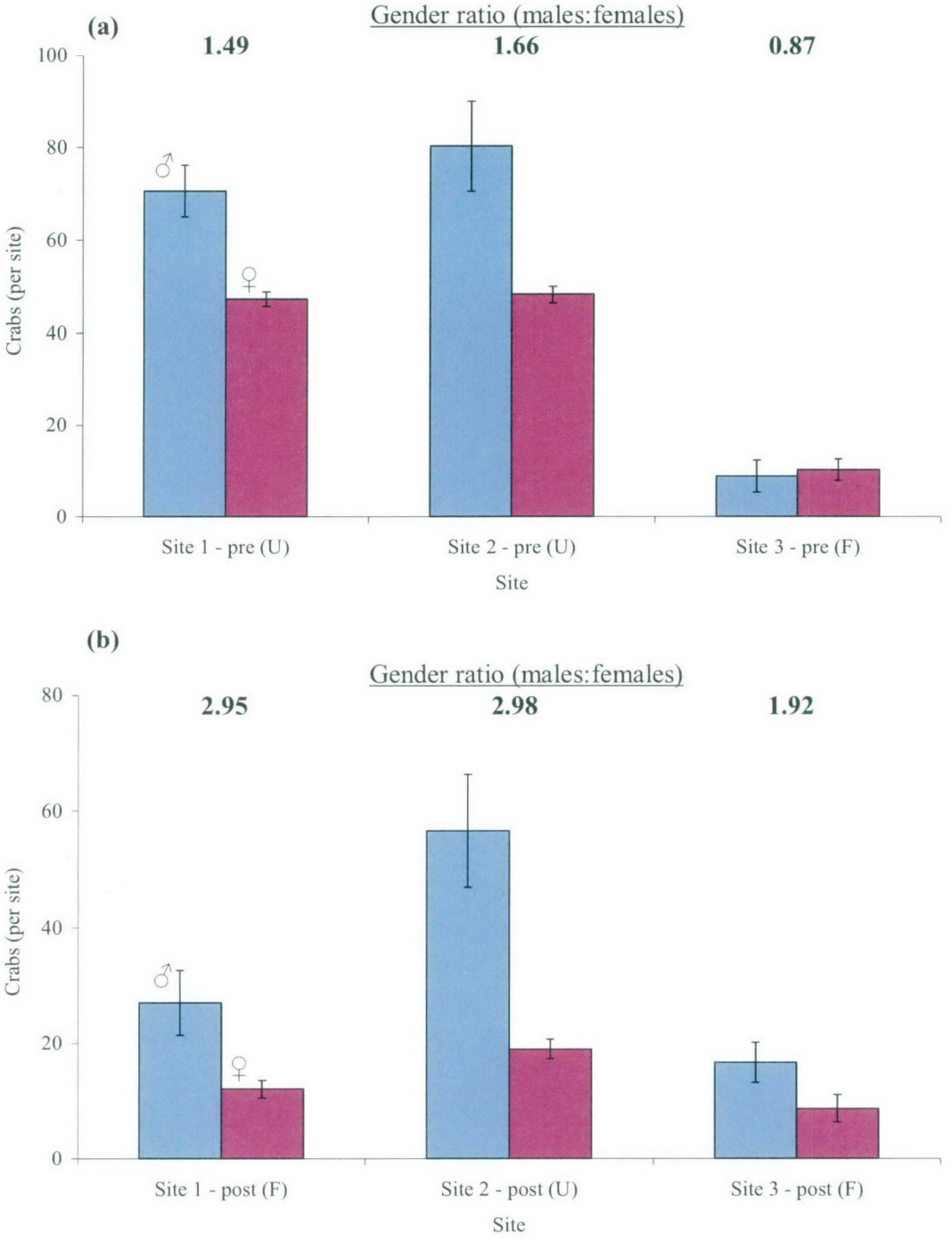


**Figure 4.24.** Average (± SE) number of male and female crabs caught at each site in the Corindi Estuary, 'before' (a) and 'after' (b) the change in zoning in August 2002.

### 4.3.3 Removing "fishing" pressure in the Sandon Estuary

**Abundance**

A total of 917 crabs was caught between July 2000 and August 2003 during monthly sampling trips. Prior to the zoning change, 472 crabs were caught in 25 months between July 2000 and July 2002. The mean number of crabs captured overall was significantly higher in the commercially fished Site 1 (CU) (245 crabs) and Site 2 (CF) (204 crabs) than the fished Site 3 (FF) (23 crabs) ($F_{2,8} = 39.07$ , $P = 0.0004$) (Figure 4.25). After the zoning change, 445 crabs were captured in 13 months between August 2002 and August 2003. More crabs were captured in this 13-month period than were caught in the previous 25 months at the fished Site 3. Significantly more crabs (240) were captured from Site 1 which had been closed to fishing at the zone change than Site 2 (139 crabs) which had been opened to all fishing and Site 3 (66 crabs) which had been fished either side of the zoning change ($F_{2,8} = 32.57$ , $P = 0.0006$) (Figure 4.25).

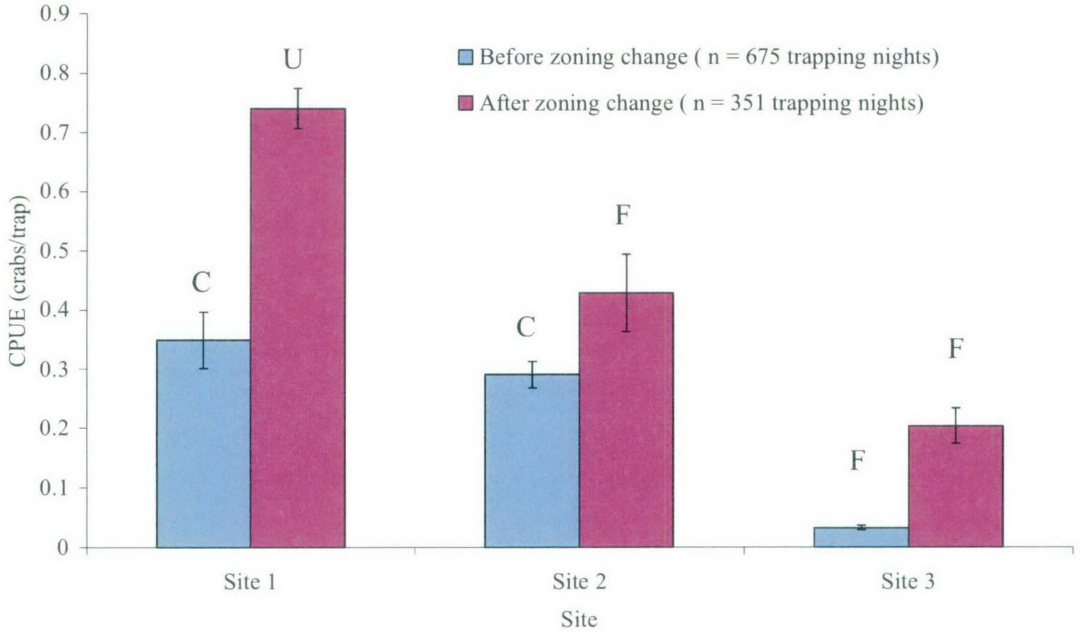


**Figure 4.25.** Average (± SE) CPUE of crabs caught in unfished (U), fished (F) and commercial fished only (C) sites in the Sandon Estuary before (July 2000 – July 2002) and after (August 2002 – August 2003) the change in zoning scheme.

The BACI analysis suggested that there was a significant change in trends between treatments after the perturbation caused by the zoning change in August 2002 (Table 4.18, Figure 4.26). This change occurred between Site 1 (CU) and Site 3 (FF) where there was a significant, although gradual increase in catches after the zoning change before catches in all treatments followed the same trend once the flood occurred in February 2003. There was no change in trends between Site 2 (CF) and Site 3 (FF). Comparison of F-ratios for the repartitioned Months x Treatment term provided further evidence of the change (Table 4.18). Prior to the zoning change, there was no difference in trends among treatments while after the zoning change there was a significant difference. This difference occurred in the interaction between Site 1 (CU) v Site 3 (FF) and between Site 2 (CF) v Site 3 (FF). The former was expected as Site 1 (CU) had become totally protected from fishing resulting in a gradual increase in abundances after the change while yields in Site 3 (FF) remained low. This response provided different trends than what occurred between the two sites before the zoning change. The difference between Site 2 (CF) and Site 3 (FF) was not expected but occurred because the Site 2 (CF) did not change in CPUE once fishing occurred. The number of crabs captured remained at levels similar to before the zoning change and it was not until the dramatic increase in catches during December 2002 that high numbers of crabs were caught at Site 3. This trend differed from before the zoning change. After December 2003, similar catches occurred in all months (Table 4.18, Figure 4.26).

Even though a significant result was found where the perturbation caused changes in the temporal trends between sites, analysis of individual months was still conducted to further support this analysis and detect where temporal differences occurred (Table 4.19). Catches in the Sandon Estuary varied with season and zoning type (Figure 4.26, Table 4.19). There was a decrease in CPUE between July and October 2000, April and October 2001, June and July 2002 and June and August 2003. Prior to the zoning change, catches in the two commercially fished sites (Site 1 and Site 2) were significantly higher than the recreational fished Site 3 in 15 of the 25 months prior to the zoning change with 4 of these having only one of the commercial sites being significantly higher than the fished site during this period (Table 4.19). There was a sustained period between December 2000 and September 2001 when March 2001 was the only month where there was a significant difference between any sites.

After the zoning change, CPUE increased sharply at Site 1 (CU) where fishing had been excluded while CPUE at Site 2 (CF) remained at levels found in pre zoning samples (Figure 4.26, Table 4.19). There were only 2 months where catches were the same among all three sites from the 13 months sampled (Table 4.19). Site 1 (CU), which had now been protected from fishing, had the highest CPUE in all months. In the 10 months where there was a difference among sites, CPUE at Site 1 was significantly different to Site 3 (FF) in all 13 months while CPUE at Site 2 (CF), which was opened to fishing for recreational fishers, was only significantly different to Site 3 in 3 months (Table 4.19). This occurred during August and September 2002 (initial months following the zoning change) and May 2003 (Figure 4.26; Table 4.19)

Catches at Site 3 were similar to those at Corindi (Section 4.3.2) where crabs were rare for most of the year except for the period between December and June each year (Figure 4.26). During this period, the CPUE increased sharply for 1 to 2 months before peaking and declining in the following months after the summer peak. Prior to the zoning change, the CPUE was low at this site with only 2 or 3 crabs encountered on each sampling trip. After the zoning change, the CPUE increased between December and April from 0.1 crabs to 0.5 crabs/trap (Figure 4.26).

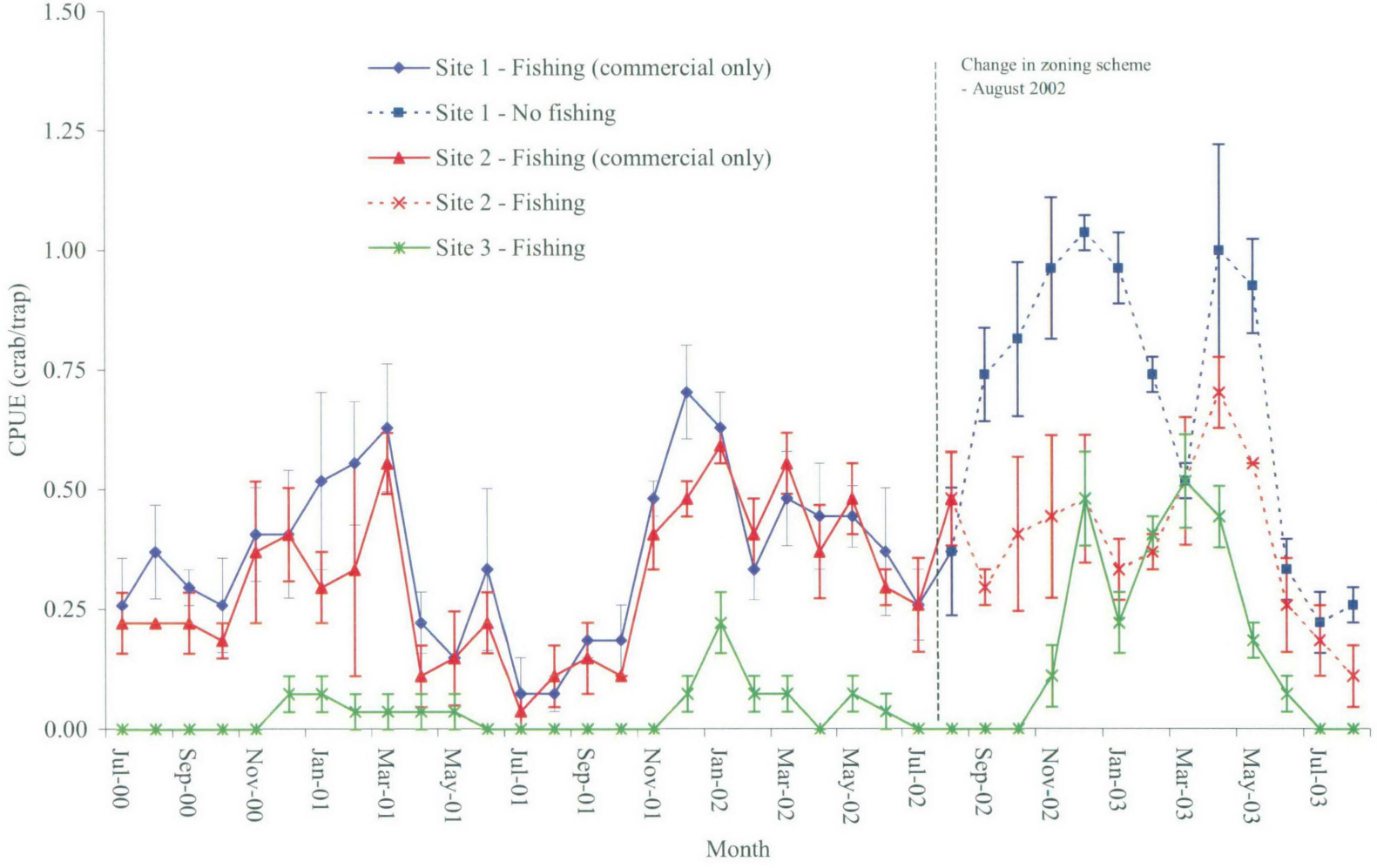


**Figure 4.26.** Temporal variations in mean abundance (±SE) of mud crabs at each site in the Sandon Estuary before and after the zoning change in August 2002

**Table 4.18.** Summary of results of BACI: replicated before/after sampling at three locations comparing the catches from three treatments (CU, CF and FF) sampled before and after changes in zoning scheme at Sandon. (pld) indicates that the F-ratio was non significant at P<0.25, and the Sums of Squares and DF were pooled with the residual. (-) = Incalculable F-ratio.

| Source of variation | DF | SS | MS | F-ratio | Sig. |
|---|---|---|---|---|---|
| **BvA** | **1** | **16.37** | **16.37** | - | |
| **Treatments** | **2** | **60.43** | **0.21** | - | |
| **BvA x Treatments** | **2** | **1.98** | **0.99** | - | |
| **Month (BvA)** | **36** | **42.95** | **1.19** | **8.17** | **<0.0001** |
| **Month (BvA) x Treatments** | **72** | **15.93** | **0.22** | **1.51** | **0.0048** |
| ***Month (B) x Treatments** | **48** | **6.46** | **0.13** | **1.56** | **ns** |
| ***Month (B) x CUvFF** [1] | **24** | **4.57** | **0.19** | **0.69** | **ns** |
| ***Month (B) x CFvFF** [2] | **24** | **4.01** | **0.17** | **2.37** | **ns** |
| ***Month (A) x Treatments** | **24** | **9.47** | **0.39** | **1.55** | **<0.0005** |
| ***Month (A) x CUvFF** [3] | **12** | **6.29** | **0.52** | **1.68** | **<0.0005** |
| ***Month (A) x CFvFF** [4] | **12** | **3.98** | **0.33** | **0.81** | **<0.01** |
| **Sites(Treatments)** | **6** | **3.49** | **0.58** | **3.98** | **0.0006** |
| **Sites(Treatments) x BvA** | **6** | **2.57** | **0.43** | **2.93** | **0.0078** |
| Sites(Treatments) x Months(BvA) | 216 | 23.74 | 0.11 | pld | |
| **Residual** | 684 | 107.71 | 0.16 | | |
| | **900 (pld)** | **131.45 (pld)** | **0.15 (pld)** | | |
| **Total** | **1025** | **275.18** | | | |

**F-ratios of interest**

| | F ratio | Significance | Critical values |
|---|---|---|---|
| **Month (B) x CUvFF / Month (A) x CUvFF** $= {}^{3/1}$: | 2.7489 | P<0.05 | (12,2) DF two-tailed = 2.54 |
| **Month (B) x CFvFF / Month (A) x CFvFF** $= {}^{4/2}$: | 1.9838 | Not Significant | (12,2) DF two-tailed = 2.54 |

* Repartitioned sources of variation

**Table 4.19**. Comparison of size classes among sites by ANOVA for individual months before and after the change in zoning in 2002. Tukey's comparison of means tests were conducted when F-ratios were significant.

| | Source of variation | | | | *Post hoc* test – Tukey's | | |
|---|---|---|---|---|---|---|---|
| | DF | MS | F-ratio | P | S1 - C (Commercial) | S2 - C (Commercial) | S3 - F |
| **July 00** | 2,18 | 0.67 | 5.38 | 0.0459 | A | A | B |
| **Aug 00** | 2,18 | 1.07 | 11.96 | 0.0081 | A | A | B |
| **Sept 00** | 2,18 | 0.67 | 12.79 | 0.0069 | A | A/B | B |
| **Oct 00** | 2,18 | 0.57 | 4.76 | 0.0182 | A | A | B |
| **Nov 00** | 2,18 | 1.46 | 7.02 | 0.0268 | A | A | B |
| **Dec 00** | 2,24 | 0.82 | 3.55 | 0.0446 | A | A | B |
| **Jan 01** | 2,24 | 0.96 | 5.20 | 0.0133 | A | A | B |
| **Feb 01** | 2,18 | 1.37 | 3.66 | 0.0915 | ---------- | ---------- | ---------- |
| **Mar 01** | 2,18 | 2.20 | 21.29 | 0.0019 | A | A | B |
| **Apr 01** | 2,18 | 0.23 | 2.20 | 0.1919 | ---------- | ---------- | ---------- |
| **May 01** | 2,18 | 0.14 | 0.60 | 0.5762 | ---------- | ---------- | ---------- |
| **June 01** | 2,18 | 0.85 | 3.62 | 0.0931 | ---------- | ---------- | ---------- |
| **July 01** | 2,18 | 0.05 | 0.60 | 0.5787 | ---------- | ---------- | ---------- |
| **Aug 01** | 2,18 | 0.12 | 1.75 | 0.1952 | ---------- | ---------- | ---------- |
| **Sept 01** | 2,18 | 0.35 | 3.34 | 0.0526 | ---------- | ---------- | ---------- |
| **Oct 01** | 2,18 | 0.29 | 6.47 | 0.0317 | A | A/B | B |
| **Nov 01** | 2,18 | 1.54 | 21.32 | 0.0019 | A | A | B |
| **Dec 01** | 2,18 | 2.14 | 45.19 | 0.0002 | A | A | B |
| **Jan 02** | 2,18 | 0.78 | 9.69 | 0.0132 | A | A/B | B |
| **Feb 02** | 2,18 | 0.90 | 10.17 | 0.0118 | A | A | B |
| **Mar 02** | 2,18 | 1.46 | 12.33 | 0.0075 | A | A | B |
| **Apr 02** | 2,18 | 1.41 | 11.41 | 0.0090 | A | A | B |
| **May 02** | 2,18 | 1.16 | 16.56 | 0.0036 | A | A | B |
| **June 02** | 2,18 | 0.85 | 5.63 | 0.0419 | A | A | A |
| **July 02** | 2,18 | 0.62 | 6.12 | 0.0356 | A | A/B | B |
| | ***Change in zoning scheme*** | | | | **S1 - U** | **S2 - F** | **S3 - F** |
| **Aug 02** | 2,18 | 1.84 | 9.90 | 0.0126 | A | A | B |
| **Sept 02** | 2,18 | 2.91 | 71.82 | 0.0001 | A | B | C |
| **Oct 02** | 2,18 | 3.00 | 10.37 | 0.0113 | A | AB | B |
| **Nov 02** | 2,18 | 2.65 | 8.59 | 0.0173 | A | AB | B |
| **Dec 02** | 2,18 | 1.05 | 5.35 | 0.0464 | A | A | A |
| **Jan 03** | 2,18 | 1.89 | 20.52 | 0.0021 | A | B | B |
| **Feb 03** | 2,18 | 0.63 | 26.02 | 0.0011 | A | B | B |
| **Mar 03** | 2,18 | 0.00 | 0.00 | 0.9970 | ---------- | ---------- | ---------- |
| **Apr 03** | 2,18 | 0.96 | 6.92 | 0.0277 | A | A/B | B |
| **May 03** | 2,18 | 1.98 | 45.32 | 0.0002 | A | B | C |
| **June 03** | 2,18 | 0.40 | 2.86 | 0.1340 | ---------- | ---------- | ---------- |
| **July 03** | 2,24 | 0.50 | 4.77 | 0.0180 | A | A | B |
| **Aug 03** | 2,18 | 0.51 | 7.60 | 0.0227 | A | A/B | B |

**Size class**

Size class distributions from areas in the Sandon Estuary were different from expectations. Prior to the zoning change, the fished Site 3 had a different distribution to the commercially fished Site 1 (KS = 0.39, P < 0.0001) and Site 2 (KS = 0.37, P < 0.0001) with no crabs being caught below the 115 mm size group and similar proportions of crabs caught in the size groups from 135 -195 mm. The other sites had similar modal distributions that peaked at the 125 mm size class (Table 4.20, Figure 4.27).

After the zoning change, the population distribution at the now protected Site 1 (KS = 0.25, P=0.0040) and fished Site 3 (KS = 0.25, P = 0.0061) contained larger crabs than it did before the change while Site 2 did not change (Table 4.20). Comparisons among sites showed that Site 1 (CU) and Site 3 (FF) had similar distributions while Site 2 (CF) contained smaller crabs than Site 1 (unfished) (KS = 0.25, P = 0.0048) and Site 3 (fished) (KS = 0.25, P = 0.0039). Site 2 had large proportions of crabs in the 115 mm and 125 mm size classes while Site 1 (CU) and Site 3 (FF) had larger proportions of crabs in all size classes from 135 – 195 mm (Table 4.20, Figure 4.28).

**Table 4.20.** Probability values using the Kolmorgorov-Smirnov goodness of fit test comparing width cohorts for mud crabs within and between treatments, before and after the change in zoning scheme in the Sandon Estuary. Bracketed numbers are the total number of crabs used in the analysis for each treatment.

| **Treatment** (1-3 = Before, 4-6 After) – zoning change) | **Treatment** 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| **1 -Site 1 – Fished (commercial)** (245) | | 1.0000 | **0.0000** | **0.0061** | 1.0000 | **0.0101** |
| **2- Site 2 - Fished (commercial)** (204) | | | **0.0000** | **0.0099** | 0.8711 | **0.0162** |
| **3- Site 3 - Fished** (23) | | | | **0.0005** | **0.0000** | **0.0040** |
| **4- Site 1 - Unfished** (239) | | | | | **0.0048** | 1.0000 |
| **5- Site 2 - Fished** (139) | | | | | | **0.0039** |
| **6- Site 3 - Fished** (66) | | | | | | |

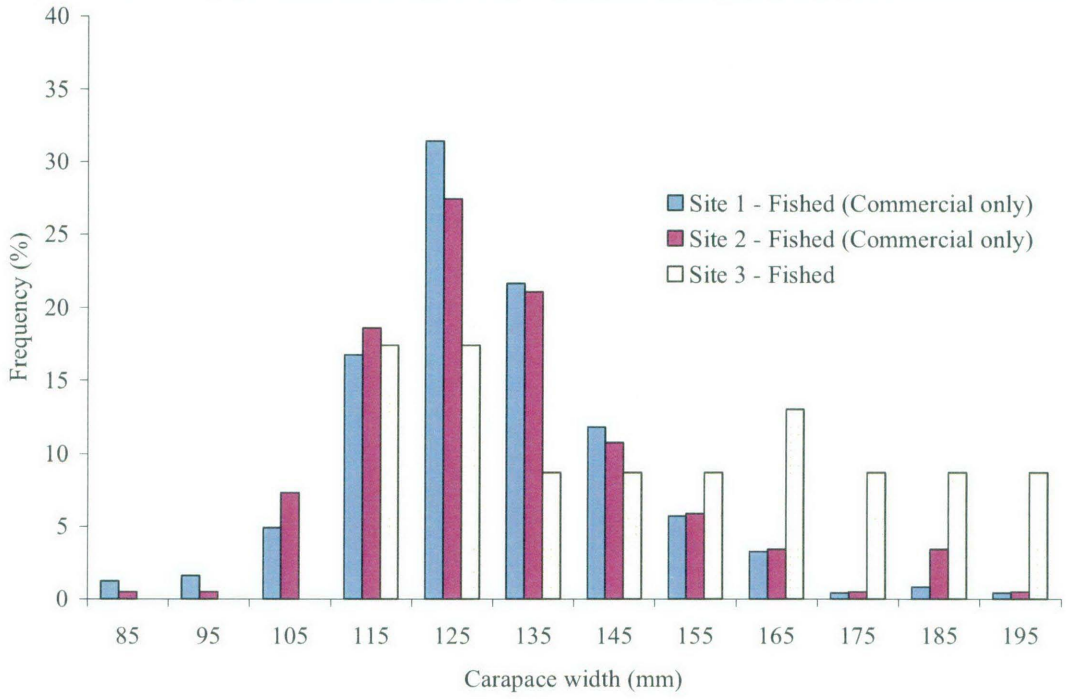


**Figure 4.27.** Size class proportion distribution for mud crabs tagged at Site 1 – fished commercial (n = 245), Site 2 – fished commercial (n = 204), and Site 3 – fished (n = 23) in the Sandon Estuary prior to the zoning change between July 2000 and July 2002.

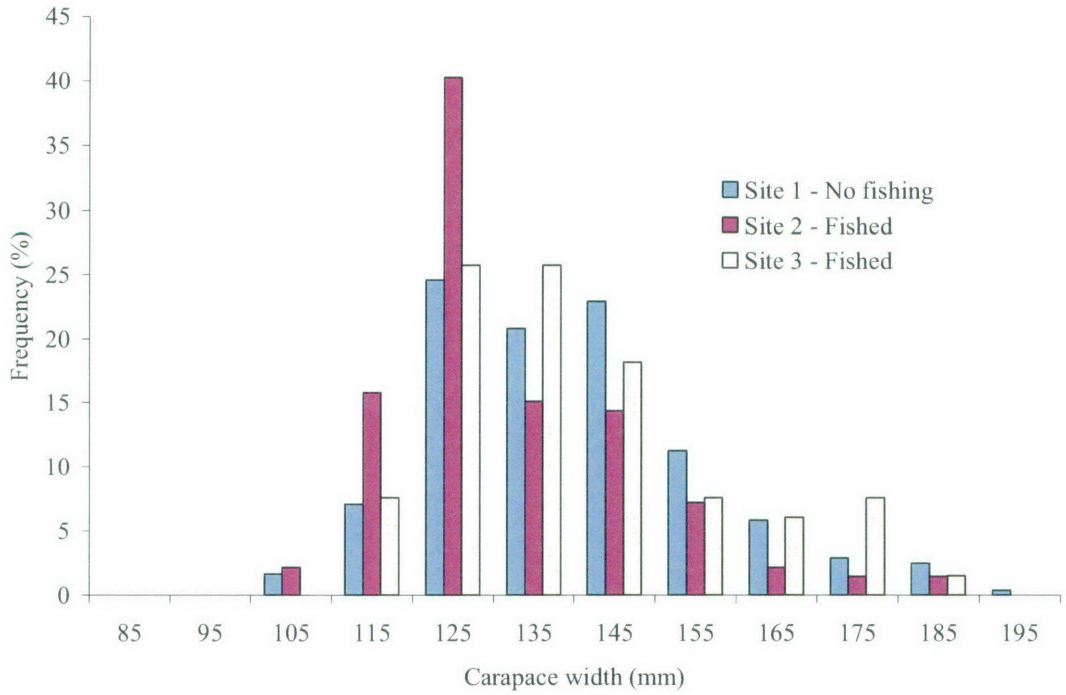


**Figure 4.28.** Size class proportion distribution for mud crabs tagged at Site 1 – unfished (n = 240), Site 2 – fished (n = 139), and Site 3 – fished (n = 66) in the Sandon Estuary after the zoning change between August 2002 and August 2003.

Prior to the zoning change, similar numbers of crabs were caught in each size class between the commercially fished Site 1 and Site 2 (Table 4.21, Figure 4.29). There were significantly more crabs in at least one commercially fished site than the fished Site 3 in all size classes between 115 - 155 mm. In the size classes above this, there was no difference among sites in any size class.

After the zoning change there was a marked difference between the number of crabs at Site 1 (CU) and Site 2 (CF) after zoning changed from commercial fished to protected (Site 1) and commercial fished to fished (Site 2) (Table 4.21; Figure 4.30). Site 1 had significantly more crabs in the size range of 135 - 165 mm. Site 1 was also significantly different from Site 3 (FF), with more crabs in the size classes of 105 mm and 125 - 165 mm. The fished Site 2 had significantly more crabs than Site 3 in the smaller size classes from 105 - 125 mm but there were no differences in size classes above this.

Comparing the number of crabs caught in each size class at Site 3 showed that the majority of crabs were large but there were only a small number of crabs in each size class (Figure 4.29, Figure 4.30). All crabs in the size classes above 135 mm were all female crabs.

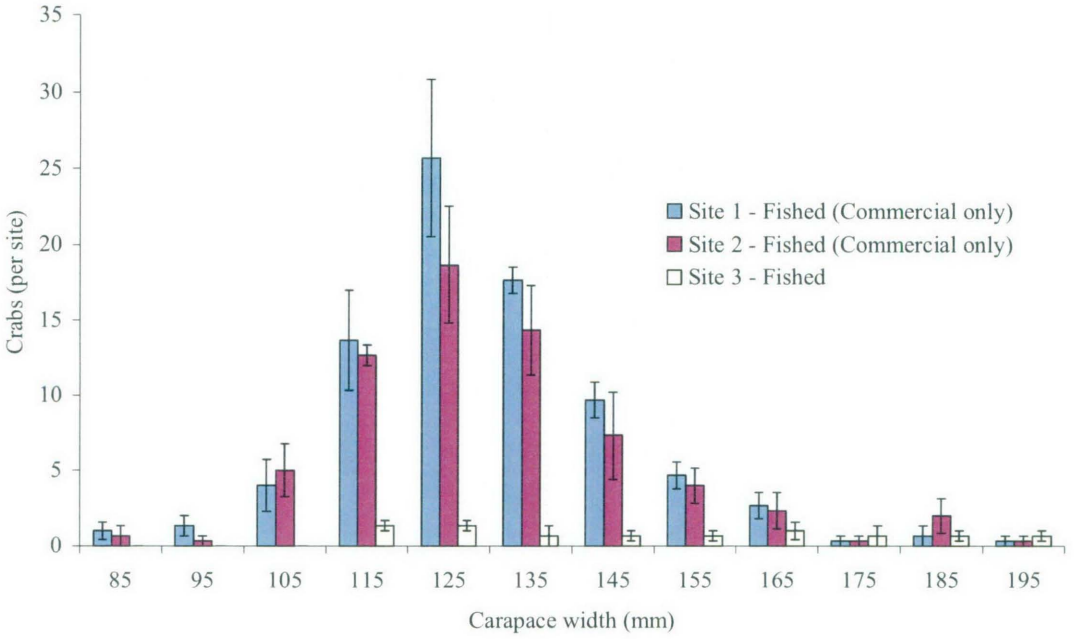


**Figure 4.29**. Mean abundance (± SE) by size class for crabs tagged in the Sandon Estuary (Site 1 – Fished commercial (n = 245), Site 2 – Fished commercial (n = 204) and Site 3 Fished (n = 23)) between July 2000 and July 2002.

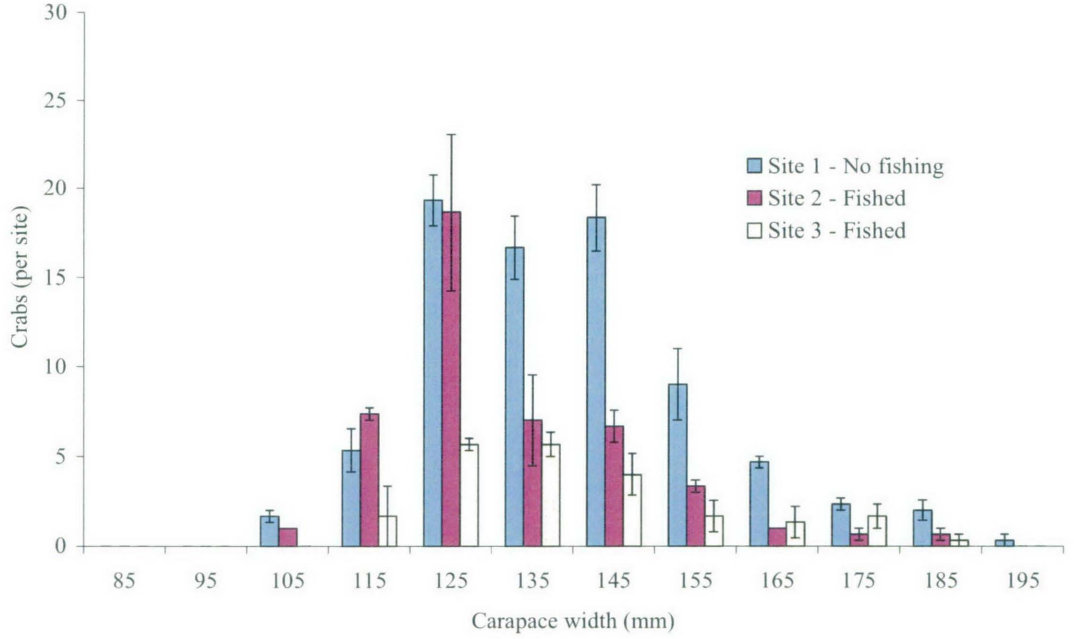


**Figure 4.30**. Mean abundance (± SE) by size class for crabs tagged in the Sandon Estuary (Site 1 - Unfished (n = 240), Site 2 - Fished (n = 139) and Site 3 - Fished (n = 66)) between August 2002 and August 2003.

**Table 4.21**. Comparison size class between sites by ANOVA for individual months before and after the change in zoning in 2002. Tukey's comparison of means tests were conducted when F ratios were significant.

| Size class | Zoning Period | Source of variation DF | MS | F | P | *Post hoc* test – Tukey's Site 1 | Site2 | Site 3 |
|---|---|---|---|---|---|---|---|---|
| **85** | **Before** | ------ | ------- | -------- | ---------- | ---------- | ---------- | ---------- |
| | **After** | ------ | ------- | -------- | ---------- | ---------- | ---------- | ---------- |
| **95** | **Before** | ------ | ------- | -------- | ---------- | ---------- | ---------- | ---------- |
| | **After** | ------ | ------- | -------- | ---------- | ---------- | ---------- | ---------- |
| **105** | **Before** | 2,8 | 21.00 | 3.50 | 0.0983 | ---------- | ---------- | ---------- |
| | **After** | 2,8 | 2.11 | 19.00 | 0.0025 | A | A | B |
| **115** | **Before** | 2,8 | 140.77 | 12.70 | 0.0079 | A | A | B |
| | **After** | 2,8 | 24.78 | 5.72 | 0.0407 | AB | A | B |
| **125** | **Before** | 2,8 | 470.77 | 11.30 | 0.0092 | A | A | B |
| | **After** | 2,8 | 178.11 | 8.22 | 0.0191 | A | A | B |
| **135** | **Before** | 2,8 | 243.44 | 24.34 | 0.0013 | A | A | B |
| | **After** | 2,8 | 108.11 | 10.93 | 0.0100 | A | B | B |
| **145** | **Before** | 2,8 | 65.44 | 6.54 | 0.0311 | A | AB | B |
| | **After** | 2,8 | 174.33 | 31.38 | 0.0007 | A | B | B |
| **155** | **Before** | 2,8 | 13.78 | 6.20 | 0.0347 | A | AB | B |
| | **After** | 2,8 | 44.33 | 9.07 | 0.0154 | A | B | B |
| **165** | **Before** | 2,8 | 2.33 | 0.91 | 0.4506 | ---------- | ---------- | ---------- |
| | **After** | 2,8 | 12.33 | 13.88 | 0.0056 | A | B | B |
| **175** | **Before** | 2,8 | 0.11 | 0.17 | 0.8503 | ---------- | ---------- | ---------- |
| | **After** | 2,8 | 2.11 | 3.17 | 0.1151 | ---------- | ---------- | ---------- |
| **185** | **Before** | 2,8 | 1.78 | 0.94 | 0.4410 | ---------- | ---------- | ---------- |
| | **After** | 2,8 | 2.33 | 4.20 | 0.0723 | ---------- | ---------- | ---------- |
| **195** | **Before** | 2,8 | 0.11 | 0.33 | 0.7290 | ---------- | ---------- | ---------- |
| | **After** | ------ | ---------- | -------- | -------- | ---------- | ---------- | ---------- |

**Monthly Size Class**

The average size of crabs at the fished Site 3 (149 mm) was significantly larger than the commercially fished Site 1 (129 mm) and Site 2 (131 mm) before the zoning change ($F_{2,6}$ = 24.55, P = 0.0013). After the zoning change, the newly protected Site 1 (139 mm) and fished Site 3 (140 mm) were significantly larger than at the fished Site 2 (132 mm) ($F_{2,6}$ =19.56 , P = 0.0024). While the average carapace width at Site 2 did not change between zoning times it increased at Site 1 from 129 mm to 139 mm while Site 3 decreased from 149 mm to 140 mm.

No seasonal trend was evident at Site 1 (CU) or Site 2 (CF), but at Site 3 (FF), the average carapace width was highest in December (Figure 4.31), and then became smaller each month until crabs were around the legal size limit by March/April. Once commercial fishing was removed from the estuary after the zoning change, the average size of crabs in the protected Site 1 increased for a sustained period of 8 months possibly due to larger, legal size crabs not being removed by fishers. The average size was higher in December 2002, than any other of the 38 months sampled during the study (Figure 4.31). At Site 2, the average size followed similar patterns to those found when only the professional fisher harvested the area prior to the zoning change, with the average width being slightly bigger than the legal size limit of 128 mm.

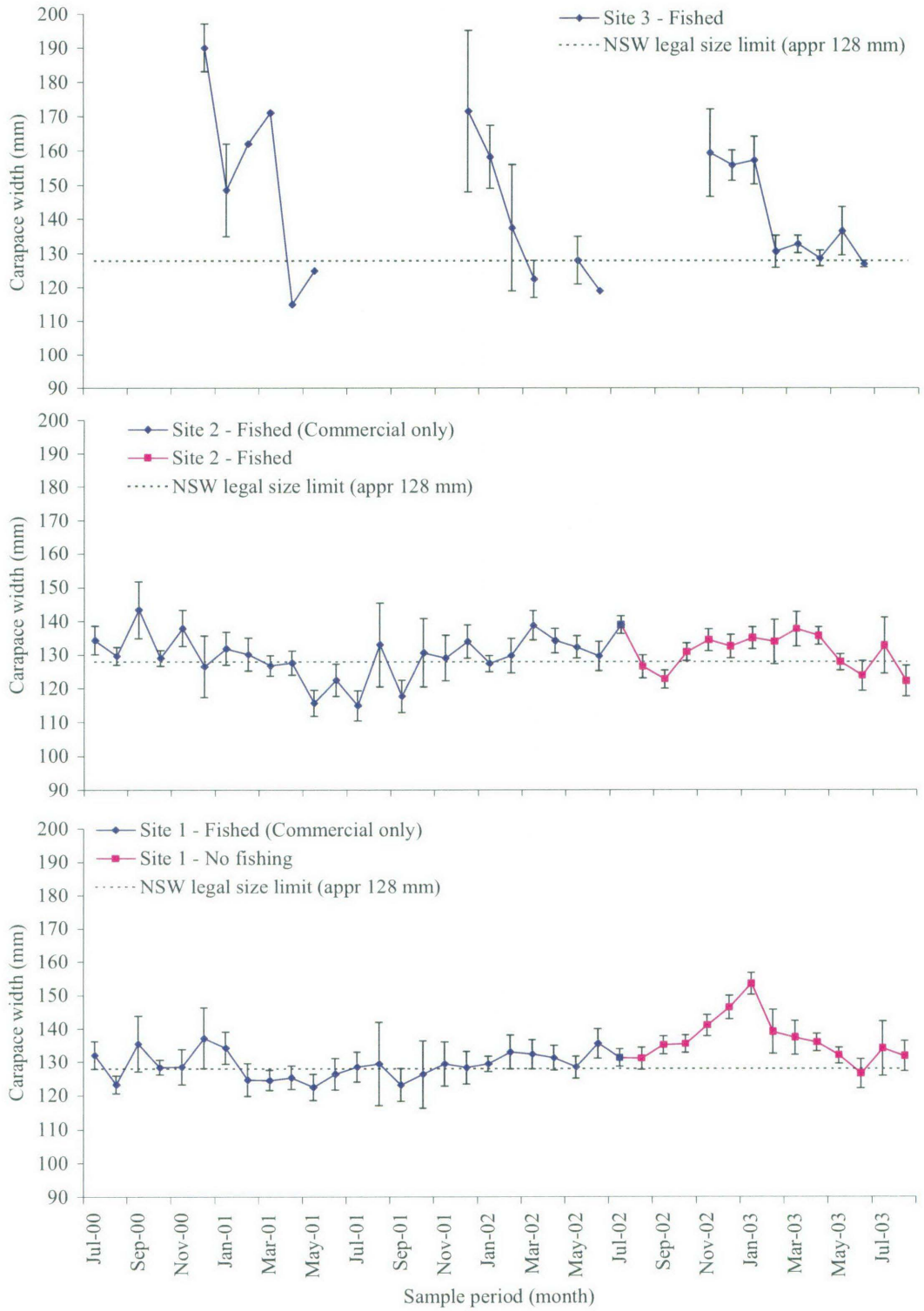


**Figure 4.31**. Average (±SE) carapace width (mm) of mud crabs caught each month in fished and unfished areas of the Sandon Estuary between July 2000 and August 2003.

**Gender**

A total of 559 male and 357 female crabs were caught in the Sandon Estuary between July 2000 and August 2003 (Figure 4.32). In the 25 months prior to the zoning change 300 male and 171 female crabs were caught in three different sites consisting of different fisher effort (Figure 4.32a). There was an association between the areas sampled and the number of male and female crabs caught ($\chi^2$ 9.37, df 2, P = 0.0092) with the largest variation occurring at Site 3. Site 3 had more female crabs caught in both periods before and after the zoning change while the gender ratio at Site 1 (1.74) and Site 2 (2.04) consisted of almost two male crabs to every one female (Figure 4.32a)

In the 13-month period after the zoning change, 259 male and 186 female crabs were captured with no association between area and gender ($\chi^2$ 4.11, df 2, P = 0.1285) (Figure 4.32b). All expected and observed $\chi^2$ square test values were similar with the biggest variation at Site 3, which had more female crabs than males. The ratio of male/females decreased after the zoning change with similar levels occurring at Site 1 (1.47) and Site 2 (1.57) even though different fishing pressure was placed on each site.

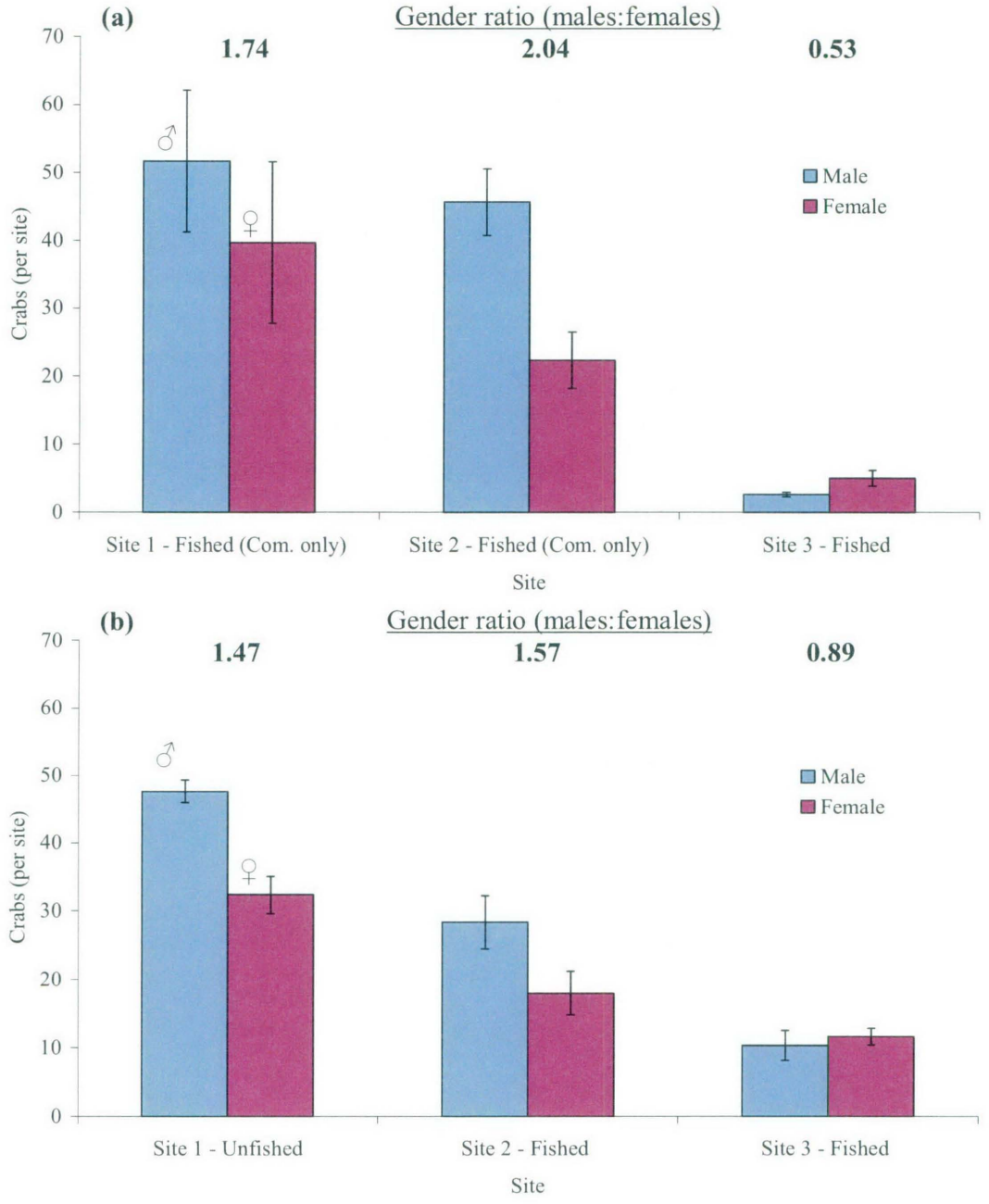


**Figure 4.32.** Average (± SE) number of male and female crabs caught and gender ratio at each site before (a) and after (b) the zoning change.

### 4.3.4 Mud crab movement

**Tag returns – recreational fishers**

A total of 249 (4.5% of the total crabs caught) crabs was reported as having been recaptured by recreational fishers during the study. Assessments of crab movements were only possible at Wooli because of the small tag returns from fishers at Sandon and Corindi. Only two tags were returned at Sandon by the professional fisher and one tag was returned from Corindi Estuary by NSW Fisheries Conservation and Technology staff conducting netting surveys.

In the Wooli Estuary prior to the zoning change, the number of tagged crabs caught by recreational fishers declined with distance from the zone border with 64%, 12% and 10% of recaptures being made in the first 1, 2 and 3 km downstream of the Sanctuary Zone (Figure 4.33). After the zoning change, 42% of crabs were caught at the Sanctuary Zone border while a further 31% of crabs were taken upstream in the area open to fishing, which included Site 4 (UF) (Figure 4.33). Very few crabs were recaptured in the area from the estuary mouth to 3 km upstream while above this, small numbers of crabs were caught at each site until the majority of recaptures occurred from Site 14 – 16 (7 – 8 km from the estuary mouth). No crabs were recaptured above the rock bar above Site 20 while two crabs were recaptured by NSW Fisheries staff in the protected northern arm of the estuary during netting surveys (Figure 4.33).

More male crabs were caught in each section of the estuary at distances greater than 1 km from the estuary mouth. One female crab was caught at the mouth of the estuary while three female crabs were caught offshore from Minnie Waters during December 2003. These three crabs were caught in the same area on a small patch of reef approximately 0.5 - 1 km offshore. Each crab had moved approximately 14 km from the mouth of the Wooli Estuary in a N/NE direction. Each of the three crabs had moved approximately 23 km from their original release site.

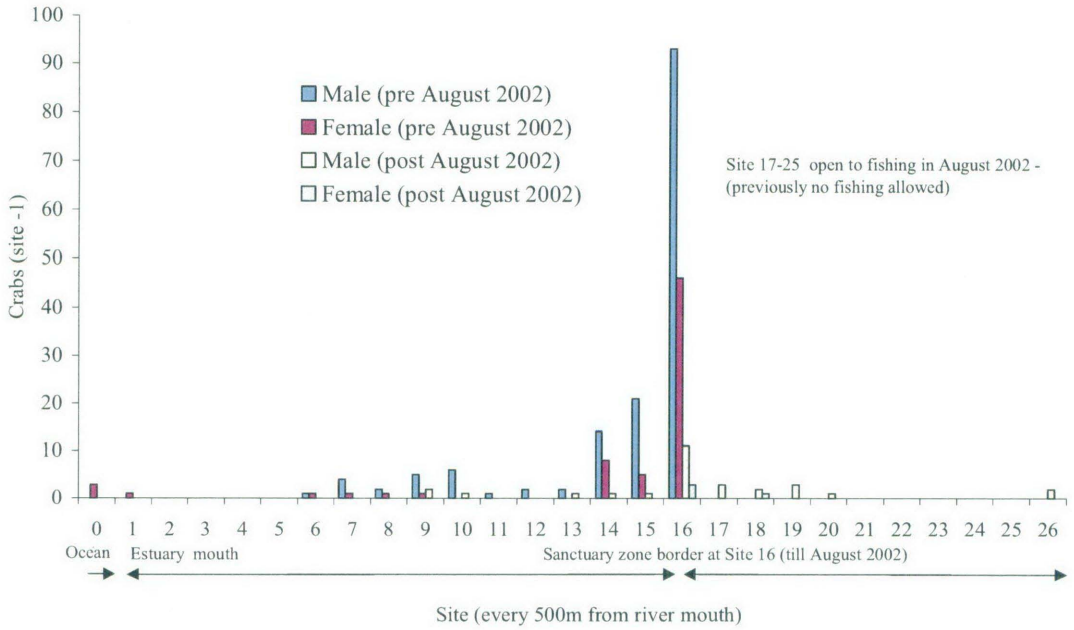


**Figure 4.33**. Location of recaptured crabs in the Wooli Estuary before and after the zoning change. Results are tags returned by recreational anglers (n = 249)

Tag returns from recreational anglers varied each year with two peak periods occurring between January 1999 - June 1999 and March 2002 - June 2002 (Figure 4.34). Increases in recaptures occurred during September 1999 and August 2002. Significant flooding events resulting in low salinity concentrations occurred in the estuary during February - August 1999, November 2000, February 2001, March - April 2002 and March - April 2003 (Appendix 8). These periods coincided with an increase in tag returns with January 1999 and March 2002 being months at the beginning of significant recapture periods (Figure 4.34)

Males dominated catches in most months with more female recaptures occurring between December - February (1999 - 2001), March - June (2002) and March - April (2003) (Figure 4.34). The largest catches of females during these periods occurred in February 1999 and May/June 2002.

Crabs recaptured by recreational anglers originated from different areas of the estuary (Figure 4.35). Similar numbers of crabs moved from the unfished Site 1 (99 crabs) and Site 2 (73 crabs) before and after the zoning change with 8 crabs (Site 1) and 15 crabs (Site 5). Once the zone was opened in August 2002, recaptures primarily came from Site 4 that month with few crab tags being returned after August 2002.

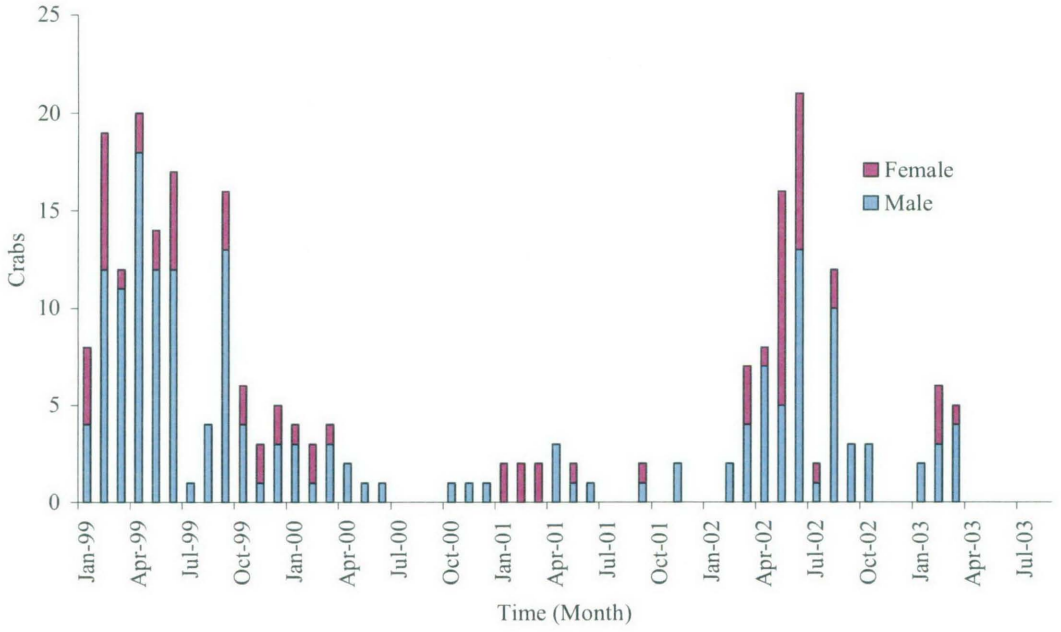


**Figure 4.34**. Total number of male and female crabs recaptured each month by recreational fishers

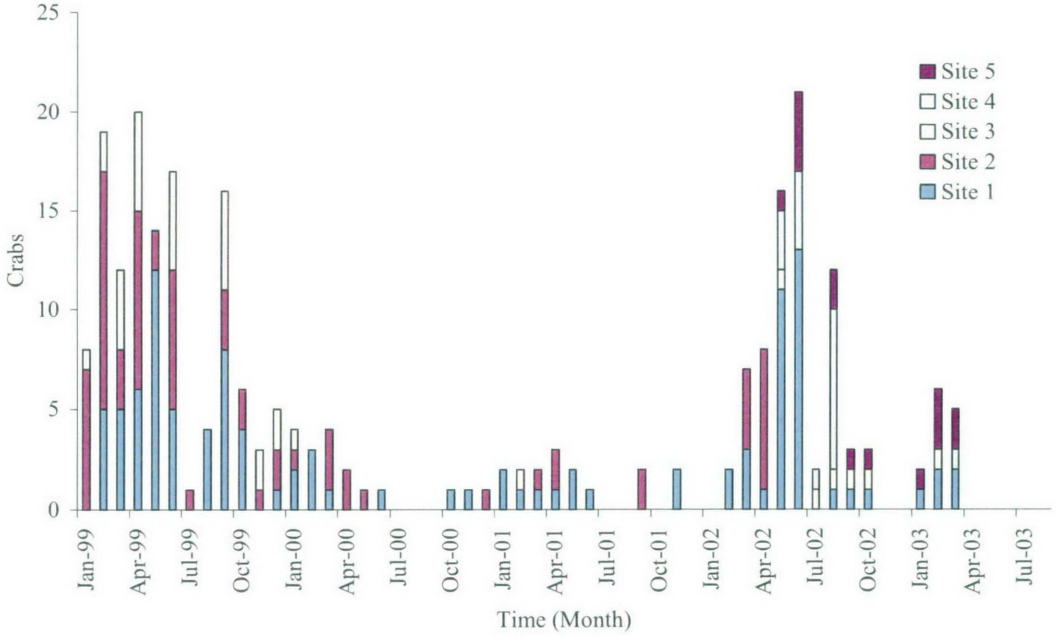


**Figure 4.35**. Total number of crabs recaptured each month by recreational fishers by reference to the site crabs had been previously released at.

**Tag returns – Research recaptures**

A total of 969 (17.6% of the total crabs caught) crabs was recaptured during the monthly sampling trips. Crabs were recaptured in all months with 596 crabs recaptured over 55 months at Wooli and a further 163 crabs at Sandon and 210 crabs at Corindi captured over 38 months (Figure 4.36).

Regular monthly recaptures occurred in each estuary with the highest average number of recaptures each month occurring at Wooli (11 crabs) than Corindi (5.5 crabs) and Sandon (4 crabs). Recaptures of crabs showed a seasonal trend with higher recaptures occurring during winter. There was an increase in catches after the zoning change in the Sandon and Corindi estuaries with the majority of crabs coming from the unfished Sanctuary Zone sites and fished Site 3 in both estuaries (Figure 4.36).

There was no change in the site of origin of recaptured crabs between the same sites before and after the zoning change in each estuary (Table 4.22). Crabs recaptured in each site showed the same trend regardless of zone type suggesting that source and sink areas are consistent in each estuary. However, the source of recaptured crabs in each estuary differed among sites before the zoning change in all estuaries and after the change at Wooli (Table 4.22). Results at Sandon, Wooli and Corindi suggest that the highest recaptures occurred from crabs which had previously been caught in the same site while the recaptures from the fished Site 3 in each estuary consisted of similar numbers of crabs from the upstream protected sites (Figure 4.37)

After the zoning change, the trend only continued at Wooli, where the unfished Site 1 and Site 5 had the highest recaptures from crabs previously caught at those sites (Table 4.22, Figure 4.37). In the two fished sites, Site 3 had similar numbers of crabs from all sites and Site 4 contained similar numbers of recaptures from Site 1, Site 4 and Site 5 (Figure 4.37).

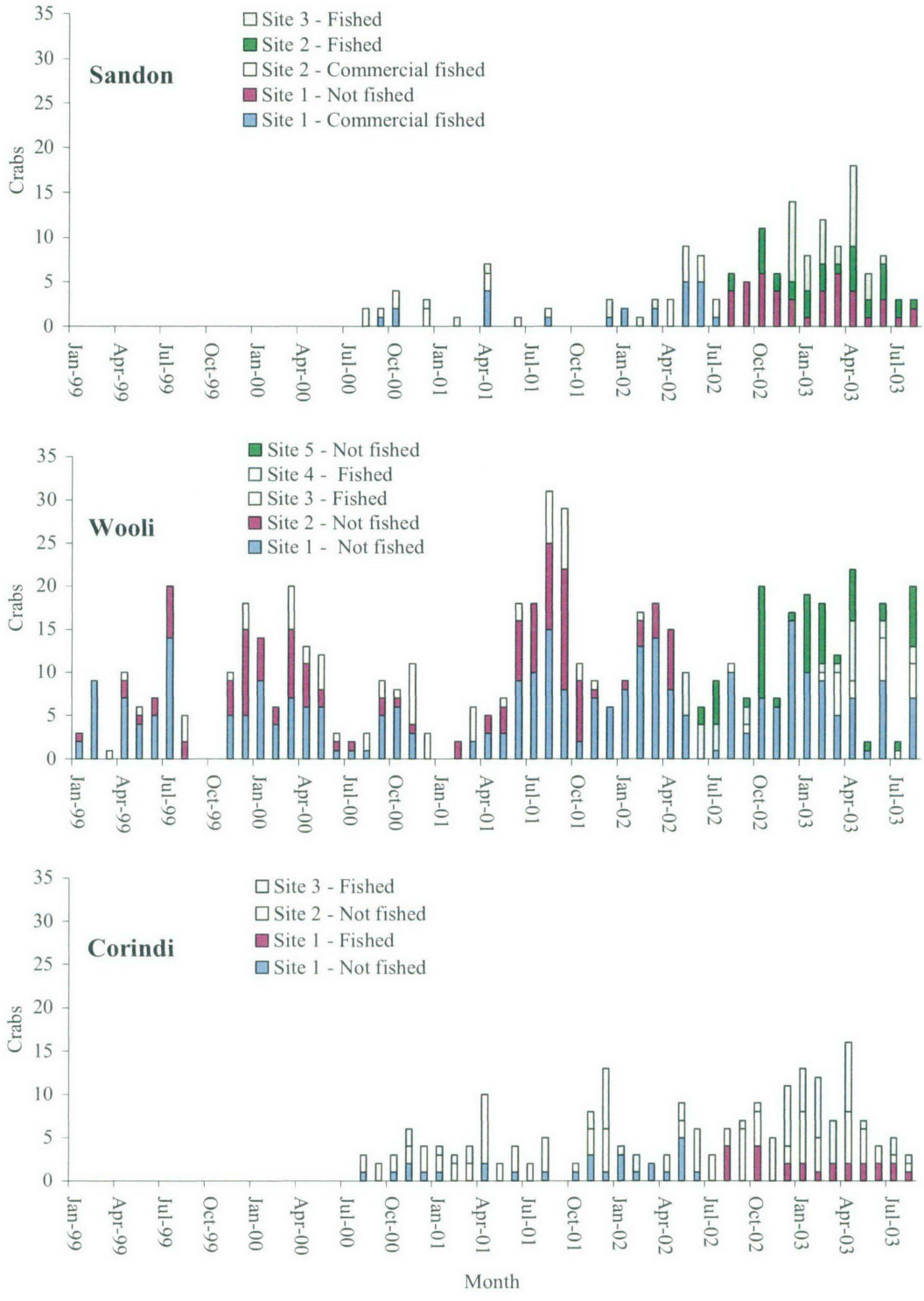


**Figure 4.36**. Temporal changes in the total number of crabs recaptured during monthly research sampling at each site in the Sandon, Wooli and Corindi estuaries.

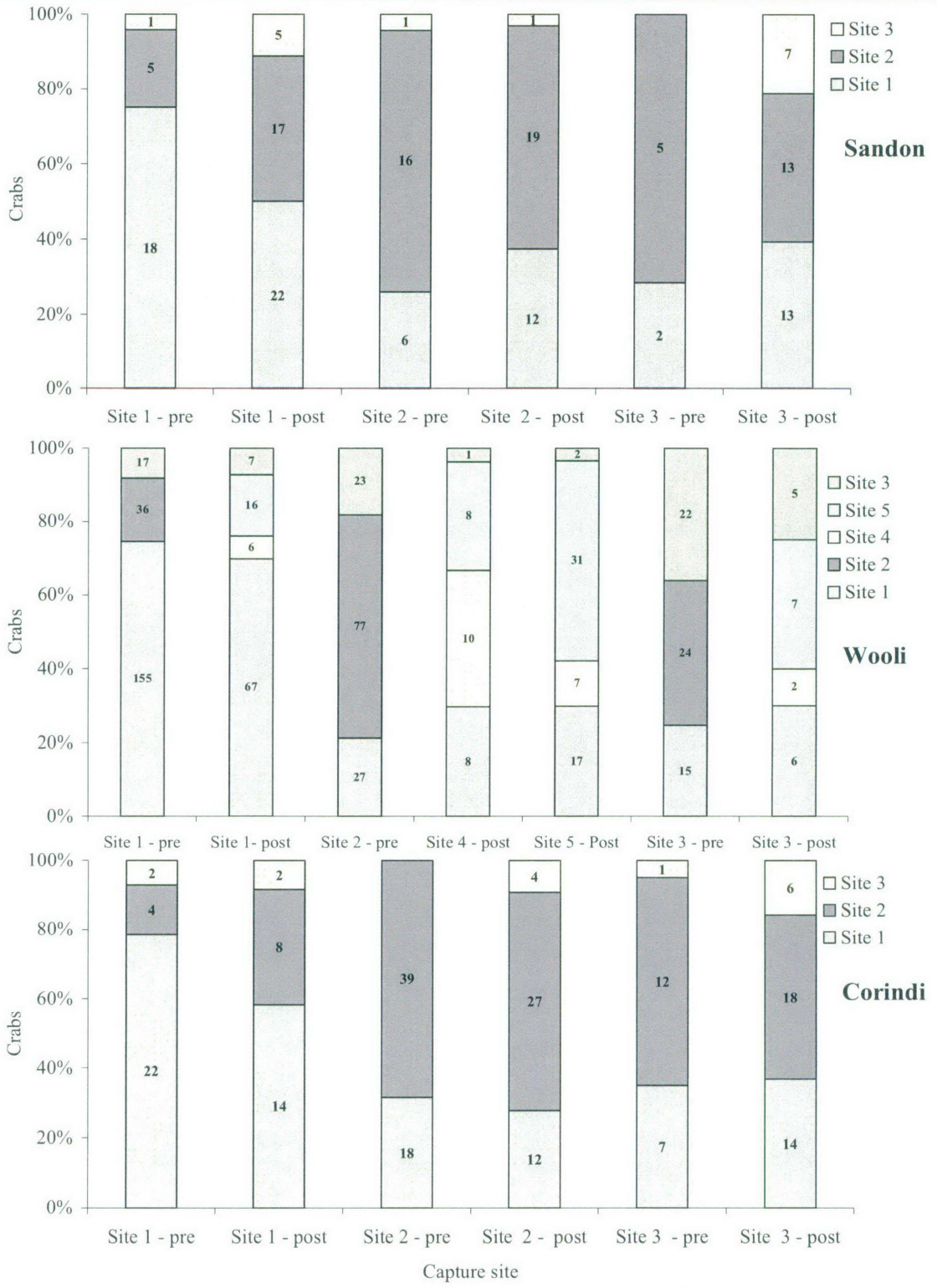


**Figure 4.37.** A comparison (as a proportion) of where recaptured crabs had initially originated and the total number (numbers in columns) of recaptured crabs that came from that site before and after the zoning change in each estuary.

**Table 4.22.** Comparison of $\chi^2$ square values comparing the association between release site and area of recapture between the same sites before and after the zoning and among different sites before and after the zoning change in each estuary.

| Estuary | Before v After | | | Before | After |
|---|---|---|---|---|---|
| | **S1 v S1** | **S2 v S2** | **S3 v S3** | **S1 v S2 v S3** | **S1 v S2 v S3** |
| **Sandon** | $\chi^2$ 4.08, df. 2, P = 0.1298 | $\chi^2$ 0.81, df. 2, P = 0.6683 | $\chi^2$ 2.98, df. 2, P = 0.2251 | $\chi^2$ 13.47, df. 4, **P = 0.0092** | $\chi^2$ 7.40, df. 4, P = 0.1163 |
| **Corindi** | $\chi^2$ 2.82, df. 2, P = 0.2441 | $\chi^2$ 5.53, df. 2, P = 0.0630 | $\chi^2$ 1.68, df. 2, P = 0.4316 | $\chi^2$ 23.76, df. 4, **P < 0.0001** | $\chi^2$ 7.53, df. 4, P = 0.1103 |
| | | | | **S1 v S2 v S3** | **S1 v S3 v S4 v S5** |
| **Wooli** | | | | $\chi^2$ 121.54, df. 4, **P < 0.0001** | $\chi^2$ 58.83, df. 9, **P < 0.0001** |

### 4.3.5 Fishing effort

The average number of traps/month for recreational and commercial fishers in each estuary before the zoning change was lower than after the zoning change (Figure 4.38). Before and after the zoning change there were considerably more traps at Wooli and similar numbers in Sandon and Corindi. After the zoning change, the average number of traps at Sandon quadrupled, those at Corindi doubled, and there was a small increase at Wooli.

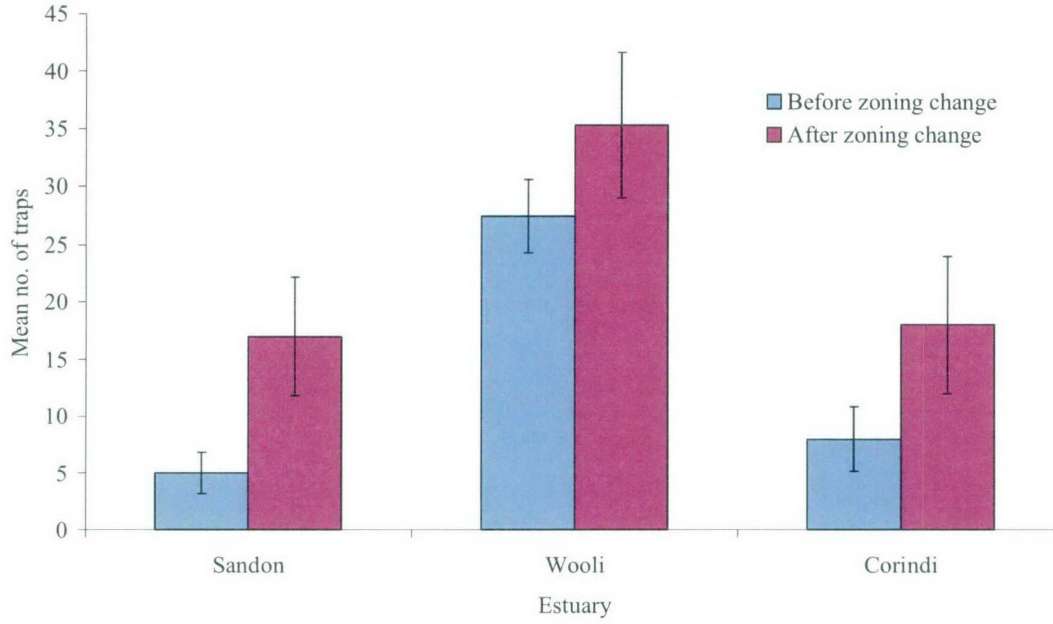


**Figure 4.38.** The mean number of traps per day in the Sandon, Wooli and Corindi estuaries over the three-day period during each sampling trip.

Prior to the zoning change, trapping at Corindi and Sandon was undertaken primarily during December and January with an average of 31 (Sandon) and 49 (Corindi) traps (Figure 4.39). Smaller numbers of traps (0 - 10 traps) were found in the months leading up to these peak periods. The majority of traps occurred adjacent to the zone borders at Site 3 with few traps being found closer to the estuary mouth. At Wooli, trapping occurs all year round peaking during summer. This effort is also aimed at the Sanctuary Zone border with 63% of traps occurring in the first 2 km downstream from the zone border within Site 3.

Changes in the zoning scheme caused changes in fisher effort (Figure 4.39). The average number of traps in the months after August 2002 in each estuary was similar to trap numbers found only in December and January in previous years (Figure 4.39). At Wooli, effort shifted

from Site 3 upstream into the new area opened to fishing at Site 4, where 25% of the fishing effort for the next 13 months was targeted. However, this effort was highest directly after the zoning change. In the first 6 months after the change, 50% of the trapping effort each month targeted this new area. This effort decreased after March 2003.

At Sandon and Corindi a small pulse in effort was recorded when the zone was opened in August 2002, with a further pulse in December 2002 and January 2003 (Figure 4.39). This effort at Sandon and Corindi was targeted upstream of the previous zone border with traps being found throughout the estuaries. The increased effort upstream was short-lived as few traps remained in the estuary each month. In particular, no fishing effort was seen again at Site 3 in Corindi and only 5 traps occurred at Site 3 during July 2003 at Sandon.

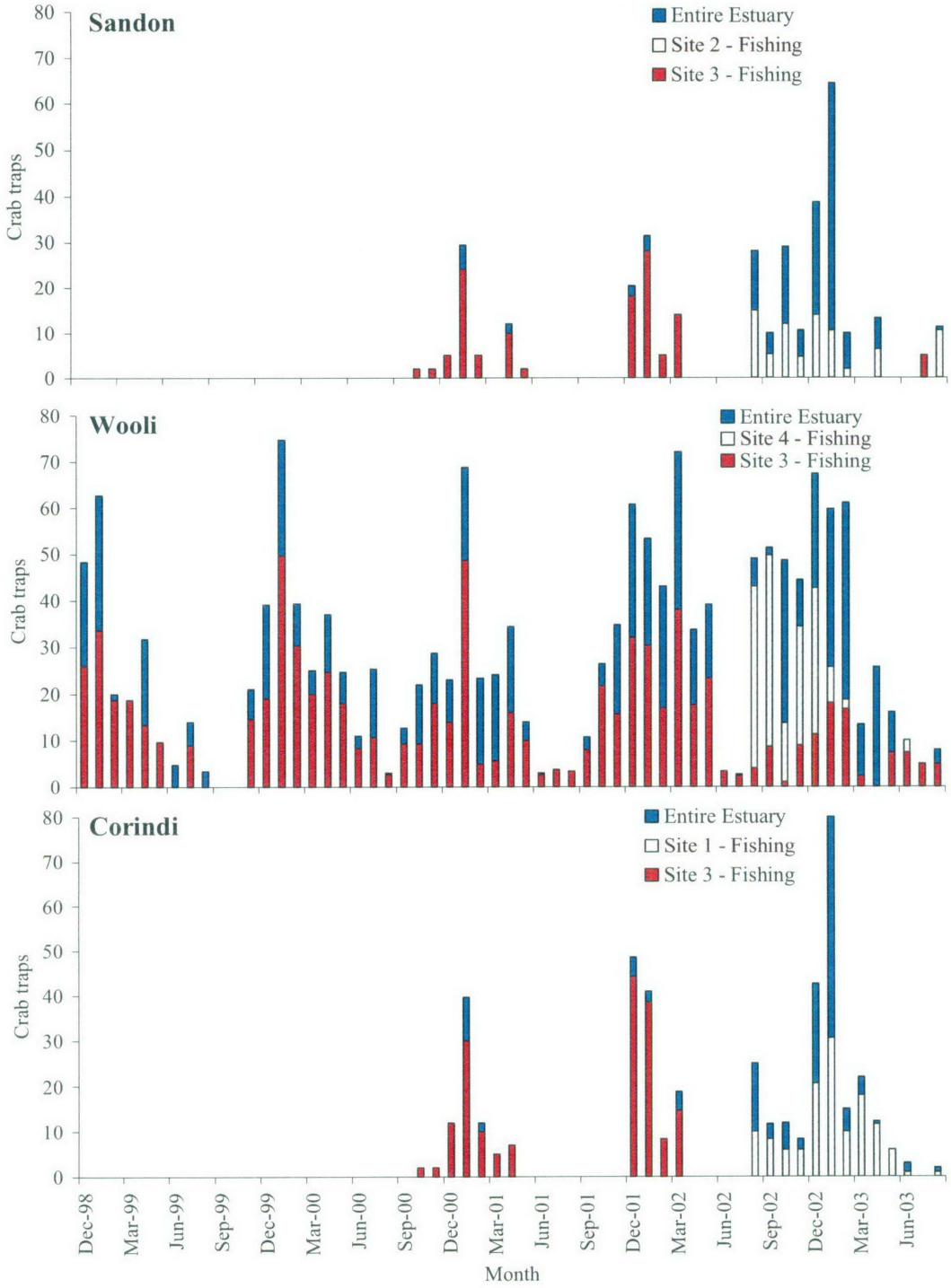


**Figure 4.39**. The mean number (± SE) of traps per day each month in the Sandon, Wooli and Corindi estuaries over the three-day period during each sampling trip.

**Short term fishing intensity survey**

Daily counts of boats and traps were taken at 1 km intervals from the estuary mouth at the Wooli Estuary between the 20th December 2002 and 28th January 2003 (Figure 4.40). The actual number of boats in the estuary at the time of sampling was small but the number of traps was high.

Fishing effort was highest during week two, three and five (26th December - 7th January and 24th January - 27th January) of the survey (Figure 4.40). Periods of low fishing effort varied during the survey depending on the weather. Strong winds during 9 - 10th January and the 23rd January coincided with low trap and boat numbers while few boats and traps occurred on the 24th and 25th December (Christmas Eve and Christmas Day).

The total number of traps in the estuary was high with more than 100 traps over 15 km of estuary on 13 of the 40 days and an overall average of 73 traps per day (Figure 4.40). Most of these were concentrated in the same area in the middle section of the estuary 7 km from the estuary mouth (Figure 4.41). In the lower estuary (1 - 6 km), each area had small numbers of traps with 3 - 6 traps per site. Further upstream (7 - 11 km), sites averaged more traps with 16 traps/km occurring 7 km from the estuary mouth. Above this, fishing effort was high for the next 4 km with 6 - 12 traps/km but few traps were found above the rock bar located 11 km upstream from the estuary mouth.

Boating activity followed trends similar to trapping effort and was greatest in the lower and middle sections of the estuary (Figure 4.40). There was not always a boat in each area (1 km section) of the estuary with the 5 km and 7 - 8 km sections the only areas to average at least one boat in that stretch of estuary on each day. Few boats occurred at distances greater than 9 km upstream.

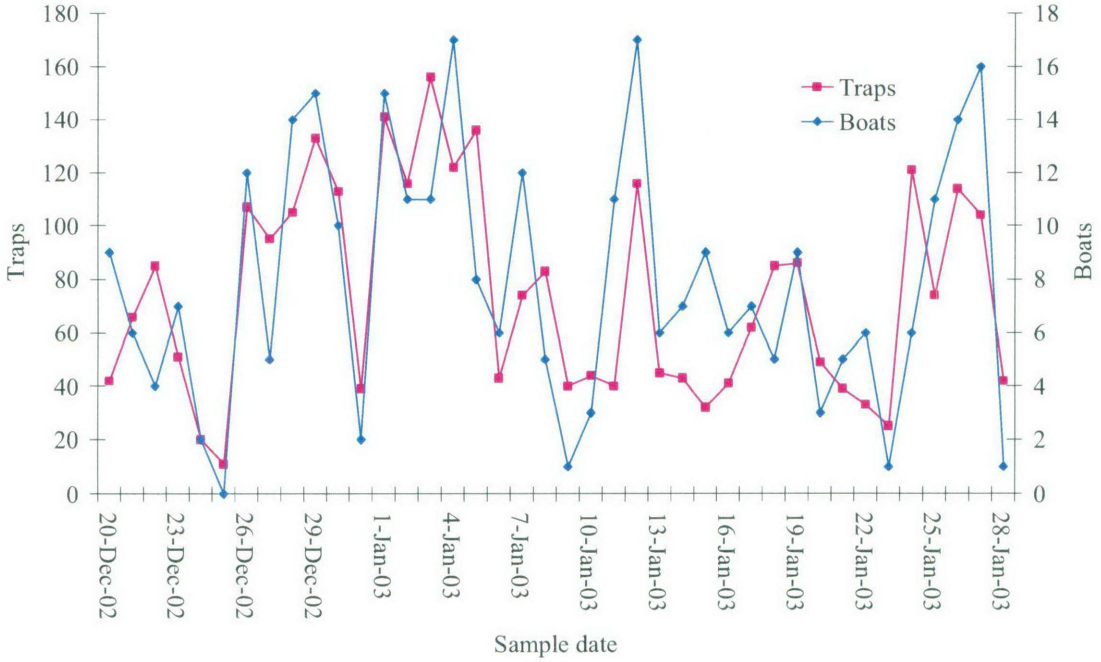


**Figure 4.40.** Temporal variation in the daily number of traps and boats in the Wooli Estuary from the 20th December 2002 - 28th January 2003.

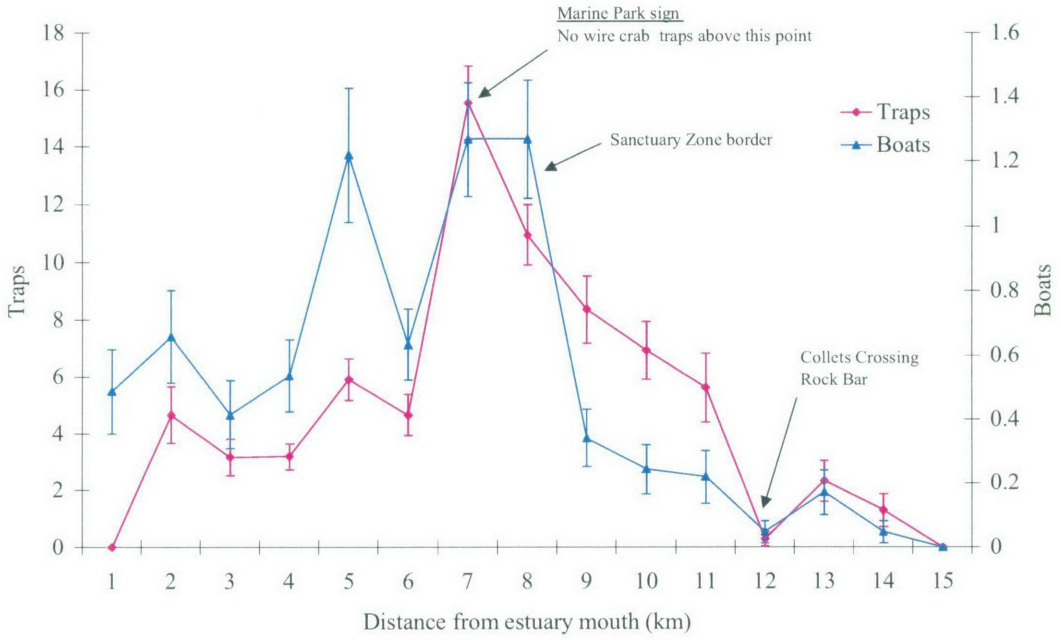


**Figure 4.41.** The average number (± SE) of traps and boats over 40 days in the Wooli Estuary at 1 km intervals from the estuary mouth.