

Biology of Four Species of Whiting (Pisces: Sillaginidae) in Botany Bay, New South Wales

J. J. Burchmore, D. A. Pollard, M. J. Middleton^A, J. D. Bell and B. C. Pease^B

Fisheries Research Institute, N.S.W. Agriculture and Fisheries, P.O. Box 21, Cronulla, N.S.W. 2230.

^A Present address: R.S.D. Wattle Grove Road, Cygnet, Tas. 7112.

^B Present address: Point Whitney Shellfish Laboratory, P.O. Box 102, Brinnon, Washington, 98320, U.S.A.

Abstract

Four species of whiting (Family Sillaginidae) were collected from Botany Bay, New South Wales, between 1977 and 1979: *Sillago ciliata* (sand whiting), *S. maculata maculata* (trumpeter whiting), *S. robusta* (stout whiting) and *S. bassensis flindersi* (eastern school whiting). *Sillago ciliata* was the most abundant species over-all. *Sillago ciliata* was caught in greatest numbers in *Zostera* seagrass and shallow sandy habitats, whereas *S. m. maculata*, *S. robusta* and *S. b. flindersi* were most abundant over deeper muddy and sandy habitats. *Sillago ciliata* and *S. b. flindersi* were present mainly as juveniles. Gonosomatic indices and gonadal maturity stages of *S. ciliata* and *S. m. maculata* peaked around February. These species probably spawn within the Bay. Length to caudal fork at first maturity was 24 cm for male and female *S. ciliata*, 19 cm for male and female *S. m. maculata*, 17 cm for male and 18 cm for female *S. robusta*, and 14 cm for male and female *S. b. flindersi*. Although all species fed mainly on polychaetes and crustaceans, there was little overlap in specific dietary items between species. Variations observed in diet were due to fish size and temporal and spatial habitat differences within and among species.

Introduction

Four species of whiting (Family Sillaginidae) occur commonly over soft substrata in the inshore waters of New South Wales: the sand whiting, *Sillago ciliata*; the trumpeter whiting, *Sillago maculata maculata*; the stout whiting, *Sillago robusta*; and the eastern school whiting, *Sillago bassensis flindersi*.

Sillago ciliata is a predominantly estuarine species that grows to a maximum length of approximately 45 cm. It is distributed from Papua New Guinea to Tasmania but is most commonly found in northern New South Wales and southern Queensland (McKay 1985). *Sillago maculata maculata* attains a maximum length of approximately 30 cm (Grant 1978) and is found in estuarine and nearshore waters off the east coast of Australia (McKay 1985). It is more abundant in warmer waters within its range. *Sillago robusta* is principally a deeper-water species, attaining a maximum length of approximately 28 cm (Grant 1978). It occurs throughout inshore marine waters off south-eastern Australia. *Sillago bassensis flindersi* is found in coastal waters from southern Queensland to Tasmania and reaches a maximum length of approximately 32 cm (McKay 1985).

Little is known about temporal and spatial habitat utilization by these species, or when and where they reproduce. This paper reports the habitat associations of these species at different stages of their life history within the shallow (<4 m) and deep (>4 m) sandy, muddy and vegetated substrata of Botany Bay. Data on the feeding habits, reproductive development and spawning seasons of the four species are also presented.

Study Area

Botany Bay ($34^{\circ}1'S$, $151^{\circ}12'E$.) is a large marine embayment in the south of the Sydney metropolitan area (Fig. 1). Its northern shore supports extensive industrial, port and airport facilities. Twelve sampling sites (Fig. 1) were chosen to represent the variety of soft substrate habitats in the Bay, as outlined in Anon. (1981). The western *Zostera* (WZ) site was sampled only in the second year to replace the northern *Zostera* (NZ) site which had been covered by dredge spoil.

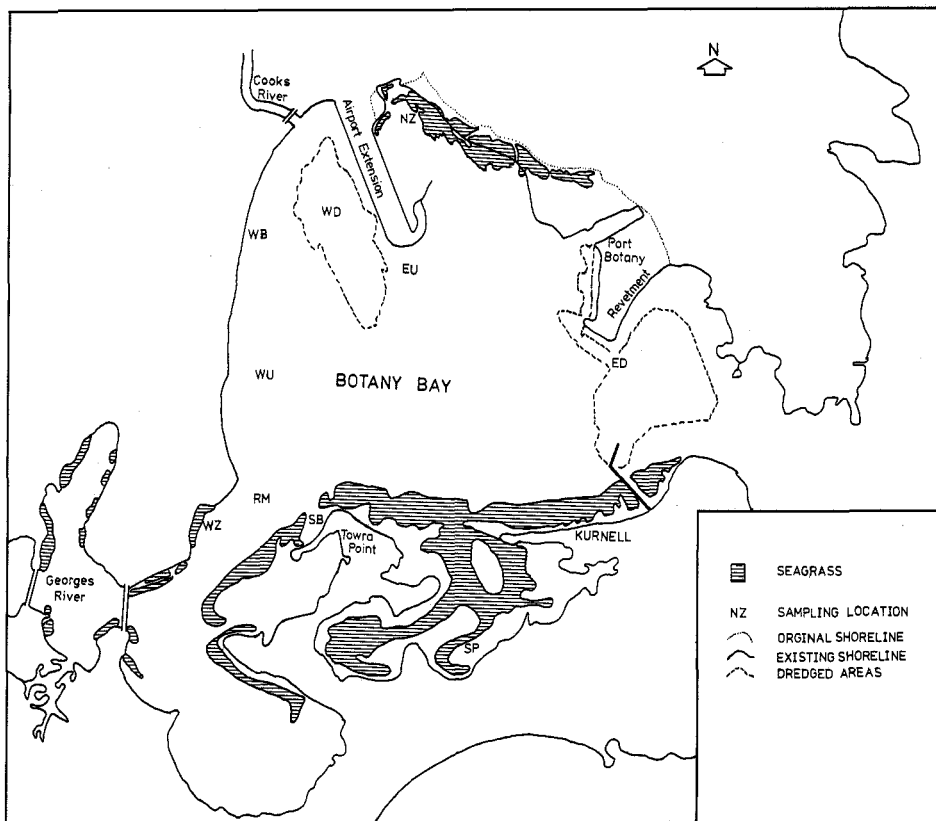


Fig. 1. Sites in Botany Bay sampled for whiting: ED, Eastern Dredged; EU, Eastern Undredged; NZ, Northern *Zostera*; RM, River Mouth; SB, Southern Beach; SP, Southern *Posidonia*; WB, Western Beach; WD, Western Dredged; WU, Western Undredged; WZ, Western *Zostera*.

Materials and Methods

Distribution and Abundance

Fish were sampled bimonthly over 2 years from December 1977 through October 1979 using a variety of fishing methods depending on habitat. Sampling regimes and techniques are outlined in Table 1 and consisted principally of replicate 5-minute otter trawls during both day and night at the offshore (deep) sites, and replicate seines during both day and night at the inshore (shallow) sites. Smaller numbers of whiting were also captured by poisoning, gill-netting and beam-trawling.

Individuals of each species were counted, measured to the nearest millimetre (length to caudal fork, LCF) and weighed to the nearest gram (wet weight).

Bimonthly length-frequency distributions were constructed for each species and subdivided by habitat to illustrate recruitment, habitat 'preference' and seasonality of various stages of the life history. Here, recruitment to a habitat refers to the first occurrence of juveniles vulnerable to the sampling methods used in that habitat.

Table 1. Sampling techniques used to catch whiting in Botany Bay and areas fished by each gear type

| Gear type | Sites | Net length (m) | Drop (m) | Length fished (m) | Width fished (m) | Area fished (m) | Mesh size (cm knot to knot) | Time set | Comments |
|----------------------------|--------------------|-------------------|----------|-------------------|------------------|----------------------------------------|----------------------------------|----------------|---------------------------------------------------------------------------------------|
| Monofilament gill nets | NZ, WZ, SP | 300 | 2 | N.A. | N.A. | N.A. | 3.8 6.3 7.6 8.9 10.2 | 2 h | 5 × 60 m panels set from 7 m runabout for 2 × 2 h periods either side of dusk. |
| Beach seine nets | NZ, WZ, SB, WB | (a) 100 (b) 50 | 2.5 2 | 90 40 | 50 25 | 5500 ^A 1250 ^A | 2.5 1 | 5 min 5 min | Set from 7 m runabout and pulled to shore. |
| Otter trawl net | RM, EU, WU, WD, ED | 18.3 | | 400 | 13.3 | 5400 ^A | 3.8 (cod end) | 5 min | Towed by FRV <i>Kamala</i> at constant engine speed. |
| Wall net (poison stations) | NZ, WZ, SP | 40 | 2 | 10 | 10 | 100 | 1 | 1 h | See Bell <i>et al.</i> (1978) for details. |
| Beam trawl | NZ, WZ, SP | 1.5 | 0.5 | 300 | 1.4 | 420 | | 5 min | Towed by 7 m runabout at constant engine speed. See Ruello (1975) for specifications. |

N.A., Not applicable. ^A Area allows for curve of net.

Data depicted in length-frequency distributions were not always based on fish collected by the same method because no single sampling method could be used in all habitats. However, this was only a problem for *S. m. maculata*, where most individuals were caught by trawling but small numbers of juveniles were also caught by seining. The three other species were caught using a single method (trawling in the case of *S. b. flindersi* and *S. robusta* and seining in the case of *S. ciliata*). Habitats that were sampled by the same method are shown in Table 1.

A three-way ANOVA was used to look for differences in abundance of *S. ciliata*, *S. m. maculata* and *S. robusta* among sites in Botany Bay, among the twelve 2-month periods (bimonths) and between times of day (day v. night). Numbers of *S. b. flindersi* collected were too low to make valid statistical comparisons. In these analyses, bimonth and time were fixed factors but site was a random factor. The Student Newman Keuls (SNK) test was used to detect means that differed significantly. Homogeneity of variances was tested using Bartlett's *F*-test, and data were transformed to $\ln(x)$ where necessary. The number of sites compared differed between species. Only data from the two sandy beach seine sites (SB, WB) were used for *S. ciliata*, whereas those from deep sand (WU, EU) and deep mud (WD, RM) otter-trawl sites were used for *S. m. maculata* and the WU, EU and RM otter-trawl sites for *S. robusta*. In each case, the data consisted of two replicates during both day and night during each month, at each site.

Reproduction

The gonads of each fish were sexed, staged and weighed to the nearest 0.01 g (preserved wet weight). The maturity of ovaries and testes was estimated using a seven-stage system similar to that developed by Hjort (1910) and modified by Pollard (1972). Length at first maturity (LFM) was estimated as the length at which 50% of fish examined had a maturity stage in the range 4–7. A similar method was used by Grey (1979) to assess the LFM of crustaceans. All fish with lengths < LFM were classified as juveniles and those with lengths \geq LFM as adults. Fish with gonads too small to be sexed accurately were classified as 'unsexed'.

A gonad maturity stage index (GMSI) was calculated bimonthly for each sex as the mean gonad stage of all adult fish (i.e. all fish \geq LFM). In calculating the means, stage 7 (spent) gonads were attributed a value of 2. Individual fish weights and gonad weights from adult fish were used to calculate a gonosomatic index (GSI), where gonad weight is expressed as a percentage of whole body weight.

Sex ratios were calculated for adult fish alone and for adults and juveniles combined. The significance of differences in sex ratios in these two groups were calculated using a χ^2 test (Siegel 1956).

Potential spawning habitats of each species were determined as those sites where fish with gonads at maturity stages 5 (maturing) and/or 6 (running ripe) were collected.

Composition of the Diet

Analyses of stomach contents were used to determine feeding habits. Each stomach was attributed a fullness index on a scale from 0–5. The percentage composition of stomach contents was determined by the points (estimated volumetric) method of Pillay (1952), where volumes of each item of stomach contents were estimated to the nearest 5%. Only items that constituted more than 2% of the overall diet are presented in the results.

Effect of fish size on diet was examined by placing individuals into groups, each of which had a 10-cm length range. Differences in diet due to site (where a sample constituted ≥ 30 fish with stomach contents) and month were also determined. The significance of variations in diet due to fish size, site and month were calculated using the Spearman rank correlation coefficient (Fritz 1974).

Results

Distribution and Abundance

S. ciliata

A total of 4287 specimens was caught, ranging from 1 to 40 cm in length to caudal fork (Fig. 2). Overall, the western *Zostera* (WZ) site showed the greatest abundances, with a total of 1997 fish, followed by the shallow sandy beach (SB, WB) sites and the northern *Zostera* (NZ) site. Catches from the NZ site were very low after mid 1978, when most of this site was covered by dredge spoil during reclamation for a foreshore road.

Recruitment of very small individuals (<5 cm LCF) coincided with the latter half of the reproductive period, i.e. April–June (Fig. 2). Juveniles (<24 cm LCF; 94.5% of the sample population; see Reproduction section of Results) were caught in greatest numbers in shallow

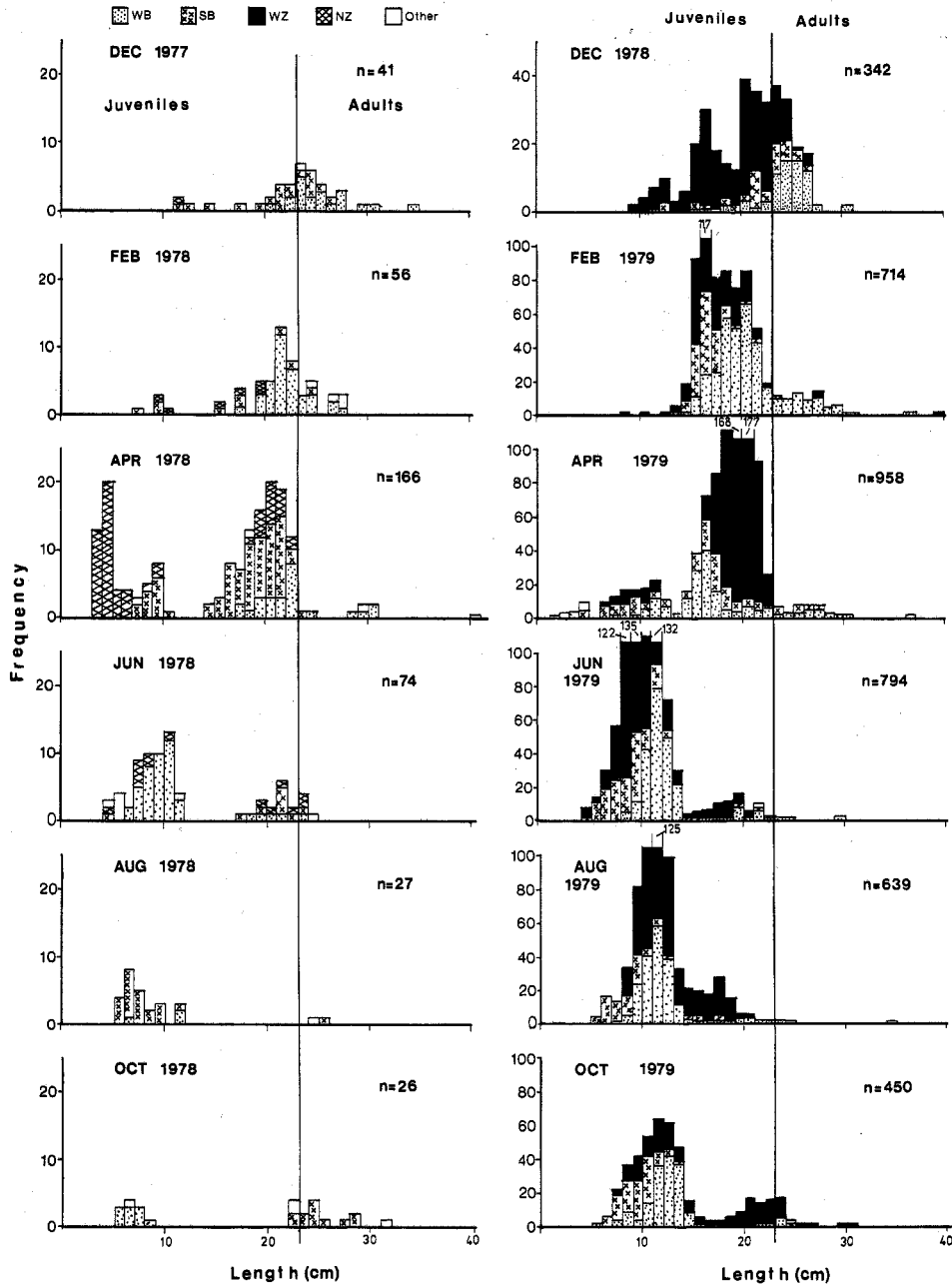


Fig. 2. Bimonthly length-frequency distributions of *S. ciliata* between December 1977 and October 1979 (WZ site was only sampled in the second year).

habitats, particularly sandy beach (SB, WB) and *Zostera* (WZ, NZ) habitats in autumn (Fig. 2). Adults (≥ 24 cm LCF; 5.5% of the sampled population) were caught in greatest

numbers along shallow sandy beach (SB, WB) habitats during summer (December–February) (Fig. 2).

The three-factor ANOVA showed that total abundances of *S. ciliata* did not differ significantly between sites (Table 2). However, there was a significant interaction between the effects of time of day and bimonth. This was due to greater abundances during the day than at night during February, June and August 1979 (SNK test).

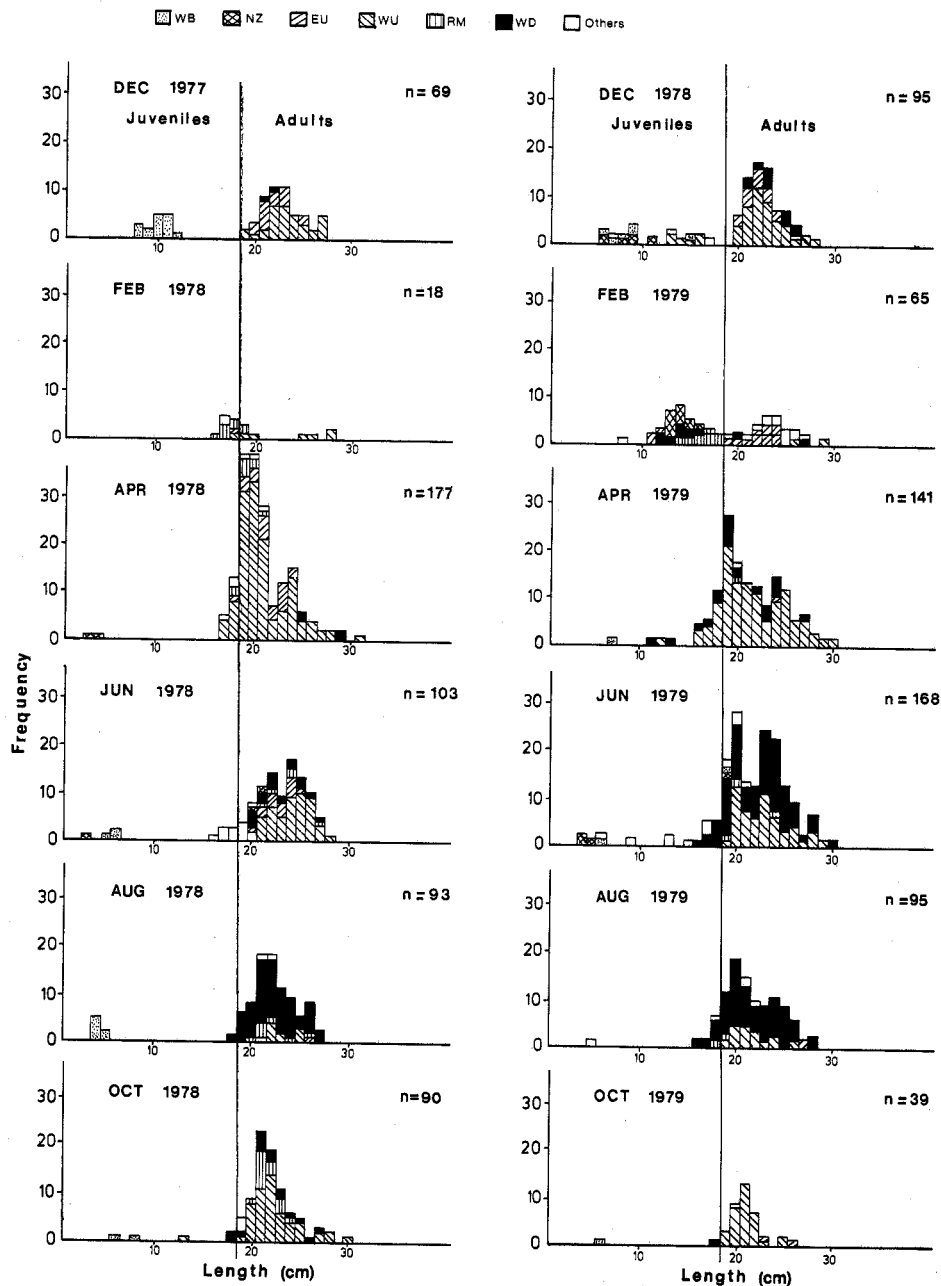


Fig. 3. Bimonthly length-frequency distributions of *S. maculata maculata* between December 1977 and October 1979.

Table 2. Summary of results for mixed ANOVA of abundance for three *Sillago* species
 Because sites are a random factor, F ratios for effects of bimonth are calculated by dividing the Mean Square (MS) by the MS for the Bimonth \times Site interaction. The MS for Time is divided by the MS for Time \times Site. The MS for Bimonth \times Time is divided by the MS for Bimonth \times Time \times Site. F ratios for all other terms are calculated by dividing the MS by the Residual MS. Mean Squares for each term can be calculated by dividing the Sum of Squares (SS) by its degrees of freedom

| Source | <i>S. ciliata</i> | | <i>S. maculata maculata</i> | | <i>S. robusta</i> | |
|-------------------------|-------------------|------|-----------------------------|------|-------------------|------|
| | SS | d.f. | SS | d.f. | SS | d.f. |
| Bimonth (B) | 54.3206941 | 11 | 18.2871726 | 11 | 22.2499732 | 11 |
| Time (T) | 0.5819617 | 1 | 17.0067434 | 1 | 1.2563266 | 1 |
| Site (S) | 0.2636321 | 1 | 23.8160789 | 3 | 16.3635161 | 2 |
| B \times T | 60.9435694 | 11 | 10.7488672 | 11 | 15.0512362 | 11 |
| B \times S | 14.3789293 | 11 | 61.3488919 | 33 | 52.8143246 | 22 |
| T \times S | 1.4440859 | 1 | 7.5274364 | 3 | 4.9189991 | 2 |
| B \times T \times S | 9.4109355 | 11 | 22.0045532 | 33 | 23.8525705 | 22 |
| Residual | 31.1763891 | 48 | 47.3800541 | 96 | 21.7806761 | 72 |

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

S. maculata maculata

A total of 1153 *S. m. maculata* specimens, with an overall length range of 3–31 cm LCF, was sampled (Fig. 3). The site with the greatest abundances were the western deep mud (WD) and deep sand (WU) sites. Recruitment occurred mainly between April and August

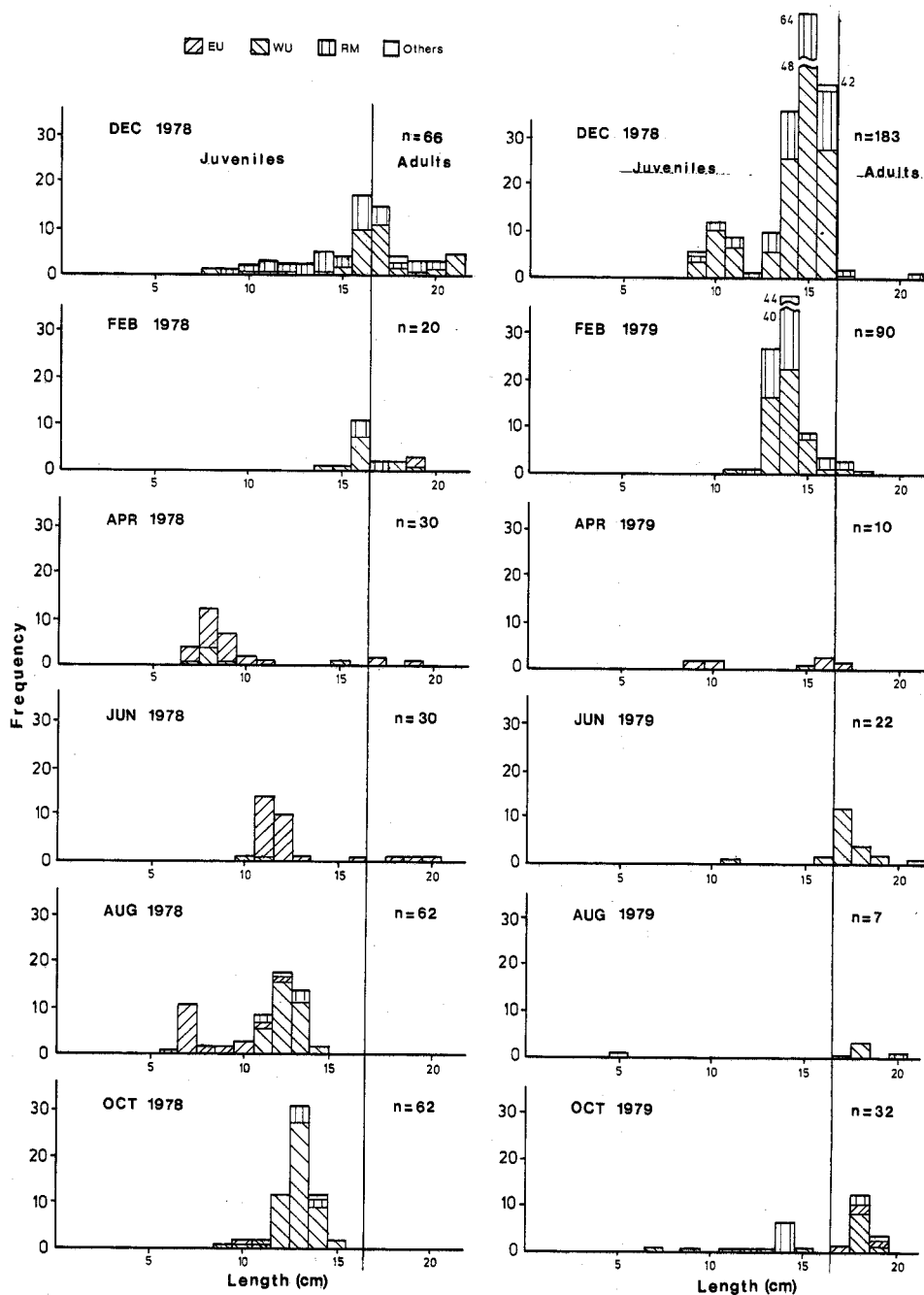


Fig. 4. Bimonthly length-frequency distributions of *S. robusta* between December 1977 and October 1979.

(Fig. 3). Juvenile fish (<19 cm LCF; 15.7% of the sampled population; see Reproduction section of Results) were found in habitats similar to those of juvenile *S. ciliata*, i.e. shallow sand (WB) and *Zostera* (NZ, WZ) habitats.

Adult fish (≥ 19 cm LCF; 84.3% of the sampled population) were most abundant in deeper habitats with a soft substrate (WU, WD, EU, RM). Abundances were greatest at

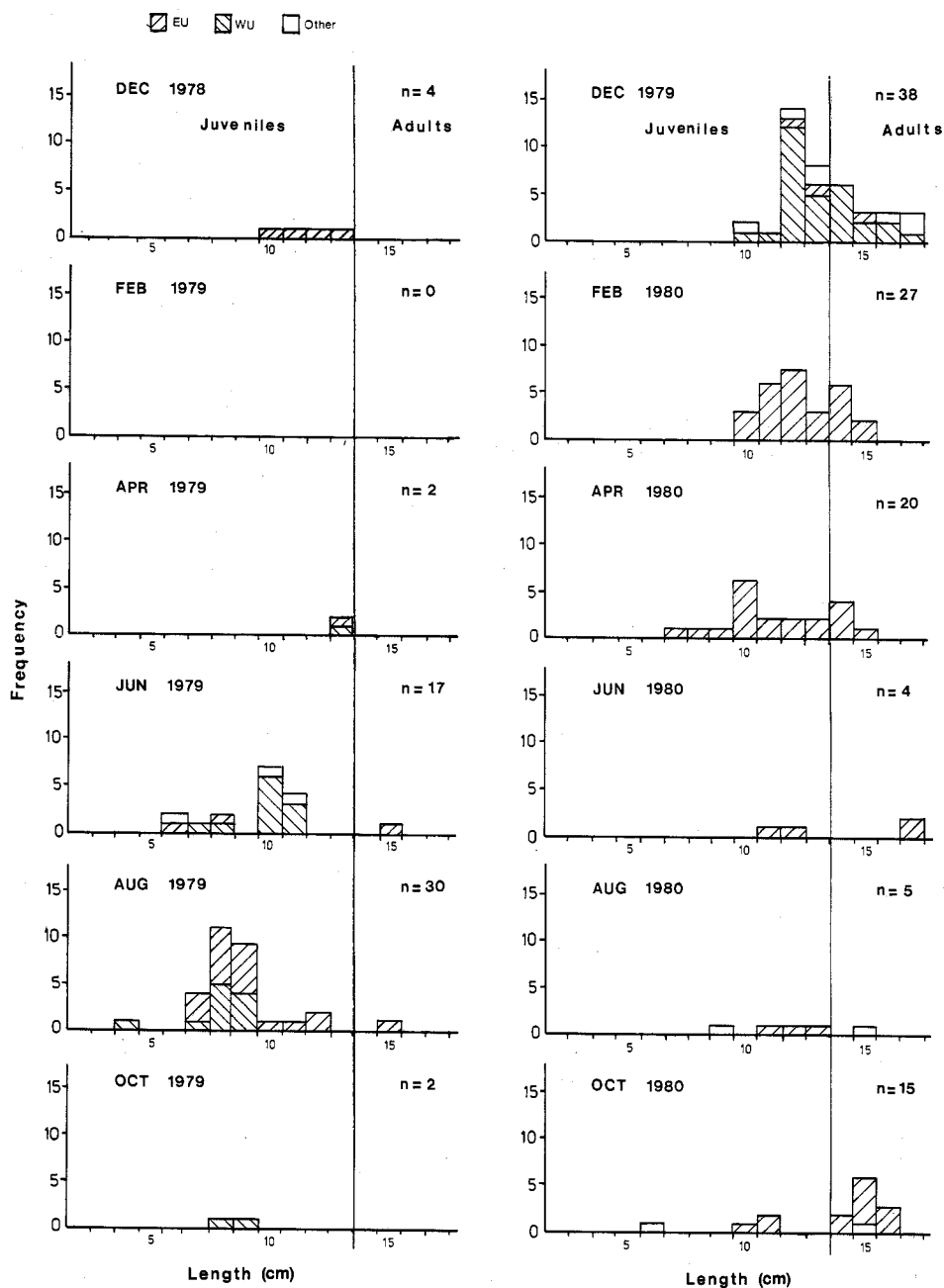


Fig. 5. Bimonthly length-frequency distributions of *S. bassensis flindersi* between December 1977 and October 1979.

the deep sandy site (WU) for most of the year (Fig. 3). However, there appeared to be a migration to the deep dredged mud site (WD) in winter. Adults were generally most abundant around April and June in Botany Bay (Fig. 3).

Three-factor ANOVA showed significant differences in total abundances of *S. m. maculata* among sites, but these differences were dependent on either the bimonth or the time of day (Table 2). Abundance at WU was greater than at the other three sites at night but not during the day (SNK test). The bimonth \times site interaction was due to significantly greater abundances at WD than at EU in June 1979. In all other bimonths, abundances did not differ significantly among sites (SNK test).

S. robusta

A total of 614 *S. robusta*, ranging in length from 5–21 cm LCF, was sampled mostly from the deep sandy sites (WU, RM, EU) (Fig. 4). Juveniles (<17 cm LCF; 84.5% of the sampled population; see Reproduction section of Results) were also most abundant at EU, WU and RM. Recruitment occurred around August, and most juveniles were collected from August through February.

Adults (≥ 17 cm LCF; 15.5% of the sampled population) were most abundant at deep sandy sites during the summer of 1977–78 and the spring of 1979 (Fig. 4). There were, however, many combinations of sites, bimonths and times when no *S. robusta* were caught. This resulted in a significant three-way interaction in the ANOVA (Table 2). Thus differences between sites were dependent on bimonth and time of day. For example, abundances of *S. robusta* at WU during December 1978 were significantly greater at night than during the day (SNK test), whereas the reverse was true during February 1979.

S. bassensis flindersi

Only 164 specimens were captured, encompassing a length range of 4–17 cm LCF (Fig. 5). Abundances were greatest at deep sandy sites (EU, WU), and during the winter of 1979 ($n = 30$, August 1979) and the summer of 1979–80.

Table 3. Sex ratios of four species of whiting in Botany Bay

* $P < 0.05$; ** $P < 0.01$; n.s., non significant ($P = 0.05$); fish > LFM, fish of lengths greater than length at first maturity

| Species | No. unsexed | No. males | No. females | Total No. | Ratio M : F | χ^2 | <i>r</i> |
|-------------------------------|----------------|--------------|----------------|--------------|----------------|----------|----------|
| Total fish | | | | | | | |
| <i>S. ciliata</i> | 458 | 578 | 456 | 1492 | 1 : 0.79 | 14.39 | ** |
| <i>S. maculata maculata</i> | 50 | 384 | 456 | 890 | 1 : 1.19 | 6.17 | * |
| <i>S. robusta</i> | 174 | 143 | 297 | 614 | 1 : 2.08 | 26.95 | ** |
| <i>S. bassensis flindersi</i> | 23 | 61 | 80 | 164 | 1 : 1.31 | 1.28 | n.s. |
| Fish > LFM | | | | | | | |
| <i>S. ciliata</i> | | 72 | 102 | 174 | 1 : 1.42 | 5.17 | n.s. |
| <i>S. maculata maculata</i> | | 318 | 410 | 728 | 1 : 1.29 | 11.63 | ** |
| <i>S. robusta</i> | | 31 | 31 | 62 | 1 : 1 | 0 | n.s. |
| <i>S. bassensis flindersi</i> | | 17 | 25 | 42 | 1 : 1.47 | 0.76 | n.s. |

Reproduction

S. ciliata

Males and females had a LFM of 24 cm LCF. Females attained a maximum of 40 cm LCF, and males 31 cm LCF in the Botany Bay samples. There was a significantly greater number of males in the entire length range of fish measured (Table 3). However, there were

more adult females than adult males present, although this difference was not significant (Table 3). This suggests either differential growth or differential mortality rates between the sexes.

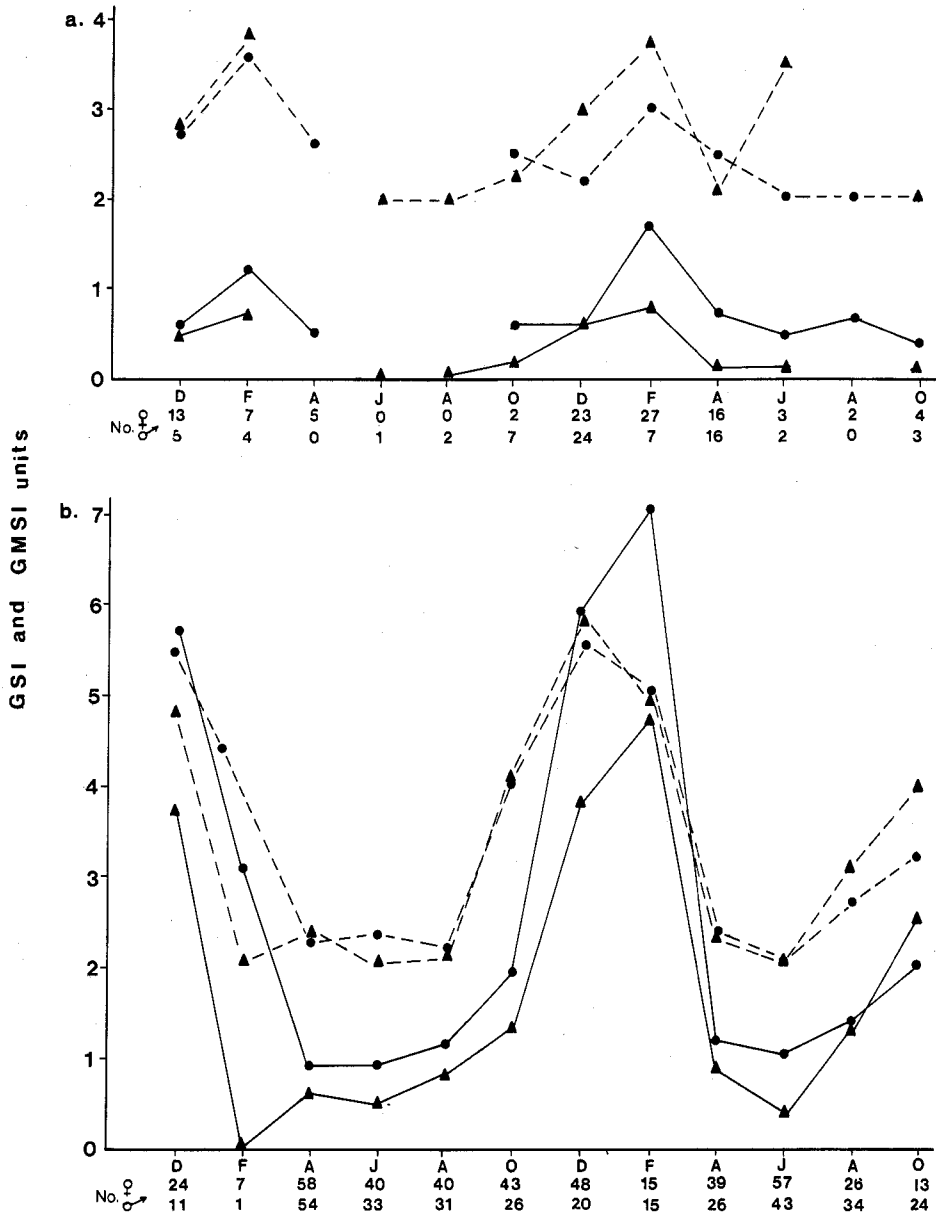


Fig. 6. Reproductive development of (a) *S. ciliata*, and (b) *S. maculata maculata*. Gonosomatic index, GSI (----), and gonad maturity stage index, GMSI (—), shown for males (●) and females (▲).

Both GSI and GMSI peaked in February (Fig. 6a), with the total period of reproductive development extending from December to April. The few running-ripe fish that were collected during February and April 1978 and February 1979 were from the western sandy sites (WB, WU).

S. maculata maculata

Males and females both had a LFM of 19 cm LCF. Females attained a maximum of 31 cm LCF, and males 28 cm LCF in the Botany Bay samples. There were significantly more females than males in the overall sample of fish and in the adult population (Table 3).

This species has an extended period of reproductive development from October to April (Fig. 6b). Reproductive development of males and females was synchronized, with a peak in February and high levels of maturation in December. Running-ripe fish were found during all sampling periods except June, but were most abundant in December and February of both years. Relatively large numbers of running-ripe fish were taken from deep sand or mud sites (WU, EU, WD). This suggests that this species spawns within the Bay.

S. robusta

The LFM was 17 cm LCF for males and 18 cm LCF for females. Females and males attained a maximum length of 21 cm LCF in the Botany Bay samples. There were significantly more females in the overall sample and there were equal numbers of adult males and females (Table 3).

Because of the small sample size of adults ($n = 31$, Table 3), it was difficult to assess the spawning season of this species. There was some evidence that female GSI and GMSI were higher from October to February, and that male values were also slightly higher in October and December. As no ripe fish were found, it appears that *S. robusta* matures and spawns outside the Bay.

S. bassensis flindersi

The LFM was 14 cm LCF both for males and for females. Both sexes attained a maximum length of 17 cm LCF in the Botany Bay samples. There were slightly more females in the overall sample of fish and in the adult population (Table 3), though these differences were not significant. Females showed increased gonadal development in June 1978 and February 1979, while male values increased in December 1978 and April and June 1979. Once again, the sample was too small and the patterns of GSI and GMSI too erratic to draw any firm conclusions regarding maturation. However, as no ripe fish were captured in the Bay, it appears that this species spawns outside Botany Bay.

*Diet**S. ciliata*

This species is a benthic carnivore, feeding principally on polychaetes (61%) and crustaceans (37%) (Table 4). Most dietary variation was due to size differences. Of the four length groups, only the diets of 11–20 cm and 21–30 cm fish were significantly correlated ($r = 0.91$, $n = 15$, $P < 0.01$). These two size classes consumed mainly nereid polychaetes, other polychaetes and amphipod crustaceans. The group of smallest fishes (0–10 cm) consumed large amounts of amphipods and fewer polychaetes. The largest (31–40 cm) consumed large amounts of bivalve molluscs and *Callinassa* sp. shrimps (Table 4).

Polychaetes were the dominant food item of *S. ciliata* at all of the sites sampled in Botany Bay. All pair-wise site comparisons were significantly correlated except NZ–WZ, NZ–SB and WB–SB. Most spatial variation was due to relatively greater consumption of amphipods at the WZ and SB sites. Temporal variation in diet was slightly greater, with only 6 of the 15 pair-wise bimonth comparisons being significantly correlated. *S. ciliata* ate mainly nereid polychaetes and fewer amphipods during the summer–autumn months. Because variation in diet due to fish size was so great, it is possible that differences in diet attributed to site and season may have been due to changes in size distributions of fish over time and among habitats (Fig. 2).

Table 4. Diet of *S. ciliata* in Botany Bay by size group, site and bimonth showing the relative importance of prey items based on estimated percentage volumes

| Food type | Size group (cm LCF) | | | | | | Sampling site ^A | | | | Bimonth | | | | Total |
|---------------------------|---------------------|-------|-------|-------|------|------|----------------------------|------|------|------|---------|------|------|------|-------|
| | 0-10 | 11-20 | 21-30 | 31-40 | NZ | WZ | WB | SB | Dec. | Feb. | Apr. | June | Aug. | Oct. | |
| Bivalve molluscs | 0.1 | 2.1 | 5.2 | 45.8 | 3.0 | 2.2 | 3.0 | 0.6 | 2.0 | 2.2 | 1.5 | 3.3 | 1.8 | 3.7 | 2.3 |
| Nereid polychaetes | 29.9 | 46.3 | 35.8 | 1.7 | 46.6 | 46.3 | 36.3 | 33.1 | 39.7 | 55.7 | 44.2 | 28.7 | 18.5 | 37.6 | 38.1 |
| Spionid polychaetes | 1.0 | 1.9 | 3.7 | 0 | 0.3 | 0.3 | 5.2 | 0.6 | 1.0 | 5.9 | 0.5 | 0 | 5.2 | 0.7 | 2.0 |
| Other polychaetes | 16.6 | 21.7 | 26.2 | 0 | 13.0 | 13.0 | 26.8 | 20.7 | 12.8 | 14.4 | 22.5 | 26.7 | 25.5 | 19.2 | 20.9 |
| Copepods | 6.9 | 0 | 0 | 0 | 4.6 | 0.1 | 2.6 | 2.3 | 0 | 0 | 2.7 | 6.3 | 3.2 | 0 | 2.4 |
| Haustoriid amphipods | 2.8 | 1.1 | 3.0 | 0 | 0 | 0.9 | 0.1 | 6.5 | 4.2 | 0 | 0.5 | 1.3 | 4.9 | 4.5 | 2.1 |
| Phoxocephalid amphipods | 6.1 | 0.7 | 0.1 | 0 | 0 | 4.8 | 0.6 | 3.2 | 0 | 0.1 | 0.5 | 8.0 | 0 | 6.7 | 2.4 |
| Other amphipods | 29.3 | 10.9 | 5.1 | 0 | 11.2 | 14.1 | 12.0 | 23.3 | 18.4 | 3.9 | 10.9 | 14.9 | 32.1 | 21.1 | 15.8 |
| <i>Callinassa</i> shrimps | 0.1 | 2.3 | 5.5 | 49.2 | 0.8 | 4.9 | 2.3 | 0.4 | 4.9 | 5.0 | 1.3 | 1.2 | 2.6 | 1.5 | 2.5 |
| Other crustaceans | 3.1 | 6.6 | 7.8 | 0 | 7.3 | 7.1 | 4.5 | 4.7 | 9.4 | 4.1 | 8.5 | 4.1 | 3.6 | 2.2 | 5.6 |
| Miscellaneous material | 4.0 | 6.5 | 7.6 | 3.3 | 13.2 | 6.3 | 6.6 | 4.5 | 7.6 | 8.7 | 7.0 | 5.4 | 2.6 | 2.8 | 5.9 |
| No. stomachs examined | 523 | 699 | 395 | 7 | 95 | 449 | 614 | 424 | 193 | 253 | 472 | 285 | 238 | 183 | 1624 |
| No. stomachs empty | 50 | 107 | 78 | 1 | 17 | 87 | 89 | 33 | 34 | 35 | 77 | 35 | 36 | 19 | 236 |

^A Data not included for fish from minor sampling sites, including mangrove creek (22 fish), RM (7), WU (5), SP (4), southern mud (2) and EU (2).

Table 5. Diet of *S. maculata maculata* in Botany Bay by size group, site and bimonth showing the relative importance of prey items based on estimated percentage volumes

| Food type | Size group (cm LCF) | | | Sampling site ^A | | | | | Bimonth | | | | | Total | | |
|---------------------------|---------------------|-------|-------|----------------------------|------|------|------|------|---------|------|------|------|------|-------|------|------|
| | 0-10 | 11-20 | 21-30 | NZ | WB | EU | WU | RM | WD | Dec. | Feb. | Apr. | June | | Aug. | Oct. |
| Bilvalve molluscs | 0.1 | 6.4 | 7.9 | 3.5 | 0 | 8.7 | 4.6 | 8.2 | 13.7 | 4.0 | 5.5 | 4.1 | 6.9 | 20.1 | 4.2 | 6.8 |
| Glycerid polychaetes | 0 | 7.2 | 8.3 | 0 | 0 | 3.7 | 7.9 | 6.4 | 13.1 | 4.3 | 11.6 | 7.7 | 7.0 | 7.3 | 7.6 | 7.3 |
| Nereid polychaetes | 36.4 | 8.3 | 2.8 | 41.6 | 34.0 | 1.4 | 1.1 | 7.5 | 6.0 | 12.5 | 12.4 | 3.9 | 4.7 | 8.4 | 6.9 | 7.3 |
| Other polychaetes | 19.4 | 28.6 | 24.6 | 23.0 | 11.6 | 13.2 | 26.0 | 27.2 | 33.3 | 16.8 | 27.0 | 25.6 | 33.4 | 22.1 | 25.2 | 25.4 |
| Corophiid amphipods | 0.1 | 2.2 | 3.0 | 0 | 7.7 | 5.9 | 3.0 | 6.8 | 0 | 7.6 | 0.9 | 0.7 | 0.3 | 1.3 | 5.0 | 2.5 |
| Other amphipods | 5.5 | 4.1 | 5.2 | 0 | 0 | 17.6 | 4.1 | 8.3 | 0.1 | 17.6 | 2.1 | 1.4 | 0.4 | 2.3 | 6.8 | 4.9 |
| Alpheid shrimps | 0 | 5.1 | 9.1 | 0 | 0 | 0 | 7.6 | 6.8 | 12.1 | 11.3 | 4.5 | 5.1 | 5.4 | 11.2 | 6.8 | 7.1 |
| Panaeid prawns | 0.4 | 2.7 | 1.9 | 0 | 0 | 0 | 2.2 | 2.0 | 1.5 | 0.8 | 3.1 | 3.3 | 1.5 | 1.4 | 1.8 | 2.0 |
| <i>Callinassa</i> shrimps | 3.8 | 15.8 | 24.1 | 12.2 | 3.2 | 35.6 | 26.8 | 10.0 | 7.5 | 8.0 | 25.7 | 30.3 | 22.2 | 12.5 | 15.6 | 19.8 |
| Other crustaceans | 26.9 | 7.6 | 6.7 | 10.3 | 40.5 | 6.5 | 5.7 | 8.6 | 8.0 | 10.2 | 5.3 | 7.7 | 9.5 | 11.3 | 6.9 | 8.6 |
| Miscellaneous material | 7.3 | 11.9 | 6.5 | 9.5 | 2.9 | 7.6 | 11.9 | 8.1 | 4.6 | 7.0 | 1.7 | 9.9 | 8.8 | 2.1 | 13.2 | 8.3 |
| No. of stomachs examined | 56 | 304 | 531 | 33 | 37 | 89 | 376 | 64 | 234 | 140 | 83 | 205 | 203 | 148 | 112 | 891 |
| No. stomachs empty | 6 | 109 | 163 | 4 | 6 | 26 | 101 | 15 | 101 | 35 | 24 | 58 | 65 | 74 | 22 | 278 |

^A Data not included for fish from minor sampling sites, including southern mud (23 fish), WZ (22), ED (12) and SP (1).

Table 7. Diet of *S. bassensis flindersi* in Botany Bay by size group, site and bimonth showing the relative importance of prey items based on estimated percentage volumes

| Food type | Size group (cm LCF) 0-10 | Sampling site ^A | | Dec. | Feb. | Bimonth | | Aug. | Oct. | Total |
|---------------------------|-----------------------------|----------------------------|------|------|------|---------|------|------|------|-------|
| | | EU | WU | | | Apr. | June | | | |
| Sabellid polychaetes | 3.0 | 2.7 | 5.3 | 0 | 3.3 | 0 | 0 | 3.9 | 11.1 | 2.8 |
| Other polychaetes | 6.4 | 12.5 | 11.0 | 8.7 | 12.4 | 0 | 22.5 | 7.4 | 29.4 | 10.7 |
| Copepods | 41.5 | 0.9 | 6.9 | 21.6 | 0 | 0.3 | 0 | 52.1 | 0 | 13.1 |
| Corophiid amphipods | 1.4 | 4.5 | 3.1 | 4.9 | 5.7 | 3.1 | 0 | 4.3 | 4.4 | 3.6 |
| Liljeborgid amphipods | 0.1 | 9.2 | 2.2 | 13.6 | 19.6 | 6.1 | 0 | 0 | 0 | 6.5 |
| Other amphipods | 4.3 | 9.9 | 8.3 | 9.5 | 11.5 | 6.6 | 5.9 | 0.9 | 32.8 | 8.2 |
| Cumaceans | 3.1 | 2.9 | 5.6 | 0 | 0 | 2.1 | 0 | 11.0 | 0 | 3.0 |
| <i>Callinassa</i> shrimps | 0 | 23.9 | 31.5 | 0 | 3.7 | 71.3 | 15.9 | 0 | 0 | 16.7 |
| Mysids | 15.3 | 15.1 | 8.3 | 17.5 | 23.5 | 5.3 | 20.8 | 7.4 | 4.4 | 15.2 |
| Other crustaceans | 6.1 | 10.2 | 6.9 | 12.4 | 15.4 | 5.3 | 8.3 | 5.7 | 5.5 | 9.0 |
| Miscellaneous material | 18.9 | 8.4 | 11.0 | 12.0 | 4.8 | 0 | 26.7 | 7.2 | 12.2 | 11.5 |
| No. stomachs examined | 49 | 115 | 97 | 56 | 42 | 27 | 22 | 35 | 17 | 164 |
| No. stomachs empty | 19 | 45 | 44 | 17 | 15 | 8 | 10 | 12 | 8 | 64 |

^A Data not included for fish from minor sampling sites, including ED (4 fish), WD (3), WB (3) and NZ (1).

S. maculata maculata

This species was also a benthic carnivore, consuming mainly crustaceans (45%) and polychaetes (40%) (Table 5). The main crustacean items were *Callianassa* sp. (20%), *Alpheus* sp. (7%) and amphipods (7%).

Diets of 0–10 cm fish were not significantly correlated with those of the 11–20 cm or 21–30 cm groups (whose diets were correlated: $r = 0.76$, $n = 17$, $P < 0.001$). Smaller fish consumed mainly polychaetes (56%) and crustaceans (37%), whereas the larger generally consumed more crustaceans (especially *Callianassa* sp.) and molluscs and fewer polychaetes (Table 5).

There was great variation in diet according to site but variation with season was minor. Although polychaetes and crustaceans were eaten at all sites, the types and proportions differed among sites; nereid polychaetes were important at NZ and WB, *Callianassa* sp. at EU and WU and *Alpheus* at WD (Table 5). There was a marked change in diet in December when more amphipods and fewer polychaetes and *Callianassa* sp. were consumed.

S. robusta

The overall diet of this species consisted of crustaceans (48%) and polychaetes (39%) (Table 6). The diets of the 0–10 cm and 11–20 cm groups were not significantly correlated. Smaller fish consumed mainly copepods (39%) and mysidaceans (15%), whereas larger fish consumed more polychaetes (44%). *S. robusta* was collected principally from three sites, EU, WU and RM. Diets from EU and WU were similar but differed from the diet at RM, where more polychaetes were consumed. This difference may have been caused by differences in fish size, because individuals collected at the RM site were larger (Fig. 4).

There was considerable temporal variation in diet. During October, December and February the diet consisted mainly of polychaetes, amphipods and decapods, whereas in April, June and August it consisted principally of copepods and decapods, and contained fewer polychaetes (Table 6).

S. bassensis flindersi

The overall diet of this species consisted mainly of crustaceans (75%), principally amphipods (18%), decapods (18%), mysidaceans (15%) and copepods (13%). Polychaetes made up only 14% of the diet (Table 7).

Diet varied significantly with fish size, site and season. Fish in the 0–10 cm group consumed mainly copepods, whereas 11–20 cm fish ate mainly *Callianassa* sp. and amphipods. Fish from the EU site consumed mainly *Callianassa* sp., polychaetes and amphipods, and those from WU mainly amphipods, copepods and mysidaceans. Mysidaceans were prominent in the diet during December, April and June; *Callianassa* sp. in February; copepods in August; amphipods in December and October; and polychaetes in April and October.

Discussion

This study shows that there are differences in the spatial distributions of the four species of whiting in Botany Bay. *S. ciliata* displayed little spatial overlap with the other three species, with juveniles 'preferring' shallower *Zostera*, and adults sandy beach habitats. Dredge (1976) also found that smaller *S. ciliata* inhabited shallow, partly vegetated estuarine areas and Weng (1983) found that they preferred sandy areas less than 1 m deep. On the other hand, although juveniles of *S. m. maculata* were also most commonly caught over the *Zostera* and shallow sand habitats, adults were most abundant over deep muddy and sandy substrata. Other workers in Queensland, such as Maclean (1971) and Weng (1983), have only defined the juvenile habitat of this species as being water 2–3 m deep. The distribution of larger *S. m. maculata* over deeper soft substrata corresponds with the observations of Maclean (1971) in Moreton Bay and Henry (1984) in Sydney Harbour.

The distribution patterns of the other two whiting species, *S. bassensis flindersi* and *S. robusta* in marine embayments had not previously been recorded. *Sillago b. flindersi* occurred in greatest numbers over deep sandy substrata under marine influence, but abundances of this species were low compared with populations offshore (D. Smith personal communication). The other offshore species, *S. robusta*, on the other hand, was most abundant over deep sandy substrata with a riverine influence.

There were also differences in population structure between the various species of whiting in Botany Bay. The populations of *S. ciliata*, *S. b. flindersi* and *S. robusta* consisted mainly of juveniles, whereas that of *S. m. maculata* comprised mainly adults.

Whilst the other two whiting species probably only reach sexual maturity in non-estuarine habitats, both *S. ciliata* and *S. m. maculata* could attain high levels of sexual maturity within the Bay. Although *S. ciliata* was previously thought to spawn only in the surf zones near the mouths of estuaries, we captured running ripe fish within the Bay. The peak in reproductive maturity that found in February is slightly later than the January peak in egg production suggested by Cleland (1947). Spawning of *S. ciliata* is known to occur earlier in Queensland (Munro 1945; Cleland 1947), which suggests that spawning may be related to water temperature.

Although Roughley (1964) suggested that *S. maculata* spawned from September to November, with, at times, another spawning in February, we found that reproductive condition peaked during February in the second year, with high levels in December of both years. This peak could again be associated with maximum water temperatures.

Even though the diets of all species consisted basically of polychaetes and crustaceans, the proportions and species compositions of these components were different. We cannot say at this stage whether these differences were due to real differences in the way that the species feed. Within species there were differences in diet due to fish size, site and season. Since species were of different sizes, preferred different sites and were most abundant at different times, the differences in diet may be due to these factors alone. If anything, the diets of whiting seemed to be opportunistic within the constraints of feeding on the epibenthic and infaunal invertebrates of soft substrata. Differences in diet between dredged and undredged areas correlated well with differences in benthic invertebrates found in these areas in Botany Bay (Jones and Candy 1981). In particular, corophiid amphipods and *Callinassa* sp. were most abundant in undredged sandy sediments.

Clearly, the soft substrata of Botany Bay provide nursery and feeding areas for *S. ciliata* and *S. b. flindersi*. However, the absence of large numbers of juvenile *S. m. maculata* and *S. robusta* may not necessarily indicate that estuarine soft substrata are of little value to the juveniles of these species. If juveniles, like adults, preferred deep soft substrata, then the 32-mm cod-end mesh of the trawl net used would not have caught them. A sampling method capable of catching small mobile fish would need to be used in order to confirm that juveniles of these species are not abundant over the deeper soft substrata of estuaries. Alternative hypotheses are that they inhabit shallower soft substrata in the upper reaches of estuaries or offshore waters—areas not sampled in this study.

The extraordinary abundance of juvenile *S. ciliata* at the western *Zostera* site indicates that patchy areas of *Zostera* are important habitats for this species. Similar patterns have been noted for juveniles of other fish species associated with seagrasses. For example, small juvenile red drum, *Sciaenops ocellatus* (Sciaenidae), were more abundant among patchy seagrass than over bare substrata in Texas (Holt *et al.* 1983); its abundance in patchy seagrass habitats was attributed to its need for both shelter (seagrass) and feeding areas (bare substrata). These factors also seem to provide a satisfactory explanation for the distribution of juvenile *S. ciliata*.

Our data on the distributions of whiting have two implications for management. Firstly, that patchy *Zostera* habitats should be maintained in estuaries within the range of *S. ciliata*. Secondly, that man-made alterations to estuaries have both costs and benefits to fish species. *S. m. maculata* were most abundant at the WD site, an area of deep muddy substratum

which was created during dredging to provide landfill for a runway extension to Sydney airport. Many other fish species were also most abundant at this site (Anon. 1981). However, the cost of this development was that it reduced the area of deep sandy substratum in the Bay, which is the preferred habitat of *S. robusta* and *S. b. flindersi*. On balance, the dredging seems to have been beneficial in that it increased the diversity of habitats by adding to the previously very limited area of deep muddy substratum.

Acknowledgments

We thank D. Crowley, P. Mort, J. Messersmith, M. Mann and P. Ryan for field assistance. A. Collins, T. Lau, D. Reid and M. King assisted with statistical matters. This study was partially funded by a grant from the Maritime Services Board administered through the State Pollution Control Commission.

References

- Anon. (1981). The ecology of fish in Botany Bay. (State Pollution Control Commission: Sydney.)
- Bell, J. D., Burchmore, J. J., and Pollard, D. A. (1978). Feeding ecology of three sympatric species of leatherjackets (Pisces: Monacanthidae) from a *Posidonia* seagrass habitat in New South Wales. *Aust. J. Mar. Freshwater Res.* **29**, 631-43.
- Cleland, K. W. (1947). Studies on the economic biology of the sand whiting [*Sillago ciliata* (C. and V.)]. *Proc. Linn. Soc. N.S.W.* **72**, 215-28.
- Dredge, M. C. L. (1976). Aspects of the ecology of three estuarine dwelling fish in south east Queensland. M.Sc. Thesis, University of Queensland.
- Fritz, E. S. (1974). Total diet comparison in fishes by Spearman rank correlation coefficients. *Copeia* (1974) **1**, 210-14.
- Grant, E. M. (1978). 'Guide to Fishes.' (Dept Harbours and Marine: Brisbane.)
- Grey, K. A. (1979). Estimates of the size at first maturity of the western rock lobster *Panulirus cygnus*, using secondary sexual characteristics. *Aust. J. Mar. Freshwater Res.* **30**, 785-92.
- Henry, G. (1984). Study of the fishes of Sydney Harbour. N.S.W. Dept Agric. Fish. Bull. No. 1. (Aust. Govt Printer: Sydney.)
- Hjort, J. (1910). Report on herring investigations until January 1910. *Publ. Cir. Const. Coun. Perm. Int. Explor. Mer.* **53**, 1-173.
- Holt, S. A., Kitting, C. L., and Arnold, C. R. (1983). Distribution of young red drums among different sea-grass meadows. *Trans. Am. Fish. Soc.* **112**, 267-71.
- Jones, G., and Candy, S. (1981). Effects of dredging on the macrobenthic infauna of Botany Bay. *Aust. J. Mar. Freshwater Res.* **32**, 379-98.
- Maclean, J. L. (1971). The food and feeding of winter whiting (*Sillago maculata* Quoy and Gaimard) in Moreton Bay. *Proc. Linn. Soc. N.S.W.* **96**(2), 87-92.
- McKay, R. (1985). A revision of the fishes of the family Sillaginidae. *Mem. Queensl. Mus.* **22**, 1-73.
- Munro, I. S. R. (1945). Postlarval stages of Australian fishes, No. 1. *Mem. Queensl. Mus.* **12**, 136-53.
- Pillay, T. V. R. (1952). A critique of the methods of study of food of fishes. *J. Zool. India* **4**, 185-200.
- Pollard, D. A. (1972). The biology of a landlocked form of the normally catadromous salmoniform fish *Galaxias maculatus* (Jenyns). III. Structure of the gonads. *Aust. J. Mar. Freshwater Res.* **23**, 17-38.
- Roughley, T. C. (1964). 'Fish and Fisheries of Australia.' (Angus and Robertson: Sydney.)
- Ruello, N. V. (1975). A small beam trawl for sampling surface or demersal benthic animals. *Limnol. Bull.* **6**, 9-16.
- Siegel, S. (1956). 'Nonparametric Statistics for the Behavioural Sciences.' (McGraw-Hill Kogakusha: Tokyo.)
- Weng, H. T. (1983). Identification habitats and seasonal occurrence of juvenile whiting (Sillaginidae) in Moreton Bay, Queensland. *J. Fish Biol.* **23**, 195-200.