Exxon Valdez Oil Spill
Restoration Project Final Report

Assessment of Spot Shrimp Abundance in Prince William Sound a Decade after the *Exxon Valdez* Oil Spill

Restoration Project 02401
Final Report

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Study History: This project began 1999. Preliminary sampling for the selection of study sites was conducted in August 1999. Complete sampling of all study sites was conducted in October 1999 and 2000. This is the final report to be issued by the project. The study has been funded from 1999 under Trustee Council studies 99401, 00401 and 01401.

Abstract: To determine the size and structure of the spot shrimp populations in western Prince William Sound we sampled shrimp with shrimp pots at 12 sites in October 1999 and 2000. Six sites are traditionally sampled by the Alaska Department of Fish and Game in their annual survey. Six sites were added by us. We used methods similar to those of the Alaska Department of Fish and Game, and we sampled at the same time as they did. Comparison of the annual survey catch data with ours for the same sites revealed that the our catches did not differ from theirs in either year. Our analyses of the annual survey data on number and weight of spot shrimp caught per station showed a significantly increasing trend in catch per unit effort between 1998 and 2000. We found no significant differences between the traditional sites and our new sites in either year for shrimp catch, mean carapace length of shrimp, or shrimp fecundity, therefore our new sites could be included in a suite of 12 sites from which six sites could be randomly chosen for the annual survey, eliminating the lack of serial independence that characterizes the historical data. A shift in the size of spot shrimp to smaller males in 1999 and 2000 compared with the results from 1993 of Trowbridge (1994) indicates restoration of a younger spot shrimp stock than that observed by Trowbridge. The carapace length at which fully functional males first represent 50% of the catch at size (ML_{50}) was directly related to fecundity indicating that ML_{50} may be a useful population parameter for spot shrimp.

Key words: *Pandalus platyceros*, spot shrimp, abundance, CPUE, size-frequency distribution, population structure.

Project Data: *Description of data* - All data are archived in spreadsheets. Graphic files are in Freelance. Text files are in WordPerfect 6.1 or Word 9.7 format. *Custodian* - Contact Mandy Lindeberg, NOAA/NMFS, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801 (work phone: (907) 789-6616, fax: (907) 789-6094, or E-mail: mandy.lindeberg@noaa.gov. *Availability* - Copies of all data and related text files are available on CDROM for cost of duplication.

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EXECUTIVE SUMMARY

The goal of the spot shrimp project was to determine the extent to which spot shrimp abundance has recovered since the population decline that began just prior to 1989. Our objectives were to: 1. estimate the abundance of adult and juvenile spot shrimp at 12 sites in western Prince William Sound (PWS), 2. determine the sex and size composition of spot shrimp at the study sites. 3. estimate spot shrimp fecundity and relative number of egg-bearing females at the study sites, and 4. where possible, compare abundance data and data on population structure obtained for this project with that collected by the Alaska Department of Fish and Game (ADF&G). We accomplished these objectives by sampling in October 1999 and 2000 the six sites traditionally included in ADF&G's annual survey using a methodology similar to that of ADF&G. Our sampling took place within a week or two of when ADF&G conducted its annual survey in 1999 and 2000. In addition, we sampled during the same periods six new sites selected during a preliminary cruise in August 1999. We sampled spot shrimp using two strings of 11 pots each at each site. Our methods differed from those of ADF&G only in the type of pot used. We used a conical pot identical to that used by ADF&G in southeastern Alaska. In PWS ADF&G uses a rectangular pot. Comparison of our catch data with a summary of ADF&G's data at the same sites also collected in October 1999 and 2000 revealed no significant difference between our estimate of the number of spot shrimp per pot or weight of the shrimp catch per pot and that of ADF&G. Nevertheless, in the interest of standardization within the ADF&G as a whole, we recommend that ADF&G in Cordova change to the conical pot as soon as resources become available to do so.

Statistical comparison of the summarized ADF&G annual survey data from 1998 to 2000 provided to us by ADF&G revealed a significantly increasing trend in the number of spot shrimp per station and weight of the shrimp catch per station from 1998 to 2000. When we tested the catch data of ADF&G and the present study collected at all sites sampled by both studies in 1999 and 2000 we observed an increase in mean number of spot shrimp in the catches but no increase in the mean fresh weight of the catches between years. These results suggest that population recovery since 1998 is taking place, but the rate of recovery of spot shrimp populations in WPWS in the first few years of the recovery phase of a population fluctuation is apparently not great enough for differences in population size to be detected unambiguously in a two year period. We also found evidence of good recruitment and the development of a younger stock of spot shrimp in western Prince William Sound than that observed by Trowbridge (1994) in 1993 including: 1. a reduction in the percentage of females in the catches in 1999 and 2000 compared to 1993, 2. a decrease in the mean carapace length of spot shrimp in our catches at the majority of sites between 1999 and 2000, 3. the appearance at four of the 11 sites we sampled in 1999 and 2000 of a modal class in 2000 at a smaller carapace length (23-25 mm) than the smallest observed at those sites in 1999. Nevertheless our estimates of mean CPUE were still well below the target survey CPUE of 1.3 lb of whole shrimp per pot (0.59 kg/pot) as the decision point for reopening the spot shrimp fishery in the Prince William Sound management area. Mean CPUE at the twelve sites sampled during the present study was 0.32 kg/pot (0.7 lb/pot)in 1999. In 2000 mean CPUE was 0.44 kg/pot (0.97 lb/pot).

We found no significant differences between ADF&G's traditional six sites and our six new sites in October 1999 or 2000 for several variables related to the spot shrimp populations at those sites including: mean number of spot shrimp per pot, mean fresh weight of spot shrimp per pot, mean carapace length of males, transitional shrimp and females, and fecundity. This suggests that our six new sites could be added to the traditional sites of ADF&G to form a suite of 12 or more sites from which six sites could be randomly chosen for the ADF&G annual survey, thereby precluding statistical difficulties from lack of serial independence that follows from sampling the same sites every year.

Our estimates of spot shrimp fecundity in 1999 and 2000 were frequently substantially higher than previously published estimates for the ADF&G traditional sites from 1989-1991. We were unable to test the difference between those estimates and ours because we lacked the raw data on fecundity used to calculate the ADF&G estimates. If the differences were real they may represent true interannual differences in the mean fecundity of the spot shrimp populations at these sites. We observed a significant reduction in mean fecundity between 1999 and 2000 at six of the sites we sampled. We also found a direct relationship between carapace length at which fully functional males first represent 50% of the catch at size (ML_{50}) and fecundity. These results indicate that spot shrimp fecundity and ML_{50} may be important variables to monitor on a periodic basis. Fecundity is not currently being monitored during ADF&G annual surveys.

INTRODUCTION

The commercial spot shrimp (*Pandalus platyceros* Brandt, 1851) fishery in Prince William Sound (PWS) began in the 1950's and remained small until the late 1970's. After 1975 the fishery expanded rapidly. The harvest increased from 5.8 tonnes in 1978 to more than 110 tonnes in 1986 as the number of vessels participating in the fishery increased ninefold to 80 vessels (Trowbridge 1994, Kimker et al. 1996). Area closures after the *Exxon Valdez* oil spill resulted in a precipitous decline in the harvest in 1989. Low stock abundance necessitated closure of the fishery in 1990 by emergency order (Orensanz et al. 1998). A reduced fishery involving 15 vessels took place in the fall of 1991, but the season was closed early when a reduced guideline harvest level was reached. Catch per unit effort (CPUE) averaged 0.4 kg of whole shrimp per pot during the 1991 season. The fishery was closed in 1992 and remains closed (Trowbridge 1994, Orensanz et al. 1998). The Alaska Department of Fish and Game (ADF&G) has tentatively set the decision point for reopening the spot shrimp fishery in the Prince William Sound management area at a survey CPUE of 1.3 lb of whole shrimp per pot (0.6 kg/pot: Trowbridge 1994).

Annual surveys of the abundance of spot shrimp in PWS begun in 1989 by the ADF&G continue to the present. The surveys sample spot shrimp at six to eight sites in the seven major statistical reporting areas that divide the Traditional Harvest Area in western PWS (Trowbridge 1992, 1994). From 1989 to 1993 the survey CPUE has declined from 0.6 kg/pot to 0.2 kg/pot. During the same period the percentage of large shrimp (females) increased from 4 to 20% indicating a somewhat reduced recruitment in the near term after 1993 (Trowbridge 1994). In the present study we sought to assess the extent to which spot shrimp abundance had recovered since the population decline which began just prior to 1989. Our objectives were to estimate relative abundance, describe population structure and determine the fecundity of spot shrimp in western Prince William Sound.

OBJECTIVES

1. Estimate abundance (CPUE) of adult and juvenile spot shrimp by weight and number of individuals.

2. Determine the sex and size composition of spot shrimp at the study sites.

3. Estimate spot shrimp fecundity and relative number of egg-bearing females at the study sites.

4. Compare abundance data and data on population structure obtained under the present project with that collected by ADF&G.

METHODS

Study Sites

Shrimp pots were fished at six sites in northern and western PWS previously surveyed by ADF&G and at six additional sites (Figure 1). The sampling sites were located in Unakwik Inlet, at Golden in Port Wells, in lower Culross Passage, in Herring Bay, at northeast Chenega Island and at northern Green Island. Six additional sites at Wells Bay, Eaglek Bay, McClure Bay, near East Finger Inlet in Port Nellie Juan, northwest Perry Island and at Jackpot Island were added to the existing traditional ADF&G sites. We were unable to find very many spot shrimp at Eaglek Bay in 1999. In 2000 a site at North Squire Island was substituted for the Eaglek Bay site to provide a sixth additional site with a population of spot shrimp large enough for possible inclusion in the ADF&G annual survey (Tables 1 and 2; Figure 1).

A preliminary sampling cruise was conducted on 3-9 August 1999 to select sites to be added to the traditional sites included in the ADF&G annual survey. The main sampling cruises were conducted from 19-29 October 1999 and from 15-26 October 2000 (Tables 1 and 2). These sampling cruises overlapped the time period of the annual survey of the ADF&G or took place within a week or two of the annual survey.

Sampling Procedures

Sampling methods were modified after Trowbridge (1992, 1994). Two strings of shrimp pots were set at each site. Each string was designated a sampling station. A string consisted of 11 pots spaced 18.9 m (62 ft) apart along a groundline and buoyed at both ends. Standard, conical (in the shape of a truncated cone), nesting pots were used (Figure 2). The diameters of the base and top of each pot were 107 cm (42 in) and 91 cm (36 in), respectively. The frame of the pot was mild steel with a black plastic coating and covered with a tar-coated mesh having stretched openings of 2.9 cm (1 1/8 in). Three tunnels the inner ends of which each had an opening 7.6 cm (3 in) in diameter were set at equal intervals into the side of the pot. A single 1 L perforated plastic jar containing chopped herring was placed in each pot at the time of deployment. The pots were fished in the depth range 27-183 m (15-100 fm) for a minimum of 18 h at each site in 1999 and in the depth range 46-193 m (25-106 fm) for a minimum of 17 h at each site in 2000 (Tables 1 and 2).

Our pots differed from those used by ADF&G which are rectangular pots measuring 41 cm x 41 cm x 91 cm (16 in x 16 in x 36 in) with 2.9 cm (stretched mesh) openings in the mesh enclosing the tunnels (for added details see Trowbridge 1994). To compare the relative efficiency of the two pot designs we interspersed pots similar in configuration to those of ADF&G in our pot strings set in October 1999. We were unable to obtain pots identical to those of ADF&G. O'Clair et al. (2001) performed a side-by-side comparison of the conical and rectangular pots in 1999 and found the rectangular pot to be less effective than the conical pot in catching spot shrimp. However, their rectangular pots were somewhat smaller and had larger openings in the mesh forming the entrance tunnels than those of ADF&G. The comparison of O'Clair et al (2001) was therefore not an adequate test of the difference in catchability between the conical pot and the rectangular pot of ADF&G. However, the difference in configuration of the two pots was apparently irrelevant because we found no significant difference in the catch of spot shrimp between the present study and that of ADF&G (see Results).

In October 2000 additional pot sets were made in the depth range 4-64 m (2-35 fm) to assess the abundance of juvenile spot shrimp. The pots were fished a minimum of 15 h at each site (Table 3). The juvenile pots were similar in design to the larger nesting pots described above but were 71 cm (28 in) and 51 cm (20 in) in bottom and top diameters, respectively. The pots were covered with mesh having 8 mm openings. The inner end of each tunnel entrance had an opening of 5 cm (2 in). Each pot contained a single 532 ml perforated plastic jar filled with freshly chopped herring at the time of deployment. We attempted to target juvenile spot shrimp habitat when setting the juvenile pots. To accomplish this we set the pots at shallow depths in areas with stands of the kelps, *Laminaria saccharina* and *Agarum clathratum* (Barr 1971, Marliave and Roth 1995).

Upon retrieval of the pot strings all pandalid shrimp in each pot were speciated. Spot shrimp were counted and the catch weighed to the nearest two grams on a Marel electronic balance equipped with a motion compensating algorithm. Other species of pandalid shrimp (eg. *P. eous* and *P. hypsinotus*) were counted. All non-shrimp bycatch was speciated and counted. The carapace length of all spot shrimp was measured to the nearest mm. In 1999 carapace length was measured with calipers except when catches were too large to do so efficiently, in which case, all shrimp not measured with calipers were photographed with a digital camera and the carapace length later determined from the digital image with Optimus image analysis software. In 2000 the carapace length of all spot shrimp was measured with calipers.

A subsample of each catch was collected for staging and sexing. In 2000 the entire catch of spot shrimp was collected, frozen in plastic bags labeled by site name, string number and pot number. The frozen shrimp were returned to the laboratory where each one was staged (see below) and its carapace length measured to the nearest 0.1 mm with a digital or dial caliper. Additional observations of ovigerous spot shrimp included egg condition (eyed vs uneyed) and egg color. The egg clutches of from 10 to 20 ovigerous females, if available, were sampled at each site for estimates of fecundity. The egg clutches were collected by clipping all of the pleopods on the female bearing eggs and immersing the pleopods with eggs in a 118 ml jar containing 10% seawater-buffered formalin or 35% isopropyl alcohol.

Nonovigerous shrimp returned to the laboratory were examined for stage of development. The right first and second pleopods were removed from the abdomen of each shrimp and examined under a dissecting microscope. The stage of development was recorded based on the morphology of the pleopods according to the scheme of Hoffman (1972). Fecundity of the egg clutches placed in fixative in the field was determined by counting all of the eggs in each clutch under a dissecting microscope. In 1999 after all of the eggs in each clutch were counted they were placed in an aluminum pan and dried in a manner similar to that for those shrimp that were dried (see below). The dry weight of each egg clutch was added to that of the female bearing the clutch to obtain the total dry weight of each ovigerous female in the subsample.

In the present report our catch statistics are expressed as number of individuals, fresh weight of catch and dry mass of catch. Fresh weight of the catch was measured in the field (see above) and dry mass, measured in the laboratory, was the sum of the dry mass of all shrimp in the catch. A total of 855 spot shrimp (from 38 to 117 per site) were selected from the catches of 1999, frozen, and returned to the laboratory for the measurement of shrimp dry mass. The shrimp were selected from all sites except Eaglik Bay where only four shrimp were caught. Shrimp were selected in as wide a range of carapace lengths as possible. Each shrimp was drip dried on a paper towel and then placed in a small aluminum pan. After the wet mass was obtained the shrimp were placed in a drying oven at 60°C and were weighed at 24 h intervals until the weights stabilized. All measurements of dry mass were taken to the nearest mg on a precision balance. We estimated the dry mass of all spot shrimp caught in both years using carapace length measured on those shrimp in conjunction with the relationship of dry mass to carapace length determined by regression for a subsample of 855 spot shrimp caught in October 1999. Dry mass and carapace length followed a power relationship (Figure 3). Dry mass of the catch was not examined in our comparisons of catch statistics from the present study with those of ADF&G because dry mass data were not available from ADF&G.

Oceanographic variables measured at each site included temperature and salinity. Bathymetric profiles of temperature and salinity were recorded at each site with a SEA-BIRD Electronics SBE 19 Seacat Profiler.

Data Analysis

Dry mass of the spot shrimp from the 1999 dried subsample was regressed on carapace length. The mass of each spot shrimp in the catches of 1999 and 2000 was calculated using the regression. We used analysis of variance to test for differences in spot shrimp CPUE (No. of individuals/pot and wet and dry mass/pot) and shrimp carapace length between sampling groups and years. The sampling unit was the site. Homogeneity of variance was tested with Levene's test (Levene 1960). If necessary, data were transformed using the logrithmic transformation [log (y + 1) if the data included zeros] or Taylor's transformation (Taylor 1961) to stabilize variances. If we could not stabilize variances with transformations, pairwise comparisons were made with the Mann-Whitney U test. Linear regression was used to test for temporal trends in CPUE. Tests of association between two variables were performed with the Pearson product-moment correlation coefficient or with Kendall's coefficient of rank correlation when the data contained many zeros (eg. number of dead eggs in the spot shrimp egg clutch). The logistic equation was used to model the proportions of functional males and females with increasing carapace length in the population based on measurements of individuals in the catch. The between-year comparison of the relative number of female spot shrimp that were nonovigerous was made with the G-test of independence (Sokal and Rohlf, 199). We tested between-site group and between year differences in spot shrimp fecundity with analysis of covariance.

RESULTS

Catches at Traditional Sites vs New Sites

Our catch of spot shrimp varied markedly between sampling sites within both the traditional and new site groups in 1999. Among the traditional sites sampled by us in 1999, the largest catch (in mean number per pot, mean fresh weight per pot and mean dry mass per pot) of spot shrimp occurred at Culross Passage (Table 4). The catch there was 3X the next largest catch (at Golden) in mean number of shrimp per pot (NPP) and twice that catch in mean fresh weight (WPP) and mean dry mass (MPP) per pot. The catch at Culross Passage was 17X the smallest catch (in NPP) which was taken at North Chenega Island. The smallest catch in WPP and MPP occurred at Green Island where the catch was 17X smaller in WPP and 14X smaller in WPP than that at Culross Passage (Table 4).

At the new sites in 1999, the difference in catch between sites was somewhat less excluding Eaglek Bay. The largest catch was taken at Wells Bay (Table 4). Our next largest catch in NPP occurred at Jackpot Island where the catch was just 1.1X smaller than that at Wells Bay. However, in WPP and MPP the catch at Wells Bay was nearly twice that at Jackpot Island. The catch in NPP at Perry Island was 1.6X smaller than that at Wells Bay, but was about the same as that at Wells Bay in WPP and MPP (Table 4). The smallest catch at the new sites occurred at Eaglek Bay where only four male spot shrimp were caught. Excluding Eaglek Bay, the fewest spot shrimp were caught at McClure Bay where the catch was half that at Wells Bay. However, because the shrimp caught at McClure Bay were on average larger than those caught at Port Nellie Juan the smallest catch in WPP and MPP at the latter site and was about one sixth that at Wells Bay (Table 4).

Catches of spot shrimp were somewhat less variable between sites in 2000 than in 1999. Among the traditional sites the largest catch of spot shrimp occurred at Golden (Table 5). The catch at Golden was about 1.5X (in NPP, WPP and MPP) that of the next largest catch which was taken at North Chenega Island. The fewest shrimp were caught at Herring Bay, Green Island and Unakwik Inlet where NPP averaged 3.5X less than that of Golden. The smallest catches in terms of WPP and MPP occurred at Herring Bay and Green Island where WPP was about 3.6X smaller and MPP was 3.3X smaller than at Golden. The WPP and MPP at Golden exceeded those at Unakwik Inlet by 2.2X (Table 5).

At the new sites in 2000, the largest catches occurred at Jackpot Island and McClure Bay (Table 5). The next largest catch occurred at Perry Island where NPP averaged 1.7X smaller and WPP and MPP averaged 1.3X smaller than at Jackpot Island and McClure Bay. The smallest catch of spot shrimp among the new sites in 2000 occurred at North Squire Island where NPP was one sixth and WPP and MPP was about one fifth those of Jackpot Island and McClure Bay (Table 5).

The mean spot shrimp catch at the newly added sites did not differ from that at the traditional ADF&G sites in 1999 or 2000. This result held whether the catch was expressed as NPP, WPP or MPP(Tables 6 and 7).

Comparison of ADF&G and ABL/VNT Catches

Our spot shrimp catches at the traditional ADF&G sites were similar in size to those of ADF&G in October 1999 and 2000 (Table 8; Figure 4). In 1999 and 2000 our estimates of NPP and WPP at the traditional survey sites of ADF&G did not differ significantly from those obtained in the ADF&G annual survey (Table 9).

When we expanded our analysis to include all sites sampled by ADF&G and us we obtained results similar to those that we obtained when we considered only the sites traditionally included in the ADF&G annual survey. In addition to the six traditional sites, ADF&G sampled a site near the southern end of Chenega Island and one in Prince of Wales Passage in October 1999 and 2000. When we compared catches from the eight sites sampled by ADF&G with those from the 12 sites (six traditional and six new sites) that we sampled we found no difference between the two studies. Both the NPP and WPP of our catches did not differ significantly from those of ADF&G in October 1999 or 2000 (Tables 8 and 10).

Interannual Changes in Spot Shrimp Catch

We examined interannual changes in spot shrimp catch in several ways. We used summaries of ADF&G survey data (provided by J. Brady) to examine the temporal trend in spot shrimp abundance in the years prior to 2000 (Figure 5). Changes in catch between 1999 and 2000 were examined by combining data from the ADF&G annual survey with data from the present study as well as by comparing data between years from the present study alone.

Trend in Spot Shrimp Catch, 1995-2000

No significant trend in the number of spot shrimp per station (regression $R^2 = 0.35$, df = 1,28, $p > 0.05$) was observed in the ADF&G survey data between 1995 and 1998. However, the fresh weight of the spot shrimp catch per station from the survey decreased between 1995 and 1998 (regression $R^2 = 0.51$, df = 1,28, $p < 0.01$). The ADF&G survey catch at the traditional ADF&G sites rebounded between 1998 and 2000 (Figure 5). Both the number of spot shrimp per station (regression $R^2 = 0.24$, df = 1,16, $p = 0.04$) and the fresh weight of the spot shrimp catch per station (regression $R^2 = 0.31$, df = 1,16, $p = 0.02$) showed a significant upward trend between 1998 and 2000 in the ADF&G annual survey data (Figure 5).

Increase in Spot Shrimp Catch Between 1999 and 2000

When all sites sampled by ADF&G and the present study were considered, the results showed an increase in mean number of spot shrimp in the catches but no increase in the mean fresh weight of the catches between 1999 and 2000. The ANOVA of the number of spot shrimp per pot revealed a significant increase in NPP between 1999 and 2000 (Tables 8 and 10). An apparent increase in the mean weight of spot shrimp per pot observed in both the ADF&G data and that of the present study between years was not statistically significant (Tables 8 and 10). When ADF&G data and data from the present study were combined and only the sites traditionally surveyed by ADF&G were considered the means of NPP and WPP appeared to increase between years, but the differences were not statistically significant (Tables 8 and 9; Figure 4).

When only data from the present study were considered, the mean spot shrimp catch did not differ between 1999 and 2000. In 2000 the means of NPP, WPP and MPP appeared somewhat greater than in 1999 in both the traditional and new site groups (Table 8). The difference appeared more pronounced in the traditional site group. However, there was no significant year effect in the ANOVAs of NPP, WPP or MPP (Table 9).

Population Structure

Males outnumbered females in the catches at all sites in both years. In 1999 males ranged from 76% (Golden) to 93% (Culross Passage) of the total catch at the traditional ADF&G sites (Table 4). At the newly added sites males composed from 54 % (Perry Island) to essentially 100% (Eaglek Bay and Port Nellie Juan) of the total catch. Females were present in the catches at all sites but Eaglek Bay. The average percentage of females in the catches was 16.5%, ranging from 0.3 % (Port Nellie Juan) to 44% (Perry Island). (Eaglik Bay was excluded from the calculation because only 4 shrimp were caught there.) The majority of females in those catches were ovigerous (Table 4). Nonovigerous females were present in the catches at eight of the 12 sites, but never exceeded 25% (Green Island) and usually represented less than 10% of the females in the total catch at a site (Table 4). Shrimp transitional between male and female were rare. Transitional shrimp occurred in the catches at eight sites but never represented more than about 5% of the total catch at a site in 1999.

In October 2000, males ranged from 73% (Unakwik) to 91% (Jackpot Island) of the total catch at the traditional ADF&G sites (Table 5). At the newly added sites males composed from 76 % (McClure Bay) to 93% (Port Nellie Juan) of the total catch. Females were present in the catches at all sites. The average percentage of females in the catches was 9.8%, ranging from 1.3 % (Jackpot Island) to 24% (Unakwik). As in 1999, the majority of females in the catches were ovigerous. Nonovigerous females appeared to occur somewhat less frequently in catches made in 2000 than in catches made in 1999 (Tables 4 and 5). Nonovigerous females were present in the catches at six sites in 2000 compared to eight sites in 1999. Although nonovigerous females comprised nearly 29% of the females in the total catch at Port Nellie Juan, they usually represented less than 5% of the females in the catch at most sites. Shrimp transitional between male and female occurred more frequently in the catches of 2000 than in those of 1999. Transitional shrimp were present in catches at all sites sampled in 2000 compared with eight of 12 sites in 1999. It is possible that the frequency of occurrence of transitional shrimp may have been underestimated in 1999 because, in contrast to 2000, not all shrimp were returned to the laboratory for staging in 1999. Rather a subsample of each catch was collected for staging in 1999. Because transitional shrimp tended to represent a small proportion of the catch, missed transitional individuals may have had a disproportional effect on the estimates of the frequency of occurrence of transitional shrimp in the catches of 1999. Transitional shrimp represented between 1.4% and 15% of the total catch at sites in 2000 (Tables 4 and 5).

Size Shifts Between Years

Mean carapace length of spot shrimp decreased between 1999 and 2000 at the majority of sites. We observed a between-year decrease in carapace length at six sites, an increase at three sites, and no change in carapace length at two sites (Table 11; Figure 6). We observed a relatively large decrease in carapace length at three sites, North Chenega Island, Golden and Perry Island, where the percentage decrease was 16.8%, 14.4% and 13%, respectively. More modest decreases were observed at the other three sites, ranging from 4.4% at Herring Bay to 7.6% at McClure Bay. Among the three sites that showed an increase in carapace length between 1999 and 2000, Unakwik Inlet showed the greatest increase (8.4%) and Port Nellie Juan showed the smallest increase (5%; Table 11; Figure 6).

The direction of change in mean dry mass of spot shrimp between 1999 and 2000 was identical to that of mean carapace length. As would be expected, the relative magnitude of change in mean dry mass was greater than that for mean carapace length. Among the six sites showing a decrease in mean dry mass, the percentage decrease ranged from 11.9% at Herring Bay to 39.3% at North Chenega Island. Among the three sites that showed an increase in mean dry mass, the percentage increase ranged from 12% at Jackpot Island to 40.9% at Port Nellie Juan (Table 12; Figure 6).

Size Structure by Sex

Mean carapace length (CL) of male, transitional and female spot shrimp generally did not vary greatly between sites in 1999 or 2000 (Figure 7). Males showed the greatest between-site variability in carapace length at the newly added sites in both years. Mean CL of males at the new sites ranged from 24.2 mm (Port Nellie Juan) to 33.5 mm (Perry Island) in 1999 and from 24.1 mm (Port Nellie Juan) to 30.4 mm (Wells Bay and North Squire Island) in 2000. No difference was observed in the site-group mean for males between traditional and new sites in either 1999 or 2000 (Table 13).

Shrimp transitional between male and female had the greatest between-site variability in CL at the traditional sites in 1999, ranging in CL from 34.0 mm (Unakwik Inlet) to 40.0 mm (Golden). Transitional shrimp were in the catches at eight of the 12 sites sampled in 1999. In 2000 transitional shrimp were in catches at all 12 sites. Transitional shrimp had about the same between-site variability in CL at the traditional sites and new sites in 2000, ranging in CL from 36.2 mm (Herring Bay) to 39.5 mm (Golden) at traditional sites and from 36.7 mm (Port Nellie Juan) to 40.4 mm (North Squire Island) at the new sites. The site-group mean CL of transitional shrimp was similar at traditional and new sites in both years (Table 13).

Females showed the least between-site variability in mean carapace length of the three segments of the population in 1999, but female variability increased to levels comparable to transitional shrimp in 2000 (Figure 7). At traditional sites the mean CL of females ranged from 42.2 mm (Culross Passage) to 45.0 mm (Golden) in 1999 and from 42.8 mm (Culross Passage and Green Island) to 45.8 mm (Golden) in 2000. At new sites the CL ranged from 42.0 mm (Port Nellie Juan) to 45.1 mm (Jackpot Island) in 1999 and from 42.9 mm (McClure Bay) to 47.1 mm (Port Nellie Juan) in 2000. No differences were observed in the site-group mean for females between traditional and new sites in either year (Table 13).

Size-frequency Distribution

In 1999 the carapace length-frequency distributions of spot shrimp from sites where our pot catches were relatively large were divided into two patterns based on the relative abundance of male versus female shrimp. Males clearly dominated the catch at Port Nellie Juan, Culross Passage, Jackpot Island and Herring Bay (Appendix A). At these sites males represented >85% of the catch, ranging from 86% at Herring Bay to nearly 100% at Port Nellie Juan. The mode of the size-frequency distribution was lowest at Port Nellie Juan (23 mm) and highest at Culross Passage (30-32 mm). The distribution of Culross Passage also showed a secondary mode at 27 mm. The modes of the distributions of Herring Bay and Jackpot Island were 27 mm and 25-27 mm, respectively (Appendices A-4 and A-8).

Most of the males at the male-dominated sites were fully functional (stages 5and 6; ≥ 65%) except at Jackpot Island where most males (65%) were stage 4 (Figure A-8). Stage 2 and stage 3 males were rare at the male-dominated sites. Stage 2 males were present in the catches from Port Nellie Juan and Culross Passage (≤ 3 shrimp/site). Stage 3 males were present at Port Nellie Juan, Culross Passage and Jackpot Island (≤ 9 shrimp/site). No stage 1 males were captured in the pots.

Because females represented a minor part of the catch (< 15%) at the male-dominated sites it was more difficult to specify the modal size of the females than it was that of the males. The modal carapace length of females was about 42 mm at Culross Passage, Herring Bay, and Port Nellie Juan (Appendices A-2, A-4, A-10). The modal size was somewhat larger (45 mm) at Jackpot Island. Virtually all of the females were ovigerous at the male-dominated sites. Three of the females (12%) from Jackpot Island were nonovigerous. No nonovigerous females were captured at Culross Passage, Herring Bay, and Port Nellie Juan (Appendices A-2, A-4, A-10). Shrimp transitioning from male to female were also rare in the catches from the male-dominated sites. Transitional shrimp represented from 0.4% to 4% of the catch from Culross Passage, Herring Bay and Jackpot Island (Appendices A-2, A-4, A-8). No transitional shrimp were present in the catch from Port Nellie Juan (Appendix A-10).

Females never dominated the catch at any site in 1999. However, they were relatively more abundant at Golden, McClure Bay, Perry Island and Wells Bay than at the sites that were clearly dominated by males. Females represented from 22% to 44% of the catch at these sites

(Appendices A-3, A-7, A-9, A-11). The modal lengths of the females were 44 mm at Golden, Wells Bay and Perry Island and 42 mm at McClure Bay. Nearly all females were ovigerous at these sites. The percentage of female shrimp that were nonovigerous ranged from 1.5% at Golden to 7.9% at Perry Island (Appendices A-3 and A-9). Transitional shrimp were also rare in catches with relatively many females. The percentage of the catch composed of transitional shrimp ranged from 0 at Wells Bay to 3% at McClure Bay (Appendices A-7 and A-11).

The modal carapace length(s) of males at the sites with high female catches was generally somewhat greater than that at male-dominated sites in 1999. Modal size at Golden and McClure Bay was 29 mm and 30 mm, respectively (Appendices A-3 and A-7). The size-frequency distribution for males caught at Wells Bay showed a modal carapace length (CL) at 25 mm with a lesser mode at 36 mm (Appendix A-11). The size-frequency distribution for males at Perry Island showed no distinct mode; males in the size range 32-39 mm CL occurred most frequently in the catch there (Appendix A-9).

Similar to the male-dominated sites, most males at the sites with high female catches were fully functional in 1999. The percentage of males in stages 5 and 6 combined ranged from 71% at Wells Bay to 92% at Perry Island (Appendices A-9 and A-11). Stage 4 males made up most of the rest of the male catch at all four sites. Males in stages 2 and 3 were rare just as they were at the male-dominated sites.

Catches at four sites (Unakwik Inlet, Green Island, North Chenega Island and Eaglek Bay) were too small (catch < 80 shrimp/site) to completely characterize the size-frequency distributions there in 1999. Females represented 21% of the catch at North Chenega Island, but catches at the other sites were either exclusively (Eaglek Bay) or predominently (88%; Unakwik Inlet and Green Island) male (Appendices A-1, A-5 and A-6). Females were too few in the catches from these sites to identify a modal size. Female carapace length ranged from 40-45 mm at Unakwik Inlet, 41-49 mm at Green Island and 41-48 mm North Chenega Island. The size-frequency distribution for Unakwik Inlet showed a modal class composed of functional males (mostly at stage 5) at 33 mm CL. Because of the low number of shrimp caught at Green Island and North Chenega Island, modal sizes could not be identified with confidence there. Males caught at Green Island and Unakwik Inlet were mostly (> 66%) at stage 5. At Unakwik Inlet the majority (54%) of males were at stage 6; 39% were at stage 5 in 1999 (Appendix A-1). Only four spot shrimp were caught at Eaglek Bay: all were stage 4 males.

In 2000, modal classes of the carapace length-frequency distributions of spot shrimp were, in general, better resolved than in 1999, and often several modal classes were apparent at individual sites (Appendix A). With the exception of Unakwik Inlet a modal length class consistently appeared in the range 22-25 mm, occurring more frequently at 24 mm (Herring Bay, Green Island, Wells Bay and North Squire Island) than at other lengths within this range (Appendices A-4, A-6, A-11, A-12). All sites showed an additional modal length class in the range 30-35 mm. This latter modal class fell at 32 mm at half of the sites (Unakwik Inlet, Culross Passage, Herring Bay, North Chenega Island, Green Island, and McClure Bay) we sampled in 2000 (Appendices A-1, A-2, A-4, A-5, A-6, A-7). Both of these modal classes were composed of males. The smaller class (22-25 mm) was dominated by stage 4 males at five sites (Culross Passage, North Chenega Island, McClure Bay, Perry Island and Port Nellie Juan). At the remaining sites, the small modal class was dominated by stage 5 males. The 30-35 mm modal class was dominated by fully functional males (stages 5 and 6) at all sites (Appendix A). Four of the 11 sites sampled in 1999 and 2000 showed a modal class (23-25 mm) at a smaller carapace length than the smallest observed at those sites in 1999 (25-29 mm; Appendix A).

In October 2000 as in October 1999 females did not represent a large part of the catch (1%-25%) at our sample sites, and the modal size of the females was less easily resolved than it was for males. At those sites where a modal size was apparent the mode ranged from 42 to 45 mm (Appendix A). At most of these sites, the modal size was 42 mm (Culross Passage, McClure Bay and Perry Island) or 43 mm (Unakwik Inlet, Herring Bay and Wells Bay). At a few sites (Unakwik Inlet, Green Island, Wells Bay and North Squire Island) there was some indication of a modal length class at 37 mm or 38 mm composed of large males and transitional spot shrimp, but the evidence for this modal class was quite weak (Appendix A).

Proportion of Fully Functional Males and Females with Size

Plots of the proportion of fully functional males (stages 5 & 6) and females against carapace length were used to determine size at stage and size at sex values for each site (Appendix B). The carapace length at which fully functional males first represented 50% of the catch at size (ML_{50}) or the length at which females represented 50% of the catch at size (FL_{50}) were estimated with the aid of the logistic model fit to observed data (Table 14). In 1999 the size at stage of fully functional males (ML_{50}) ranged from 23.6 mm at Port Nellie Juan to 28 mm at Jackpot Island. The size at sex of females (FL_{50}) ranged from 39.6 mm at McClure Bay to 42.8 mm at North Chenega Island (Table 14).

The mean ML_{50} decreased by 6% between 1999 and 2000 (Mann-Whitney U, $p = 0.01$; Table 14). We attempted to gain some insight into the cause of the decrease by determining whether ML_{50} was associated in any way with spot shrimp abundance as estimated by CPUE or with water temperature. As seen above, when ADF&G catch data and catch data from the present study were combined we observed an increase in the number of spot shrimp between 1999 and 2000 at the study sites. However, when we examined the relationship between mean ML_{50} and CPUE expressed as mean number of spot shrimp caught per station, we found the variables to be uncorrelated over the two-year period (Pearson product-moment correlation, $p = 0.78$; Figure 8). Similar results were obtained when the relationship of ML_{50} to water temperature was tested. Mean ML_{50} was not correlated with mean water temperature in the depth range where males were captured in 1999 and 2000 combined (Pearson correlation, $p = 0.94$; Figure 8; Appendix C). Interestingly, ML_{50} was correlated with female spot shrimp fecundity over the two-year period (Pearson correlation, $p < 0.01$; Figure 9; see fecundity section below).

Mean FL_{50} did not change between 1999 and 2000 (Mann-Whitney U, p = 0.55). As would be expected from this result ML_{50} and FL_{50} were uncorrelated (Pearson correlation, p = 0.78) over the two-year period (Figure 8). As with ML_{50}, FL_{50} showed no relationship to CPUE or water temperature. Mean FL_{50} was not correlated with mean number of spot shrimp caught per station (Pearson correlation, p = 0.66), nor was it correlated with mean water temperature in the depth range where females were caught (Pearson correlation, p = 0.61; Figure 8; Appendix C).

Fecundity

Mean spot shrimp fecundity did not differ between traditional and new sites in 1999 or 2000. Fecundity was directly related to carapace length (Figure 10, Tables 15 and 16). Adjusted mean fecundity ranged from 2707 eggs (Wells Bay) to 3187 eggs (North Chenega Island) in 1999 and from 2033 (Green Island) to 3020 eggs (Perry Island) in 2000 (Figure 11). Adjusted mean fecundity for each site was evaluated at a carapace length of 44.2 mm. No females were caught in Eaglek Bay and only one female was caught at Port Nellie Juan in 1999. The slope of the relationship between fecundity and carapace length did not differ significantly between years (F-test, p>0.05; Figure 10). The analysis of covariance (ANCOVA) test of site-group effects (traditional sites versus new sites) by year effects was not definitive because variances were nonhomogeneous and irregular in nature, and we were unable to stabilize them despite applying transformations (Table 15). We therefore tested the site-group effect separately for each year. Fecundities were lumped within each site group. Mean fecundity at traditional sites was similar to that at new sites in 1999 and 2000 (Table 15).

Mean fecundity differed between years at some sites. Between-year differences in mean fecundity at individual sites were tested with separate ANCOVA's because the overall site by year ANCOVA was not definitive owing to irregular heteroscedasticity (Levene's test, p<0.001), as in the case of the traditional sites versus new sites comparison above. Mean fecundity decreased between 1999 and 2000 at six of the 10 sites tested (Table 16, Figure 11). (Eaglek Bay and North Squire Island were sampled in one year only, and only one female was captured a Port Nellie Juan in 1999.) The percent decrease in mean fecundity ranged from 14% (Unakwik Inlet) to 19% at four of the remaining five sites showing a decrease. The fifth site, Green Island, showed a 29% decrease in mean fecundity between years, but the number of ovigerous shrimp captured there in 1999 was only three. Therefore, mean fecundity may not have been accurately estimated at Green Island in 1999. Fecundity at four of the 10 sites tested did not differ between years (Table 16, Figure 11).

In general, neither the relative number of female shrimp that were nonovigerous nor the number of dead eggs in the egg clutches of the spot shrimp differed between 1999 and 2000. Because the number of nonovigerous female spot shrimp in our catches was small (see section on population structure above), when we compared the relative number of females that were nonovigerous between years we lumped females over all sites within years. The percentage of females that were ovigerous was 95.7% and 96.7% in 1999 and 2000, respectively. As would be expected, the G-test revealed that the number of ovigerous versus nonovigerous females in our catches was independent of year (G = 0.75, p > 0.05). The only site where we observed a difference in the number of dead eggs in the shrimp egg clutch between 1999 and 2000 was North Chenega Island. There the mean number of dead eggs per clutch increased from 0.18 in 1999 to 11.8 in 2000 (Mann-Whitney U, $p < 0.05$; Figure 12). The number of dead eggs in an egg clutch was not related to spot shrimp fecundity (Kendall's $\tau = -0.045$, $p > 0.05$).

Bathymetric Distribution

Ovigerous spot shrimp tended to be distributed to greater depths than males in 1999 but not in 2000. Because transitional and nonovigerous female shrimp were not distinguished from males by pot in 1999, in our analysis of depth distribution "males" included what few transitional and nonovigerous female shrimp were collected in the pots. The mean depth of the modal catch per unit effort (CPUE) of males (86.6 m) at the 12 sites was significantly less than that of ovigerous females (126 m) in 1999 (Table 17, Figure 13). In 2000, all shrimp caught in the pots were collected. We were therefore able to obtain information on depth distribution for transitional shrimp and nonovigerous females as well as for males. However, to ensure that we used comparable data for the statistical analysis, transitional shrimp and nonovigerous females were lumped with males in 2000 as well as in 1999 for the anovas (Table 17). When we performed the analysis on the 2000 data removing transitional shrimp and nonovigerous females from the "male" category and including nonovigerous and ovigerous females together, thereby testing male versus female depth distribution, the results were virtually identical (MS = 45.4, F = 0.07, $p > 0.05$) to those shown in Table 17 for 2000. Male versus female depth distribution is shown in Figure 13B.

The difference in depth distribution between males and females resulted in the two groups being exposed to different temperatures in October 1999 (Table 17, Figure13). However, the difference between the mean temperature at the depth of the modal CPUE of "males" (7.7 °C) and that of ovigerous females (6.3 °C) in October 1999 was probably not biologically significant. In October 2000, the mean temperature at the depth of the modal CPUE of "males" (7.7 °C) and that of ovigerous females (7.6 °C) were nearly identical (Appendix C).

The mean salinity at the depth of the modal CPUE of "males" (31.2 PSU) was somewhat lower than that of ovigerous females (31.8 PSU; Mann-Whitney U, 11.5; $p < 0.01$) in October 1999. (The ANOVA of the salinity data was not definitive because the variances could not be stabilized.) In October 2000, the mean salinities at the depth of the modal CPUE of "males" and ovigerous females were identical (31.2 PSU; Table 17, Figure 13; Appendix C).

Catches in Juvenile Pots

With the exception of the catches at Golden and Perry Island the catches of spot shrimp in the juvenile pots was generally poor in 2000 (no juvenile pots were fished in 1999). The greatest total number of spot shrimp were caught at Golden (Table 18). No spot shrimp were caught in the juvenile pots at Unakwik Inlet, Culross Passage, Green Island and Wells Bay.

Despite our attempt to target juvenile spot shrimp habitat with the juvenile pots (see Methods) we caught very few juvenile spot shrimp (Table 18). We define juveniles as those spot shrimp that have yet to develop an *appendix masculina* on the second pleopod [see Hoffman (1972) for a description of the reproductive morphology of spot shrimp]. The juveniles that we caught ranged in size from 10.3 to 16.8 mm in carapace length. Juveniles were caught in the depth range 5.5 m to 36 m at Herring Bay (5.5 m), McClure Bay (36 m) and North Chenega Island (7.0 to 16.5 m).

As in the adult pots males dominated the catches of spot shrimp in the juvenile pots. Catches at Golden, North Squire Island, Port Nellie Juan and Jackpot Island were composed exclusively of males (Table 18). Shrimp transitional between male and female were caught only at North Chenega Island (one individual) and Perry Island (seven shrimp). Females (all ovigerous) were caught in the juvenile pots only at Perry Island (Table 18).

DISCUSSION

The rapid decline in the commercial catch of spot shrimp after the peak harvest of over 110 tonnes in 1986 (Figure 14) has been offered as an example of the vulnerability of Alaskan crustacean stocks to depletion through overfishing (Orensanz et al. 1998). The Alaska Department of Fish and Game (ADF&G) has continued to monitor the stock in western Prince William Sound (WPWS) with annual surveys since the closure of the commercial fishery in 1992 (Trowbridge 1994; Table 19). Although the stock in WPWS has remained depressed since the fishery closure, there is not unequivocal evidence that it has continued to decline since 1992. We were unable to test, statistically, whether a post-closure decline in the stock was evident in the ADF&G data in the first few years after the fishery closure because no estimates of between-site variability were available to us prior to 1995. Summaries of ADF&G survey data collected from 1995 to 1998 revealed no significant trend in the number of spot shrimp per station. However, the fresh weight of the spot shrimp catch per station from the survey decreased between 1995 and 1998.

Since 1998 spot shrimp abundance and biomass have increased in WPWS. The ADF&G survey catch at the traditional ADF&G sites rebounded between 1998 and 2000 (Figure 5). Both the number of spot shrimp per station and the weight of the spot shrimp catch per station showed a significant upward trend between 1998 and 2000 in the ADF&G annual survey data. Over the two years of the present study the trend in spot shrimp abundance and biomass was inconclusive. When we tested all sites sampled by ADF&G and the present study we observed an increase in mean number of spot shrimp in the catches but no increase in the mean fresh weight of the catches between 1999 and 2000. When we combined ADF&G data and data from the present study but considered only the sites traditionally surveyed by ADF&G spot shrimp abundance and biomass appeared to increase between years, but the differences were not statistically significant.

Not surprisingly, the rate of recovery of spot shrimp populations in WPWS in the first few years of the recovery phase of a population fluctuation is not great enough for differences in population size to be detected conclusively in a two year period. These results also emphasize the importance of collecting stock assessment data in a form appropriate for statistical treatment (see below).
The ADF&G has tentatively set a target survey CPUE of 1.3 lb of whole shrimp per pot (0.59 kg/pot) as the decision point for reopening the spot shrimp fishery in the Prince William Sound management area (Trowbridge 1994). The mean CPUE of spot shrimp averaged over the ADF&G traditional sites and the new sites added by us in 1999 and 2000 was still well below the target CPUE of ADF&G despite the apparent rebound in the spot shrimp stock since 1998. Our mean CPUE estimate in 1999 was 0.32 kg/pot (0.7 lb/pot); that in 2000 was 0.44 kg/pot (0.97 lb/pot).

We were able to combine ADF&G survey data with that of the present study in our analysis of the trend in spot shrimp population size between 1999 and 2000 because between-study differences in pot configuration did not significantly influence the catch of spot shrimp. The catches of ADF&G were comparable to ours in October 1999 and 2000 (Tables 12 and 13, Figure 4). Although no consistent differences were observed in the catches of ADF&G's rectangular pots and our conical pots, ADF&G in Cordova should consider changing their pot design to the conical pot. The ADF&G in their surveys in southeastern Alaska uses a pot identical to the one that we used in PWS (G. Bishop, pers. comm.). In the interests of pot standardization within ADF&G and to provide convincing comparisons of spot shrimp population structure in PWS where the population is depleted with southeastern Alaska where the population is generally healthy and is currently commercially fished, the conical pot may be preferable to the rectangular pot currently in use by ADF&G in PWS.

Systematic annual resampling of the same index sites may provide a sensitive measure of temporal changes in spot shrimp abundance at those sites, but because of the lack of serial independence in the resulting data, statistical analysis of temporal trends in the data is rendered problematical. In any statistical design it is central that estimates of the expected value of a variate be independent. To ensure serial independence of spot shrimp catch data, sampling the same sites between years should be avoided. If ADF&G has time and resources to sample six sites in Prince William Sound during their annual survey, rather than resampling the same six sites it would be preferable to identify, for example, 12 sites, and to choose randomly six sites among those 12 sites to sample annually. We found no significant differences in the site-group means between ADF&G's traditional six sites and our six new sites in October 1999 or 2000 for several variables related to the spot shrimp populations at those sites including: mean number of spot shrimp per pot, mean weight of spot shrimp per pot, mean carapace length of males, transitional shrimp and females, and fecundity. With the exception of Eaglek Bay where our catch of spot shrimp was very low, the new sites that we sampled in October 1999 and 2000 may be good candidates to be added to a larger group of sites from which ADF&G could randomly choose six sites to sample each year.

Accompanying the decline in spot shrimp abundance between 1989 and 1993 in WPWS Trowbridge (1994) found an increase in the percentage of large shrimp (females) from 4% in 1989 to 20% in 1993 indicating a shift to "an aging stock with little recruitment in the near term" (Trowbridge 1994). Our data indicates a reversal of this trend in 1999 and 2000. The percentage of females in our catches averaged 16% in 1999. In 2000 the percentage decreased further to about 10%. In addition, we observed a decrease in the mean carapace length of spot shrimp in our catches at the majority of sites between 1999 and 2000, providing further evidence of the restoration in 1999 and 2000 of a younger stock than that observed by Trowbridge (1994) in 1993. The appearance at four of the 11 sites sampled in 1999 and 2000 of a modal class in 2000 at a smaller carapace length (23-25 mm) than the smallest observed at those sites in 1999 (25-29 mm) indicated strong recruitment between 1999 and 2000 at least at those sites. Mixture modal analysis of our length-frequency distributions indicates that the smaller modal class will reach the mean length (40.8 mm) at which females represent 50% of the catch at size by 2006 (Appendix D).

Our estimate of mean fecundity per site in 1999 and 2000 (by actual count of all eggs in each clutch) appeared to be nearly uniformly higher than that of Trowbridge (1992). For the comparison of our fecundity estimates with those of Trowbridge (1992) we chose the largest estimate of mean fecundity at each site among three years (1989,1990 and 1991) from Trowbridge (1992; see Table 19 of Trowbridge). The fecundity estimates presented in Table 19 of Trowbridge (1992) are from his November surveys. Eggs may be lost over the course of the brooding period owing to egg mortality, loss in cleaning of the clutch by the female, etc.. Although the loss may be substantial over the entire period between egg extrusion and egg hatching, we assumed that egg loss between the time we sampled in mid to late October and November would be minimal. Our fecundity estimates in 1999 ranged from 2.1% higher (Green Island) to 52.8% higher (North Chenega Island) than those of Trowbridge (1992). Our fecundity estimates in 2000 were significantly lower than those of 1999 at six of the 10 sites that we tested (Table 17). Four of the six sites were ADF&G traditional sites. At three of those four sites our fecundity estimates in 2000 ranged from 12% higher (Herring Bay) to 26% higher (North Chenega Island) than the largest estimate of mean fecundity at those sites by Trowbridge (1992). At one site (Green Island) our 2000 fecundity estimate was 5% lower than the lowest estimate of mean fecundity at that site by Trowbridge (1992). We were unable to test the difference between Trowbridge's estimates and ours because we lacked his raw data on fecundity, however the differences seem notable to us. If the differences are real, they may simply be ascribed to the different estimation techniques of Trowbridge and us or they may represent real interannual differences in the mean fecundity of the shrimp populations at these sites. The ADF&G does not routinely estimate spot shrimp fecundity in its annual survey. Of course, estimates of fecundity are critical to our knowledge of the reproductive potential of a population. If real interannual differences occur in spot shrimp fecundity in Prince William Sound as indicated by the significant reduction in mean fecundity that we observed between 1999 and 2000 at six of the sites we sampled, then periodic monitoring of fecundity at ADF&G's sites may be warranted. Moreover, the direct relationship that we observed between the carapace length at which fully functional males first represent 50% of the catch at size (ML_{50}) and fecundity (see below) deserves more study, further emphasizing the importance of obtaining data on interannual differences in fecundity.

Armstrong et al. (1995) also give fecundity estimates for spot shrimp from nine bays in western Prince William Sound. Their estimates ranged from 450 to 4400 eggs/female for females ranging in carapace length from 35 to 50 mm in carapace length. However, Armstrong et al. (1995) do not break their fecundity estimates down by bay.

The significant decrease in size at stage of males as estimated by ML_{50} between 1999 and 2000 may indicate that size at maturity is not constant over time. If pleopod morphology is a reliable indicator of reproductive function in spot shrimp and stage five is the stage at which males first become reproductively functional (Hoffman 1972) then ML_{50} should be a dependable estimator of size at functional maturity. The lack of constancy in ML_{50} between years suggests several interesting questions: 1. What factors control size at functional maturity? 2. Are those factors demographic or environmental? 3. Does the value of ML_{50} have important consequences at the population level of spot shrimp? We found no correlation between ML_{50} and spot shrimp abundance nor between ML_{50} and water temperature. However, ML_{50} and female fecundity were directly related over the two year period. Does a shift in the mean size of functionally mature males to smaller individuals translate to reduced mean fecundity of the population? If so, what is the mechanism? Conclusive evidence of this relationship awaits further study. If the size at male functional maturity and spot shrimp fecundity are directly related, then ML_{50} may be an important population parameter warranting further study.

CONCLUSIONS

Our analysis of the spot shrimp catch per unit effort (CPUE) data collected by the Alaska Department of Fish and Game (ADF&G) in their annual survey of traditionally sampled sites revealed a significant increasing trend in CPUE between 1998 and 2000, regardless of whether CPUE was measured as mean number of shrimp per station or mean fresh weight of shrimp per station. Moreover, our estimates of the CPUE of spot shrimp from our own catches at the traditional sites during the same period are consistent with those of ADF&G. In addition, we observed two strong peaks in the carapace length distributions of spot shrimp caught by us in October 2000. One of these peaks occurred in the carapace length range 22-25 mm; the other in the range 30-35 mm. These peaks indicate relatively strong recruitment of small males into the populations at most of our sites. The direct relationship that we observed between the carapace length at which fully functional males first represent 50% of the catch at size (ML_{50}) and fecundity indicates that ML_{50} deserves further scrutiny as a population parameter for spot shrimp. We recommend: 1. that ADF&G standardize the pots used in PWS with those used by the same agency elsewhere in Alaska, ie. change to the conical pot described in the methods section of this report, 2. that in future surveys ADF&G randomly select their sites from a larger group of potential sampling sites, our six additional sites being good candidates for inclusion in the larger group of sites.

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Table 1 . Location, date set, depth and soak time of pot strings set to sample spot shrimp at 12 sites in Western Prince William Sound in October 1999.

Site	Station	Date set	Latitude	Longitude	Depth (m) Minimum	Depth (m) Maximum	Soak time (h)
ADF&G Traditional Sites							
Unakwik Inlet	1	10/19/99	61°00' N	147°32' W	92	159	18
	2	10/19/99	61°00' N	147°33' W	43	72	19
Culross Passage	1	10/21/99	60°37' N	148°10' W	60	130	19
	2	10/21/99	60°36' N	148°10' W	94	102	19
Golden	1	10/22/99	60°58' N	148°01' W	69	170	18
	2	10/22/99	60°58' N	148°02' W	46	99	20
Herring Bay	1	10/25/99	60°29' N	147°46' W	55	133	19
	2	10/25/99	60°28' N	147°46' W	26	136	21
North Chenega Island	1	10/27/99	60°24' N	147°59' W	103	172	18
	2	10/27/99	60°24' N	148°00' W	70	148	19
Green Island	1	10/29/99	60°16' N	147°33' W	74	136	18
	2	10/29/99	60°17' N	147°32' W	115	159	19
New Sites							
Wells Bay	1	10/18/99	60°58' N	147°28' W	80	119	16
	2	10/18/99	60°59' N	147°28' W	65	184	19
Eaglek Bay	1	10/20/99	60°54' N	147°46' W	90	129	20
	2	10/20/99	60°53' N	147°46' W	158	166	20
McClure Bay	1	10/23/99	60°34' N	148°11' W	111	153	19
	2	10/23/99	60°33' N	148°10' W	72	175	20
Port Nellie Juan	1	10/24/99	60°31' N	148°20' W	54	132	18
	2	10/24/99	60°32' N	148°19' W	67	138	20
Perry Island	1	10/26/99	60°44' N	148°01' W	74	157	19
	2	10/26/99	60°43' N	148°02' W	147	176	21
Jackpot Island	1	10/28/99	60°19' N	148°11' W	48	143	20
	2	10/28/99	60°19' N	148°13' W	40	158	22

Table 2 . Location, date set, depth and soak time of pot strings set to sample spot shrimp at 12 sites in Western Prince William Sound in October 2000.

Site	Station	Date set	Latitude	Longitude	Depth (m) Minimum	Depth (m) Maximum	Soak time (h)
ADF&G Traditional Sites							
Unakwik Inlet	1	10/16/00	61°00' N	147°33' W	81	144	20
	2	10/16/00	60°59' N	147°34' W	70	122	20
Culross Passage	1	10/19/00	60°36' N	148°10' W	86	107	19
	2	10/19/00	60°36' N	148°10' W	80	144	20
Golden	1	10/17/00	60°58' N	148°01' W	69	170	18
	2	10/17/00	60°59' N	148°02' W	46	123	20
Herring Bay	1	10/22/00	60°29' N	147°46' W	50	111	18
	2	10/22/00	60°29' N	147°46' W	48	112	19
North Chenega Island	1	10/23/00	60°23' N	148°00' W	96	138	19
	2	10/23/00	60°23' N	147°59' W	83	126	20
Green Island	1	10/26/00	60°16' N	147°33' W	76	101	19
	2	10/26/00	60°17' N	147°33' W	68	99	19
New Sites							
Wells Bay	1	10/15/00	60°58' N	147°28' W	96	143	17
	2	10/15/00	60°59' N	147°28' W	64	172	18
North Squire Island	1	10/25/00	60°17' N	147°56' W	87	119	19
	2	10/25/00	60°17' N	147°57' W	51	108	19
McClure Bay	1	10/21/00	60°33' N	148°10' W	58	127	19
	2	10/21/00	60°34' N	148°11' W	82	119	19
Port Nellie Juan	1	10/20/00	60°32' N	148°19' W	131	173	20
	2	10/20/00	60°32' N	148°19' W	64	137	20
Perry Island	1	10/18/00	60°43' N	148°02' W	122	193	19
	2	10/18/00	60°42' N	148°00' W	66	126	19
Jackpot Island	1	10/24/00	60°19' N	148°11' W	50	102	19
	2	10/24/00	60°19' N	148°12' W	48	104	20

Table 3 . Location, date set, depth and soak time of pot strings set to sample juvenile spot shrimp at 12 sites in Western Prince William Sound in October 2000.

Site	Date set	Latitude	Longitude	Depth (m) Minimum	Depth (m) Maximum	Soak time (h)
ADF&G Traditional Sites						
Unakwik Inlet	10/16/00	60°58' N	147°37' W	9	19	20
Culross Passage	10/19/00	60°37' N	148°10' W	17	25	20
Golden	10/17/00	60°58' N	148°01' W	14	44	16
Herring Bay	10/22/00	60°28' N	147°46' W	6	21	19
North Chenega Island	10/23/00	60°23' N	148°00' W	6	16	20
Green Island	10/26/00	60°15' N	147°30' W	8	14	19
New Sites						
Wells Bay	10/15/00	61°00' N	147°30' W	20	30	15
North Squire Island	10/25/00	60°17' N	147°56' W	4	22	19
McClure Bay	10/21/00	60°33' N	148°11' W	11	47	19
Port Nellie Juan	10/20/00	60°32' N	148°19' W	23	64	20
Perry Island	10/18/00	60°43' N	148°01' W	15	33	19
Jackpot Island	10/24/00	60°19' N	148°12' W	10	16	20

Table 4. Catch statistics of spot shrimp study at 12 sites in western Prince William Sound in October 1999. The number of pots fished at each site was 22. SE = one standard error of the mean.

		Catch (no./pot)			Catch Weight (g/pot)		Dry Mass (g/pot)		Males		Transitional		Ovigerous Females		Nonovigerous Females	
Site	No. Shrimp	Mean	SE	Total weight [kg(lb)]	Mean	SE	Mean	SE	Total No.	%	Total No.	%	Total No.	%	Total No.	%
ADF&G Traditional Sites																
Unakwik Inlet	78	3	1.4	1.7 (3.8)	76	18	19	6.0	69	88	1	1	7	9	1	1.3
Culross Passage	893	40	27	16 (37)	765	494	155	95	797	93	16	2	45	5	0	0
Golden	300	13	5.3	8.3 (18)	377	169	84	34	228	76	6	2	66	22	1	0.3
Herring Bay	237	10	8.7	4.9 (11)	222	164	49	34	205	86	1	0	34	14	0	0
North Chenega Island	58	2.4	2	1.5 (3.3)	66	63	16	15	46	79	0	0	11	19	1	1.7
Green Island	59	2.6	0.8	1.0 (2.2)	44	14	11	3.5	52	88	3	5	3	5	1	1.7
New Sites																
Wells Bay	697	26	3.6	15 (33)	687	252	156	82	413	72	0	0	154	22	4	0.7
Eaglek Bay	4	0.2	0.09	0.06 (0.1)	2.9	2	0.36	0.2	4	100	0	0	0	0	0	0
McClure Bay	299	13	7.8	8.1 (18)	368	229	84	52	207	68	9	3	87	28	2	0.7
Port Nellie Juan	326	14	6.2	2.5 (5.5)	114	59	28	13	323	100	0	0	1	0	0	0
Perry Island	372	16	7.6	15 (33)	671	386	139	73	199	54	9	2	151	41	13	3.5
Jackpot Island	513	23	16	8.9 (20)	403	189	85	38	465	91	19	4	23	5	3	0.6

Table 5. Catch statistics of spot shrimp study at 12 sites in western Prince William Sound in October 2000. The number of pots fished at each site was 22. SE = one standard error of the mean.

		Catch (no./pot)			Catch Weight (g/pot)		Dry Mass (g/pot)		Males		Transitional		Ovigerous Females		Nonovigerous Females	
Site	No. Shrimp	Mean	SE	Total weight [kg(lb)]	Mean	SE	Mean	SE	Total No.	%	Total No.	%	Total No.	%	Total No.	%
ADF&G Traditional Sites																
Unakwik Inlet	321	15	5.4	9.5 (21)	431	162	98	37	231	73	8	2.5	74	23	2	1
Culross Passage	587	27	17	12 (26)	535	304	116	64	449	77	74	13	57	10	1	0
Golden	1180	54	29	21 (46)	960	159	204	30	994	89	22	2	103	9.2	0	0
Herring Bay	348	16	4.2	6.0 (13)	274	69	61	14	281	85	19	5.7	31	9	0	0
North Chenega Island	817	37	2.6	13 (29)	595	94	137	22	733	88	36	4.4	51	6	5	1
Green Island	359	16	1.4	5.9 (13)	268	46	61	11	295	91	13	4	17	5	0	0
New Sites																
Wells Bay	353	16	2.6	8.1 (18)	368	42	79	7.8	309	88	5	1.4	38	11	0	0
North Squire Island	113	5.1	0.4	2.6 (5.7)	120	13	27	1.8	92	82	7	6.2	13	12	0	0
McClure Bay	609	28	8.2	13 (29)	606	169	131	37	457	76	92	15	50	8	2	0
Port Nellie Juan	299	14	0.3	3.4 (7.5)	158	48	36	14	274	93	7	2.4	10	3	4	1
Perry Island	398	18	3.2	9.5 (21)	432	53	102	10	319	81	13	3.3	60	15	3	1
Jackpot Island	699	32	5.4	13 (29)	572	104	131	24	638	91	52	7.4	9	1	0	0

Table 6. Mean number of individuals, fresh weight and dry mass of spot shrimp in catches at two site groups (six traditional sites and six new sites) in western Prince William Sound in 1999 and 2000.

	Catch (no./pot)			Catch fresh weight (kg/pot)			Catch dry mass (g/pot)		
Site group	N	Mean	SE	N	Mean	SE	N	Mean	SE
1999									
Traditional	6	11.8	5.9	6	0.258	0.114	6	55.7	22.9
New	6	15.4	3.7	6	0.374	0.114	6	82.2	24.8
2000									
Traditional	6	27.4	6.3	6	0.511	0.083	6	112.9	22.1
New	6	18.7	3.9	6	0.376	0.105	6	84.3	18.6

Table 7. Analysis of variance of the spot shrimp catch (no./pot), catch fresh weight (kg/pot) and dry mass of catch (g/pot) at two site groups (six traditional sites and six new sites) in western Prince William Sound in 1999 and 2000.

Catch Variable Source of Variation	df	MS	F	P
Spot shrimp catch				
Data untransformed; Levene's test[a], P = 0.564				
Site group	1	39.7	0.255	0.62
Year	1	532	3.42	0.08
Site group x Year	1	223	1.43	0.24
Error	20	156		
Catch fresh weight				
Data untransformed; Levene's test[a], P = 0.921				
Site group	1	5.1×10^{-4}	0.008	0.93
Year	1	9.7×10^{-2}	1.47	0.24
Site group x Year	1	9.4×10^{-2}	1.43	0.25
Error	20	6.6×10^{-2}		
Shrimp dry mass				
Data untransformed; Levene's test[a], P = 0.967				
Site group	1	6.8	0.002	0.96
Year	1	5275	1.78	0.20
Site group x Year	1	4547	1.54	0.23
Error	20	2958		

a. Test of homogeneity of variances.

Table 8. Mean number of spot shrimp and mean fresh weight of spot shrimp in catches of the Alaska Department of Fish and Game (ADF&G) annual survey versus the present study at traditional ADF&G survey sites and at all sites sampled in western Prince William Sound in 1999 and 2000. N = number of sites, SE = standard error.

	Catch (no./pot)			Catch fresh weight (kg/pot)		
Organization	N	Mean	SE	N	Mean	SE
Traditional sites						
1999						
ADF&G	6	13.4	3.2	6	0.222	0.051
ABL/VNT	6	11.8	5.9	6	0.258	0.114
2000						
ADF&G	6	17.5	2.5	6	0.287	0.036
ABL/VNT	6	27.4	6.3	6	0.511	0.105
All sites						
1999						
ADF&G	8	12.5	2.5	8	0.213	0.042
ABL/VNT	12	13.6	3.4	12	0.316	0.079
2000						
ADF&G	8	18.6	2.2	8	0.318	0.046
ABL/VNT	12	23.0	3.8	12	0.443	0.067

Table 9. Analysis of variance of the mean number of spot shrimp/pot and mean fresh weight (kg) of spot shrimp/pot in catches of the Alaska Department of Fish and Game (ADF&G) annual survey versus the present study at traditional ADF&G survey sites in western Prince William Sound in 1999 and 2000.

Source of Variation	df	MS	F	P
Number of individuals				
Data untransformed; Levene's test[a], P = 0.257				
Organization	1	105	0.767	0.391
Year	1	574	4.215	0.053
Organization x Year	1	197	1.444	0.244
Error	20	136		
Weight				
Data untransformed; Levene's test[a], P = 0.151				
Organization	1	0.102	2.439	0.134
Year	1	0.151	3.611	0.072
Organization x Year	1	0.052	1.253	0.276
Error	20	0.042		

a. Test of homogeneity of variances.

Table 10. Analysis of variance of the mean number of spot shrimp/pot and mean fresh weight (kg) of spot shrimp/pot in catches at all sites sampled by the Alaska Department of Fish and Game (ADF&G) or by the present study in western Prince William Sound in 1999 and 2000.

Source of Variation	df	MS	F	P
Number of individuals				
Data untransformed; Levene's test[a], P = 0.186				
Organization	1	72	0.648	0.426
Year	1	579	5.213	0.028
Organization x Year	1	26	0.236	0.630
Error	36	111		
Weight				
Data untransformed; Levene's test[a], P = 0.045				
Organization	1	0.126	2.781	0.104
Year	1	0.128	2.834	0.101
Organization x Year	1	0.001	0.027	0.870
Error	36	1.045		

a. Test of homogeneity of variances.

Table 11. Significance test results of difference in mean carapace length of spot shrimp at 11 sites in western Prince William Sound between 1999 and 2000. N is number of shrimp measured.

	1999		2000			
Site	N	Mean carapace length (mm)	N	Mean carapace length (mm)	Type of Analysis	Significance level
Traditional Sites						
Unakwik Inlet	78	33.7	315	36.6	Mann-Whitney U	p<0.001
Culross Passage	858	30.6	580	30.9	Mann-Whitney U	ns[2]
Golden	301	34.7	1119	29.7	Anova	p<0.001
Herring Bay	237	31.4	331	30.0	Anova	p<0.05
North Chenega Island	58	34.4	825	28.6	Anova	p<0.001
Green Island	59	30.2	325	30.8	Anova	ns
New Sites						
Wells Bay	573	33.6	352	32.1	Mann-Whitney U	p<0.05
McClure Bay	301	34.7	602	32.0	Anova[1]	p<0.001
Port Nellie Juan	325	24.3	295	25.5	Mann-Whitney U	p<0.05
Perry Island	372	38.7	395	33.6	Anova	p<0.001
Jackpot Island	508	29.3	699	30.9	Anova[1]	p<0.001

1. Data log transformed for analysis.
2. ns = not significant.

Table 12. Significance test results of difference in mean dry mass of spot shrimp at 11 sites in western Prince William Sound between 1999 and 2000. N is number of shrimp weighed.

	1999		2000			
Site	N	Mean dry mass (g)	N	Mean dry mass (g)	Type of Analysis	Significance level
ADF&G Traditional Sites						
Unakwik Inlet	78	5.26	315	6.85	Mann-Whitney U	p<0.001
Culross Passage	858	3.99	580	4.41	Mann-Whitney U	ns[3]
Golden	301	6.14	1119	4.02	Anova[1]	p<0.001
Herring Bay	237	4.58	331	4.03	Anova[1]	p<0.05
North Chenega Island	58	6.03	825	3.66	Anova[1]	p<0.001
Green Island	59	4.06	325	4.12	Anova	ns
New Sites						
Wells Bay	573	6.00	352	4.95	Mann-Whitney U	p<0.05
McClure Bay	301	6.11	602	4.77	Anova[1]	p<0.001
Port Nellie Juan	325	1.90	295	2.67	Mann-Whitney U	p<0.05
Perry Island	372	8.25	395	5.68	Anova[2]	p<0.001
Jackpot Island	508	3.69	699	4.13	Anova[1]	p<0.001

1. Data log transformed for analysis.
2. Data transformed with Taylor's transformation for analysis.
3. ns = not significant.

Table 13. Analysis of variance of the carapace length (mm) in male, transitional and female spot shrimp at two site groups (traditional sites and new sites) in western Prince William Sound in 1999 and 2000.

Shrimp Stage Source of Variation	df	MS	F	P
Male				
Data untransformed; Levene's test[a], P = 0.407				
Site group	1	5.51	0.768	0.39
Year	1	0.70	0.098	0.76
Site group x Year	1	7.82	1.090	0.31
Error	20	7.17		
Transitional				
Data untransformed; Levene's test[a], P = 0.097				
Site group	1	4.48	1.514	0.24
Year	1	0.02	0.006	0.94
Site group x Year	1	2.10	0.708	0.41
Error	16	2.96		
Female				
Data untransformed; Levene's test[a], P = 0.913				
Site group	1	0.38	0.228	0.64
Year	1	4.00	2.371	0.14
Site group x Year	1	0.68	0.401	0.53
Error	19	1.69		

a. Test of homogeneity of variances.

Table 14. Carapace length at which the percentage of fully functional males (ML50) or females (FL50) represented 50% of the catch at size at 12 locations in western Prince William Sound in 1999 and 2000.

	1999		2000	
Location	ML50 (mm)	FL50 (mm)	ML50 (mm)	FL50 (mm)
Wells Bay	26.1	41.3	23.8	42
Unakwik Inlet	27.0	39.7	26	40.3
Golden	27.4	41.4	24.5	41.3
Perry Island	27.9	41.3	25.4	41.4
Culross Passage	27.4	40.2	23.7	39.6
McClure Bay	27.2	39.6	24.4	40.1
Port Nellie Juan	23.6	-[1]	23.9	40.6
Herring Bay	24.5	40.5	24.4	39.2
North Chenega Island	24.9	42.8	24.6	39.7
Jackpot Island	28.0	41.2	25.4	42.5
North Squire Island	-[2]	-[2]	24.8	41.6
Green Island	24.8	41.6	23.9	39.4
Mean	26.2	41.0	24.6	40.6
SE	0.47	0.31	0.21	0.32

1. Only one female caught.
2. Site not sampled in 1999.

Table 15. Analysis of covariance of the fecundity of female spot shrimp at traditional versus new site groups in western Prince William Sound in 1999 and 2000. Fecundities are lumped within site groups.

Source of Variation	df	MS	F	P
1999 and 2000				
Data untransformed; Levene's test[b], $P < 0.001$				
Carapace length	1	1.1×10^8	350	<0.001
Site Group	1	1.3×10^4	0.04	0.840
Year	1	1.4×10^7	46.3	<0.001
Site x Year	1	7.2×10^5	2.3	0.128
Error	303	3.1×10^5		
1999				
Data untransformed; Levene's test[b], $P = 0.092$				
Carapace length	1	6.7×10^7	367	<0.001
Site Group	1	3.0×10^5	1.6	0.203
Error	157	1.8×10^5		
2000				
Data untransformed; Levene's test[b], $P = 0.542$				
Carapace length	1	4.1×10^7	93.3	<0.001
Site Group	1	5.3×10^5	1.2	0.275
Error	145	4.4×10^5		

a. Eaglek Bay was excluded because no females were captured there. Data from North Squire Island were excluded because the site was not sampled in 1999.
b. Test of homogeneity of variances.

Table 16. Analysis of covariance results of difference in mean fecundity of spot shrimp at 11 sites in western Prince William Sound between 1999 and 2000.

	Source of Variation					
	Carapace length[a]			Year		
Site	MS	F	Sig.	MS	F	Sig.
ADF&G Traditional Sites						
Unakwik Inlet	1.3×10^6	10.2	$p<0.01$	7.7×10^5	5.9	$p<0.05$
Culross Passage	6.9×10^6	43.5	$p<0.001$	3.7×10^5	2.3	ns[c]
Golden	1.3×10^7	23.1	$p<0.001$	6.7×10^5	1.2	ns
Herring Bay	8.7×10^6	20.4	$p<0.001$	2.8×10^6	6.4	$p<0.05$
North Chenega Island	3.0×10^6	10.2	$p<0.01$	1.5×10^6	5.1	$p<0.05$
Green Island[a]	1.6×10^6	26.9	$p<0.001$	2.0×10^6	34.6	$p<0.001$
New Sites						
Wells Bay	8.7×10^5	1.9	ns	1.2×10^5	0.25	ns
McClure Bay	1.6×10^7	127	$p<0.001$	2.7×10^6	21.6	$p<0.001$
Perry Island[b]	1.5×10^7	123	$p<0.001$	4800	0.04	ns
Jackpot Island	4.3×10^6	13.5	$p=0.001$	2.4×10^6	7.5	$p<0.05$

a. Covariate
b. No. of ovigerous females only three in 1999.
b.Levene's test significant ($p<0.05$).
c. ns = not significant.

Table 17. Analysis of variance of the depth, temperature and salinity at the modal CPUE in the distribution of CPUE with depth in "male"[a] versus ovigerous female spot shrimp at 12 sites in western Prince William Sound in 1999 and 2000.

	"Males"		Ovigerous females				
Year	N	Mean	N	Mean	MS	F	Sig.
Depth (m)							
1999	12	86.6	10	126	8518	10.9	$p < 0.01$
2000	12	88.0	12	94.6	260	0.38	ns[b]
Temperature (°C)							
1999	12	7.7	7	6.3	0.026[c]	4.6	$p < 0.05$
2000	11	7.7	12	7.6	0.055	0.038	ns
Salinity (PSU)							
2000[d]	11	31.2	12	31.2	0.022	0.058	ns

a. "Male" includes transitional and nonovigerous female shrimp.
b. ns = not significant.
c. Data log transformed for analysis.
d. See text for 1999 statistical results.

Table 18. Catch statistics of spot shrimp in juvenile pots at 12 sites in western Prince William Sound in October 2000. The number of pots fished at each site was 11. SE = one standard error of the mean.

Site	No. Shrimp	Catch (no./pot) Mean	Catch (no./pot) SE	Juveniles Total No.	Juveniles %	Males Total No.	Males %	Transitional Total No.	Transitional %	Ovigerous Females Total No.	Ovigerous Females %	Nonovigerous Females Total No.	Nonovigerous Females %	All Females Total No.	All Females %
ADF&G Traditional Sites															
Unakwik Inlet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Culross Passage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Golden	542	45	4.9	0	0	542	100	0	0	0	0	0	0	0	0
Herring Bay	15	1.4	0.7	7	47	8	53	0	0	0	0	0	0	0	0
North Chenega Island	80	7.3	2.5	7	8.8	72	90	1	1.2	0	0	0	0	0	0
Green Island	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New Sites															
Wells Bay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
North Squire Island	9	0.8	0.4	0	0	9	100	0	0	0	0	0	0	0	0
McClure Bay	50	4.5	1.8	1	2.0	49	98	0	0	0	0	0	0	0	0
Port Nellie Juan	3	0.3	0.2	0	0	3	100	0	0	0	0	0	0	0	0
Perry Island	199	17	4.3	0	0	186	94	7	3.5	6	3.0	0	0	6	3.0
Jackpot Island	7	0.6	0.6	0	0	7	100	0	0	0	0	0	0	0	0

Table 19. Spot Shrimp catch statistics from six of the sites[1] sampled traditionally by the Alaska Department of Fish and Game (ADF&G) during their Prince William Sound spot shrimp surveys from 1991 to 2000 (data courtesy of R. Berceli, ADF&G). Data collected at the same sites and at six new sites during the Auke Bay Lab/Valdez Native Tribe (ABL/VNT) cruises in 1999 and 2000 added for comparison. (Difference between totals and sum of male and female counts caused by exclusion of transitional shrimp.)

						Males			Females		
Year	No. pots	Catch weight kg (lbs)	Mean wt/pot kg (lbs)	No. shrimp	Mean no. shrimp/pot	No.	%	Mean carapace length (mm)	No.	%	Mean carapace length (mm)
1991	194	118 (260)	0.59 (1.3)	5964	31	5535	93	30.5	429	7	41.3
1992	281	91.6 (202)	0.36 (0.8)	3962	15	3480	88	31.7	482	12	41.9
1993	250	47.6 (105)	0.18 (0.4)	2075	8	1654	80	28.1	421	20	42.5
1994	264	40.4 (89)	0.14 (0.3)	2541	10	2416	95	27.5	123	5	43.5
1995	262	59.4 (131)	0.23 (0.5)	3418	13	3280	96	28.7	138	4	43.1
1996	263	63.5 (140)	0.09 (0.2)	3679	14	-[4]	-	-	-	-	-
1997	262	49.4 (109)	0.09 (0.2)	3031	11	2858	95	29	173	5	41.8
1998	219	29.5 (65.1)	0.04 (0.1)	2013	9.2	1913	95	28.3	100	5	44.1
1999	262	58.1 (128)	0.22 (0.5)	3525	14	-	-	-	-	-	-
2000	263	74.9 (165)	0.28 (0.6)	4594	18	6224	95	28.6	318	5	43.8
1999A[2]	132	34.1 (75.2)	0.27 (0.6)	1594	12	1397	86	30.6	170	10	43.7
2000A[2]	132	67.4 (148)	0.51 (1.1)	3496	27	2983	83	29.2	341	9	44.2
1999B[3]	132	49.4 (109)	0.36 (0.8)	2086	15	1611	73	28.5	438	20	43.6
2000B[3]	132	49.5 (109)	0.38 (0.8)	2455	19	2089	85	29.3	190	8	44.8

1. South Chenega and Prince of Wales Passage not sampled by present study. ADF&G data from these sites excluded from table.
2. ADF&G traditional sites; data from present study.
3. New sites; data from present study.
4. Dashes indicate data lost (1996) or data not available from ADF&G at this time (1999).

FIGURES

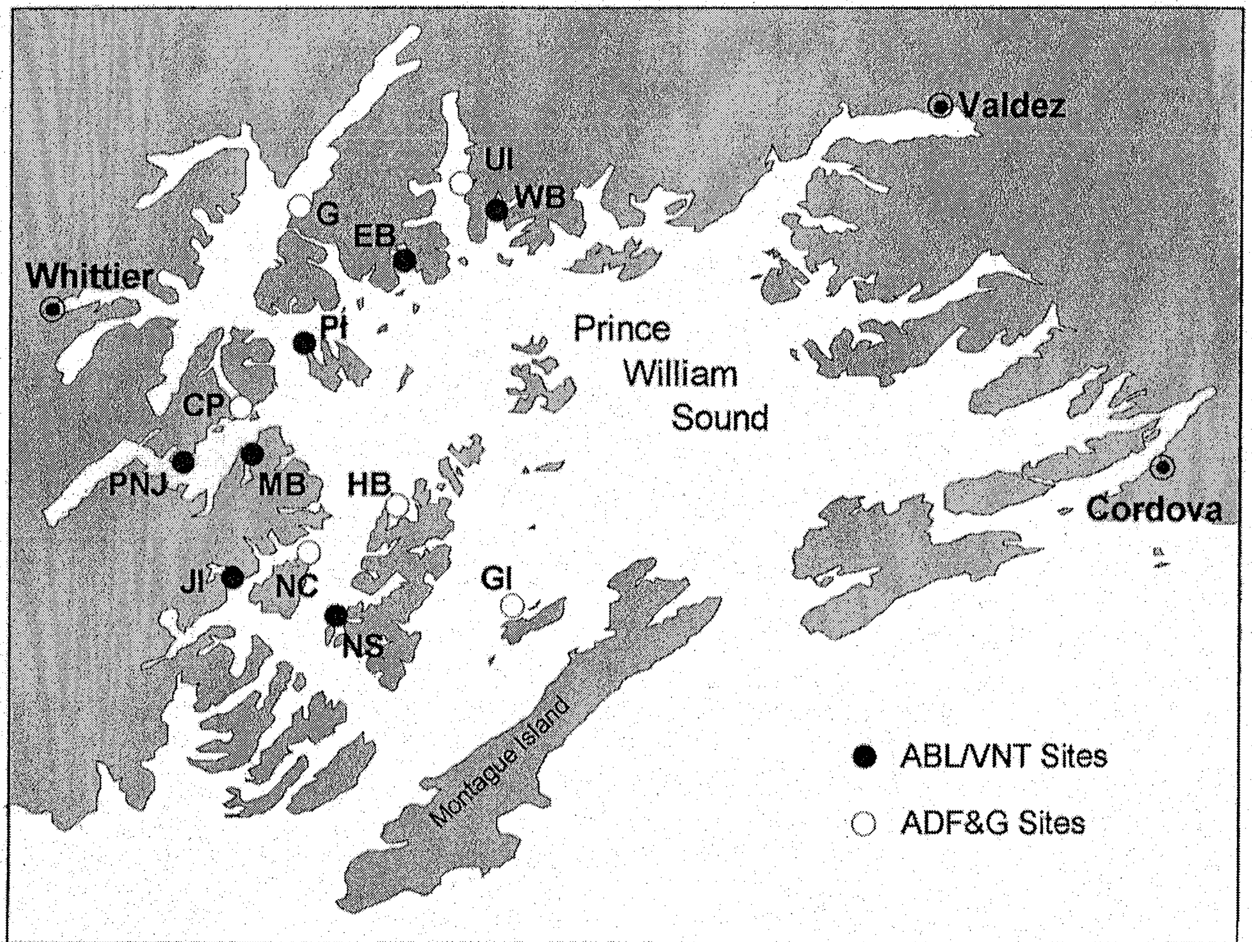


Figure 1. Location of spot shrimp study sites in Prince William Sound. Site abbreviations are: CP, Culross Passage; EB, Eaglek Bay; G, Golden; GI, Green Island; HB, Herring Bay; JB, Jackpot Island; MB, McClure Bay; NS, North Squire Island; NCI, North Chenega Island; PI, Perry Island; PNJ, Port Nellie Juan; UI, Unakwik Inlet; WB, Wells Bay.

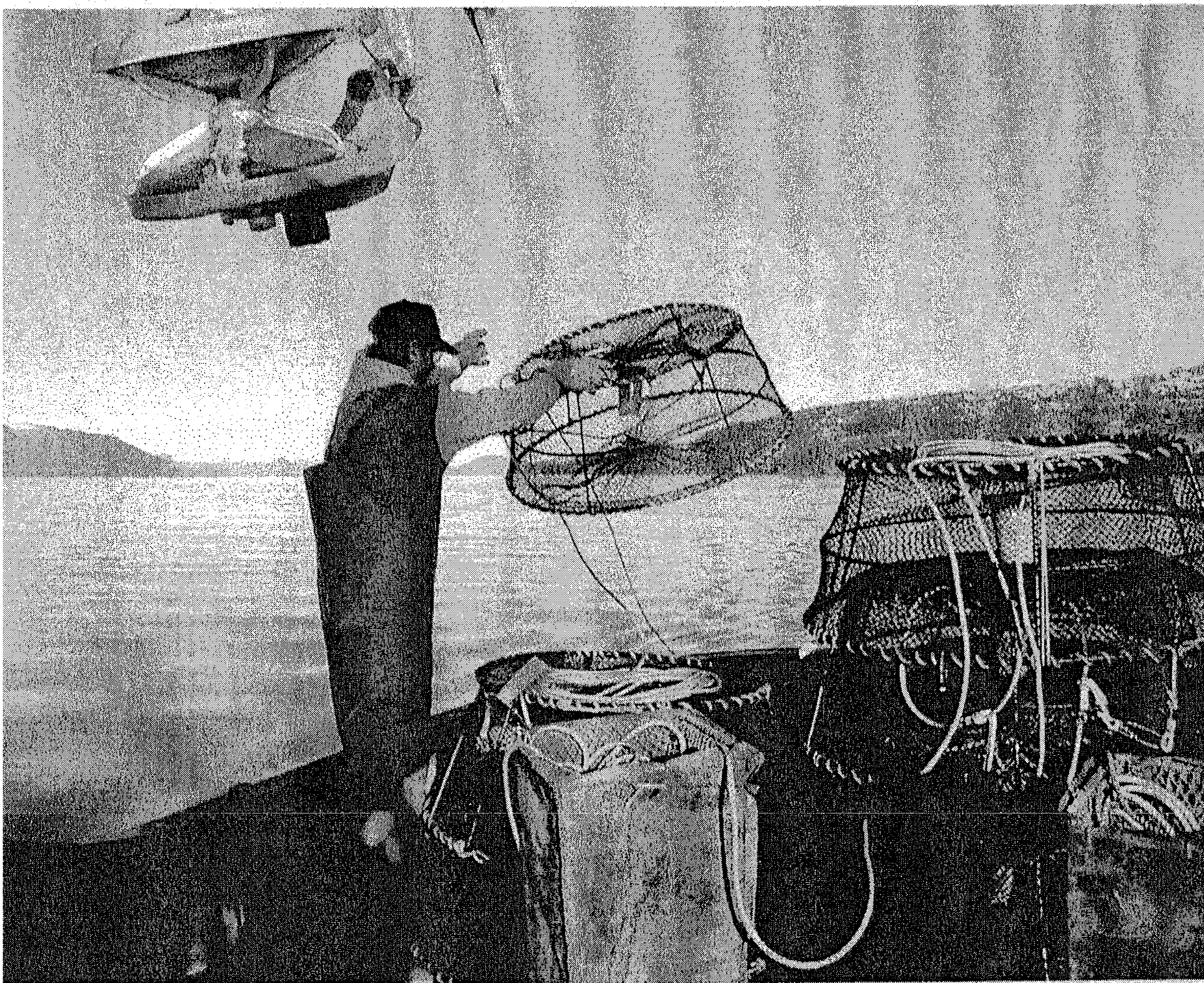


Figure 2. Deployment of shrimp pot at a study site in western Prince William Sound, October 1999.

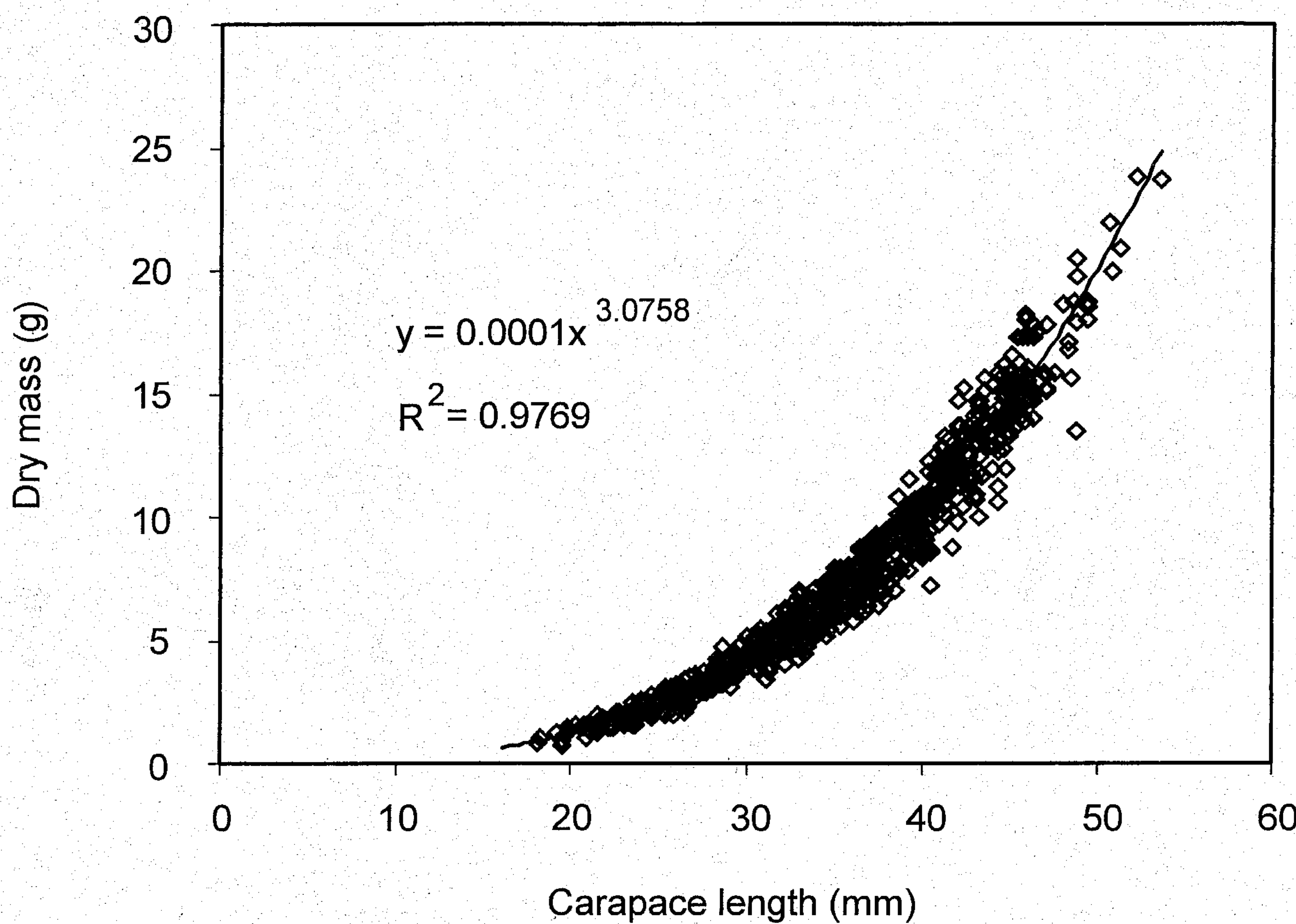


Figure 3. Relationship of dry mass to carapace length of spot shrimp from western Prince William Sound in October 1999.

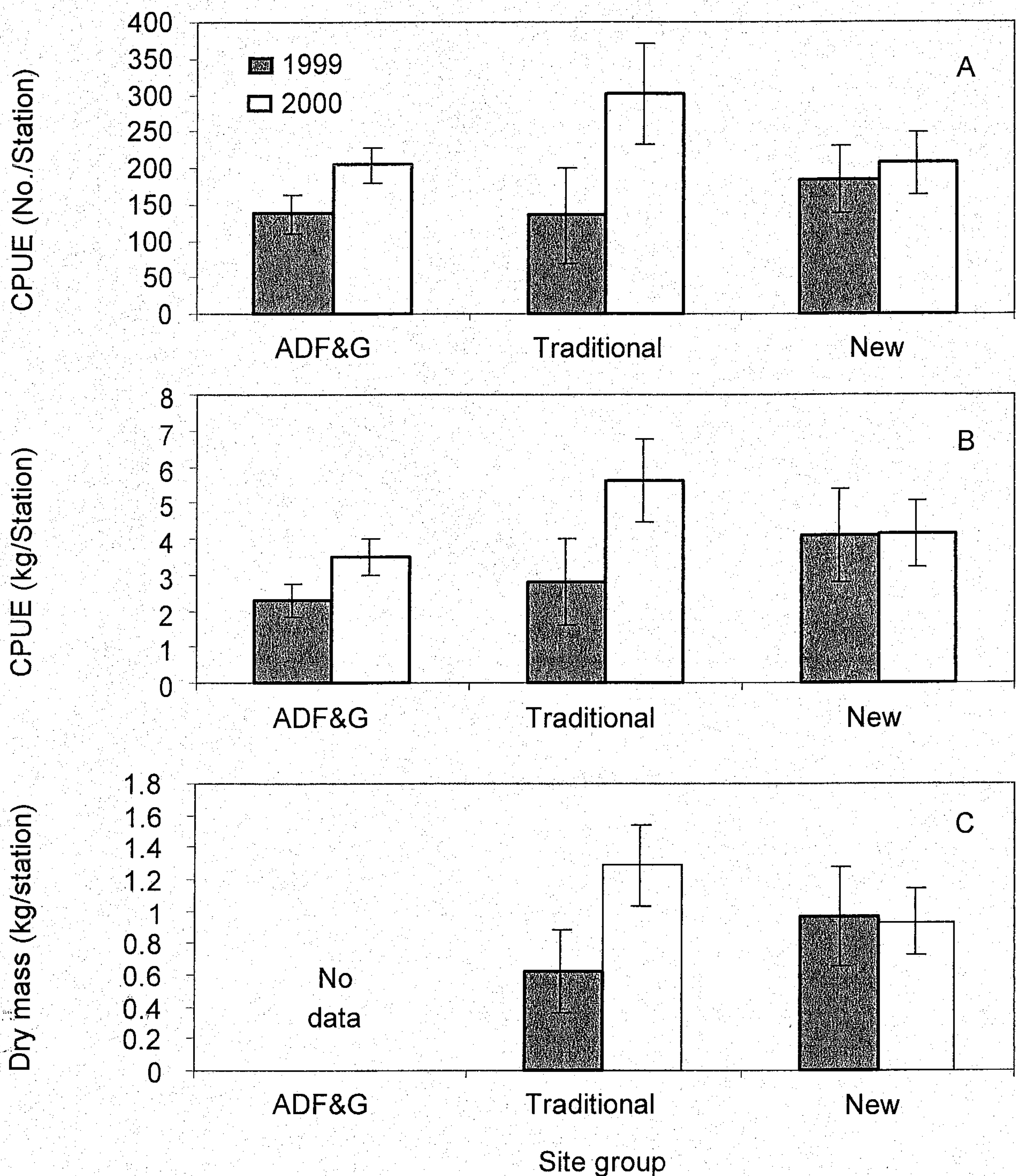


Figure 4. Catch per unit effort (CPUE) of spot shrimp expressed as number per station (A), fresh weight per station (B) or dry mass per station of spot shrimp at Alaska Department of Fish and Game (ADF&G) traditional sites during the ADF&G annual survey in western Prince William Sound (WPWS) in October 1999 and 2000 compared with the CPUE at ADF&G traditional sites and at six new sites in WPWS sampled jointly by the Auke Bay Lab and the Valdez Native Tribe (ABL/VNT) in October 1999 and 2000. Error bars are one standard error of the mean. (ADF&G data provided by J. Brady and R. Berceli).

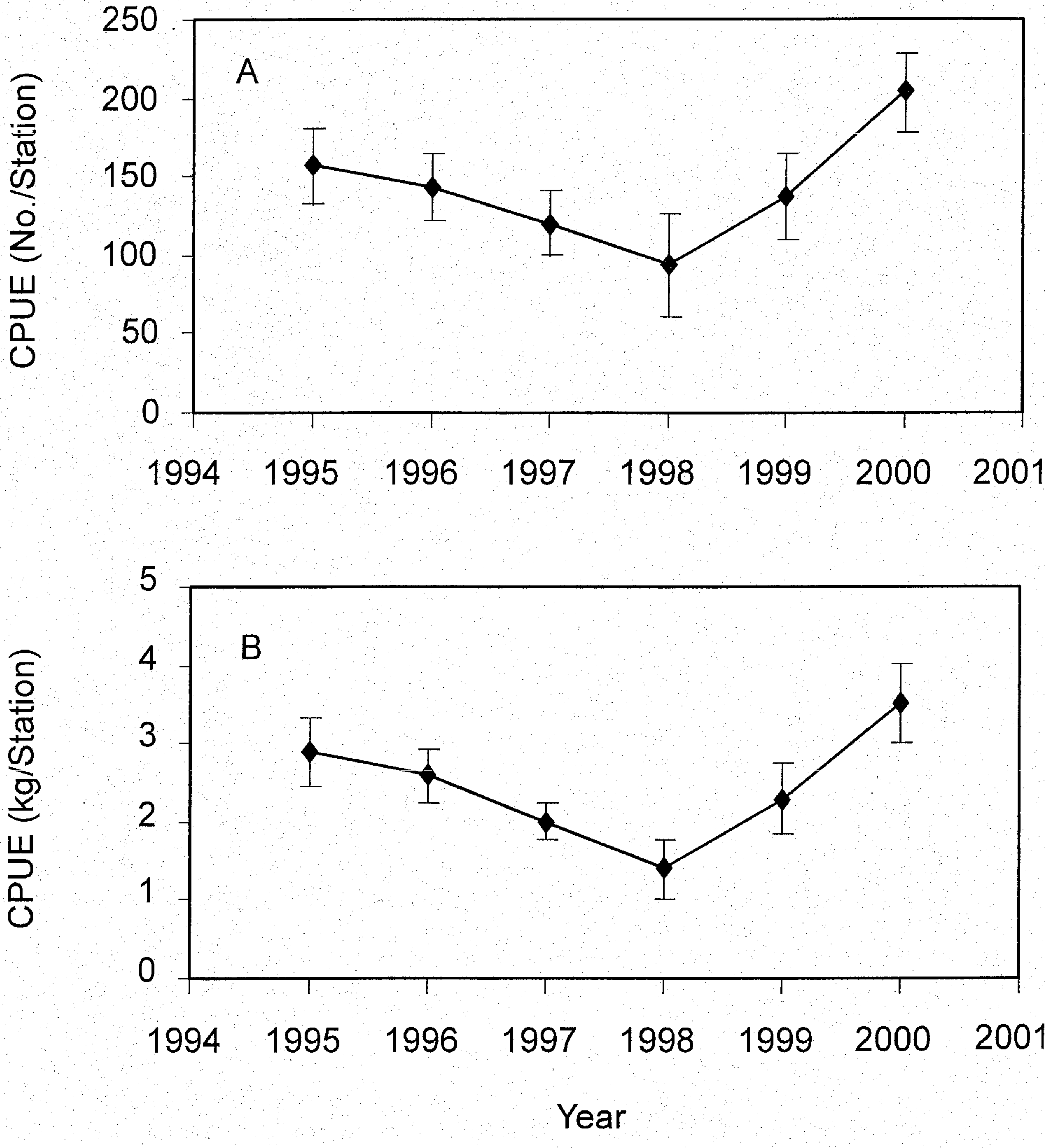


Figure 5. Mean catch per station (CPUE) of spot shrimp at sites traditionally sampled by the Alaska Department of Fish and Game (ADF&G) during ADF&G annual surveys in western Prince William Sound from 1995 to 2000. Error bars are one standard error of the mean. (Data provided by J. Brady and R. Berceli, ADF&G).

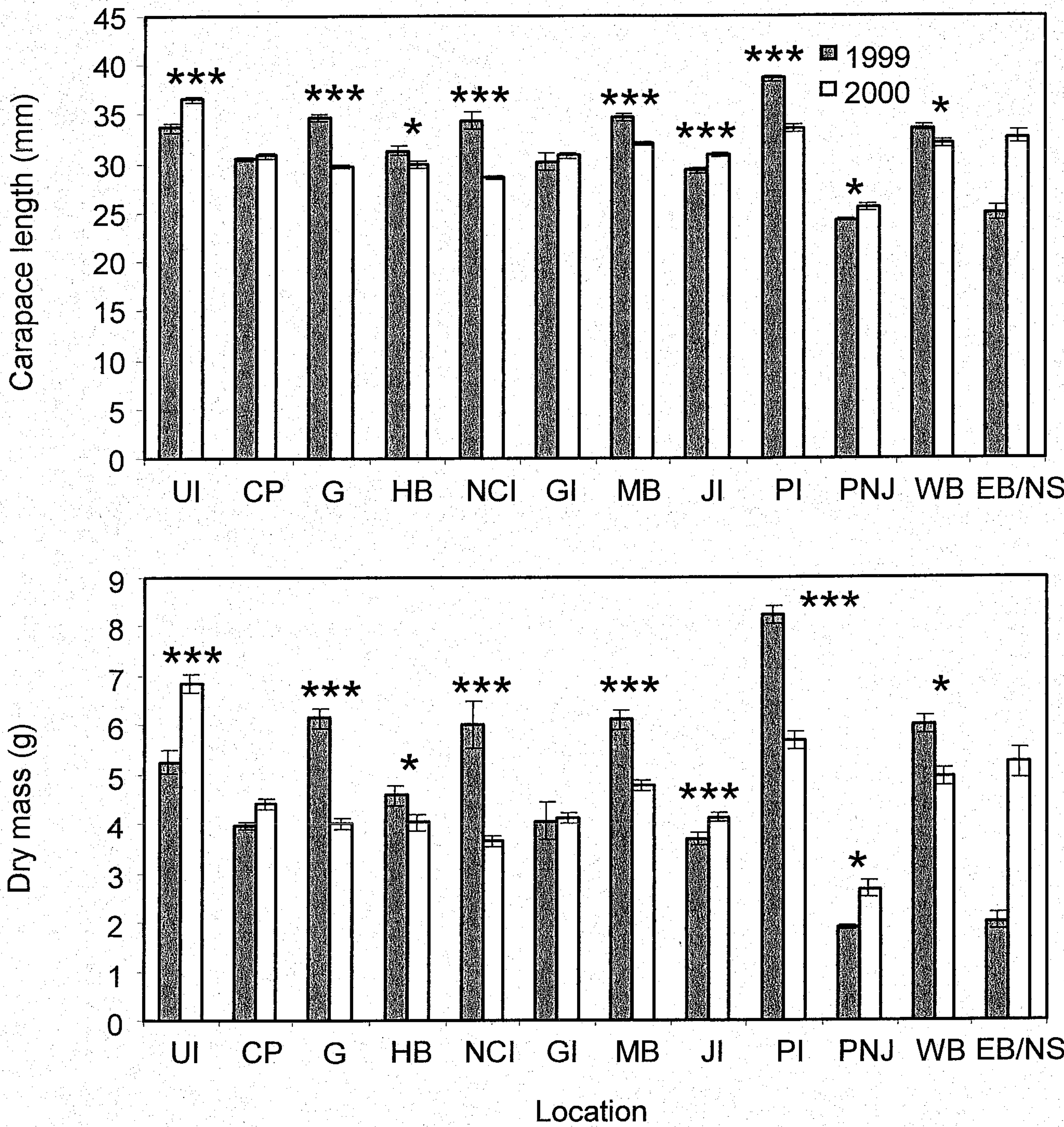


Figure 6. Mean carapace length of spot shrimp at 12 sites in western Prince William Sound in October 1999 and 2000. Error bars are one standard error of the mean. Asterisks denote significance of statistical tests; * = $p < 0.05$, *** = $p < 0.001$. Site abbreviations are: UI, Unakwik Inlet; CP, Culross Passage; G, Golden; HB, Herring Bay; NCI, North Chenega Island; GI, Green Island; MB, McClure Bay; JB, Jackpot Island; PI, Perry Island; PNJ, Port Nellie Juan; WB, Wells Bay; EB, Eaglek Bay; NS, North Squire Island.

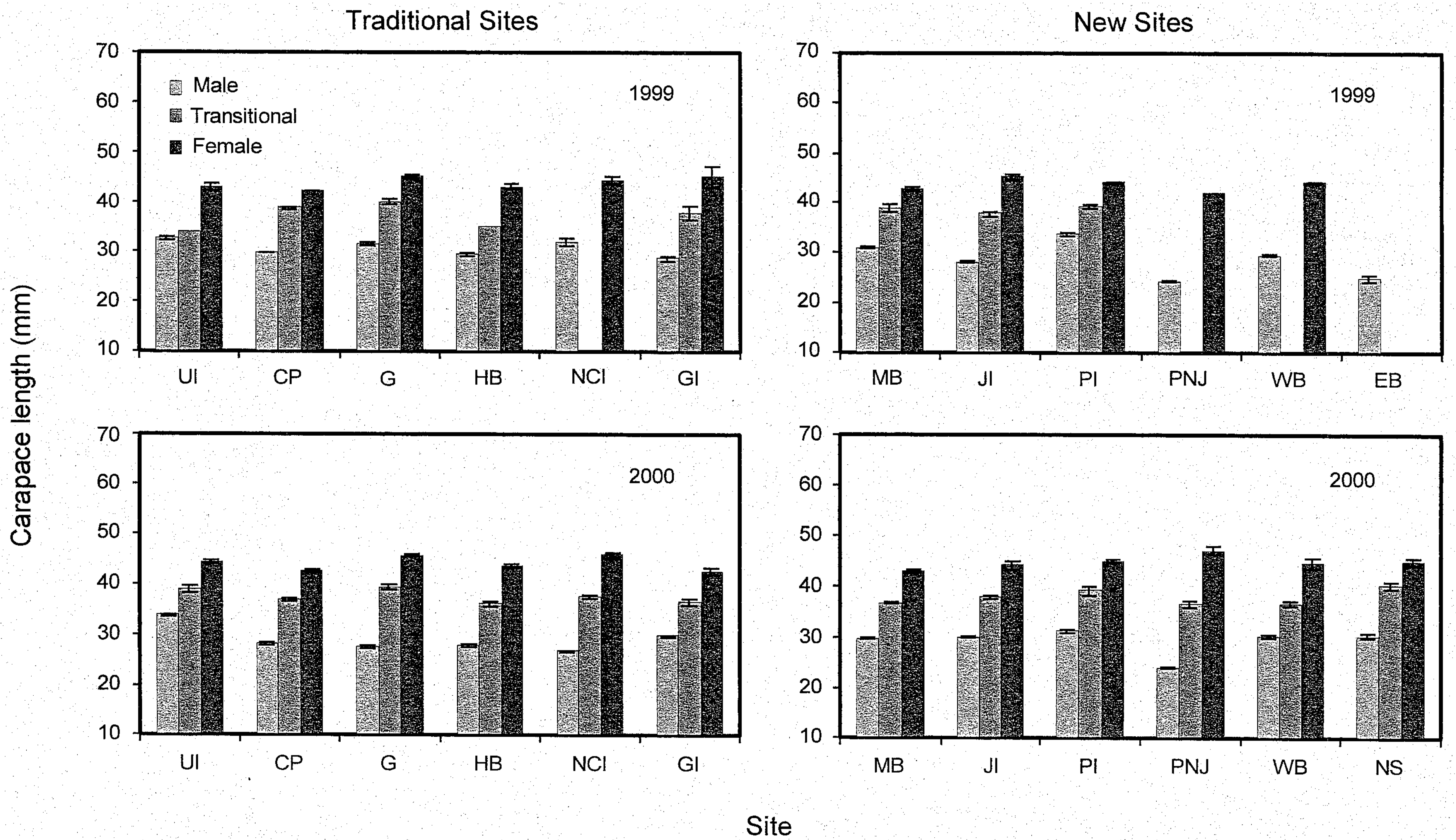


Figure 7. Mean carapace length of male, transitional and female spot shrimp at 12 sites in western Prince William Sound in October 1999 and 2000. Missing bars indicate that no shrimp of the appropriate life stage were caught at the site. Error bars are one standard error of the mean. Site abbreviations are: UI, Unakwik Inlet; CP, Culross Passage; G, Golden; HB, Herring Bay; NCI, North Chenega Island; GI, Green Island; MB, McClure Bay; JB, Jackpot Island; PI, Perry Island; PNJ, Port Nellie Juan; WB, Wells Bay; EB, Eaglek Bay; NS, North Squire Island.

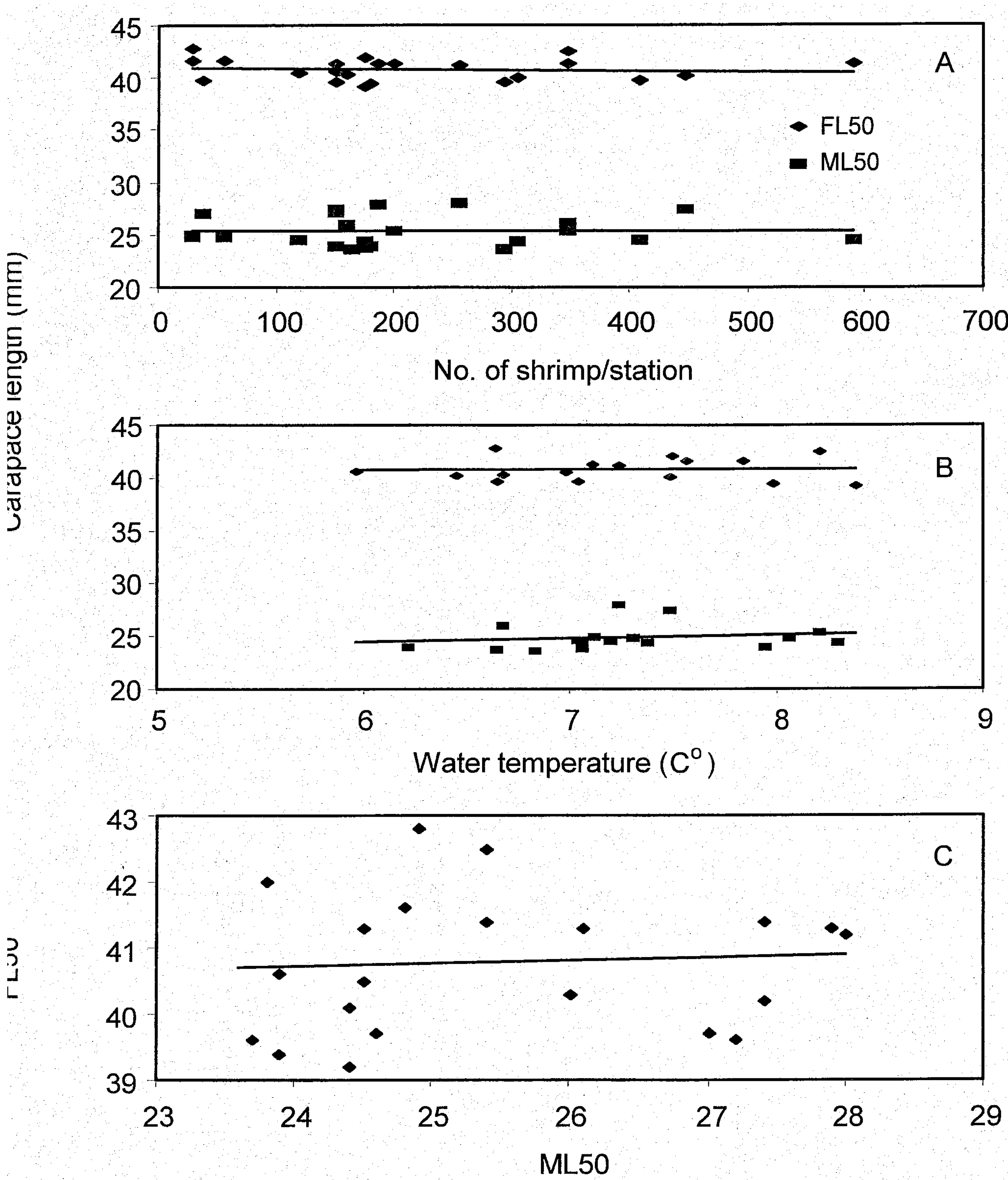


Figure 8. Relationship of the carapace length at which fully functional male spot shrimp first represented 50% of the catch at size (ML_{50}) and the length at which female spot shrimp represented 50% of the catch at size (FL_{50}) to the number of spot shrimp per station (A) and water temperature (B). Also shown is the relationship between FL_{50} and ML_{50} (C)

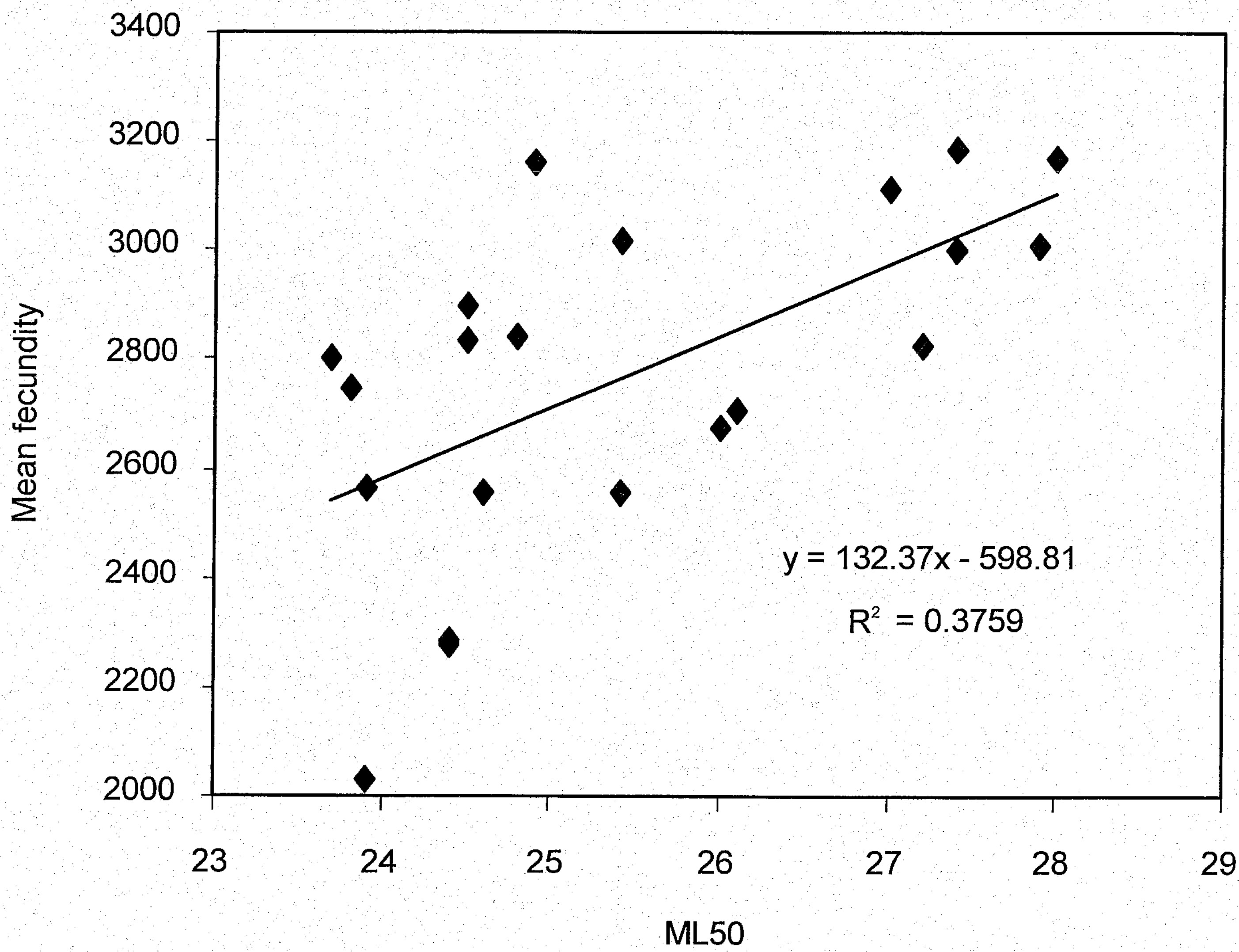


Figure 9. Relationship of spot shrimp fecundity to the carapace length at which fully functional male spot shrimp first represented 50% of the catch at size (ML_{50}) at study sites in western Prince William Sound in 1999 and 2000.

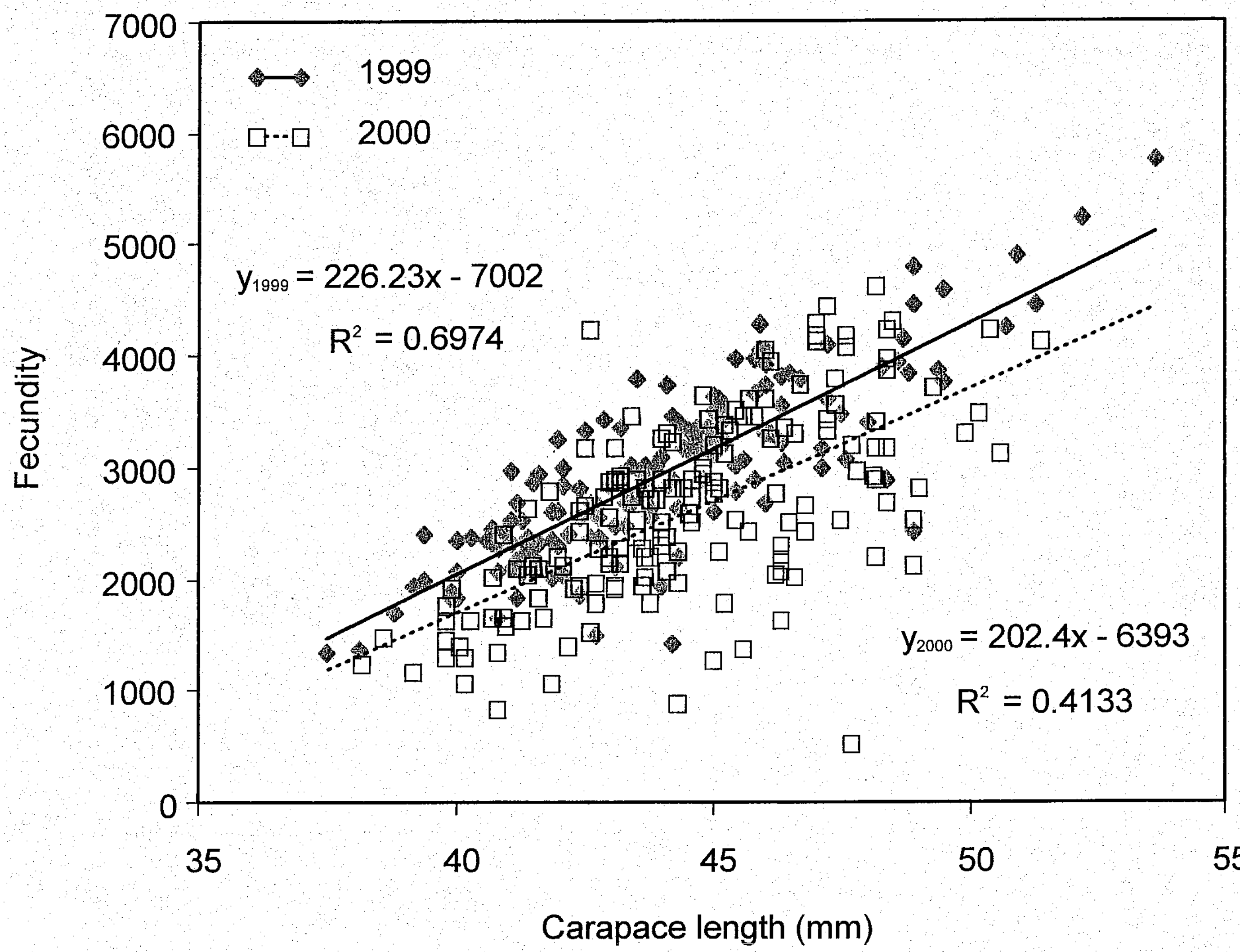


Figure 10. Relationship of fecundity to carapace length of spot shrimpat 12 sites in western Prince William Sound in 1999 and 2000.

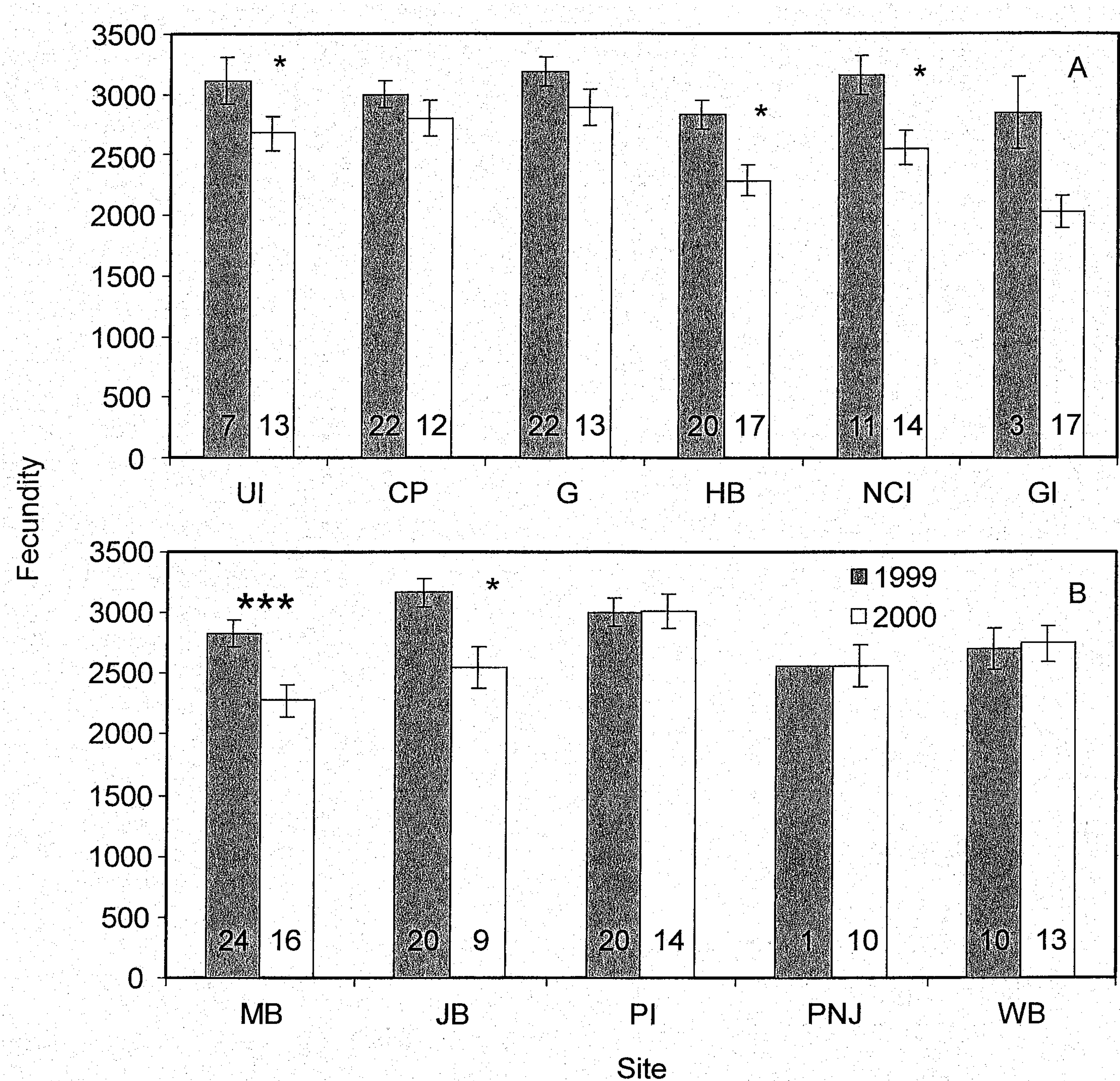


Figure 11. Adjusted mean fecundity (covariate, carapace length) of spot shrimp caught at six sites (A) traditionally sampled in the Alaska Department of Fish and Game annual survey and five new sites (B) in Prince William Sound in 1999 and 2000. Means evaluated at carapace length = 44.2 mm. The number at the base of each bar is the number of egg clutches used to estimate fecundity. Error bars are one standard error of the mean. Asterisks denote significance of between- year statistical tests: * = $p < 0.05$, *** = $p < 0.001$. Site abbreviations are: UI, Unakwik Inlet; CP, Culross Passage; G, Golden; HB, Herring Bay; NCI, North Chenega Island; GI, Green Island; MB, McClure Bay; JB, Jackpot Island; PI, Perry Island; PNJ, Port Nellie Juan; WB, Wells Bay.

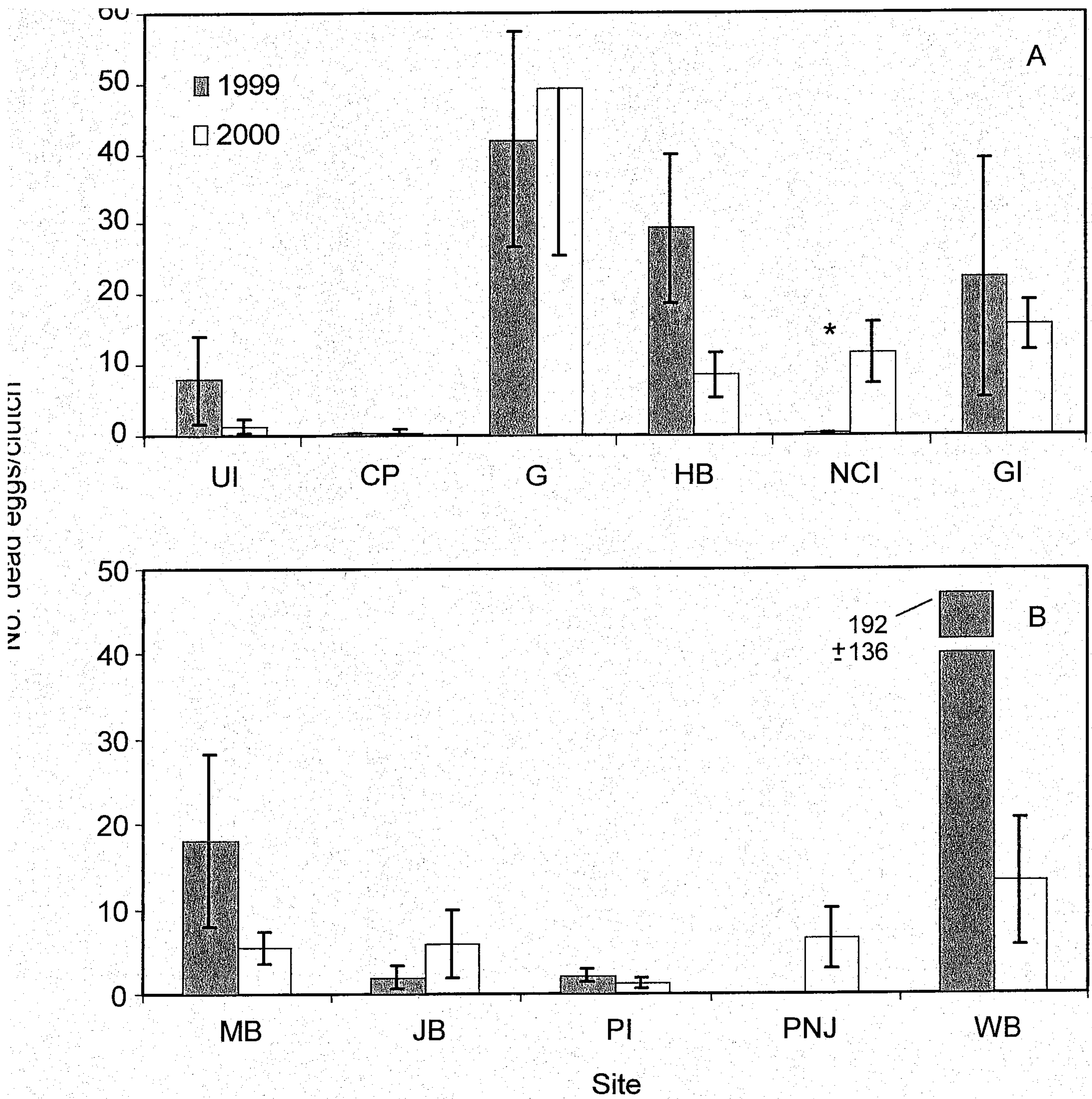


Figure 12. Count of dead eggs in the egg clutches of spot shrimp caught at six sites (A) traditionally sampled in the Alaska Department of Fish and Game annual survey and five new sites (B) in Prince William Sound in 1999 and 2000. Error bars are one standard error of the mean. Asterisk denotes significance of statistical test: * = $p < 0.05$. All other between-year tests were not significant. Site abbreviations are: UI, Unakwik Inlet; CP, Culross Passage; G, Golden; HB, Herring Bay; NCI, North Chenega Island; GI, Green Island; MB, McClure Bay; JB, Jackpot Island; PI, Perry Island; PNJ, Port Nellie Juan; WB, Wells Bay.

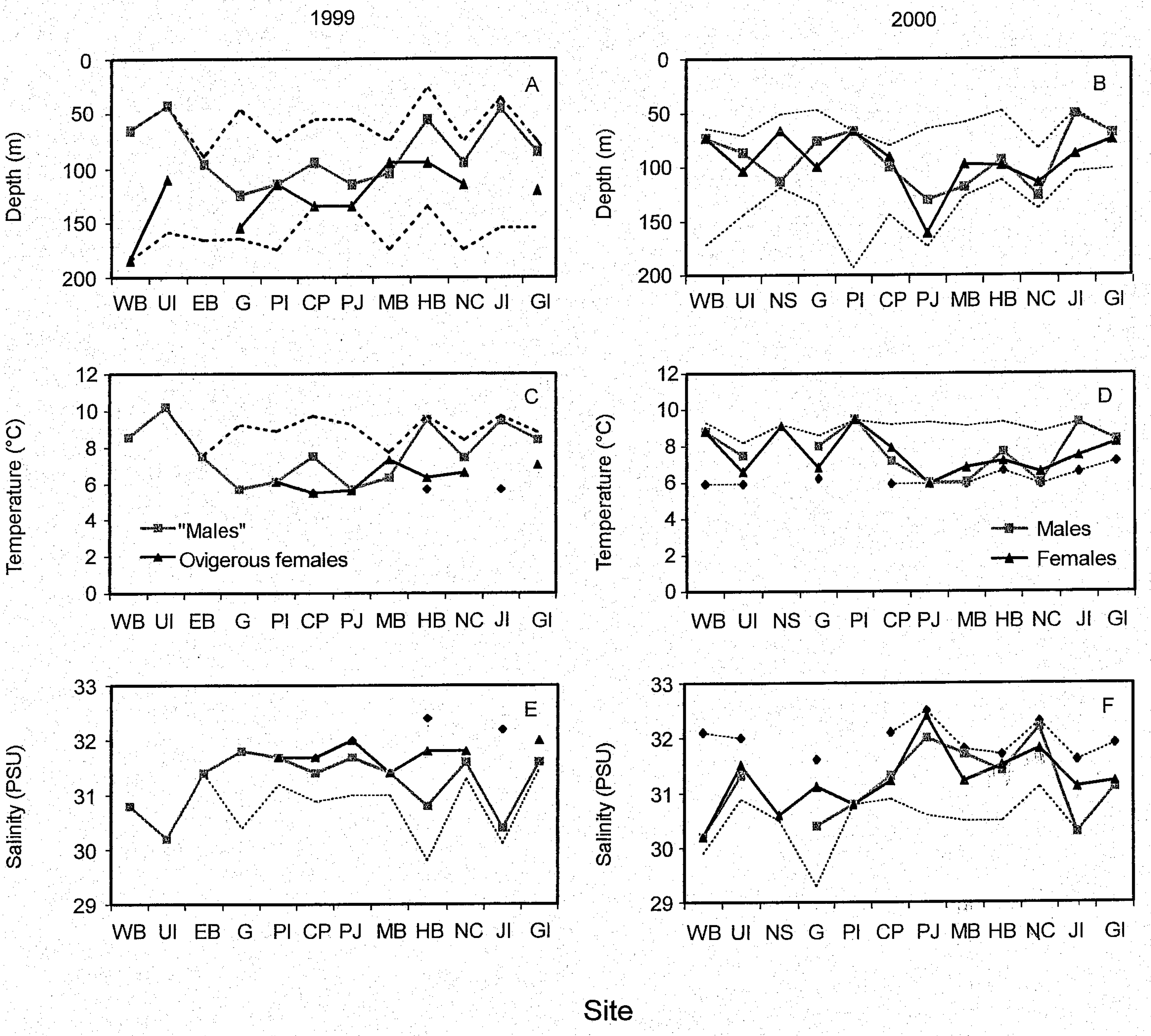


Figure 13. Mean depth (A), temperature (B) and salinity (C) of the modal CPUE in the distribution of spot shrimp with depth at 12 sites in western Prince William Sound in 1999 and 2000. "Males" and ovigerous females are plotted separately in 1999. "Males" includes transitional, and nonovigerous female shrimp. In 2000, males and females are plotted separately (see text). Dashed lines indicate the range in values of each variable in the depth range over which the shrimp pots were set. Site abbreviations are: WB, Wells Bay; UI, Unakwik Inlet; Eaglek Bay; G, Golden; PI, Perry Island; CP, Culross Passage; PNJ, Port Nellie Juan; MB, McClure Bay; HB, Herring Bay; NC, North Chenega Island; JI, Jackpot Island; GI, Green Island.

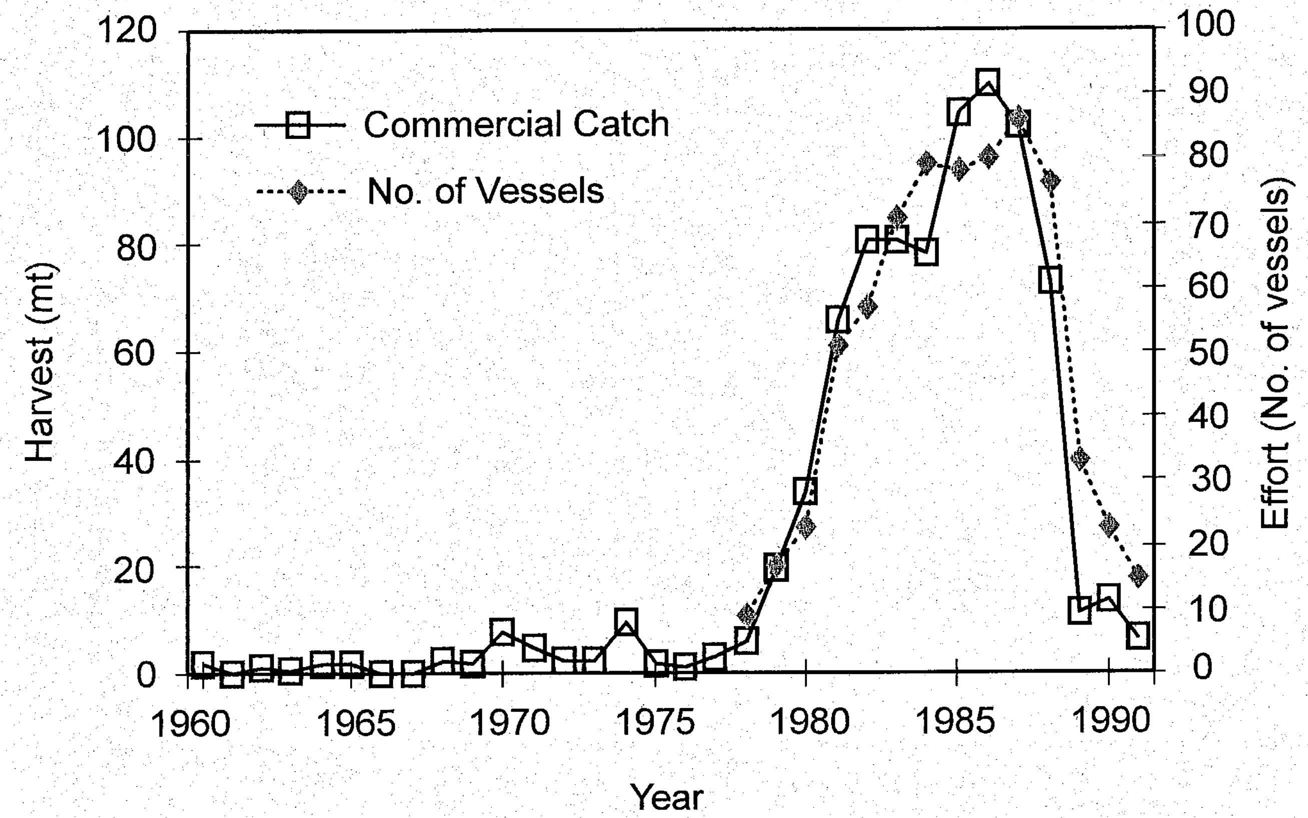
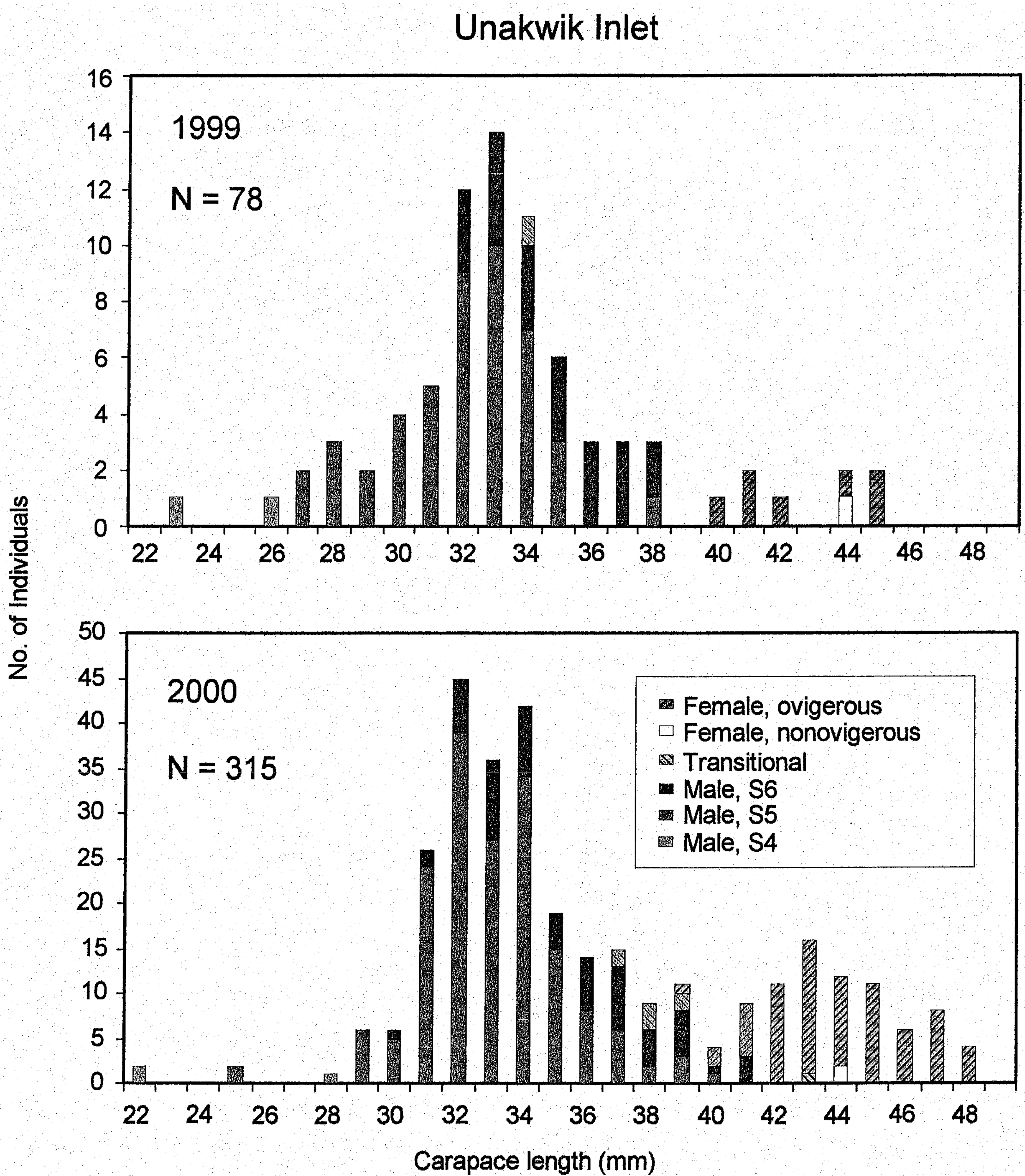


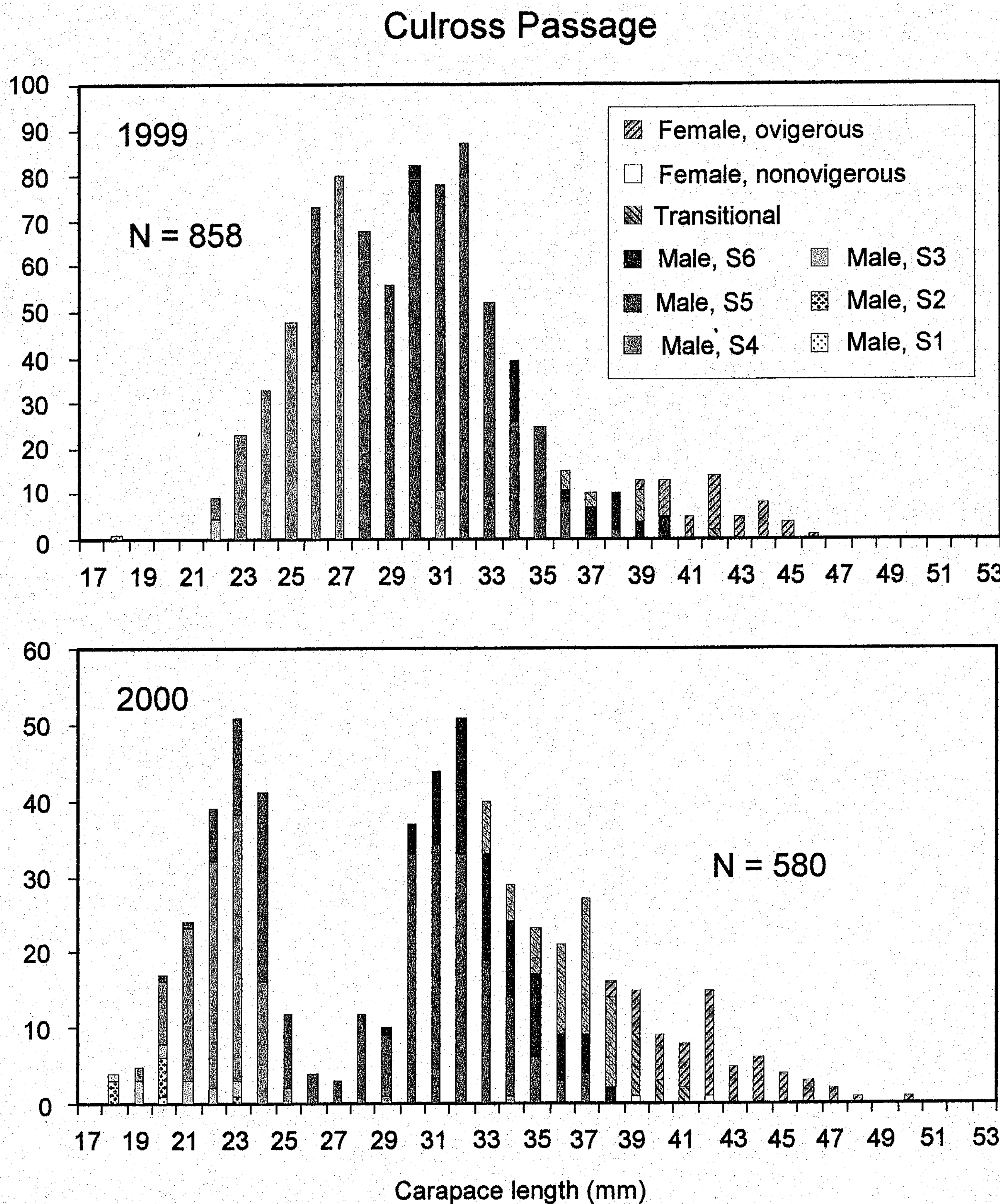
Figure 14. Commercial catch of spot shrimp and fishing effort in Prince William Sound from 1960 to 1991 [Data from Table 1 of Kimker et al. (1996)].

APPENDICES

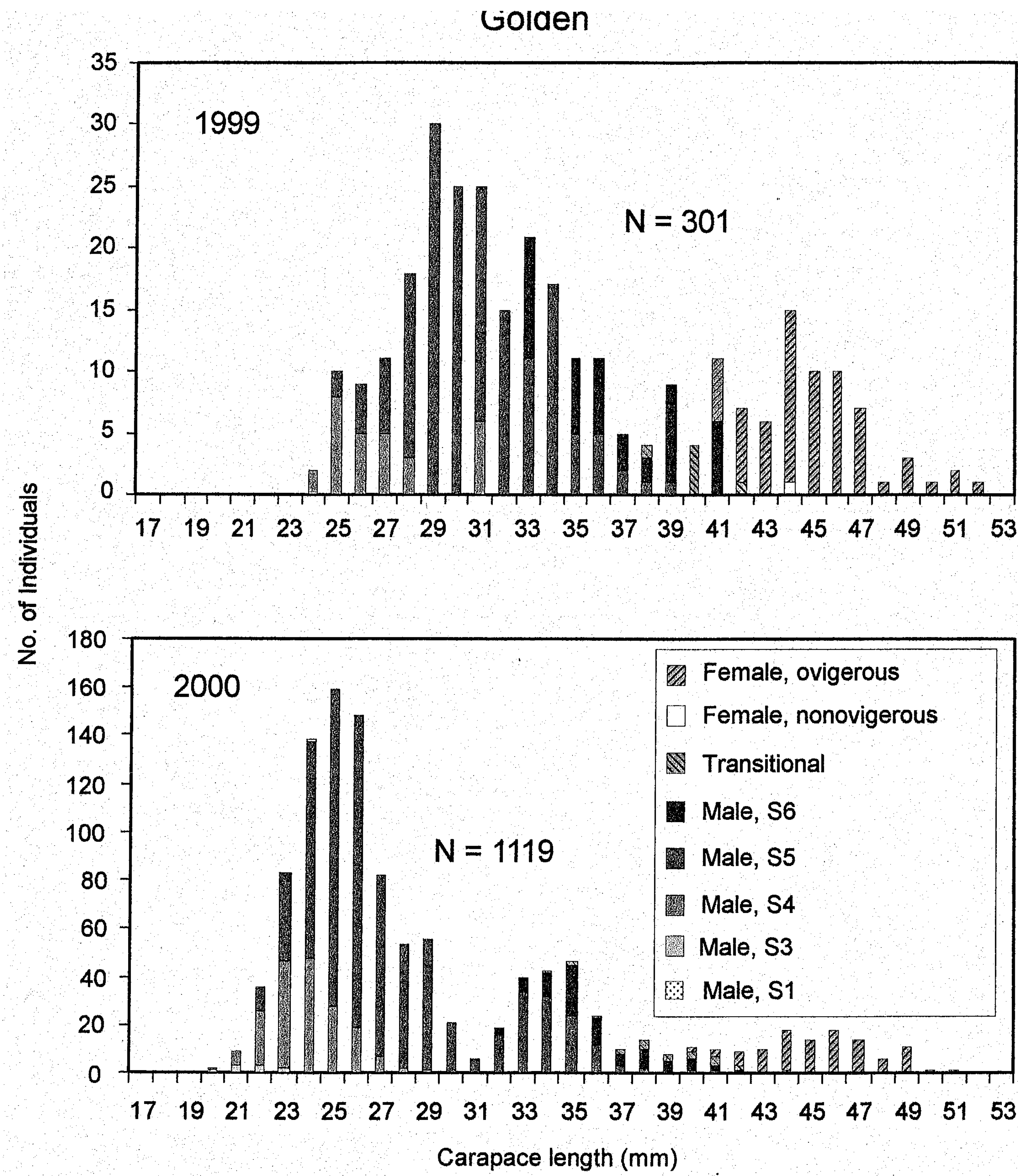
APPENDIX CONTENTS



Appendix A-1 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Unakwik Inlet, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.

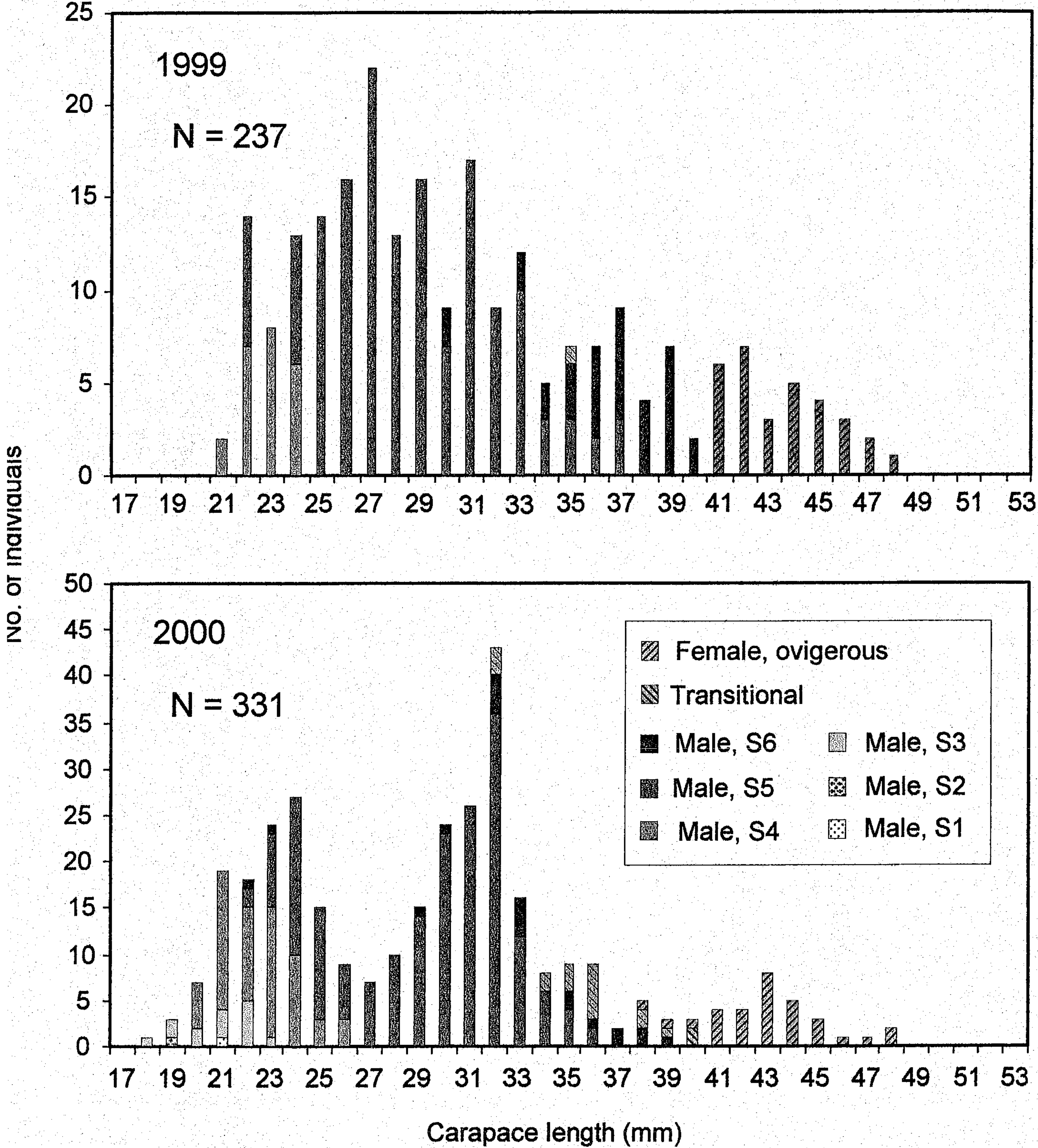


Appendix A-2 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Culross Passage, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.

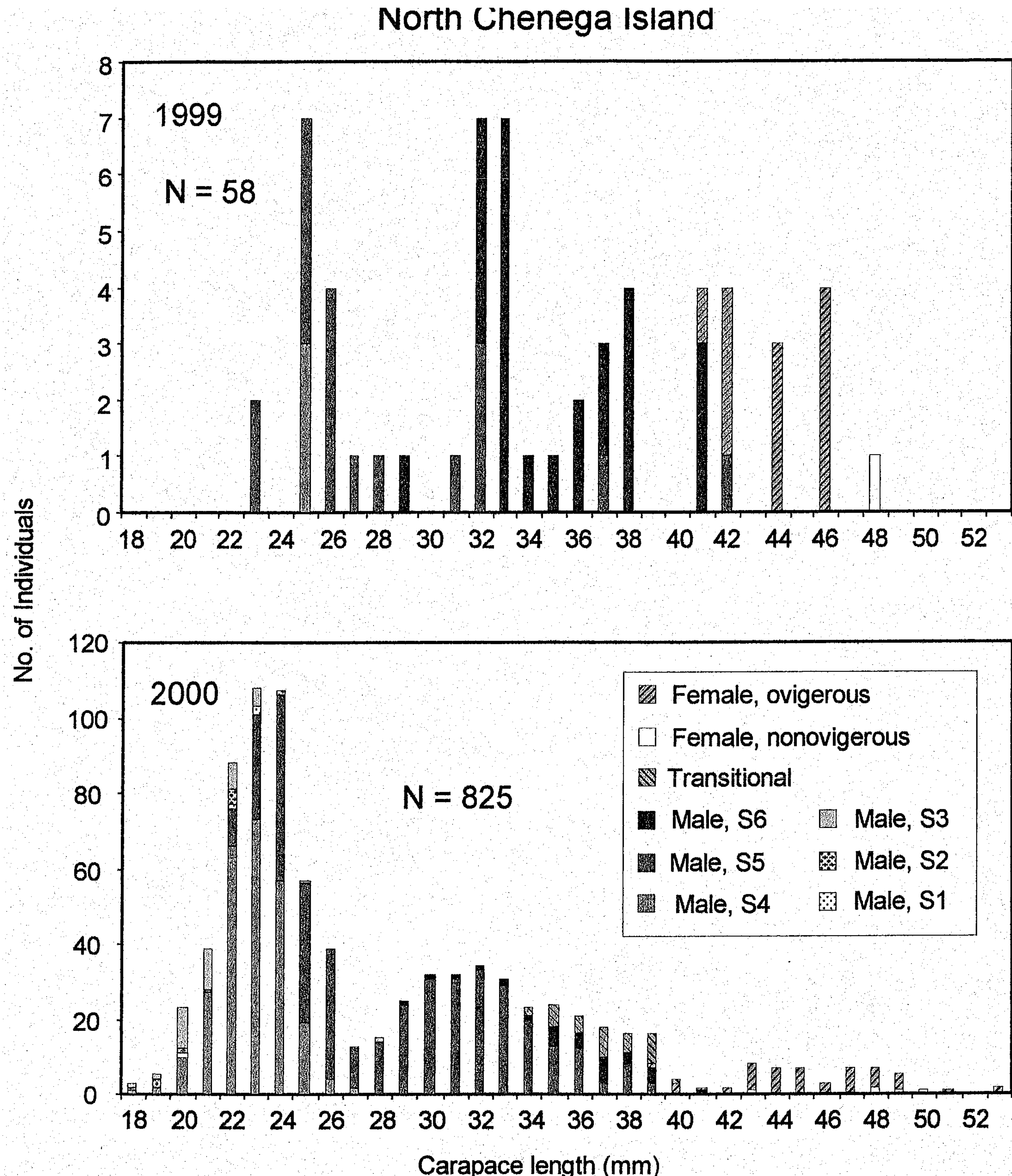


Appendix A-3 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Golden, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.

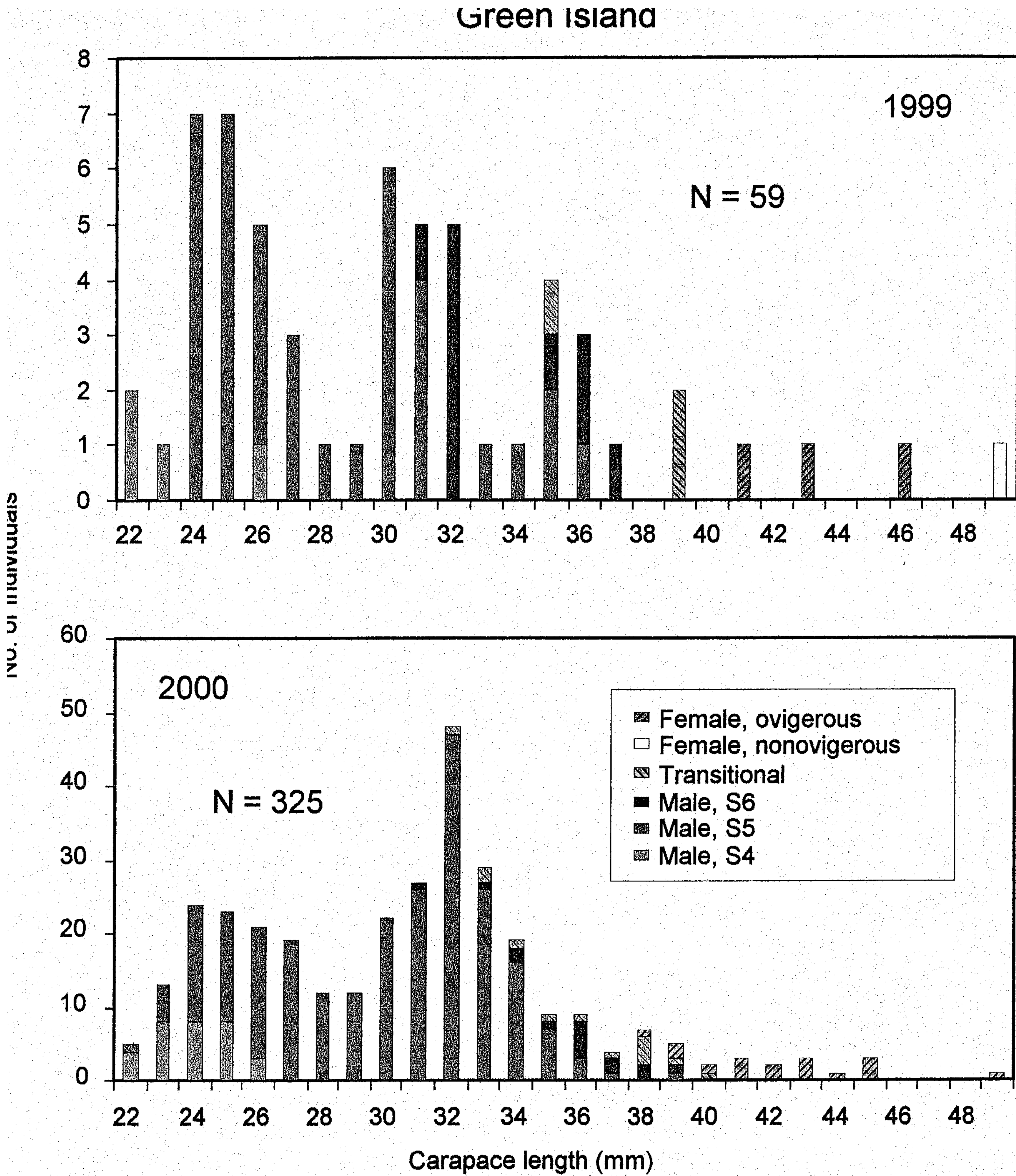
Herring Bay



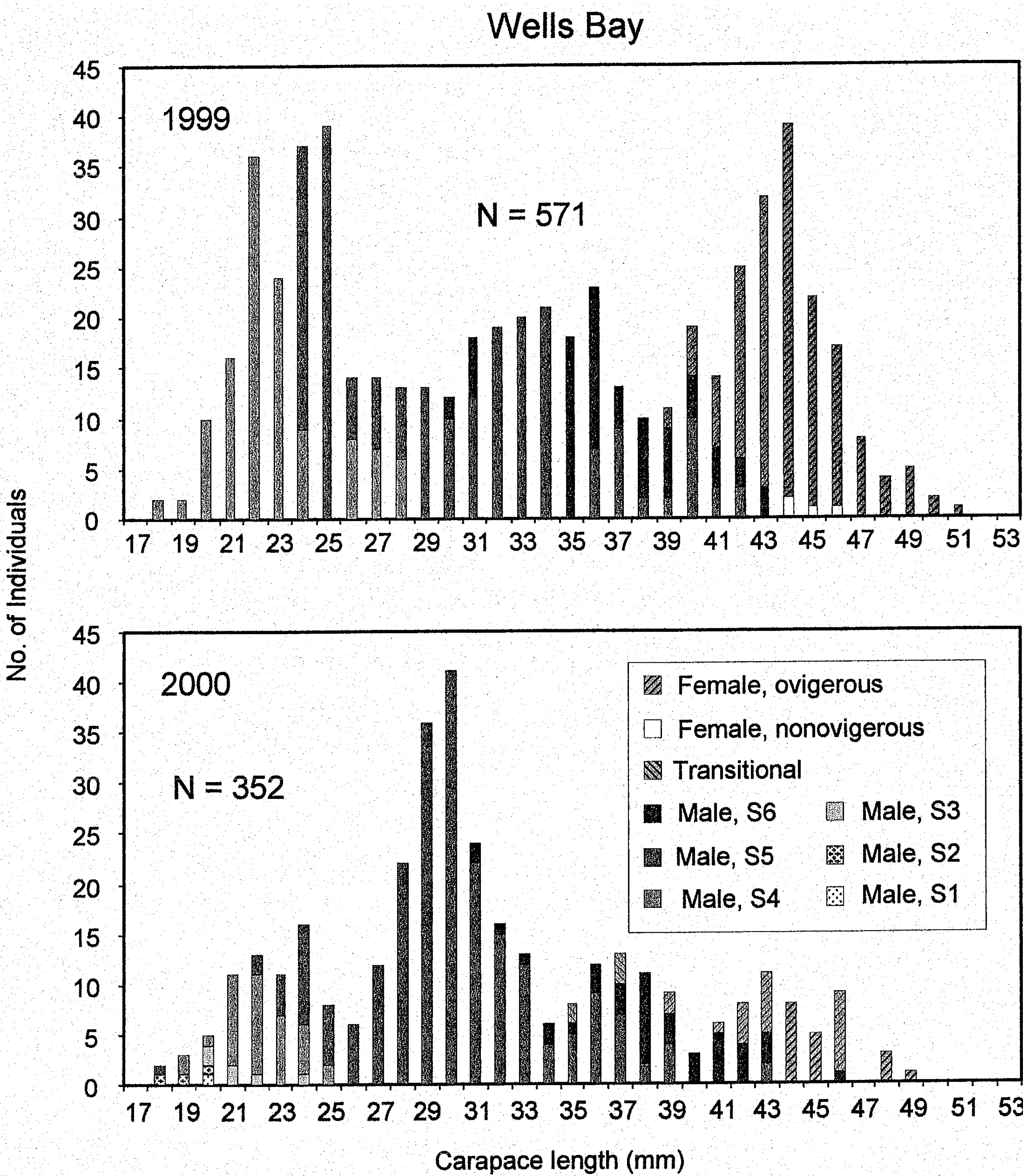
Appendix A-4 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Herring Bay, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



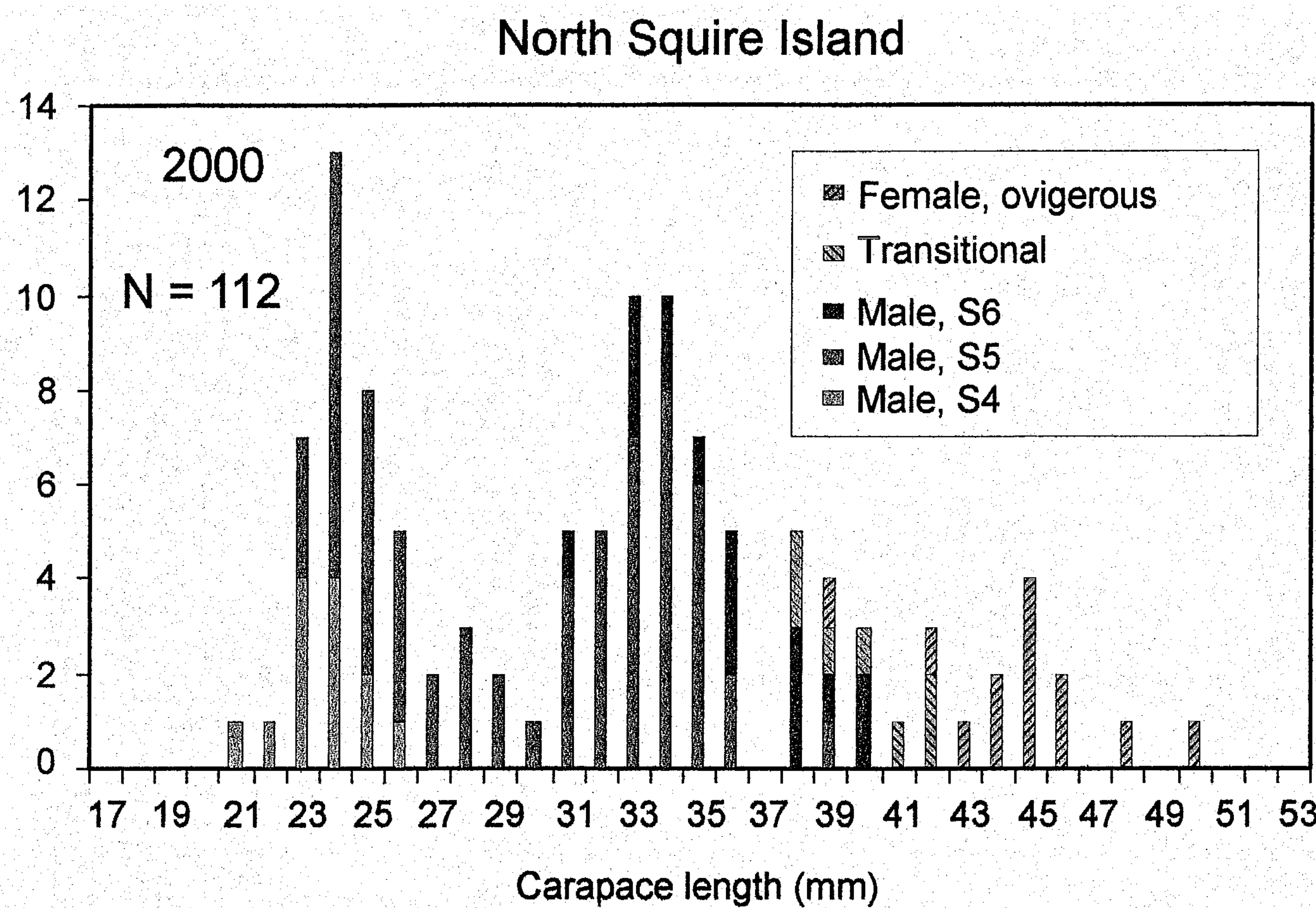
Appendix A-5 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at North Chenega Island, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



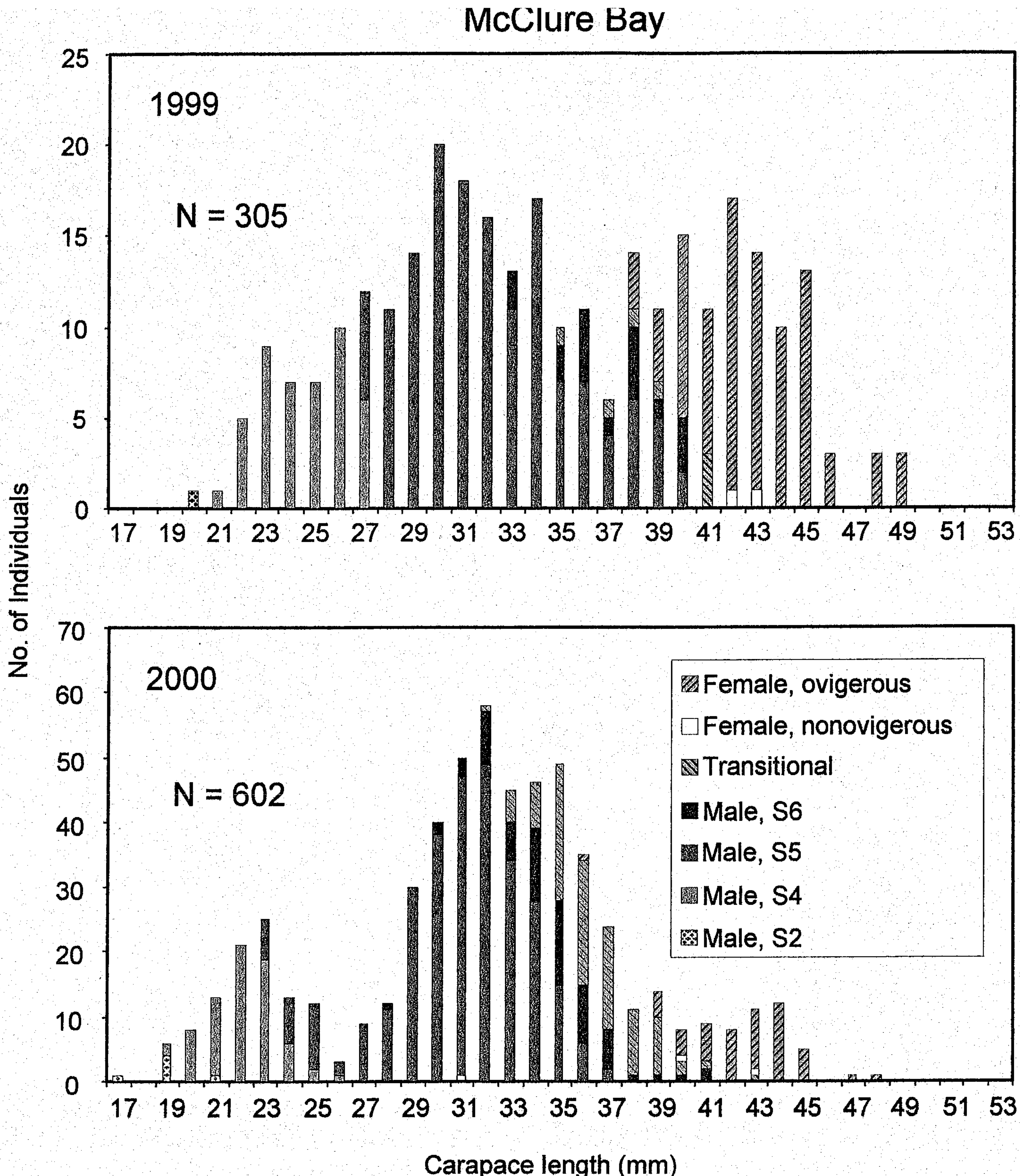
Appendix A-6 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Green Island, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



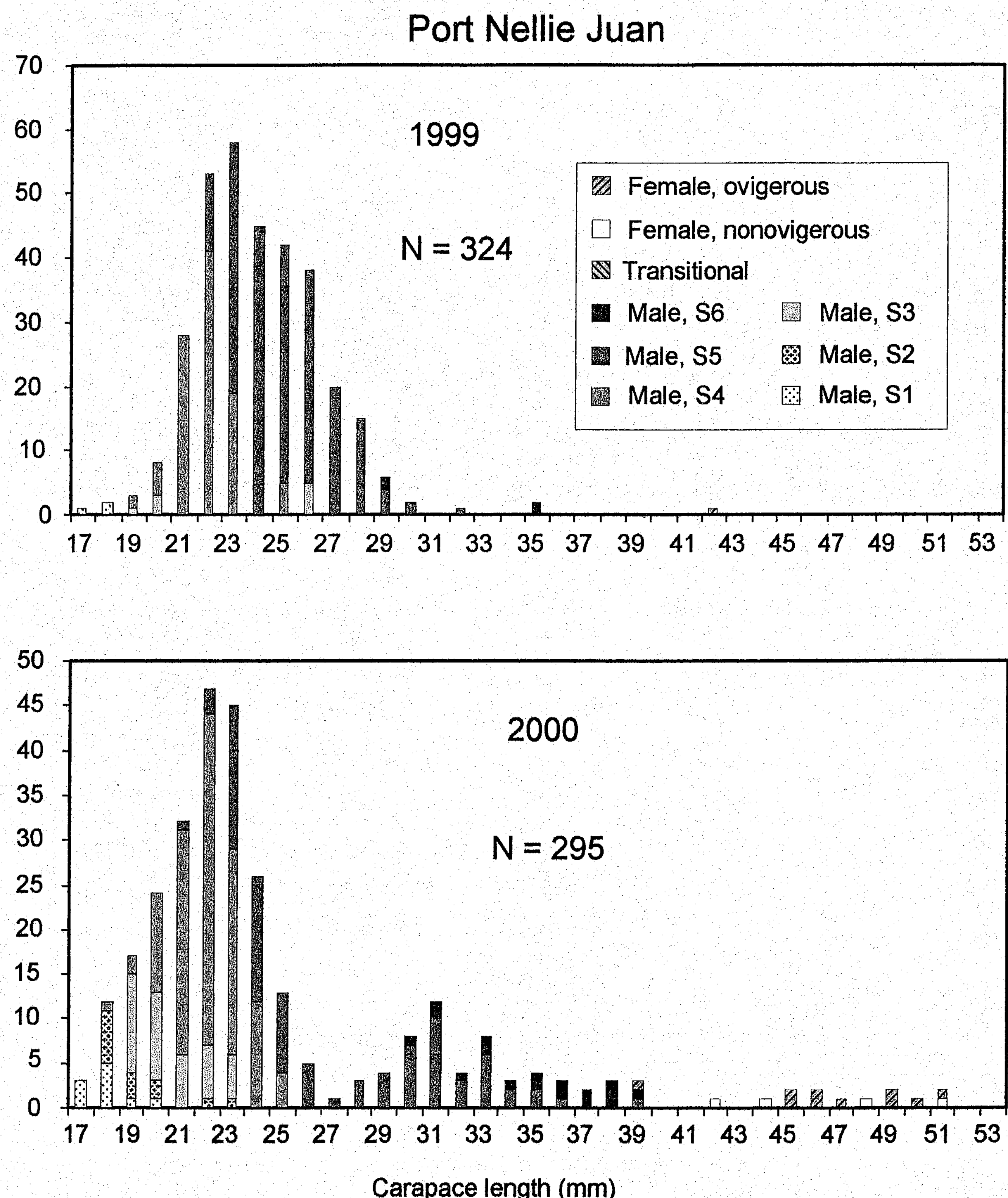
Appendix A-7 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Wells Bay, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



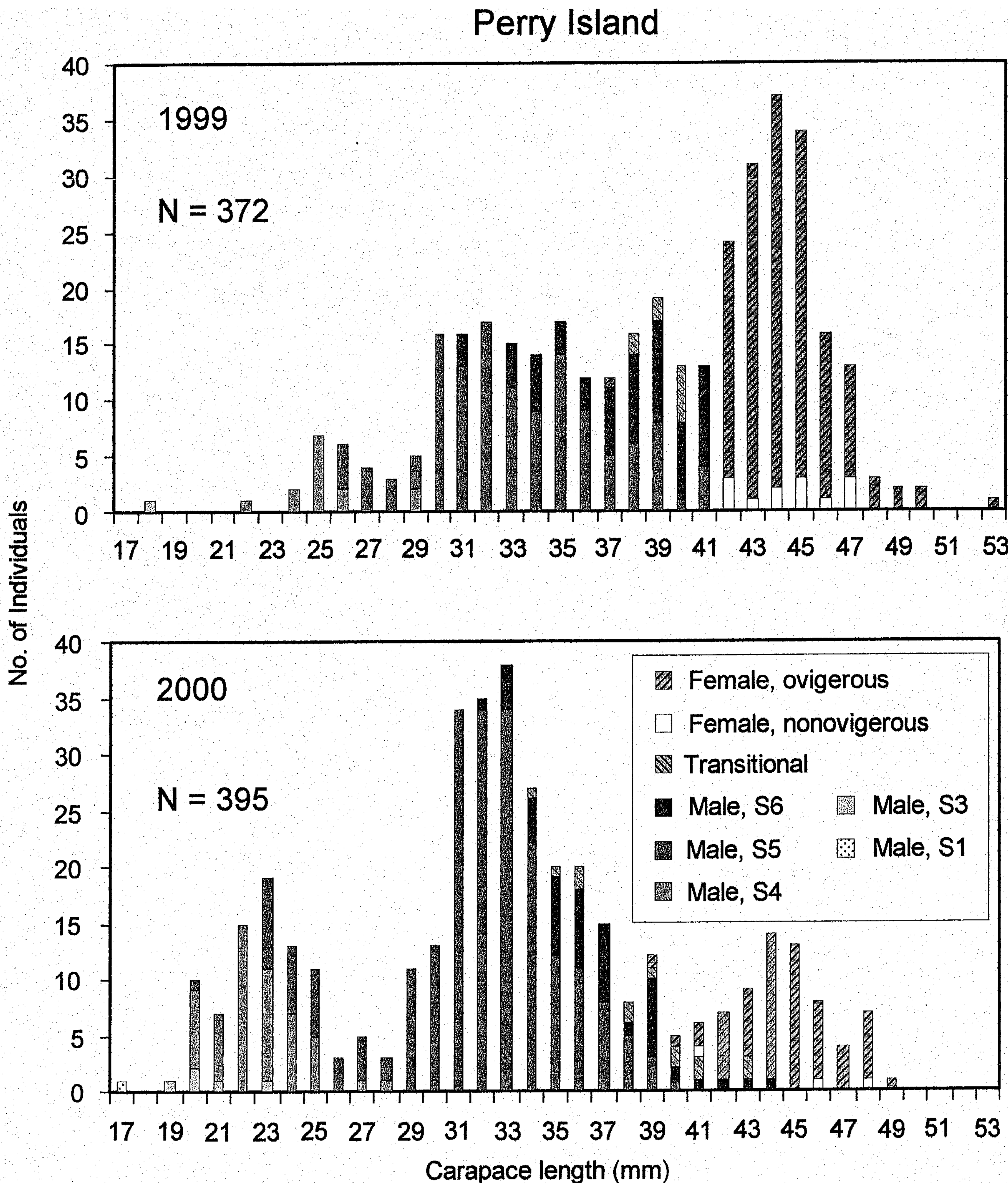
Appendix A-8 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at North Squire Island, Prince William Sound in October 2000. N = number of spot shrimp measured.



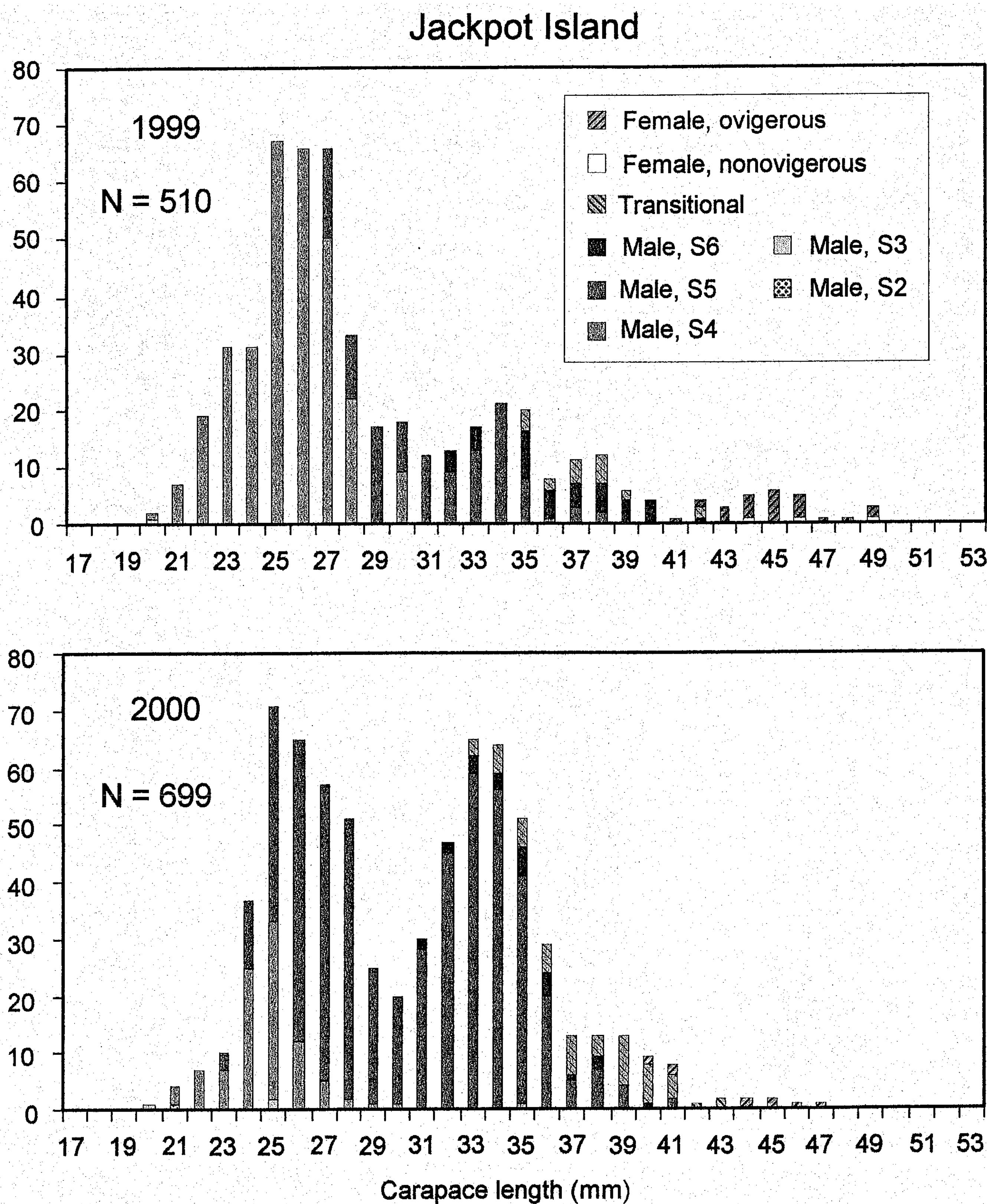
Appendix A-9 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at McClure Bay, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



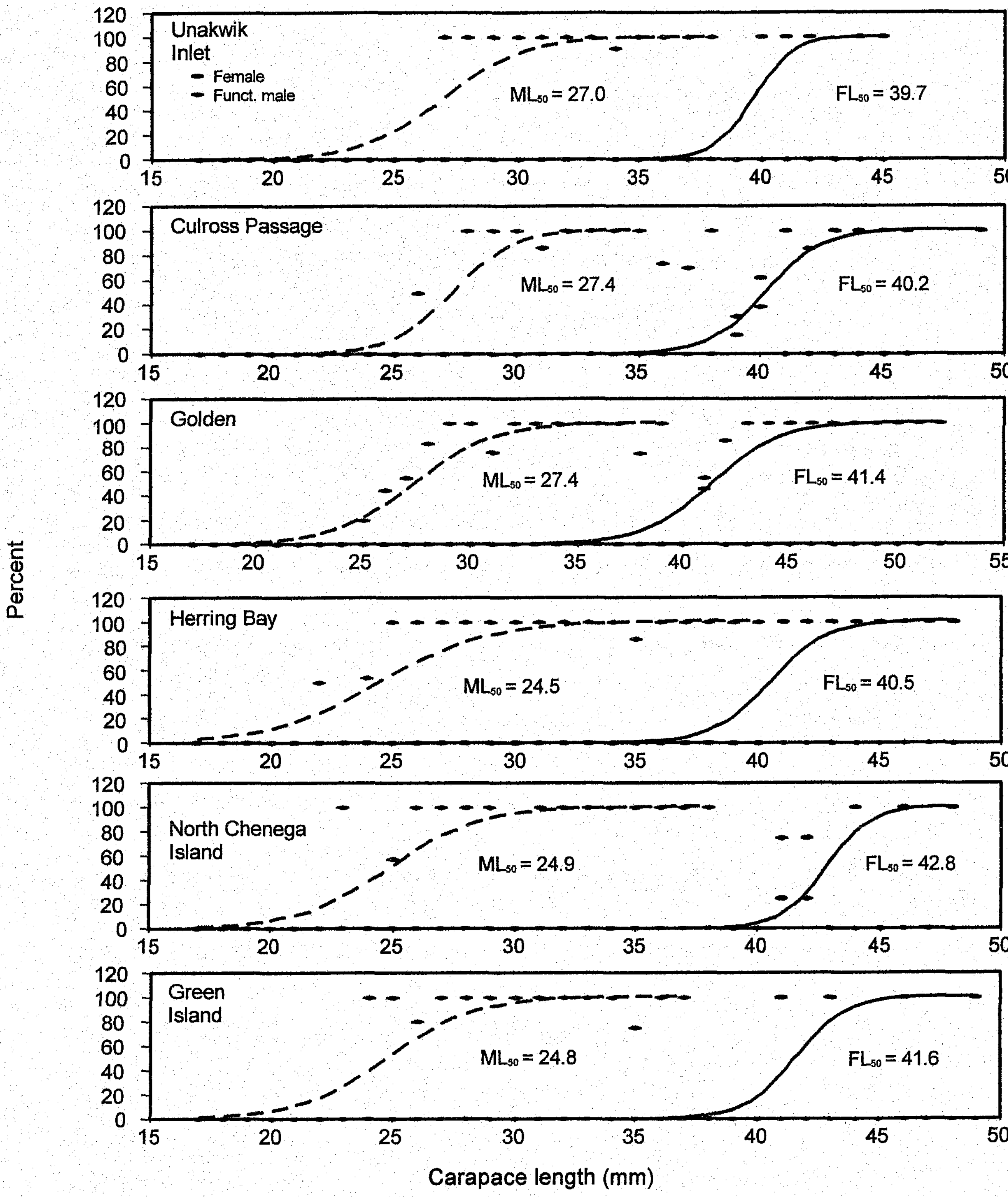
Appendix A-10 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Port Nellie Juan, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



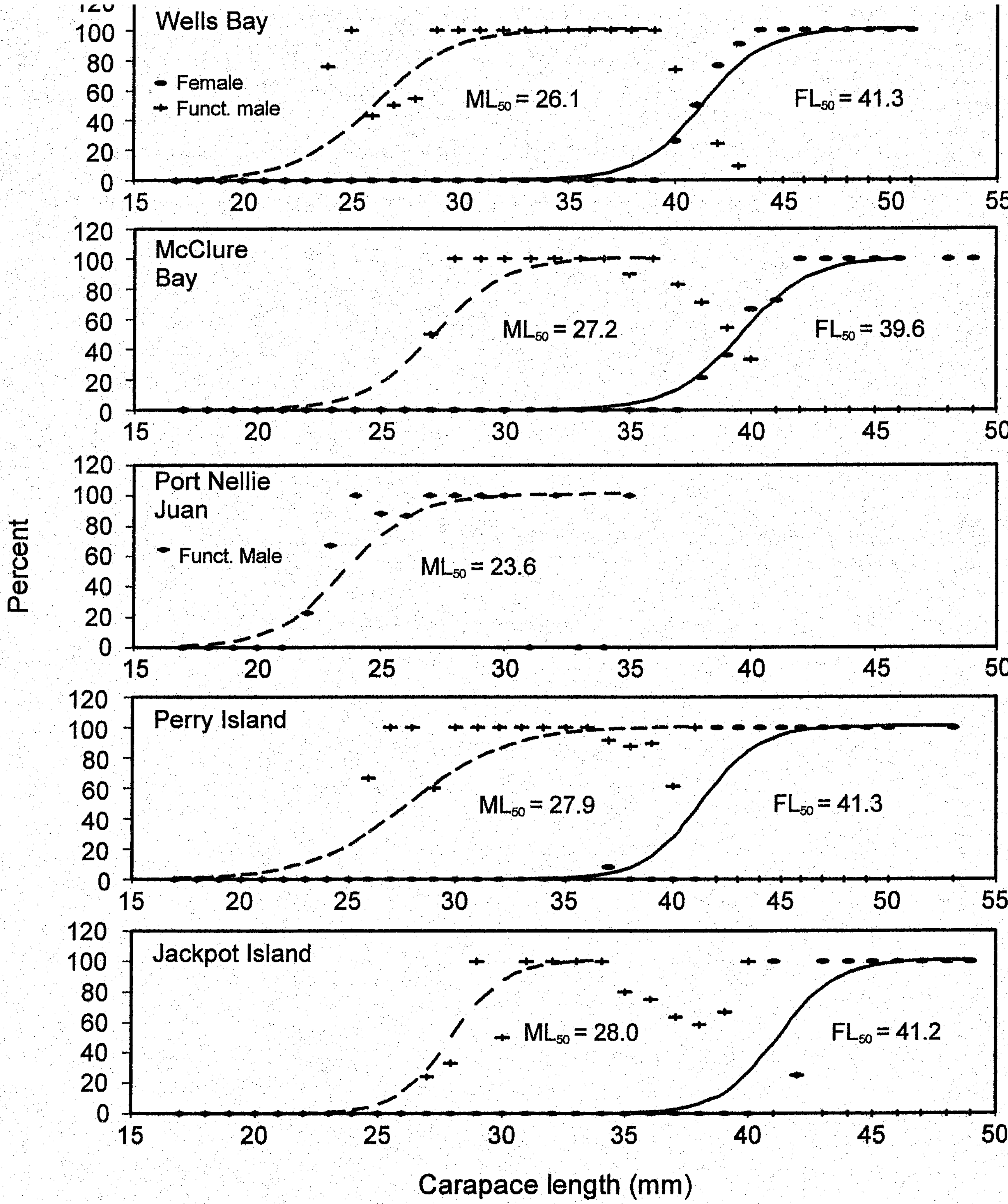
Appendix A-11 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Perry Island, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



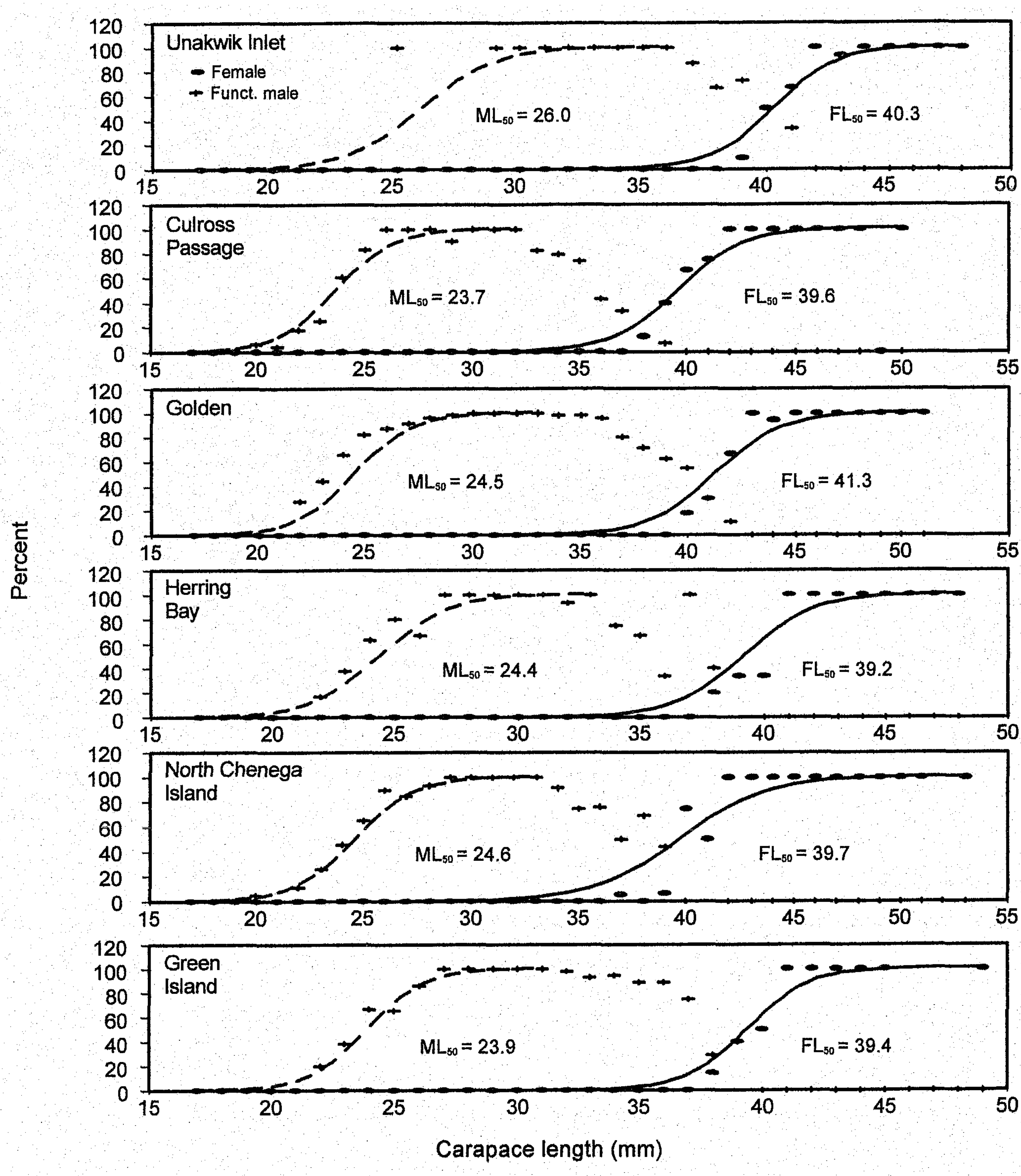
Appendix A-12 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Jackpot Island, Prince William Sound in October 2000. N = number of spot shrimp measured.



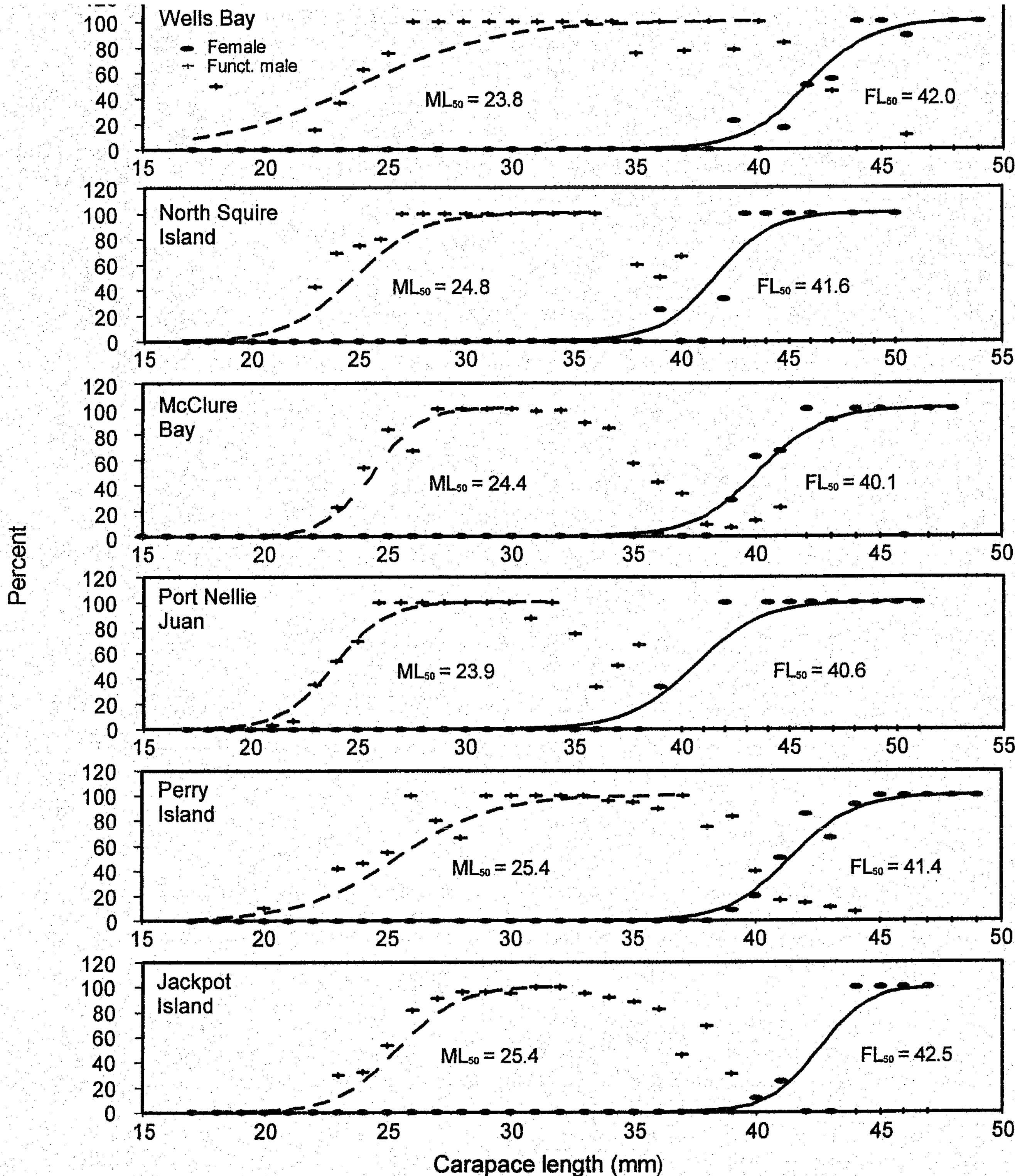
Appendix B-1 Percentage of fully functional males and females versus carapace length of spot shrimp at Unakwik Inlet, Culross Passage, Golden, Herring Bay, North Chenega Island and Green Island in 1999. ML_{50} = carapace length at which fully functional males first represented 50% of the catch at size. FL_{50} = length at which female spot shrimp represented 50% of the catch at size. ML_{50} and FL_{50} were estimated by the logistic model.



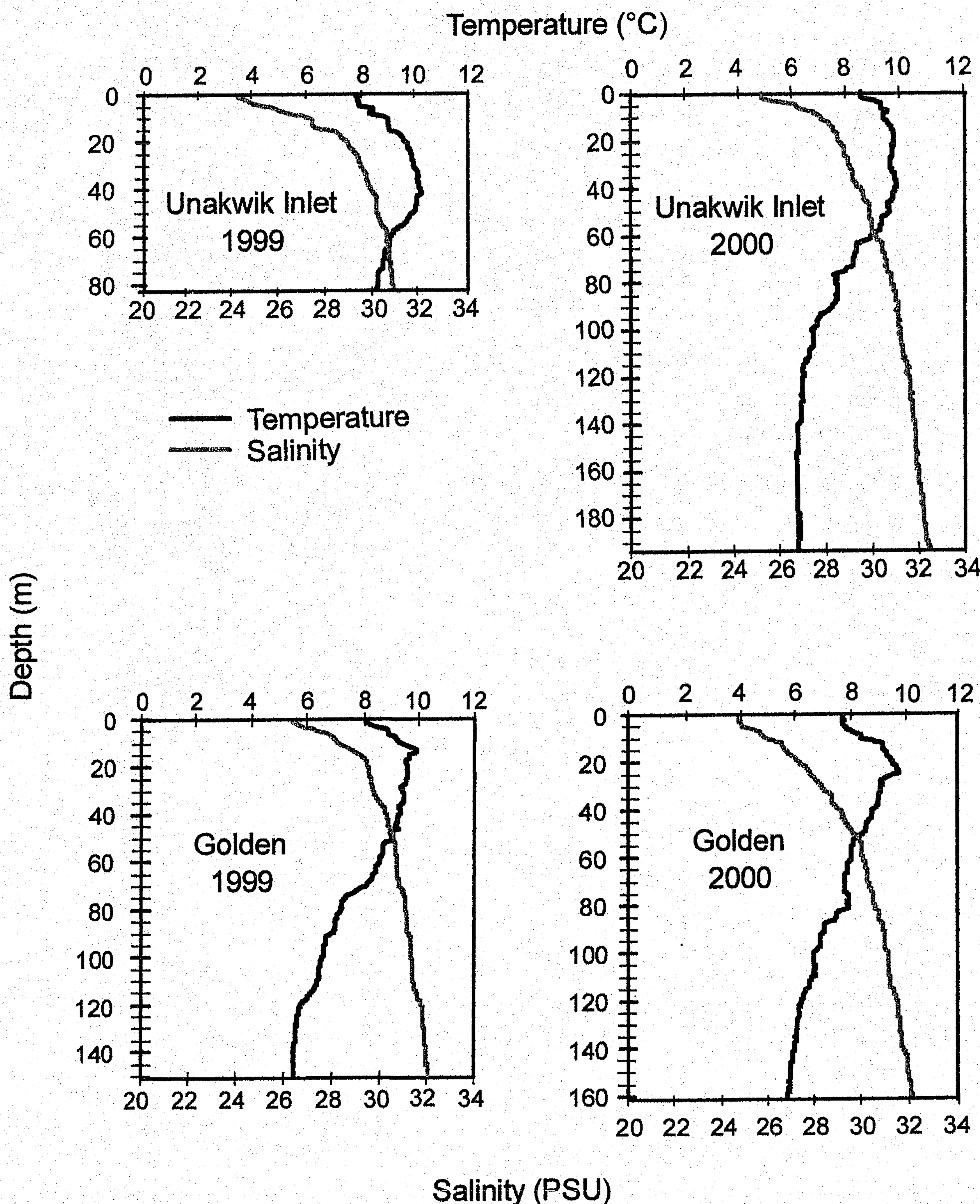
Appendix B-2 Percentage of fully functional males and females versus carapace length of spot shrimp at Wells Bay, McClure Bay, Port Nellie Juan, Perry Island and Jackpot Island in 1999. ML_{50} = carapace length at which fully functional males first represented 50% of the catch at size. FL_{50} = length at which female spot shrimp represented 50% of the catch at size. ML_{50} and FL_{50} were estimated by the logistic model.



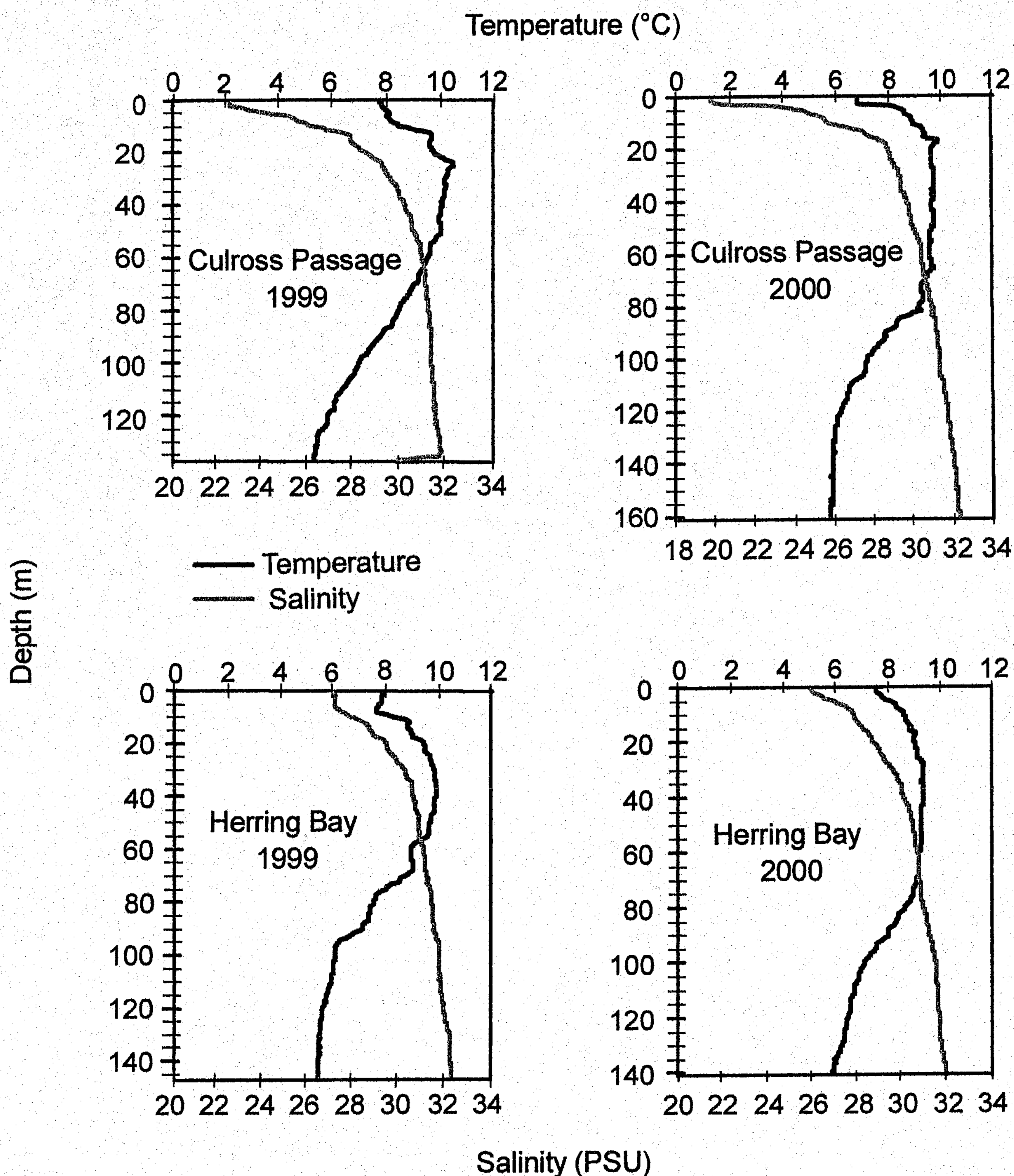
Appendix B-3 Percentage of fully functional males and females versus carapace length of spot shrimp at Unakwik Inlet, Culross Passage, Golden, Herring Bay, North Chenega Island and Green Island in 2000. ML_{50} = carapace length at which fully functional males first represented 50% of the catch at size. FL_{50} = length at which female spot shrimp represented 50% of the catch at size. ML_{50} and FL_{50} were estimated by the logistic model.



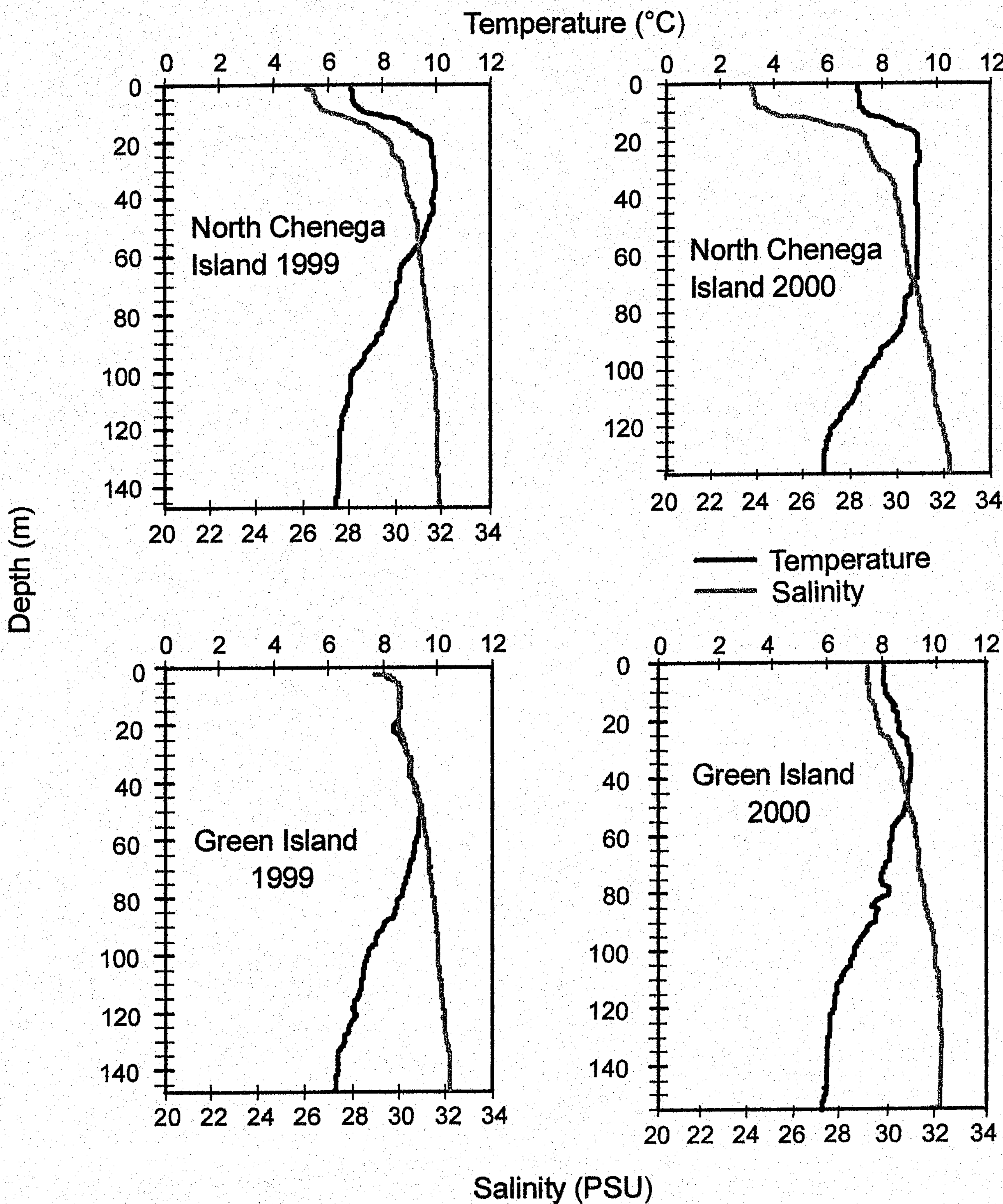
Appendix B-4 Percentage of fully functional males and females versus carapace length of spot shrimp at Wells Bay, North Squire Island, McClure Bay, Port Nellie Juan, Perry Island and Jackpot Island in 2000. ML_{50} = carapace length at which fully functional males first represented 50% of the catch at size. FL_{50} = length at which female spot shrimp represented 50% of the catch at size. ML_{50} and FL_{50} were estimated by the logistic model.



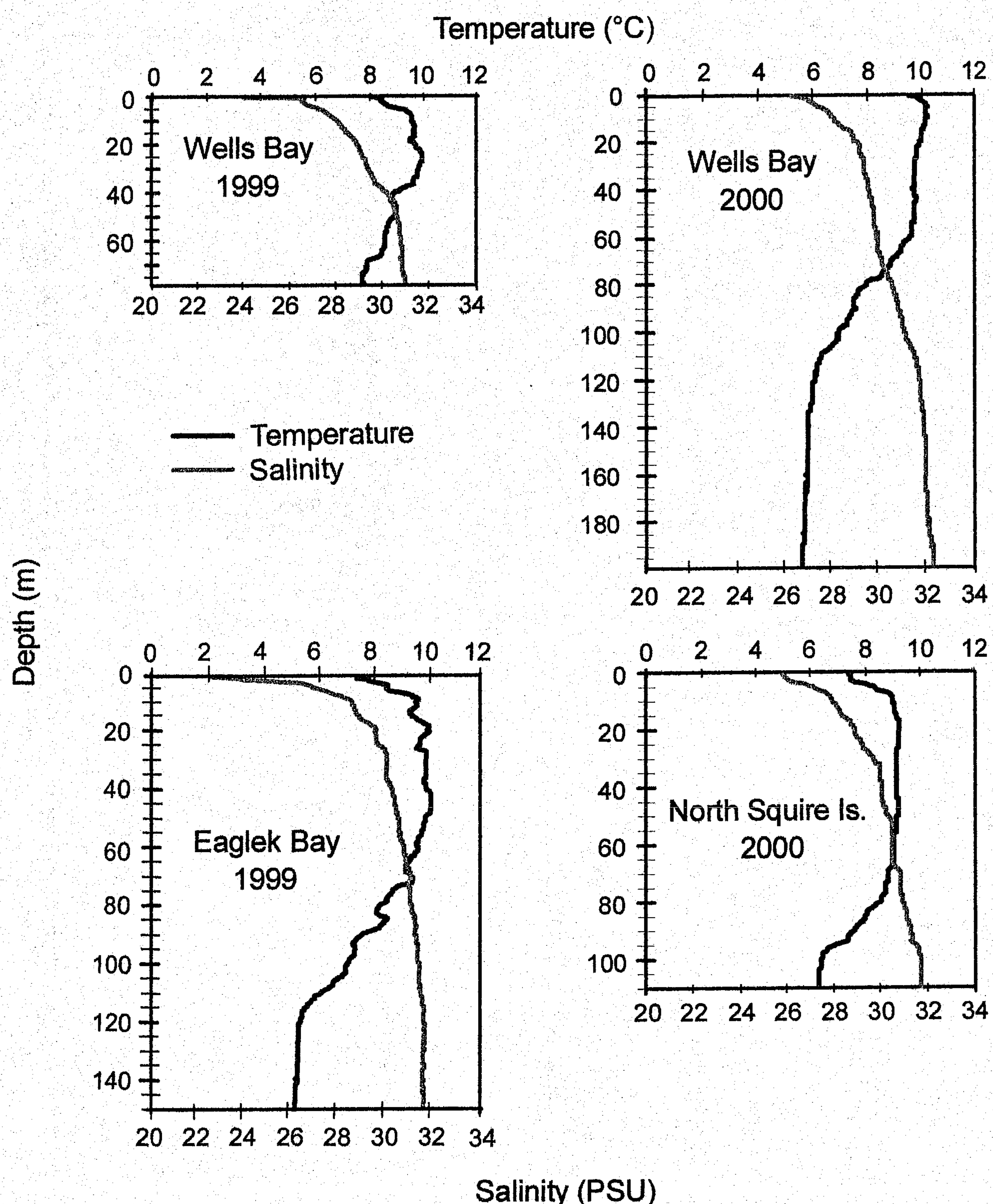
Appendix C-1 Water temperature and salinity profiles at Unakwik Inlet and Golden, Prince William Sound in October 1999 and 2000.



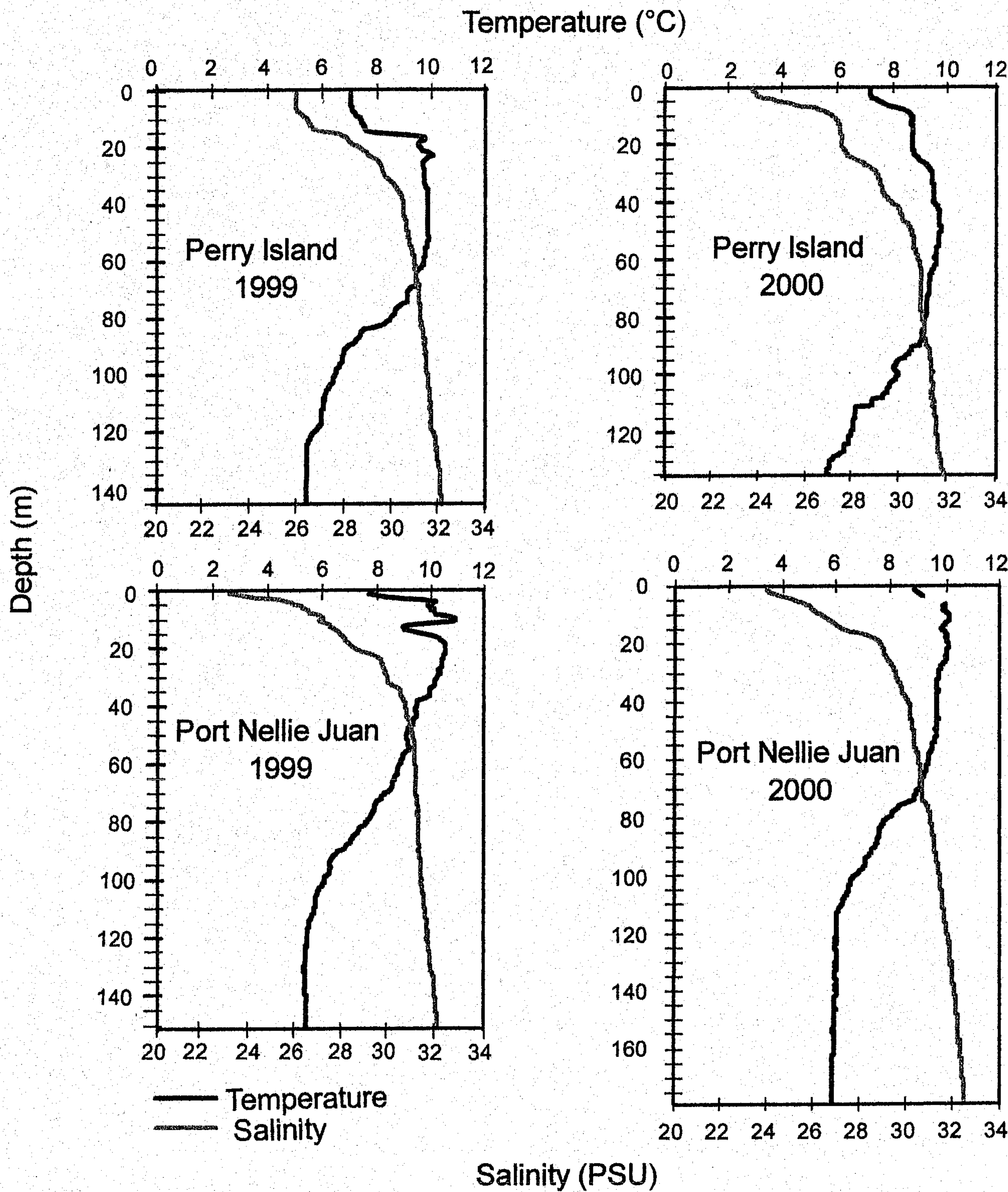
Appendix C-2 Water temperature and salinity profiles at Culross Passage and Herring Bay, Prince William Sound in October 1999 and 2000.



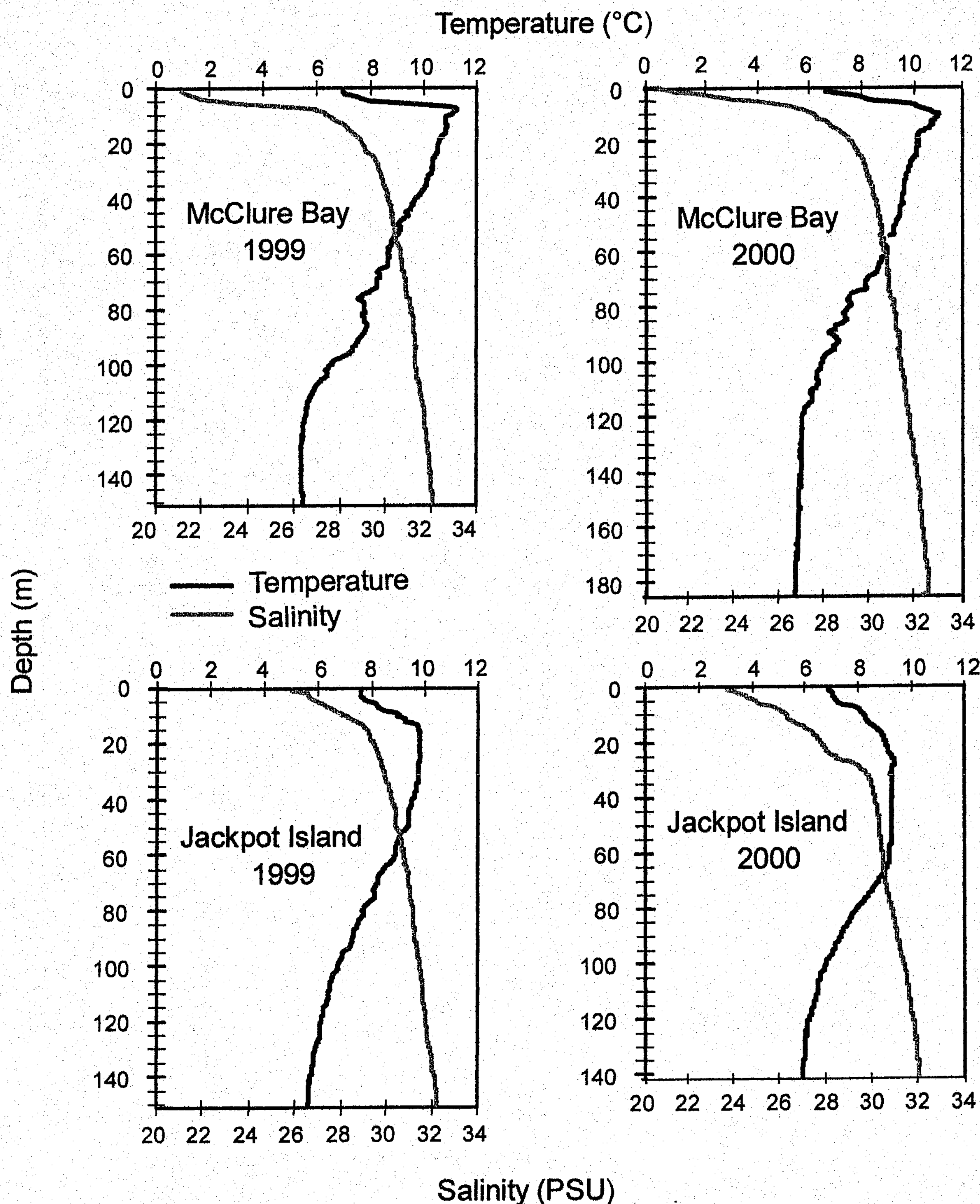
Appendix C-3 Water temperature and salinity profiles at North Chenega Island and Green Island, Prince William Sound in October 1999 and 2000.



Appendix C-4 Water temperature and salinity profiles at Wells Bay, Eaglek Bay and North Squire Island, Prince William Sound in October 1999 and 2000.



Appendix C-5 Water temperature and salinity profiles at Perry Island and Port Nellie Juan, Prince William Sound in October 1999 and 2000.



Appendix C-6 Water temperature and salinity profiles at McClure Bay and Jackpot Island, Prince William Sound in October 1999 and 2000.

Appendix D

Analysis of Spot Shrimp Length-frequency Data in Relation to Shrimp Growth

Joshua Millstein and Charles E. O'Clair

INTRODUCTION

Stock assessment of shrimp and other commercially important Crustacea relies heavily on length information because members of this group of invertebrates are difficult to age. To gain some insight into growth rates of spot shrimp in western Prince William Sound we subjected the length-frequency histograms of the spot shrimp in our catches to mixture modal analysis.

A histogram of length frequencies can be thought of as a mixture of length distributions of several age classes. For species that spawn simultaneously during certain seasons, enough growth may occur between spawning periods for the age class distributions to separate into several distinct modes. Assuming that these modes are approximately normal, mixture modal analysis can then be used to estimate the means for each age-class. These means can then be fit to a von Bertalanffy curve to estimate growth (Trowbridge 1992, Kimker et al. 1996). In Prince William Sound, spot shrimp larvae are released into the water during a restricted period that includes late March and throughout April (Strathmann 1987), therefore spot shrimp are candidates for mixture modal analysis.

METHODS

We performed the calculations for the mixture modal analysis with the statistical software package Multifan (Otter Research Ltd 1992). This package allows the simultaneous fit of several length frequency distributions. Multifan was used to estimate spot shrimp growth in PWS by Trowbridge et al. (1992), thus the use of Multifan here may provide some constancy of methods for comparison purposes. The main assumptions of the Multifan model are: 1. The lengths of the individuals in each age class are normally distributed around their mean length. 2. The mean lengths at age lie on (or near) a von Bertalanffy growth curve. 3. The standard deviations of the actual lengths about the mean length at age are a simple function of the mean length at age. An additional assumption that was followed by Roa and Ernst (1996) was that for every calendar year there is 1 and no less than 1 recruitment period leading to 1 age-class. We followed this assumption loosely in order to determine the initial constraints required to fit the Multifan model. The model was fit simultaneously to length frequency data from 1999 and 2000 for each area (with the exception of North Squire Island in which the model was fit to 2000 data only).

RESULTS AND DISCUSSION

We present here the carapace length-frequency histograms of spot shrimp at each study site in 1999 and 2000 with curves superimposed to indicate the predicted distributions based on the fitted models (Appendices 4.1-4.12). The horizontal bars present in selected modes indicate contraints that were placed on means for selected age-classes. Constraints were usually placed on means for the first and second age classes of the sample (constraints were placed on only one of the two samples for each area) with the most well defined modes. The search for the best fitting model was restricted to parameter estimates that represented a parsimonious or biologically likely model. For instance, a model that included many more age-classes than visually apparent modes or a model in which shrimp reached age 5 at a length of 20mm was excluded. Visual assessment for goodness-of-fit was done by observing how closely the top yellow curve followed the length frequency distribution. There is no absolute measure of goodness-of-fit, so the results must be viewed with caution if the visual test is unsatisfying. In general the results here more closely resemble growth estimates from the tagging study of Kimker et al. (1996) than the mixture model analysis by Trowbridge (1992). In the tagging study of Kimker et al. (1996) the von Bertalanffy parameters were estimated to be L = 49.2 mm and K = 0.29. However, in their Figure 4 showing carapace length as a function of time at liberty, there appears to be a rather large number of shrimp that did not grow at all (Kimker et al. 1996). If these zero growers were affected by tagging then the growth estimates may also exhibit some bias caused by tagging. Trowbridge (p. 50, 1992) estimated von Bertalanffy growth parameters for spot shrimp in Unakwik Inlet (L = 57.0, K = .16) Culross Passage (L = 57.8, K = .13), Herring Bay (L = 55.2, K = .16) and Chenega Island (L = 55.8, K = .16). Their estimates were remarkably consistent across areas but differed notably from Kimker et al. (1996). For growth estimated from our data, the K was usually between 0.2 and 0.3 while L was usually between 50 and 60 mm. The extreme exception was Wells Bay with L = 142 and K = 0.062. These parameters seem to be drastically different than estimates for the other areas, however the goodness-of-fit visual test did not reveal any obvious inconsistencies, and the estimates of length at age seem biologically plausible. It must be kept in mind that true shrimp growth will be affected by environmental factors and thus will not exactly fit a von Bertalanffy model even if this is the true underlying growth form.

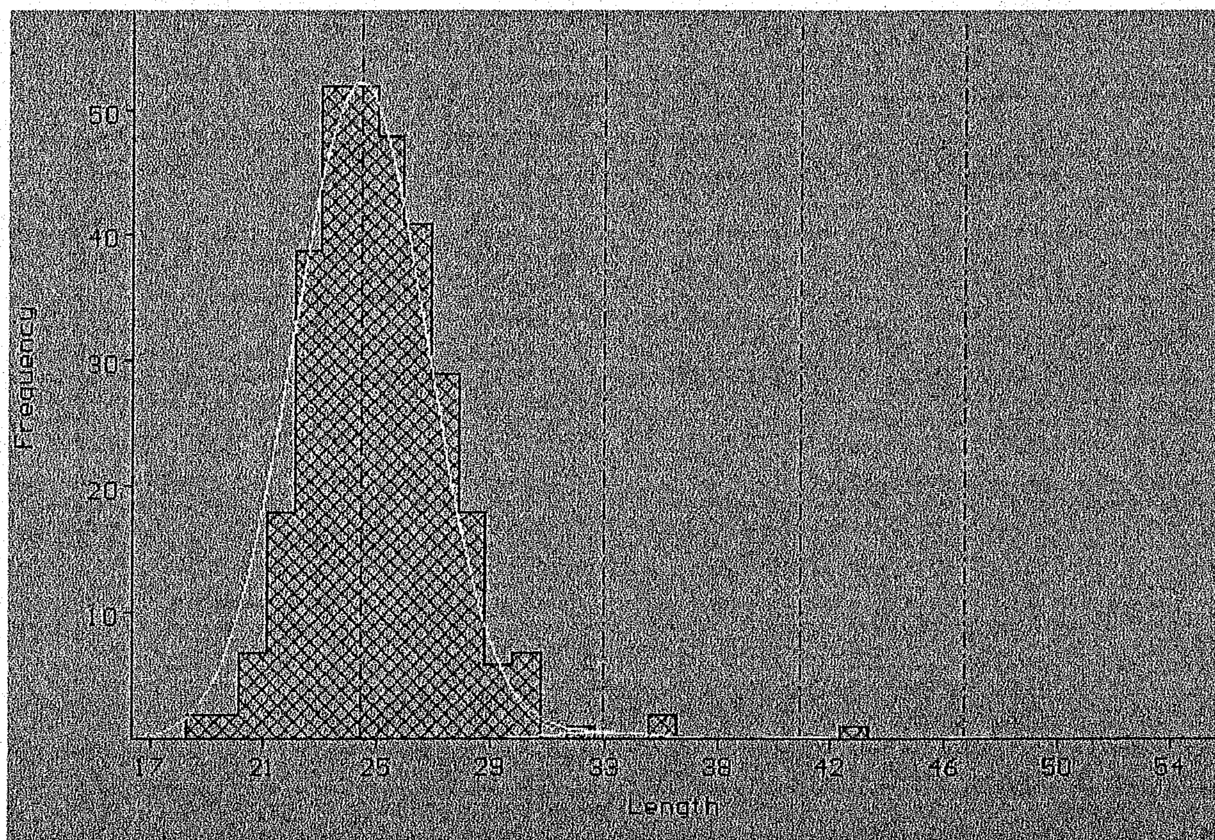
<u>Final Multifan growth estimates for each area (see pg 25 for discription of output)</u>

Appendix D-1 Port Nellie Juan

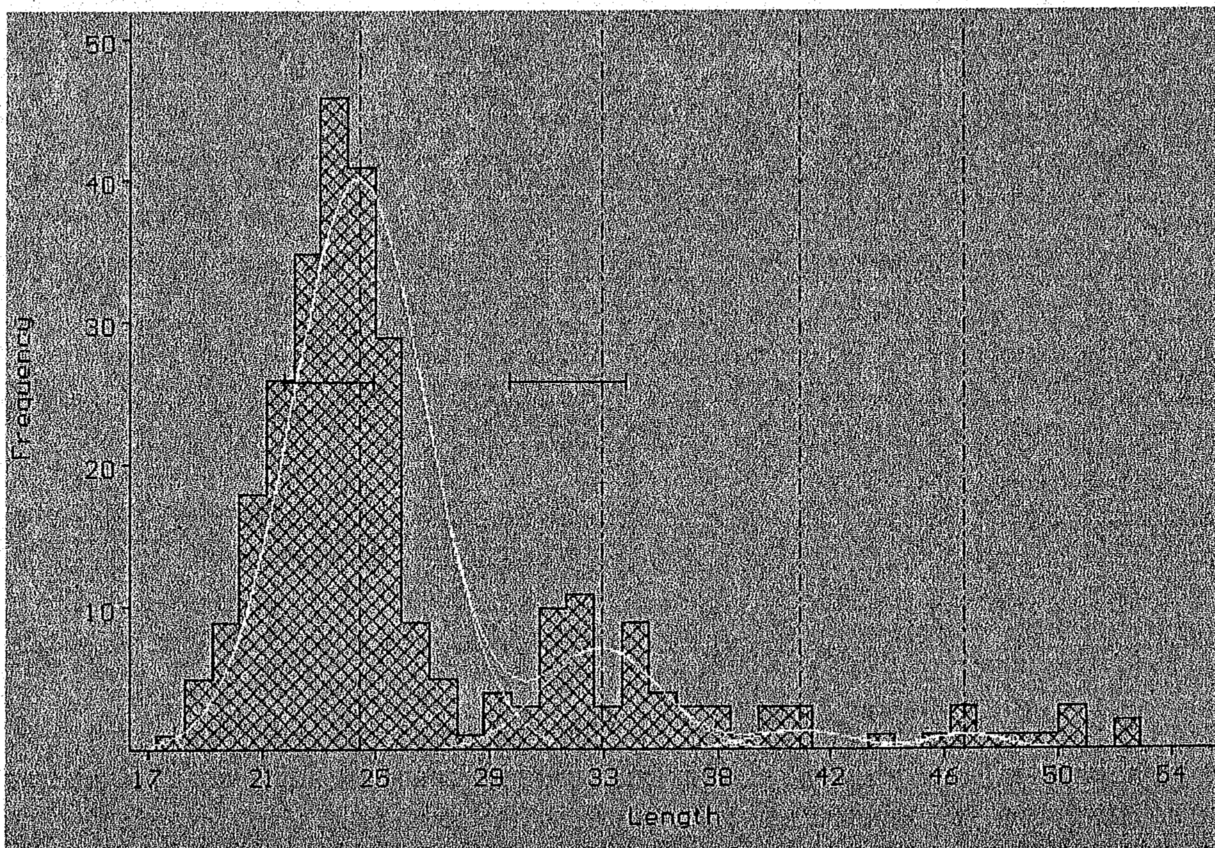
Fit: xd
Objective function value = 1085.00000; total penalty = 0.70752
Maximum gradient component = 0.00016
Number of non-empty length intervals: 48; Number of estimated parameters: 11
Approximate number of degrees of freedom: 37

Number of age classes: 4
Parameter Estimates:
von Bertalanffy K = 0.194 (1/year); L infinity = 74.6
First Length = 24.415; Last Length = 46.566; Brody rho = 0.824 (1/year).
Estimated age of the first age class = 2.04 years.
Mean length at age in month 1:
24.41 33.27 40.56 46.57
Standard Deviations of length at age in month 1:
2.52 2.07 1.76 1.54
Average Standard Deviation = 1.974; ratio of first to last S.D.= 0.612

Port Nellie Juan, 1999



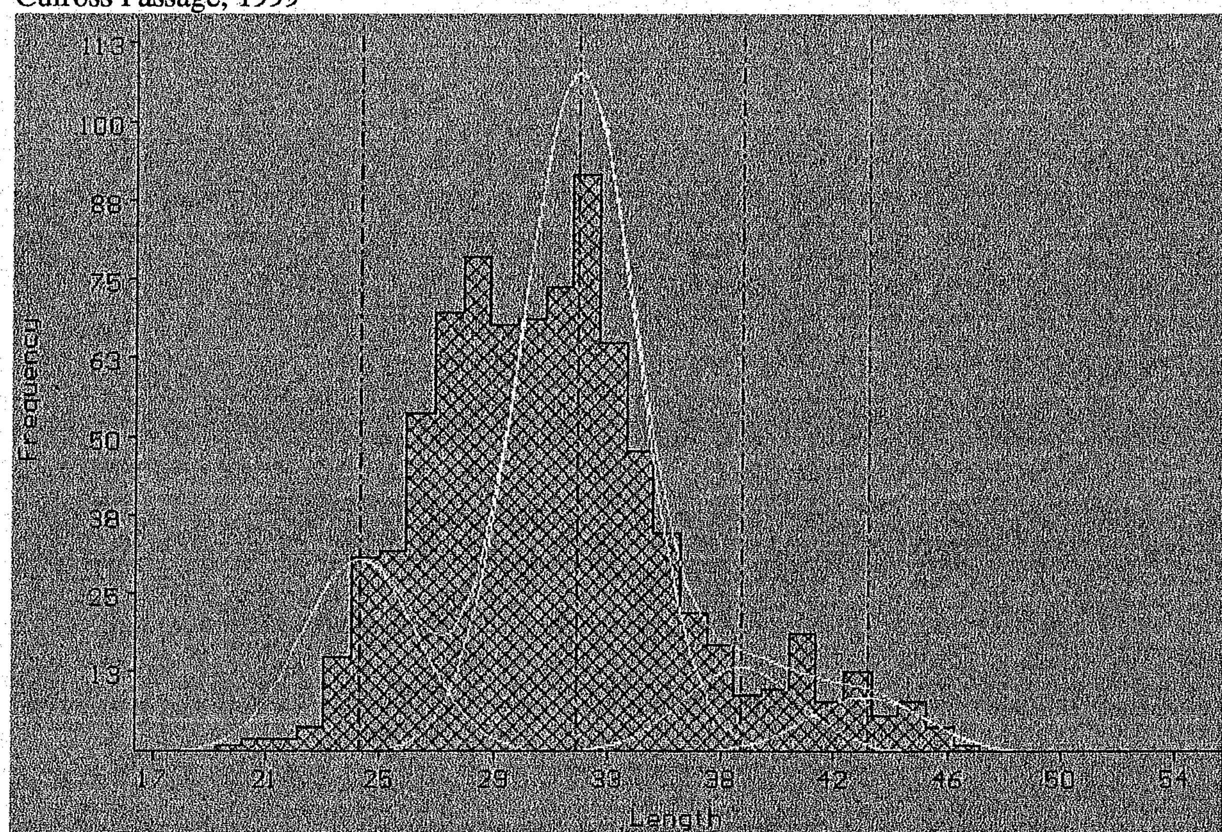
Port Nellie Juan, 2000



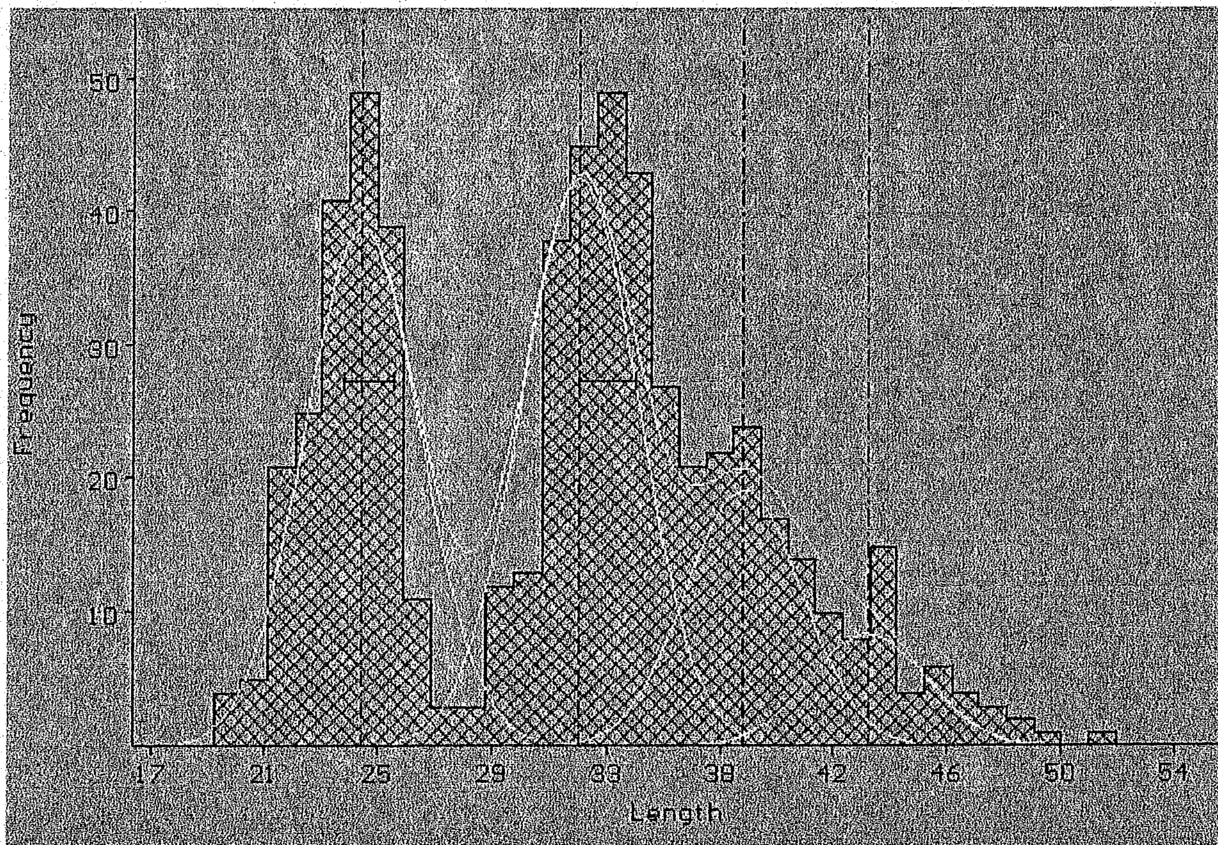
Appendix D-2 Culross Passage
Fit: ya
Objective function value = 1063.00000; total penalty = 0.00710
Maximum gradient component = 0.00005
Number of non-empty length intervals: 60; Number of estimated parameters: 10
Approximate number of degrees of freedom: 50

Number of age classes: 4
Parameter Estimates:
von Bertalanffy K <= 0.275 (1/year); L infinity = 57.3
First Length = 24.284; Last Length = 42.845; Brody rho = 0.759 (1/year).
Estimated age of the first age class = 2.00 years.
Mean length at age in month 1:
24.28 32.23 38.26 42.84
Standard Deviations of length at age in month 1:
2.12 2.12 2.12 2.12
Average Standard Deviation = 2.124; ratio of first to last S.D.= 1.000

Culross Passage, 1999



Culross Passage, 2000



Appendix D-3 Green Island

Fit: u1

Objective function value = 1020.00000; total penalty = 0.35861

Maximum gradient component = 0.00075

Number of non-empty length intervals: 47; Number of estimated parameters: 10

Approximate number of degrees of freedom: 37

Number of age classes: 4

Parameter Estimates:

von Bertalanffy K = 0.314 (1/year); L infinity = 51.2

First Length = 25.935; Last Length = 41.350; Brody rho = 0.731 (1/year).

Estimated age of the first age class = 2.25 years.

Mean length at age in month 1:

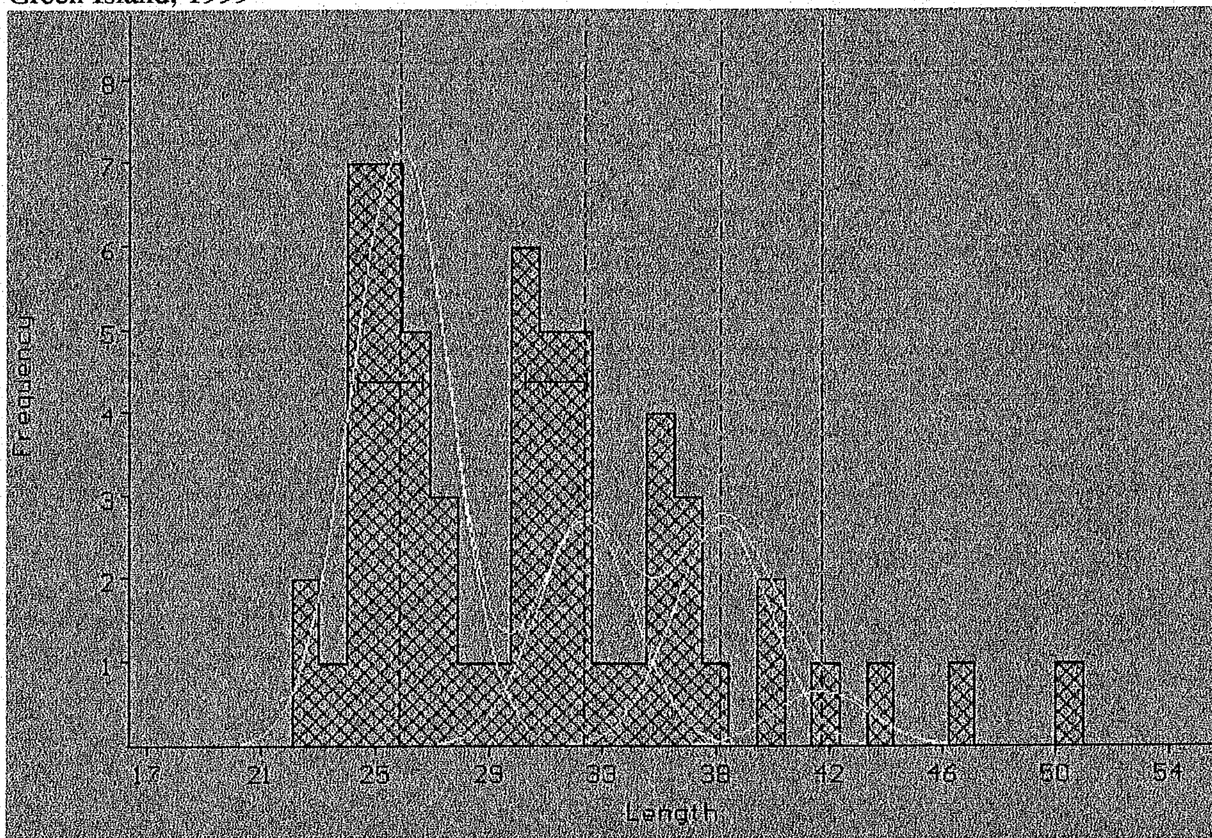
25.94 32.74 37.72 41.35

Standard Deviations of length at age in month 1:

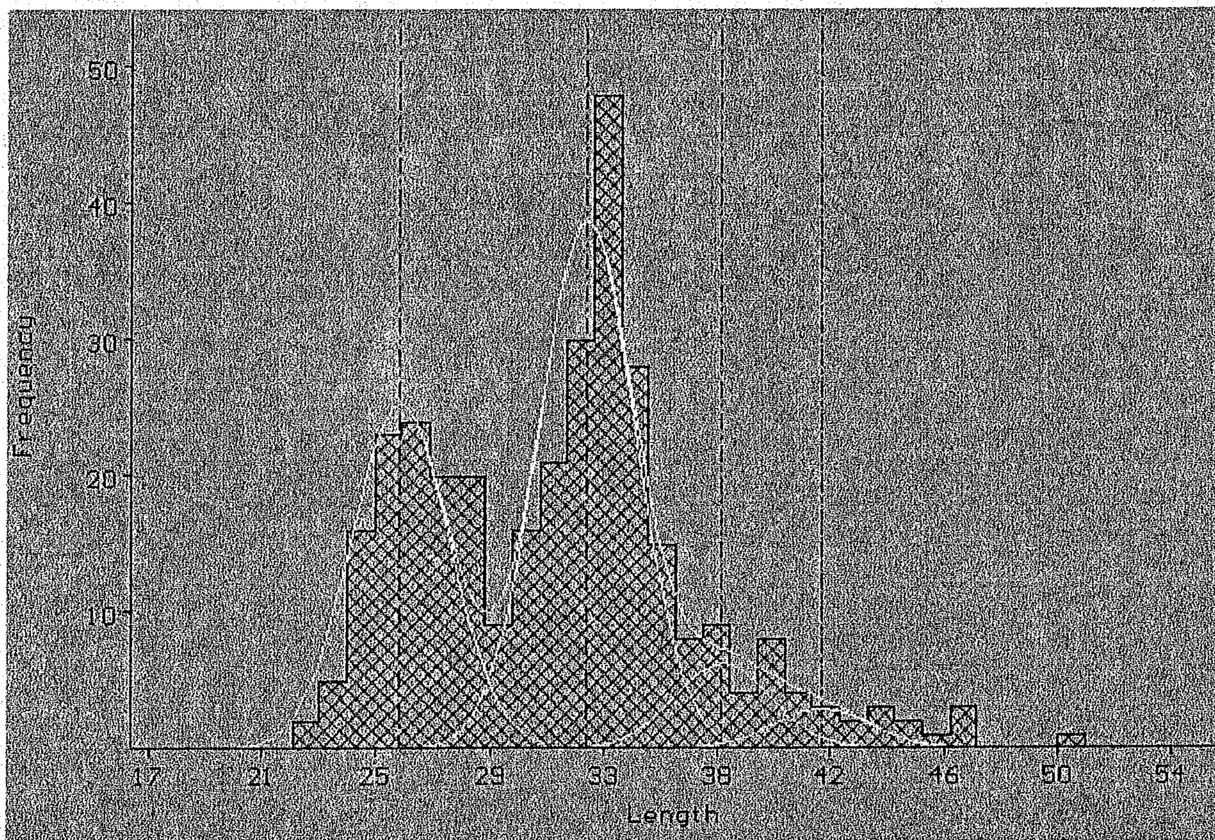
1.77 1.77 1.77 1.77

Average Standard Deviation = 1.773; ratio of first to last S.D.= 1.000

Green Island, 1999



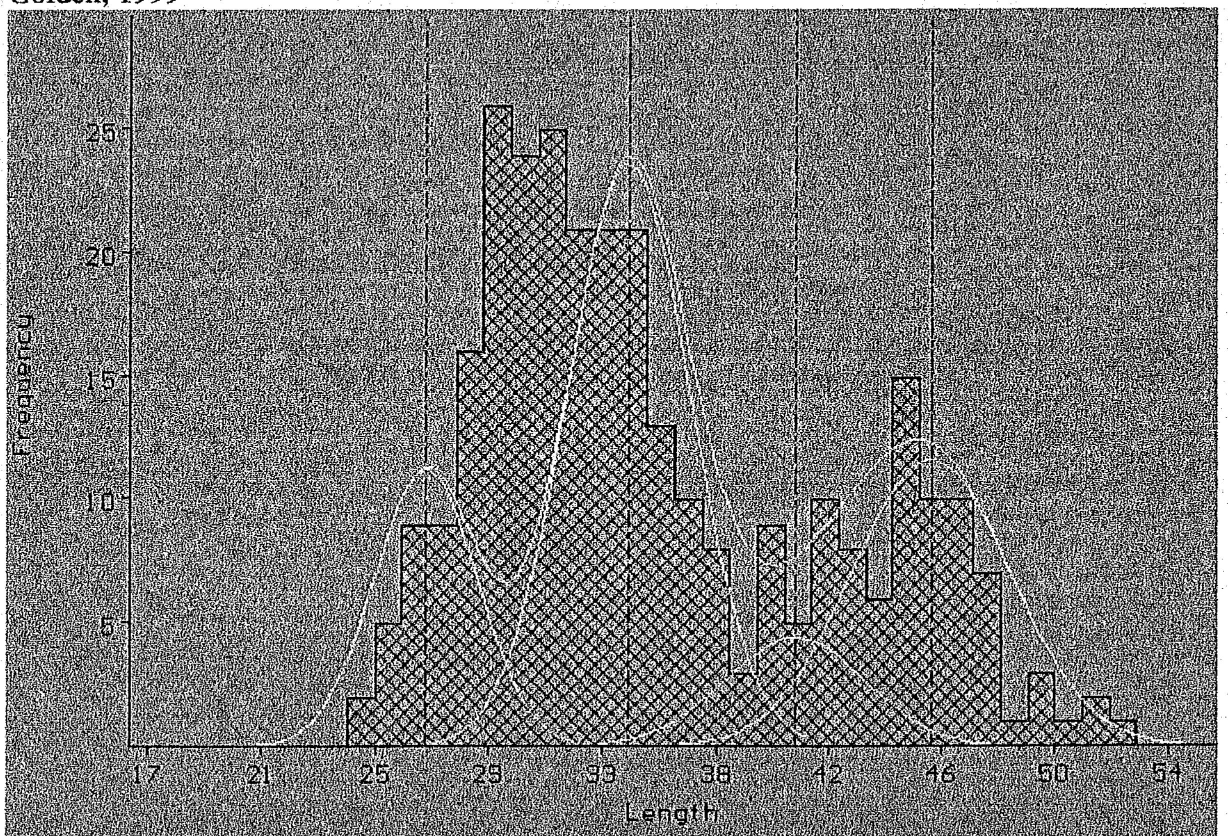
Green Island, 2000



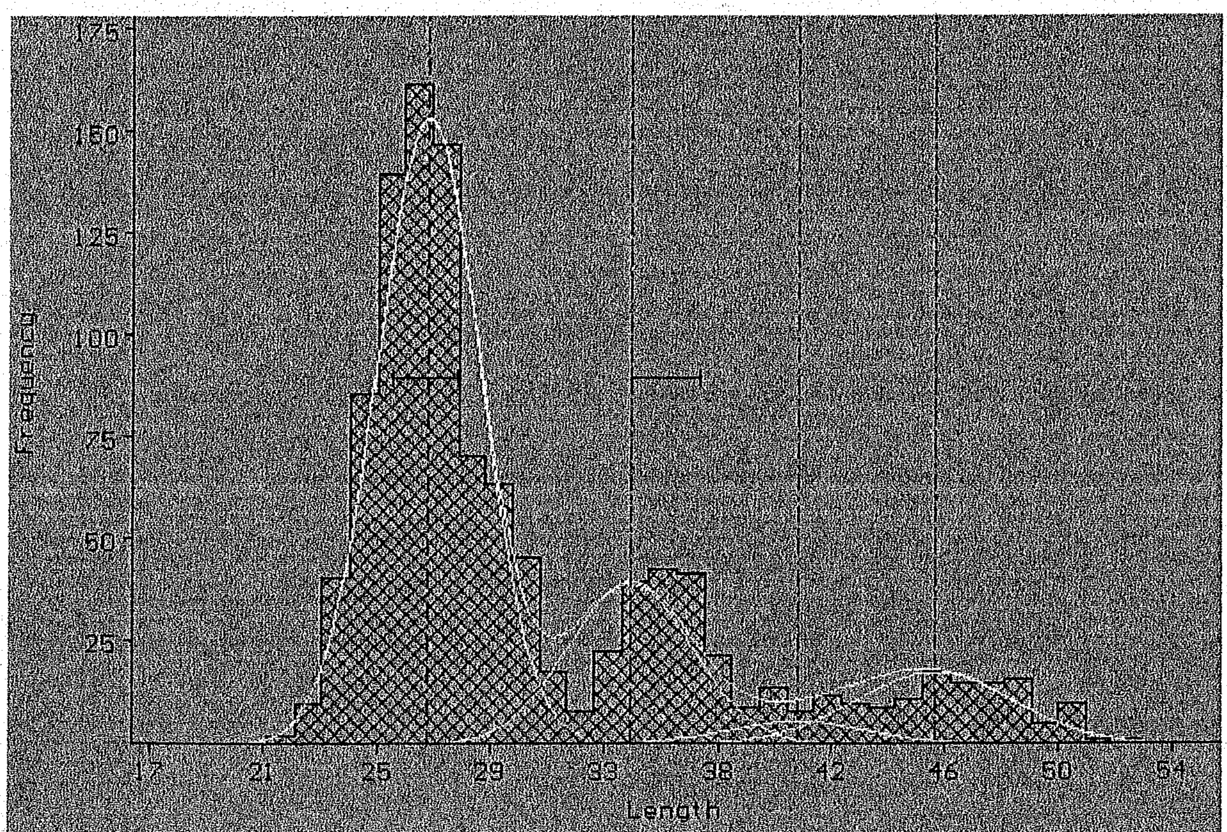
Appendix D-4 Golden
Fit: xi
Objective function value = 1067.00000; total penalty = 0.00744
Maximum gradient component = 0.00007
Number of non-empty length intervals: 61; Number of estimated parameters: 11
Approximate number of degrees of freedom: 50

Number of age classes: 4
Parameter Estimates:
von Bertalanffy K = 0.198 (1/year); L infinity = 68.2
First Length = 26.885; Last Length = 45.406; Brody rho = 0.820 (1/year).
Estimated age of the first age class = 2.53 years.
Mean length at age in month 1:
26.88 34.31 40.41 45.41
Standard Deviations of length at age in month 1:
1.95 2.32 2.67 3.00
Average Standard Deviation = 2.417; ratio of first to last S.D.= 1.542

Golden, 1999

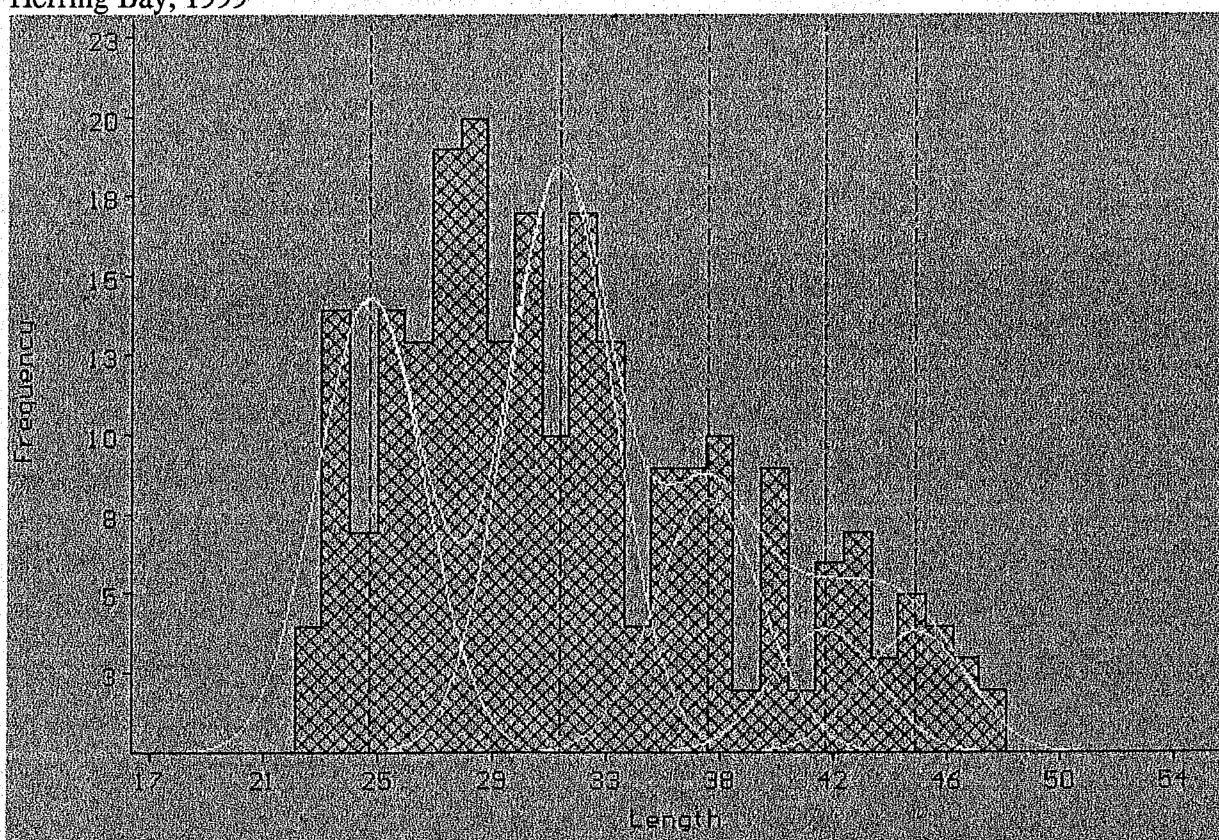


Golden, 2000

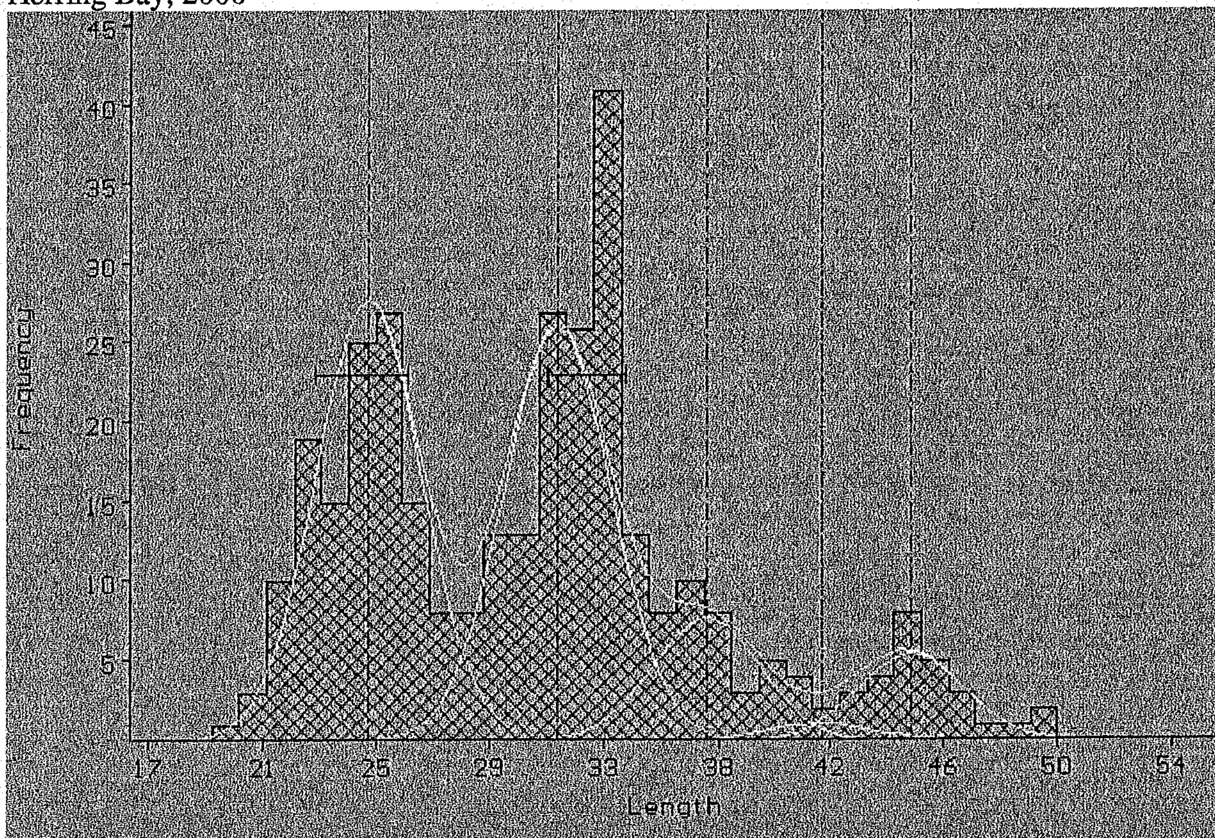


Appendix D-5 Herring Bay
Fit: uc
Objective function value = 1070.00000; total penalty = 0.00893
Maximum gradient component = 0.00042
Number of non-empty length intervals: 57; Number of estimated parameters: 12
Approximate number of degrees of freedom: 45

Number of age classes: 5
Parameter Estimates:
von Bertalanffy K = 0.245 (1/year); L infinity = 56.5
First Length = 24.767; Last Length = 44.633; Brody rho = 0.782 (1/year).
Estimated age of the first age class = 2.35 years.
Mean length at age in month 1:
24.77 31.68 37.09 41.32 44.63
Standard Deviations of length at age in month 1:
1.94 1.94 1.94 1.94 1.94
Average Standard Deviation = 1.940; ratio of first to last S.D.= 1.000

Herring Bay, 1999


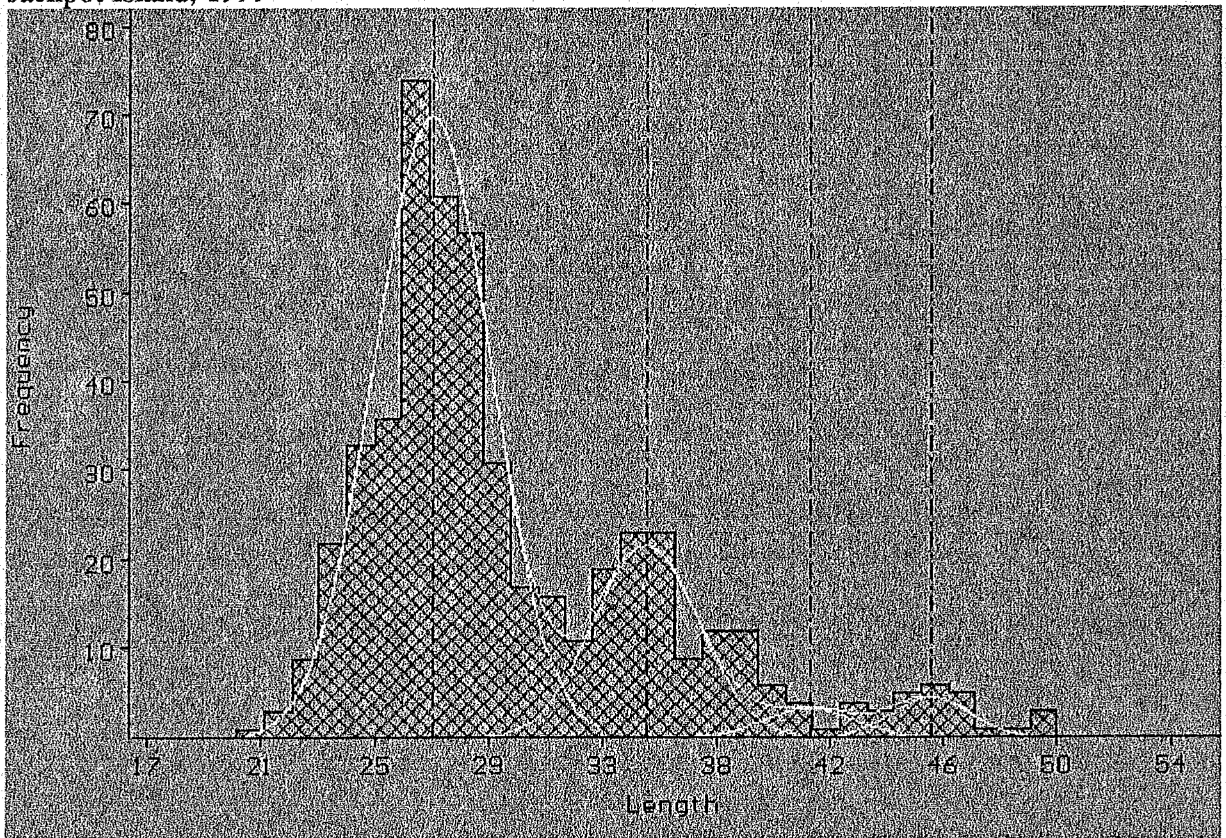
Herring Bay, 2000



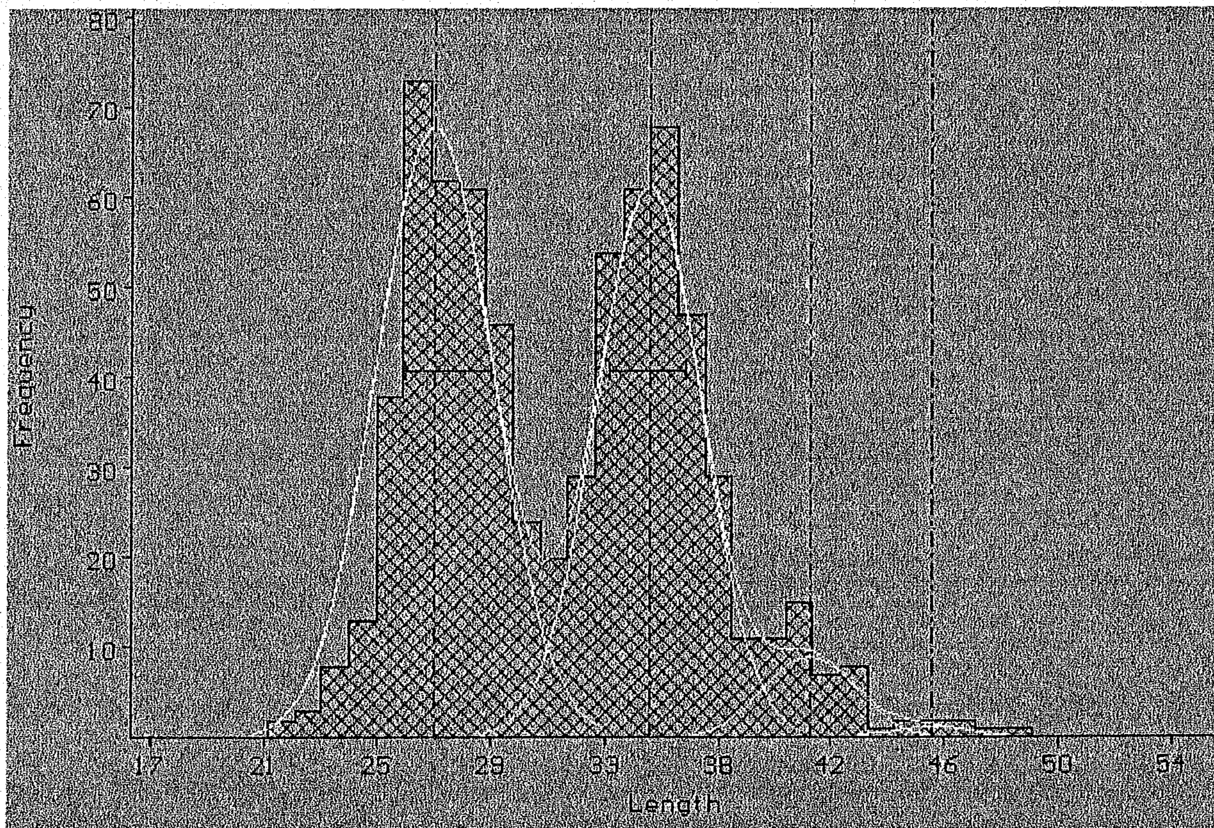
Appendix D-6 Jackpot Island
Fit: xj
Objective function value = 1169.00000; total penalty = 0.01089
Maximum gradient component = 0.00080
Number of non-empty length intervals: 58; Number of estimated parameters: 11
Approximate number of degrees of freedom: 47

Number of age classes: 4
Parameter Estimates:
von Bertalanffy K = 0.281 (1/year); L infinity = 59.1
First Length = 27.119; Last Length = 45.340; Brody rho = 0.755 (1/year).
Estimated age of the first age class = 2.19 years.
Mean length at age in month 1:
27.12 34.96 40.87 45.34
Standard Deviations of length at age in month 1:
2.16 1.85 1.64 1.50
Average Standard Deviation = 1.800; ratio of first to last S.D.= 0.692

Jackpot Island, 1999



Jackpot Island, 2000



Appendix D-7 McClure Bay

Fit: xm

Objective function value = 1096.00000; total penalty = 0.00609

Maximum gradient component = 0.00066

Number of non-empty length intervals: 60; Number of estimated parameters: 11

Approximate number of degrees of freedom: 49

Number of age classes: 4

Parameter Estimates:

von Bertalanffy K = 0.311 (1/year); L infinity = 54.5

First Length = 24.872; Last Length = 42.888; Brody rho = 0.732 (1/year).

Estimated age of the first age class = 1.95 years.

Mean length at age in month 1:

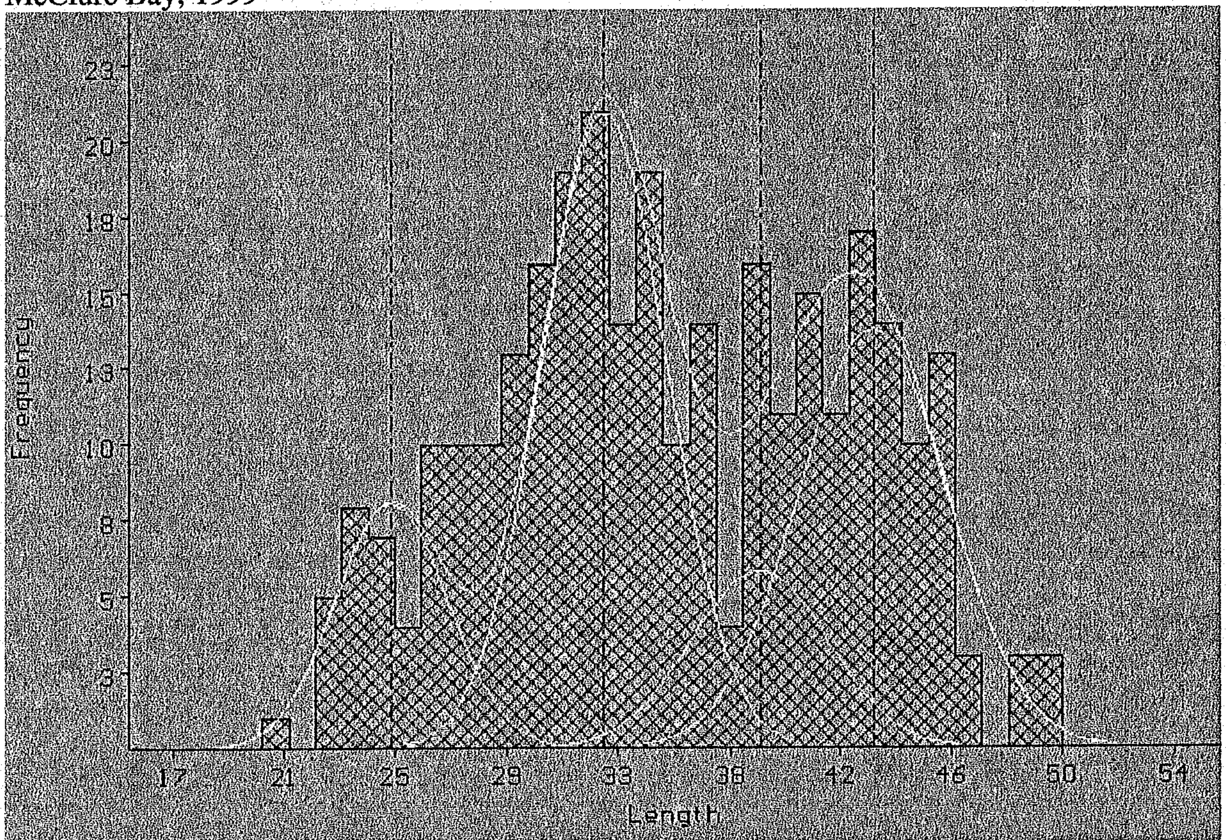
24.87 32.81 38.63 42.89

Standard Deviations of length at age in month 1:

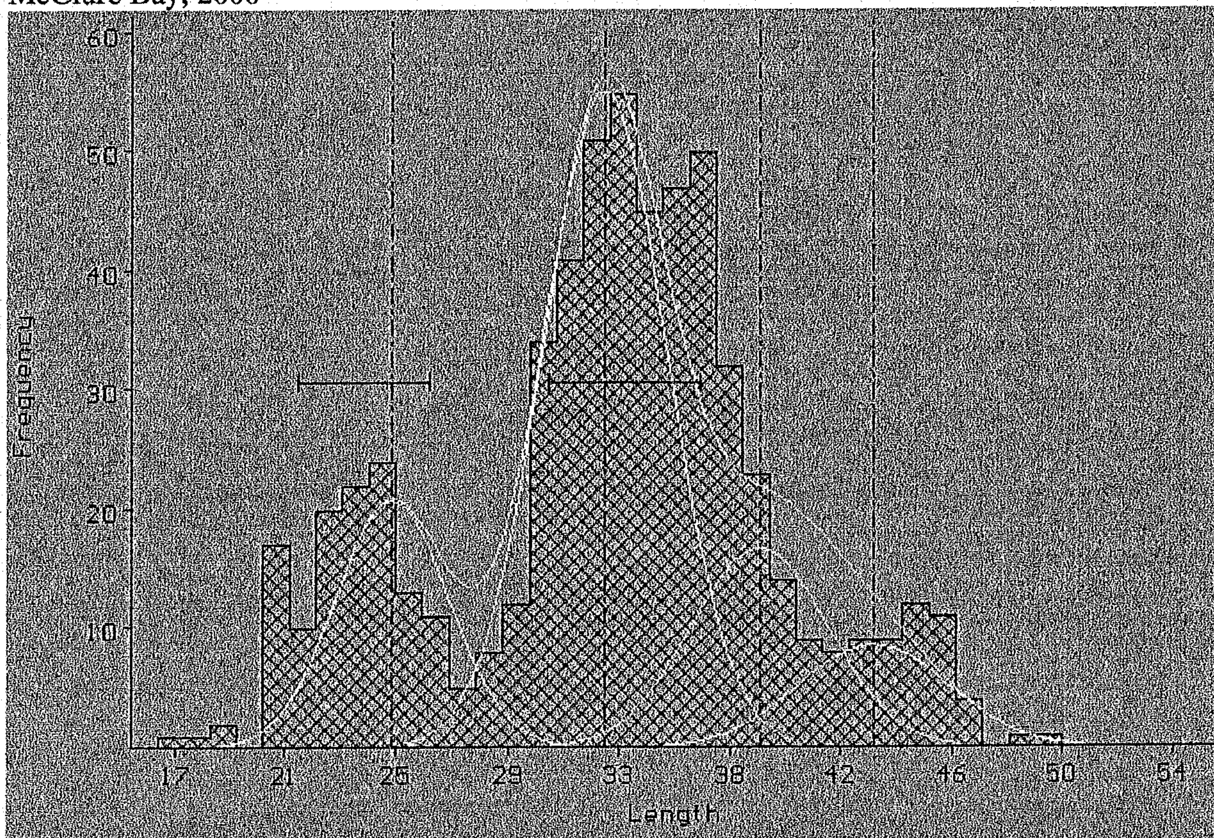
2.12 2.42 2.66 2.85

Average Standard Deviation = 2.458; ratio of first to last S.D.= 1.340

McClure Bay, 1999



McClure Bay, 2000

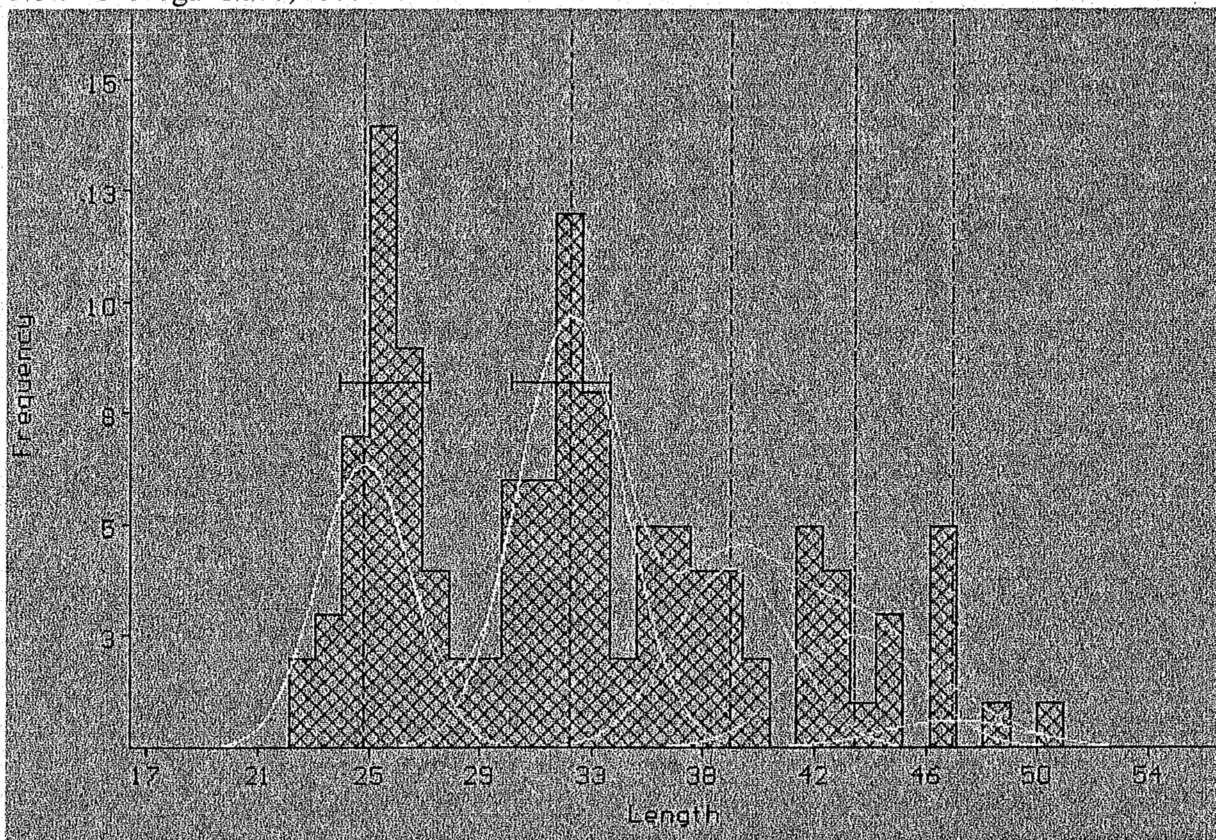


Appendix D-8 North Chenega Island

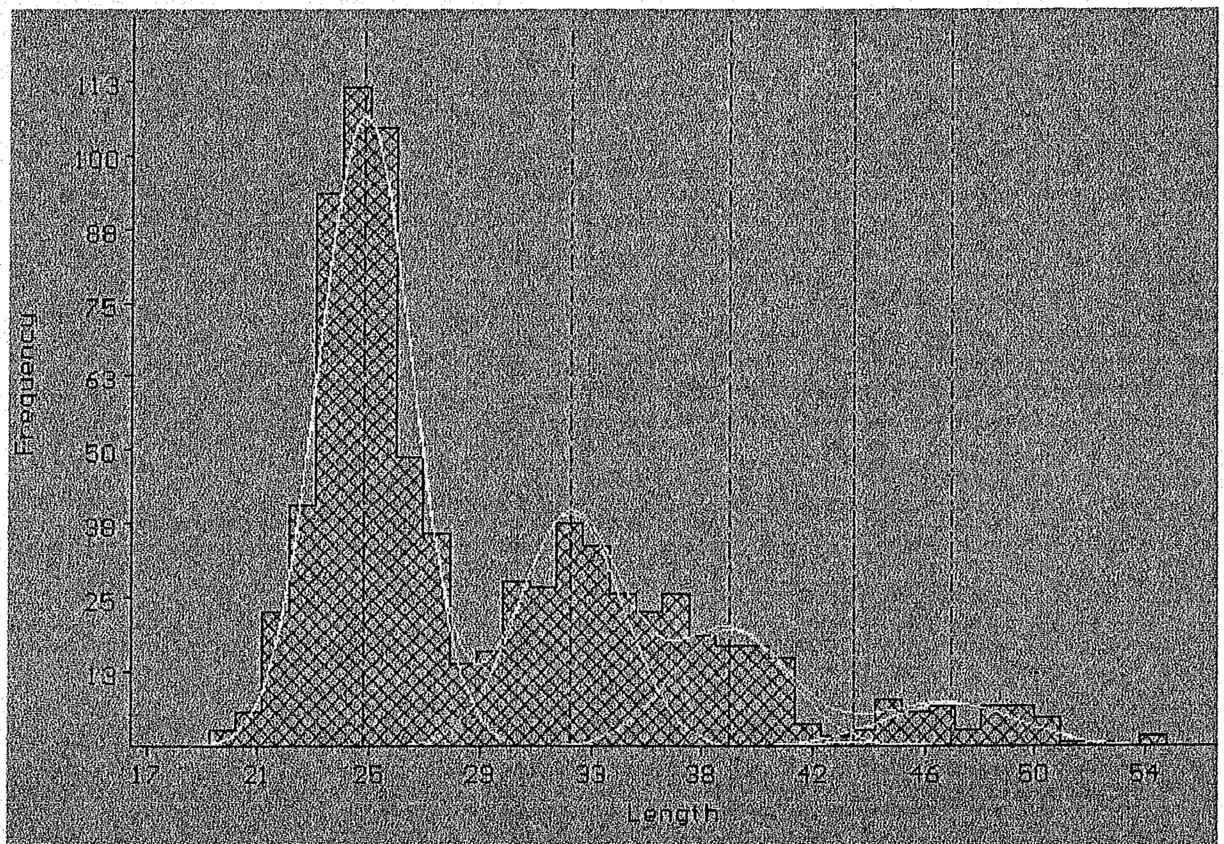
Fit: xr
Objective function value = 1102.00000; total penalty = 0.01256
Maximum gradient component = 0.00048
Number of non-empty length intervals: 60; Number of estimated parameters: 13
Approximate number of degrees of freedom: 47

Number of age classes: 5
Parameter Estimates:
von Bertalanffy K = 0.251 (1/year); L infinity = 59.6
First Length = 24.837; Last Length = 46.833; Brody rho = 0.778 (1/year).
Estimated age of the first age class = 2.15 years.
Mean length at age in month 1:
24.84 32.54 38.54 43.20 46.83
Standard Deviations of length at age in month 1:
1.78 2.05 2.30 2.51 2.69
Average Standard Deviation = 2.185; ratio of first to last S.D.= 1.514

North Chenega Island, 1999



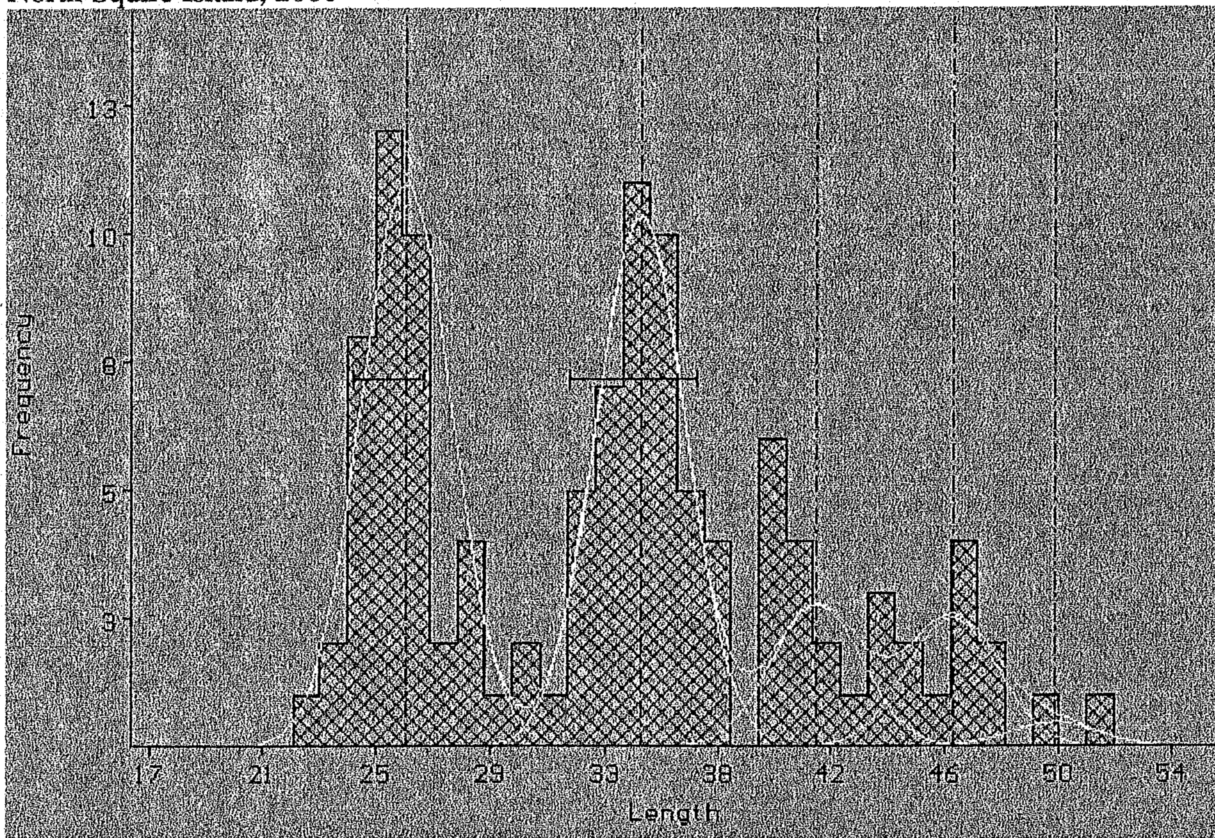
North Chenega Island, 2000



Appendix D-9 North Squire Island (only sampled in 2000)
Fit: ub
Objective function value = 526.59998; total penalty = 0.00497
Maximum gradient component = 0.00027
Number of non-empty length intervals: 27; Number of estimated parameters: 8
Approximate number of degrees of freedom: 19

Number of age classes: 5
Parameter Estimates:
von Bertalanffy K = 0.275 (1/year); L infinity = 61.6
First Length = 26.153; Last Length = 49.794; Brody rho = 0.760 (1/year).
Estimated age of the first age class = 2.01 years.
Mean length at age in month 1:
26.15 34.67 41.14 46.06 49.79
Standard Deviations of length at age in month 1:
1.65 1.65 1.65 1.65 1.65
Average Standard Deviation = 1.648; ratio of first to last S.D.= 1.000

North Squire Island, 2000



Appendix D-10 Perry Island

Fit: u4

Objective function value = 1076.00000; total penalty = 0.00619

Maximum gradient component = 0.00002

Number of non-empty length intervals: 62; Number of estimated parameters: 10

Approximate number of degrees of freedom: 52

Number of age classes: 4

Parameter Estimates:

von Bertalanffy K <= 0.269 (1/year); L infinity = 60.7

First Length = 25.207; Last Length = 44.831; Brody rho = 0.764 (1/year).

Estimated age of the first age class = 2.00 years.

Mean length at age in month 1:

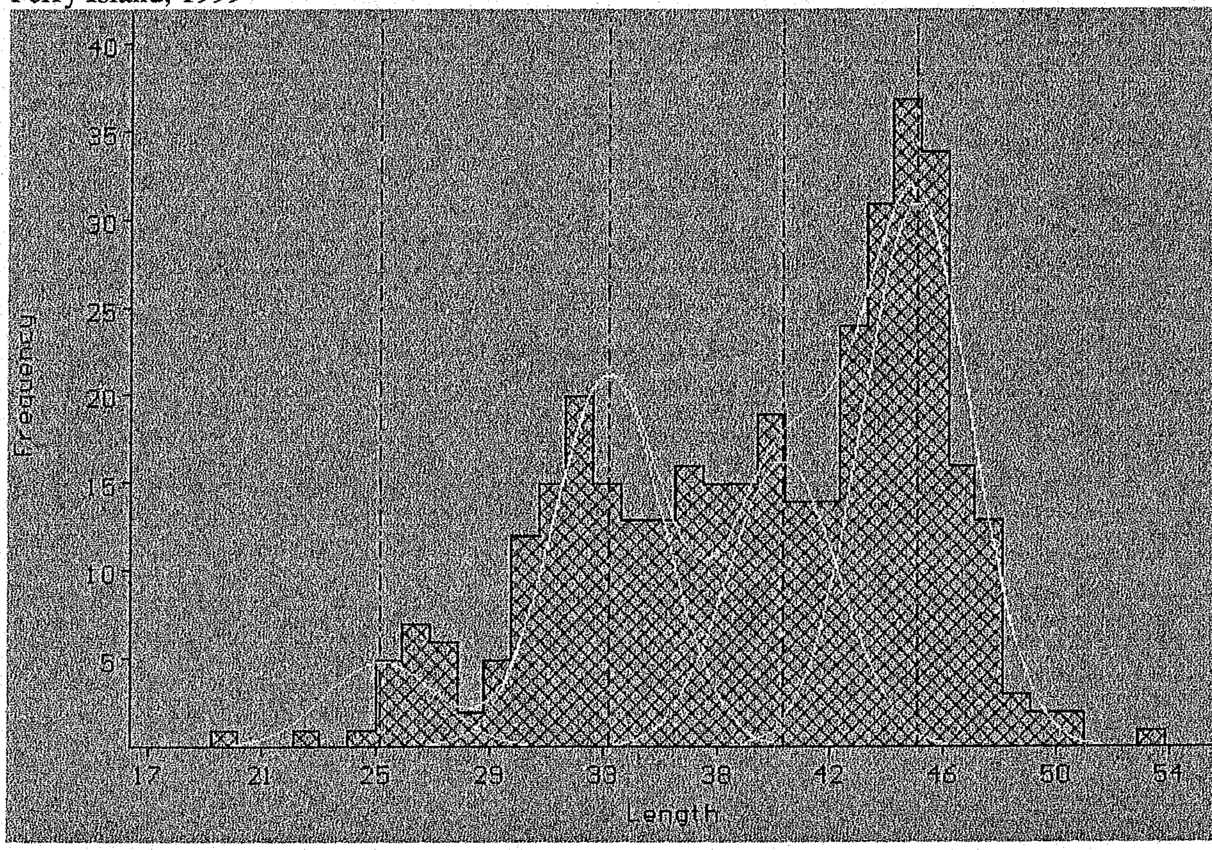
25.21 33.56 39.95 44.83

Standard Deviations of length at age in month 1:

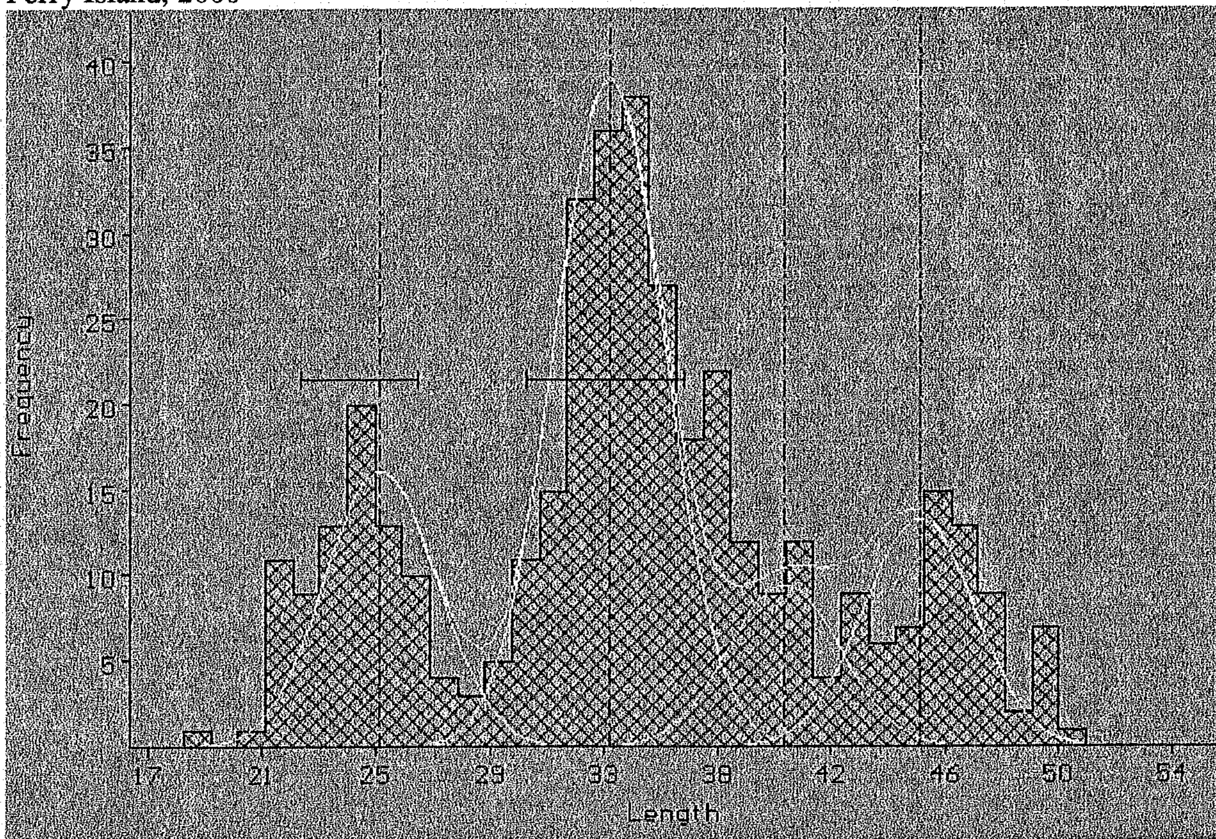
2.02 2.02 2.02 2.02

Average Standard Deviation = 2.021; ratio of first to last S.D.= 1.000

Perry Island, 1999



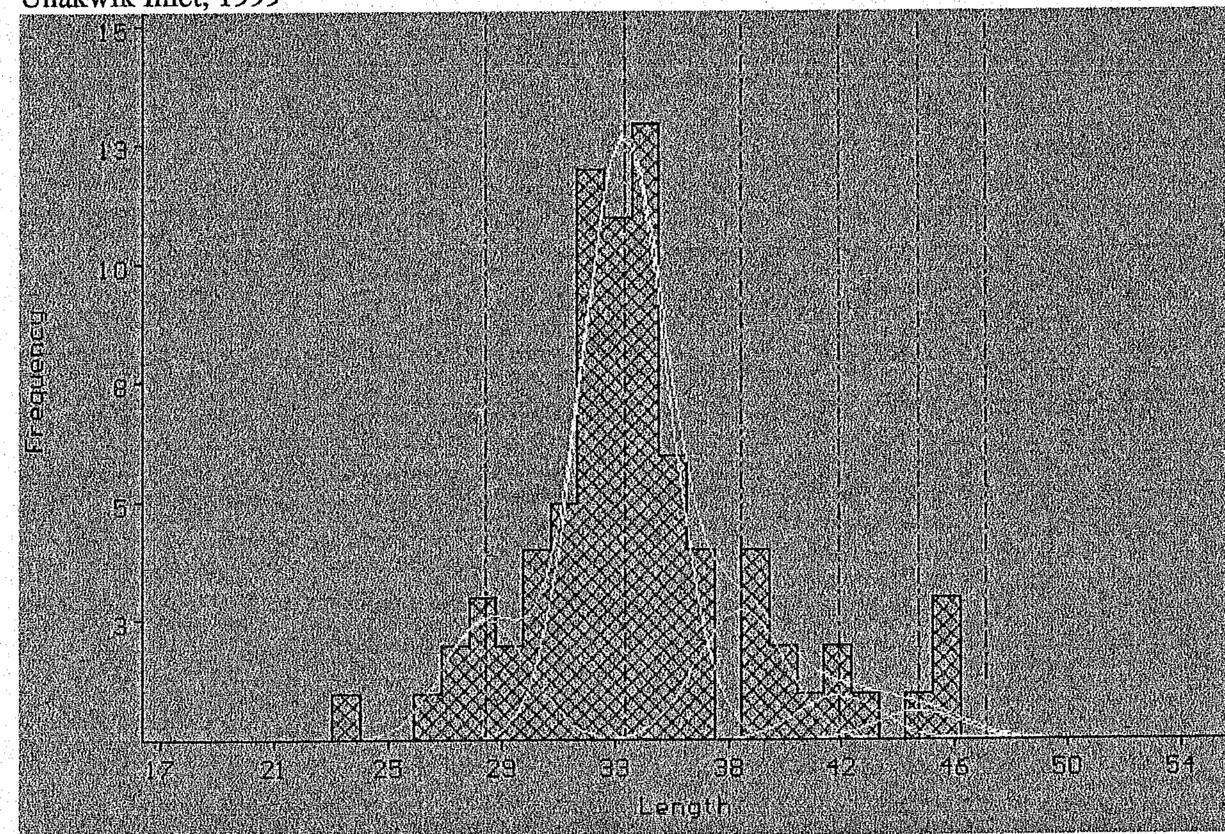
Perry Island, 2000



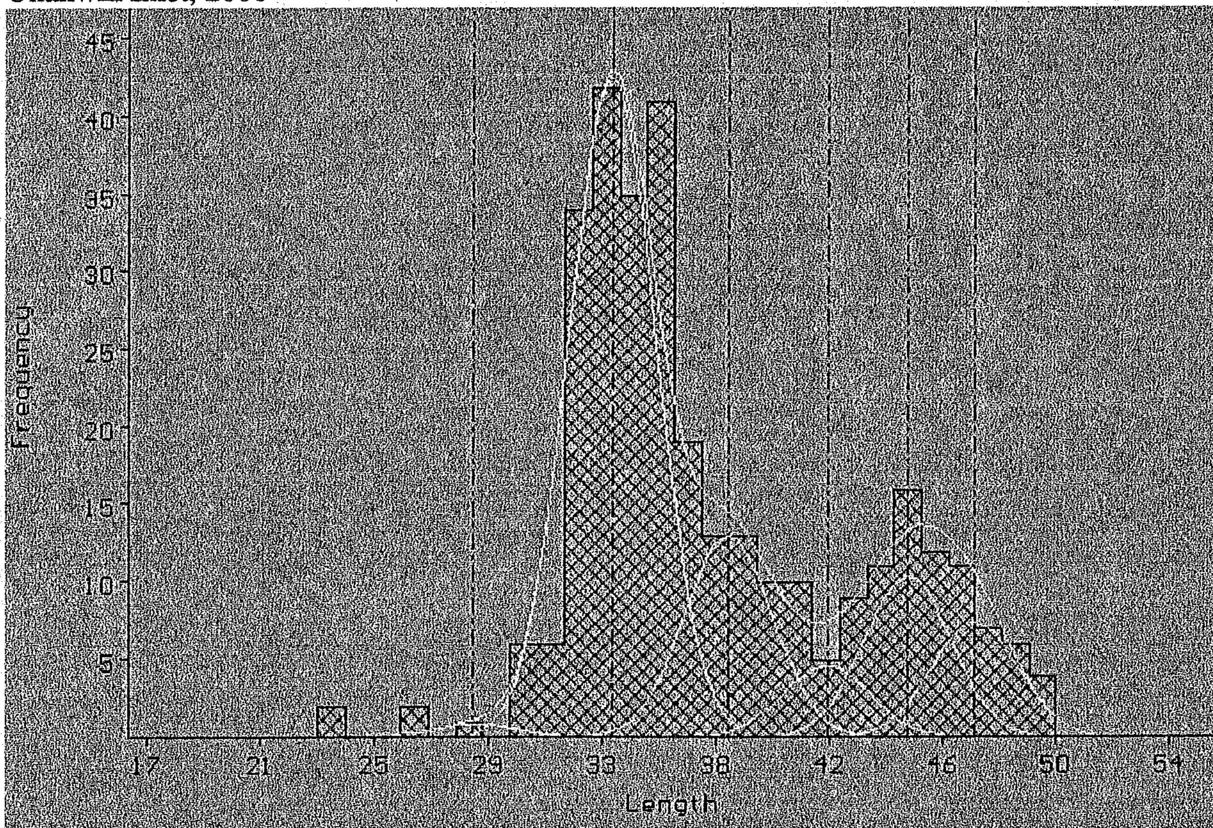
Appendix D-11 Unakwik Inlet
Fit: uj
Objective function value = 1114.00000; total penalty = 0.20773
Maximum gradient component = 0.00021
Number of non-empty length intervals: 42; Number of estimated parameters: 14
Approximate number of degrees of freedom: 28

Number of age classes: 6
Parameter Estimates:
von Bertalanffy K <= 0.179 (1/year); L infinity = 59.7
First Length = 28.644; Last Length = 46.992; Brody rho = 0.836 (1/year).
Estimated age of the first age class = 3.66 years.
Mean length at age in month 1:
28.64 33.73 37.98 41.53 44.51 46.99
Standard Deviations of length at age in month 1:
1.59 1.59 1.59 1.59 1.59 1.59
Average Standard Deviation = 1.590; ratio of first to last S.D.= 1.000

Unakwik Inlet, 1999



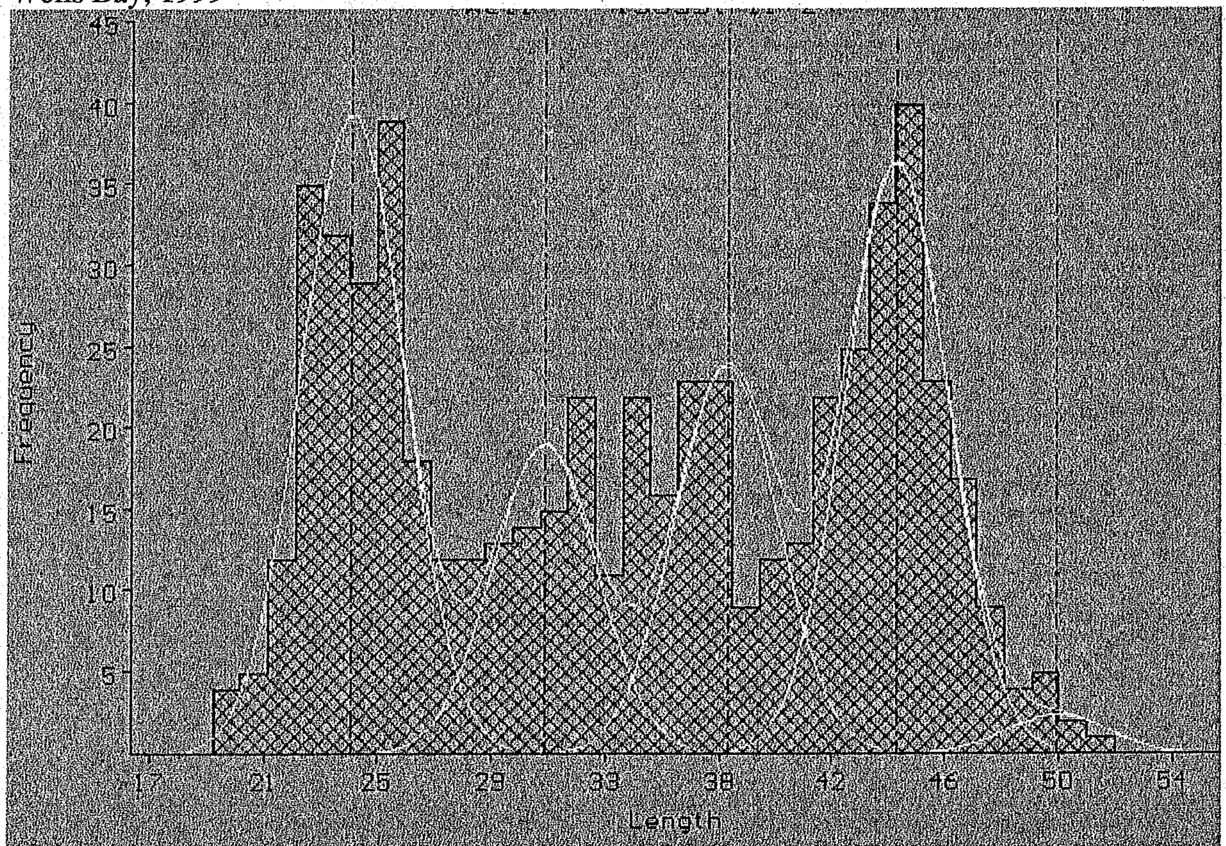
Unakwik Inlet, 2000



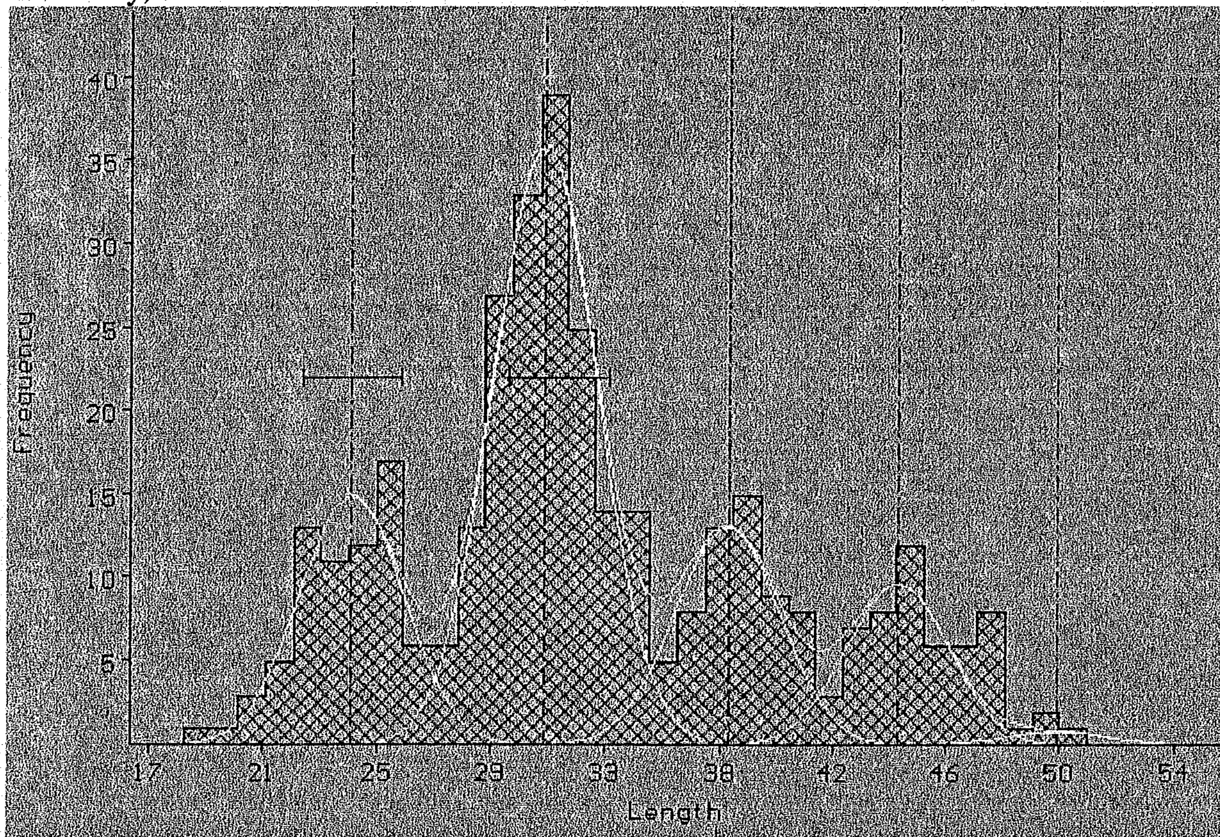
Appendix D-12 Wells Bay
Fit: u6
Objective function value = 1117.00000; total penalty = 0.00931
Maximum gradient component = 0.00018
Number of non-empty length intervals: 66; Number of estimated parameters: 12
Approximate number of degrees of freedom: 54

Number of age classes: 5
Parameter Estimates:
von Bertalanffy K = 0.062 (1/year); L infinity = 142.2
First Length = 24.116; Last Length = 49.893; Brody rho = 0.940 (1/year).
Estimated age of the first age class = 3.02 years.
Mean length at age in month 1:
24.12 31.17 37.80 44.03 49.89
Standard Deviations of length at age in month 1:
1.89 1.89 1.89 1.89 1.89
Average Standard Deviation = 1.888; ratio of first to last S.D.= 1.000

Wells Bay, 1999



Wells Bay, 2000



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Roa, R. and B. Ernst. 1996. Age structure, annual growth, and variance of size-at-age of the shrimp Heterocarpus reedi. Mar. Ecol. Prog. Ser. 137:59-70.

Kimker, A., W. Donaldson and W. R. Bechtol. 1996. Spot shrimp growth in Unakwik Inlet, Prince William Sound, Alaska. Alaska Fish. Res. Bull. 3: 1-8.

Description of Output (from Multifan "help")
Fit: the number of the parameter file of the present fit.

Objective function value: the value of the log-likelihood function including any contribution from the various penalty functions which are used to constrain the solution.

Total penalty: The contribution of all the penalty functions to the objective function. If this is larger than about 5 - 10 the fit is suspect. Usually it should be about 0.0 - 0.5

Maximum gradient component: The size of the largest partial derivative of the objective function with respect to the parameters. It should usually be less than 0.5. If it is larger than this it is possible that the function minimizer did not converge. You can rerun this fit using the Estimation main menu option. (But keep in mind that some of the fits in the systematic search may fit the data so badly that it may not be possible for the function minimizer to make the gradient components smaller than 0.5.)

Number of non-empty length intervals ... degrees of freedom: These entries have no real statistical significance. They are only there to give you a rough idea of how many observations you have to fit and how many parameters you have used to fit them.

Parameter Estimates:

von Bertalanffy K; L infinity:

These are the estimates for these parameters associated with the von bertalanffy growth curve.

First Length; Last Length:

Multifan uses the parameterization of the von Bertalanffy growth curve found in Schnute and Fournier (1980). This includes the parameters First Length (the mean length of the first age class on the von Bertalanffy curve in month 1) and Last Length (the mean length of the last age class on the von Bertalanffy curve in month 1).

Brody rho:

This is related to the von Bertalanffy K by the relationship

$$\text{rho} = \exp(-K)$$

Mean length at age in month 1: These are the mean lengths of the fish in each age class on the von Bertalanffy curve in month 1[sample where the youngest age class appears for the first time].

Standard Deviations of length at age in month 1: These are the standard deviations of the distribution of the lengths of the fish in each age class in month 1.

The standard deviation of the distribution of the lengths of the fish in each age class are parameterized by two parameters, the overall average S.D. and the ratio of the first S.D. to the last S.D.