Exxon Valdez Oil Spill
Restoration Project Annual Report

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

Restoration Project 00401
Annual Report

This annual report has been prepared for peer review as part of the Exxon Valdez Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

Charles E. O'Clair[1]
Mandy Lindeberg[1]
Charles Hughey[2]

1. National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Auke Bay Laboratory
11305 Glacier Highway
Juneau, Alaska 99801-8626

2. Valdez Native Tribe
P. O. Box 1108
Valdez, AK 99686

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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 second annual 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 independence that characterizes the historical data.

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

Project Data: (will be addressed in the final report)

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EXECUTIVE SUMMARY

The goal of the spot shrimp project is to determine the extent to which spot shrimp abundance has recovered since the population decline which began just prior to 1989. Our objectives in FY2000 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. 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 the six sites traditionally included in ADF&G's annual survey using a methodology similar to that of ADF&G. In addition, we sampled for a second time 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 in October 1999 and 2000. 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. In a side-by-side comparison of the conical and rectangular pots in 1999 we found the rectangular pot to be less effective than the conical pot in catching spot shrimp. However, our pot was somewhat smaller and had larger openings in the mesh forming the entrance tunnels. 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, in our 1999 annual report we recommended 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. This suggests that population recovery may be taking place. 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 independence that follows from sampling the same sites each year. Our estimates of spot shrimp fecundity in 1999 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 shrimp populations at these sites suggesting that spot shrimp fecundity may be an important variable 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 decision point for reopening the fishery has been set tentatively at a survey CPUE of 0.6 kg/pot (Trowbridge 1994).

Annual surveys of the abundance of spot shrimp in PWS begun in 1989 by the Alaska Department of Fish and Game (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).

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 . The rectangular pots that we used differed from those of ADF&G chiefly in being somewhat smaller (33 cm x 33 cm x 81 cm) and in having larger openings (3.3 cm stretched opening) in the mesh enclosing the tunnels. Two rectangular pots were added to each of the two pot strings fished at each site. The rectangular pots were attached to the ground line midway between the third and fourth (ordered shallow to deep) and the seventh and eighth conical pot on each string.

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.

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.

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

Paired t-tests were used to compare the CPUEs of rectangular pots versus conical pots. The sampling unit for this analysis was the station. Analysis of variance was used to test for differences in CPUE (No. of individuals/pot and weight/pot) 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 log-transformed [log (y + 1) if the data included zeros] to stabilize variances. Linear regression was used to test for temporal trends in CPUE. Analysis of covariance was used to test between-site differences in spot shrimp fecundity. The Bonferroni procedure was used for pairwise comparisons of spot shrimp fecundity between sites.

RESULTS

Conical Pots vs Rectangular Pots

Rectangular pots had smaller catches than did conical pots (Table 4). When all stations were considered together the mean number of spot shrimp per pot (NPP) in the conical pot (NPP = 11.8 shrimp/pot) was 2.5 x that of the adjacent rectangular pot (NPP = 4.7 shrimp/pot) nearest in depth (paired t-test, $t = 4.15$, $df = 22$, $p > 0.001$). Similarly, the mean weight of the spot shrimp catch per pot (WPP) in the conical pot (WPP = 290 g/pot) was 2 x that of the rectangular pot (WPP = 144 g/pot; paired t-test, $t = 3.61$, $df = 22$, $p > 0.01$). The weights of both variables were transformed [log (y + 1)] for the analyses. For all subsequent analyses covered in this report only data from the conical pots was used.

Catches at Traditional Sites vs New Sites

The catch of spot shrimp varied greatly between sampling sites both within the group of traditional sites and within that of new sites in 1999. Among the traditional sites the greatest total number and weight of spot shrimp were caught at Culross Passage (Table 5). The lowest total numbers of shrimp were caught at North Chenega Island and Green Island where catch weights were also lowest. At the new sites, the greatest total number of shrimp was caught at Wells Bay (Table 5). Both Wells Bay and Perry Island had the greatest catch weight of spot shrimp. The lowest total number and weight of spot shrimp caught at the new sites were at Eaglek Bay where only four male spot shrimp were caught (Table 5).

Catches of spot shrimp were somewhat less variable between sites in 2000. Among the traditional sites the greatest total number and weight of spot shrimp were caught at Golden (Table 6). The lowest total number and weight of shrimp were caught at Herring Bay and Green Island, respectively. At the new sites, the greatest total number of shrimp was caught at Jackpot Island (Table 6). Both Jackpot Island and McClure Bay had the greatest catch weight of spot shrimp in 2000. The lowest total number and weight of spot shrimp caught at the new sites were at North Squire Island (Table 6).

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 (Table 7). In 1999 the mean number of spot shrimp per pot (NPP) was 15.4 shrimp/pot at the new sites; that at the Traditional sites was 11.8 shrimp/pot. In 2000 the NPP was somewhat greater at both sites (NPP = 18.7 shrimp/pot at the new sites; NPP = 27.4 shrimp/pot at the traditional sites). However, there was no significant year effect nor was there a significant site-group by year interaction in the mean spot shrimp catch (Table 7). Similarly, the mean weight of the spot shrimp catch per pot (WPP) at the new sites did not differ from that at the traditional sites in either year (Table 7). In 1999 WPP was 374 g/pot at the new sites; that at the Traditional sites was 258 g/pot. In 2000 WPP was 376 g/pot and 511 g/pot at the new sites and traditional sites, respectively. As with the mean spot shrimp catch there was neither a significant year effect nor a significant site-group by year interaction in the mean weight of the spot shrimp catch per pot (Table 7).

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 5). 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 majority of females in those catches were ovigerous (Table 5). 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 5. 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% (Green Island) of the total catch at the traditional ADF&G sites (Table 6). 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. 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 5 and 6). 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. Transitional shrimp represented between 1.4% and 15% of the total catch at sites in 2000 (Tables 5 and 6).

Mean carapace length (CL) of male, transitional and female spot shrimp generally did not vary greatly between sites in 1999 or 2000 (Figure 3). 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 8).

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 of the eight sites completely processed to date. 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 8).

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 3). 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 8).

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 1). 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 (Figures 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; Figure 4). 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 (Figures 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 (Figures 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 (Figures A-2, A-4 and A-8). No transitional shrimp were present in the catch from Port Nellie Juan (Figure 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 (Figures 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 (Figures 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 (Figures 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 (Figures 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 (Figure 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 (Figure 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 (Figures 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 (Figures 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 (Figure 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 1). 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 (Appendix 1). 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 (Appendix 1). Both of these modal classes were composed of males. The smaller class (22-25) 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 1).

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 1). 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 1)

Fecundity

Analysis of covariance (ANCOVA) of the 1999 spot shrimp fecundity data revealed that fecundity was significantly related to carapace length (Figure 4, Table 9). Although the ANCOVA revealed a significant site effect (Table 9), variances of the log-transformed data were not homogeneous and pairwise comparisons between sites were not significant (Bonferroni test, $p > 0.05$). Adjusted mean fecundity ranged from 2668 eggs (Wells Bay) to 3128 eggs (North Chenega Island) evaluated at a carapace length of 44 mm (Figure 5). No females were caught in Eaglek Bay. Analysis is not yet complete of the 2000 fecundity data.

Bathymetric Distribution

Ovigerous spot shrimp tended to be distributed to greater depths than males in 1999. For our analysis of depth distribution "males" included what few transitional and nonovigerous female shrimp were collected in the pots as well. The mean depth of the modal catch per unit effort (CPUE) of males (90 m) at the 12 sites was significantly less than that of ovigerous females (126 m; Table 10, Appendix 2). The difference in depth distribution between males and females resulted in the two groups being exposed to different temperatures. However, the differences

were probably not biologically significant. The mean temperature at the depth of the modal CPUE of males (7.7 °C) was somewhat greater than that at the depth of the modal CPUE of ovigerous females (6.3 °C, Table 10, Figure 6). The mean salinities at the depths of the modal CPUE of males and ovigerous females were nearly identical (males, 31.2 PSU; ovigerous females, 31.8 PSU). The ANOVA of the salinity data was not definitive because the variances could not be stabilized (Table 10).

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 11). 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 11). 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 11). 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 11).

Comparison of ADF&G and ABL/VNT Catches

Our spot shrimp catches were similar in size to those of ADF&G in October 1999 and 2000 (Table 12; Figure 7). In 1999 our estimate of the mean number of spot shrimp per pot (NPP) at the traditional survey sites of ADF&G (NPP = 11.8 shrimp/pot) did not differ from that obtained in the ADF&G annual survey (NPP = 13.4 shrimp/pot). Similarly, in 2000 our catches (NPP = 27.4 shrimp/pot) of spot shrimp did not differ on average from those of ADF&G at the traditional sites (NPP = 17.5 shrimp/pot). Results were similar when we compared catch weights. Our estimate of the mean weight of the spot shrimp catch per pot (WPP = 0.26 kg/pot) did not differ from that of the ADF&G annual survey (WPP = 0.22 kg/pot) in 1999. In 2000 our estimate of the mean weight of the spot shrimp catch per pot (WPP = 0.54 kg/pot) also did not differ from that of the ADF&G annual survey (WPP = 0.29 kg/pot; Table 11; Figure 7). No significant year effect was revealed by the ANOVA of number or weight of spot shrimp (Table 12).

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 (Table 13). The mean number of spot shrimp per pot (NPP = 13.6 shrimp/pot) and the mean weight of the spot shrimp catch per pot (WPP = 0.32 kg/pot) of our catches did not differ significantly from those of ADF&G (NPP = 12.5 shrimp/pot, WPP = 0.21 kg/pot) in October 1999. Similarly, in October 2000 our catches (NPP = 23.0 shrimp/pot; WPP = 0.46 kg/pot) did not differ significantly from those of ADF&G (NPP = 18.6 shrimp/pot; WPP = 0.32 kg/pot; Table 13). In contrast to the results we obtained when we considered only the traditional sites, the ANOVAs of both the number of spot shrimp per pot and the weight of the spot shrimp catch per pot revealed a significant increase in NPP and WPP in 2000 compared with 1999 (Table 13). Some caution should taken in interpreting the WPP increase, however, because variances could not be stabilized with the log transformation.

DISCUSSION

The rapid decline in the commercial catch of spot shrimp after the peak harvest of over 110 tonnes in 1986 (Figure 8) 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 14). 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 (Table 14). However, J. Brady kindly gave us summaries of ADF&G survey data collected from 1995 to 1999 that allowed us to estimate between-site variability within years (Figure 8). Statistical tests revealed no significant trend in the number of spot shrimp per station (regression $R^2 = 0.35$, df = 1,28, $p > 0.05$) in the ADF&G survey data between 1995 and 1998. However, the weight of the spot shrimp catch per station (regression $R^2 = 0.51$, df = 1,28, $p < 0.01$) from the survey decreased between 1995 and 1998. The ADF&G survey catch at the traditional ADF&G sites rebounded between 1998 and 2000 (Figure 9). Both the number of spot shrimp per station (regression $R^2 = 0.24$, df = 1,16, $p = 0.04$) and the 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 9).

Between-study differences in pot configuration did not appear to significantly influence the catch of spot shrimp. The side-by-side comparison of rectangular pots and conical pots in the present study revealed that the rectangular pots that we used were much less effective than the conical pots at catching spot shrimp. Nevertheless, the catches of ADF&G were comparable to ours in October 1999 and 2000 (Tables 12 and 13, Figure 7). Apparently, the somewhat larger rectangular pot with a smaller mesh enclosing the tunnels that ADF&G used accounted for the difference in effectiveness of their rectangular pots compared to ours. 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.). For the sake of pot standardization within ADF&G and to facilitate more realistic 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 independence in the resulting data, statistical analysis of temporal trends in the data is rendered problematical. 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, say, 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 (analysis is not yet complete of our 2000 fecundity data.). 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.

Our estimate of mean fecundity per site in 1999 (by actual count of all eggs in each clutch) appeared to be uniformly higher than that of Trowbridge (1992). Armstrong et al. (1995) also give fecundity estimates for spot shrimp from nine bays in western Prince William Sound. Their estimates range 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. 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 14 of Trowbridge). Although our fecundity estimate for Green Island was only 2.1% higher than that of Trowbridge, our estimates were often substantially higher for Unakwik Inlet (28.7% higher), Culross Passage (13.3%), Golden (41.7%), Herring Bay (36.7%), and North Chenega Island (52.8%). 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. If real interannual differences occur in spot shrimp fecundity in Prince William Sound, and in view of the importance of fecundity estimates to our knowledge of the reproductive potential of a population, periodic monitoring of fecundity at ADF&G's sites may be warranted.

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. Although our catches did not differ from those of ADF&G at the same sites in October 1999 or 2000 despite the different pot configurations used by the two investigations, we recommend 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. We also recommend that in future surveys ADF&G randomly select their sites from a larger group of potential sampling sites, the six additional sites that we sampled 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)		Soak time (h)
				Minimum	Maximum	
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 . Catches of spot shrimp in rectangular pots compared to those of adjacent conical pots nearest in depth at 12 sites in western Prince William Sound in October 1999. SE = one standard error of the mean.

		Conical pots					Rectangular pots				
Site	Station	No. pots	Mean no./pot	SE no./pot	Mean wt/pot (g)	SE wt/pot (g)	No. pots	Mean no./pot	SE no./pot	Mean wt/pot kg	SE wt/pot kg
ADF&G Traditional Sites											
Unakwik Inlet	1	2	3	3	99	99	2	0	0	0	0
	2	2	1.5	1.5	32.5	32.5	2	5	4	98	86
Culross Passage	1	2	9.5	9.5	169	169	2	7	7	154	154
	2	2	25.5	4.5	531	60	2	1.5	0.5	31	9
Golden	1	2	29	7	934	142	2	6	5	170	136
	2	2	4.5	3.5	71.5	49.5	2	4.5	2.5	192	182
Herring Bay	1	2	25.5	23.5	496	442	2	2	1	16.5	16.5
	2	2	1.5	1.5	33.5	33.5	2	1	1	28.5	28.5
North Chenega Is.	1	2	0.5	0.5	2.5	2.5	2	0	0	0	0
	2	2	2.5	2.5	90	90	2	3	3	83	83
Green Island	1[a]	0	-	-	-	-	0	-	-	-	-
	2	2	0.5	0.5	0.5	0.5	2	0	0	0	0
New Sites											
Wells Bay	1	2	25	1	452	102	2	21.5	4.5	526	19.5
	2	3	41.7	19.8	1339	696	3	30	13.3	1184	452
Eaglek Bay	1	2	0.5	0.5	4.5	4.5	2	0	0	0	0
	2	2	0.5	0.5	4.5	4.5	2	0	0	0	0
McClure Bay	1	2	1.5	0.5	46.5	22.5	2	1	1	34	34
	2	2	16.5	14.5	520	428	2	8	8	226	226
Port Nellie Juan	1	2	5	0	13.5	6.5	2	0	0	0	0
	2	2	16.5	8.5	128	79	2	5	3	39.5	33.5
Perry Island	1	2	13.5	4.5	568	53.5	2	7	2	375	170
	2	2	6.5	3.5	210	86.5	2	4	1	130	58.5
Jackpot Island	1	2	20.5	20.5	360	360	2	1	0	19.5	9.5
	2	2	19	7	560	113	2	0	0	0	0

a. No rectangular pots fished at this station.

Table 5. 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)		Males		Transitional		Ovigerous Females		Nonovigerous Females		All Females	
Site	No. Shrimp	Mean	SE	Total weight [kg(lb)]	Mean	SE	Total No.	%	Total No.	%	Total No.	%	Total No.	%	Total No.	%
ADF&G Traditional Sites																
Unakwik Inlet	78	3	1.4	1.7 (3.8)	76	18.1	69	88	1	1.3	7	9.0	1	1.3	8	10
Culross Passage	893	40	27	16 (37)	765	494	797	93	16	1.9	45	5.0	0	0	45	5.0
Golden	300	13	5.3	8.3 (18)	377	169	228	76	6	2.0	66	22	1	0.3	67	22
Herring Bay	237	10	8.7	4.9 (11)	222	164	205	86	1	0.4	34	14	0	0	34	14
North Chenega Island	58	2.4	2.0	1.5 (3.3)	66	63	46	79	0	0	11	19	1	1.7	12	21
Green Island	59	2.6	0.8	1.0 (2.2)	44	14	52	88	3	5.1	3	5.1	1	1.7	4	6.8
New Sites																
Wells Bay	697	26	3.6	15 (33)	687	252	413	72	0	0	154	22	4	0.7	158	28
Eaglek Bay	4	0.2	0.09	0.06 (0.1)	2.9	2.0	4	100	0	0	0	0	0	0	0	0
McClure Bay	299	13	7.8	8.1 (18)	368	229	207	68	9	3.0	87	28	2	0.7	89	29
Port Nellie Juan	326	14	6.2	2.5 (5.5)	114	59	323	100	0	0	1	0.3	0	0	1	0.3
Perry Island	372	16	7.6	15 (33)	671	386	199	54	9	2.4	151	41	13	3.5	164	44
Jackpot Island	513	23	16	8.9 (20)	403	189	465	91	19	3.7	23	4.5	3	0.6	26	5.1

Table 6. 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)		Males		Transitional		Ovigerous Females		Nonovigerous Females		All Females	
Site	No. Shrimp	Mean	SE	Total weight [kg(lb)]	Mean	SE	Total No.	%	Total No.	%	Total No.	%	Total No.	%	Total No.	%
ADF&G Traditional Sites																
Unakwik Inlet	321	15	5.4	9.5 (21)	431	162	231	73	8	2.5	74	23	2	0.6	76	24
Culross Passage	587	27	17	12 (26)	535	304	449	77	74	13	57	9.7	1	0.2	58	9.9
Golden	1180	54	29	21 (46)	960	159	994	89	22	2.0	103	9.2	0	0	103	9.2
Herring Bay	348	16	4.2	6.0 (13)	274	69	281	85	19	5.7	31	9.4	0	0	31	9.4
North Chenega Island	817	37	2.6	13 (29)	595	94	733	88	36	4.4	51	6.2	5	0.6	56	6.8
Green Island	359	16	1.4	5.9 (13)	268	46	295	91	13	4.0	17	4.7	0	0	17	4.7
New Sites																
Wells Bay	353	16	2.6	8.1 (18)	368	42	309	88	5	1.4	38	11	0	0	38	11
North Squire Island	113	5.1	0.4	2.6 (5.7)	120	13	92	82	7	6.2	13	12	0	0	13	12
McClure Bay	609	28	8.2	13 (29)	606	169	457	76	92	15	50	8.3	2	0.3	52	8.6
Port Nellie Juan	299	14	0.3	3.4 (7.5)	158	48	274	93	7	2.4	10	3.4	4	1.4	14	4.8
Perry Island	398	18	3.2	9.5 (21)	432	53	319	81	13	3.3	60	15	3	0.8	63	16
Jackpot Island	699	32	5.4	13 (29)	572	104	638	91	52	7.4	9	1.3	0	0	9	1.3

Table 7. Analysis of variance of the spot shrimp catch (no./pot) and catch weight (kg/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 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}		

a. Test of homogeneity of variances.

Table 8. 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 9. Analysis of covariance of the fecundity of female spot shrimp at nine sites[a] in western Prince William Sound in 1999.

Source of Variation	df	MS	F	P
Data transformed (log y); Levene's test[b], P = 0.012				
Carapace length	1	1.08	238	<0.001
Site	8	0.01	2.455	0.016
Error	146	0.004		

a. Includes all sites where the number of shrimp for which fecundity estimates were made exceeded three.
b. Test of homogeneity of variances.

Table 10. Analysis of variance of the depth, temperature and salinity of 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.

Source of Variation	*df*	MS	F	P
Depth				
Data untransformed; Levene's test[b], P = 0.834				
Sex	1	7772	10.5	0.004
Error	22	743		
Temperature (°C)				
Data transformed (log y); Levene's test[b], P = 0.094				
Sex	1	0.026	4.556	0.048
Error	17	0.006		
Salinity (PSU)				
Data transformed (log y); Levene's test[b], P = 0.01				
Sex	1	2.5×10^{-4}	6.133	0.024
Error	17	4.0×10^{-5}		

a. Male includes transitional and nonovigerous female shrimp.
b. Test of homogeneity of variances.

Table 11. 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.

		Catch (no./pot)		Juveniles		Males		Transitional		Ovigerous Females		Nonovigerous Females		All Females	
Site	No. Shrimp	Mean	SE	Total No.	%	Total No.	%	Total No.	%	Total No.	%	Total No.	%	Total No.	%
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 12. Analysis of variance of the mean number of spot shrimp/pot and mean 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 Spot Shrimp				
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 of Spot Shrimp				
Data untransformed; Levene's test[a], P = 0.180				
Organization	1	0.124	2.983	0.100
Year	1	0.178	4.271	0.052
Organization x Year	1	0.069	1.649	0.214
Error	20	0.042		

a. Test of homogeneity of variances.

Table 13. Analysis of variance of the mean number of spot shrimp/pot and mean 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 Spot Shrimp				
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 of Spot Shrimp				
Data transformed (log y); Levene's test[a], P = 0.004				
Organization	1	0.011	0.057	0.813
Year	1	0.838	4.520	0.040
Organization x Year	1	0.078	0.418	0.522
Error	36	0.185		

a. Test of homogeneity of variances.

Table 14. 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.

						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)	1625	12	1397	86	30.6	170	10	43.7
2000A[2]	132	67.4 (148)	0.51 (1.1)	3612	27	2983	83	29.2	341	9	44.2
1999B[3]	132	49.4 (109)	0.36 (0.8)	2211	15	1611	73	28.5	438	20	43.6
2000B[3]	132	49.5 (109)	0.38 (0.8)	2466	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

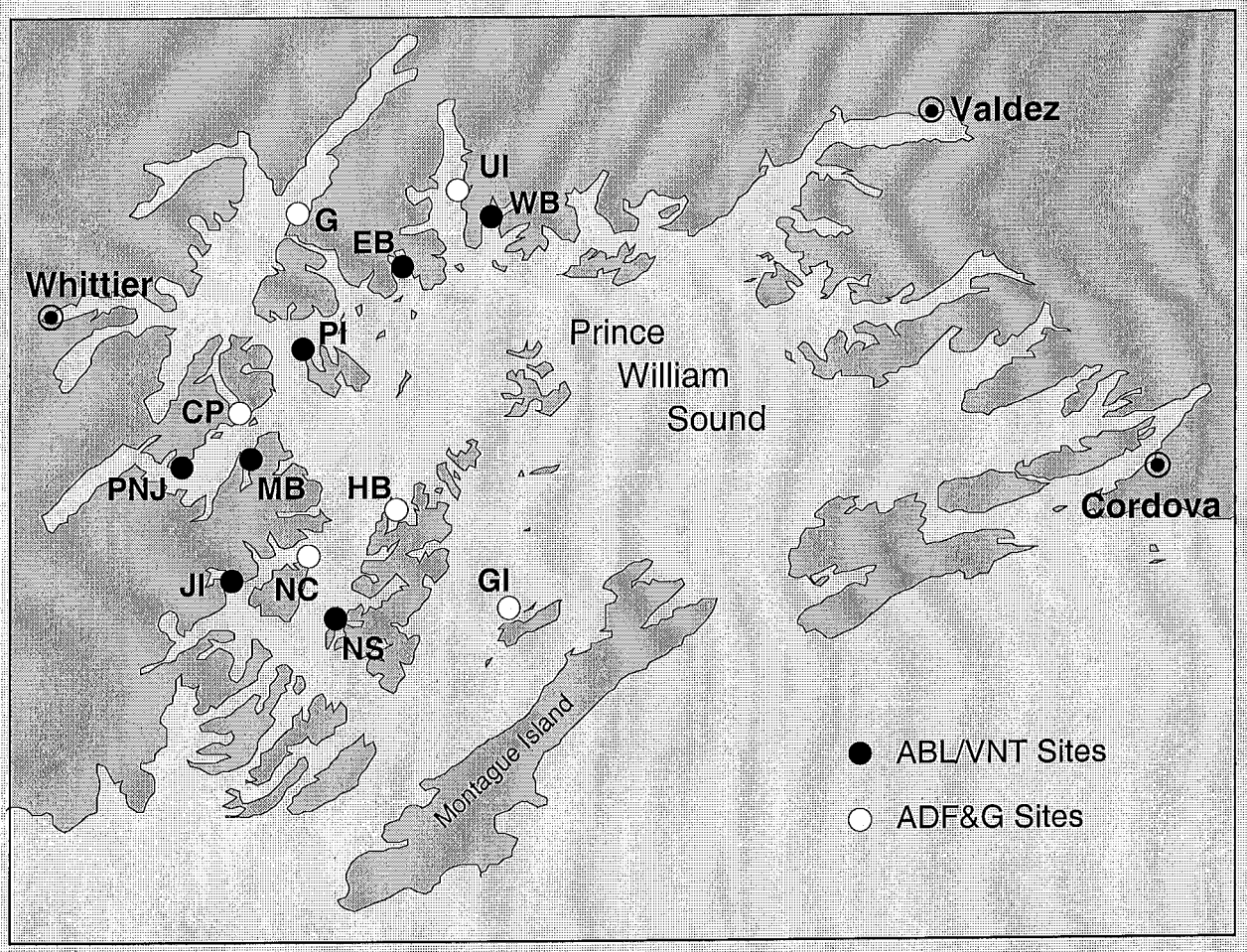


Figure 1. Location of spot shrimp study sites in Prince William Sound. The ADF&G sites are those traditionally sampled during the ADF&G annual survey. The Auke Bay Lab/Valdez Native Tribe (ABL/VNT) sites were added in October 1999. Site abbreviations are: CP, Culross Passage; EB, Eaglek Bay; G, Golden; GI, Green Island; HB, Herring Bay; JB, Jackpot Island; MB, McClure Bay; NCI, North Chenega Island; PI, Perry Island; PNJ, Port Nellie Juan; UI, Unakwik Inlet; WB, Wells Bay. The North Squire Island (NS) site was substituted for Eaglek Bay in 2000.

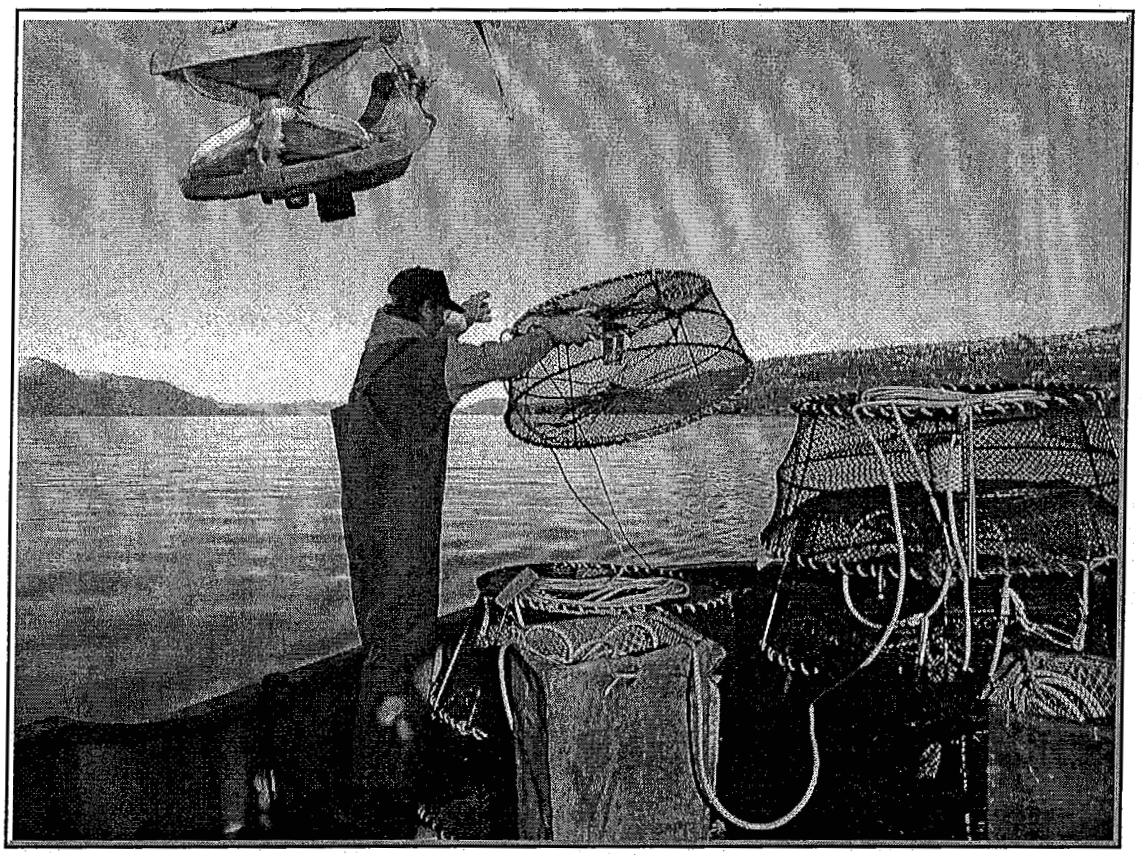


Figure 2. Setting shrimp pots at spot shrimp study sites in Prince William Sound.

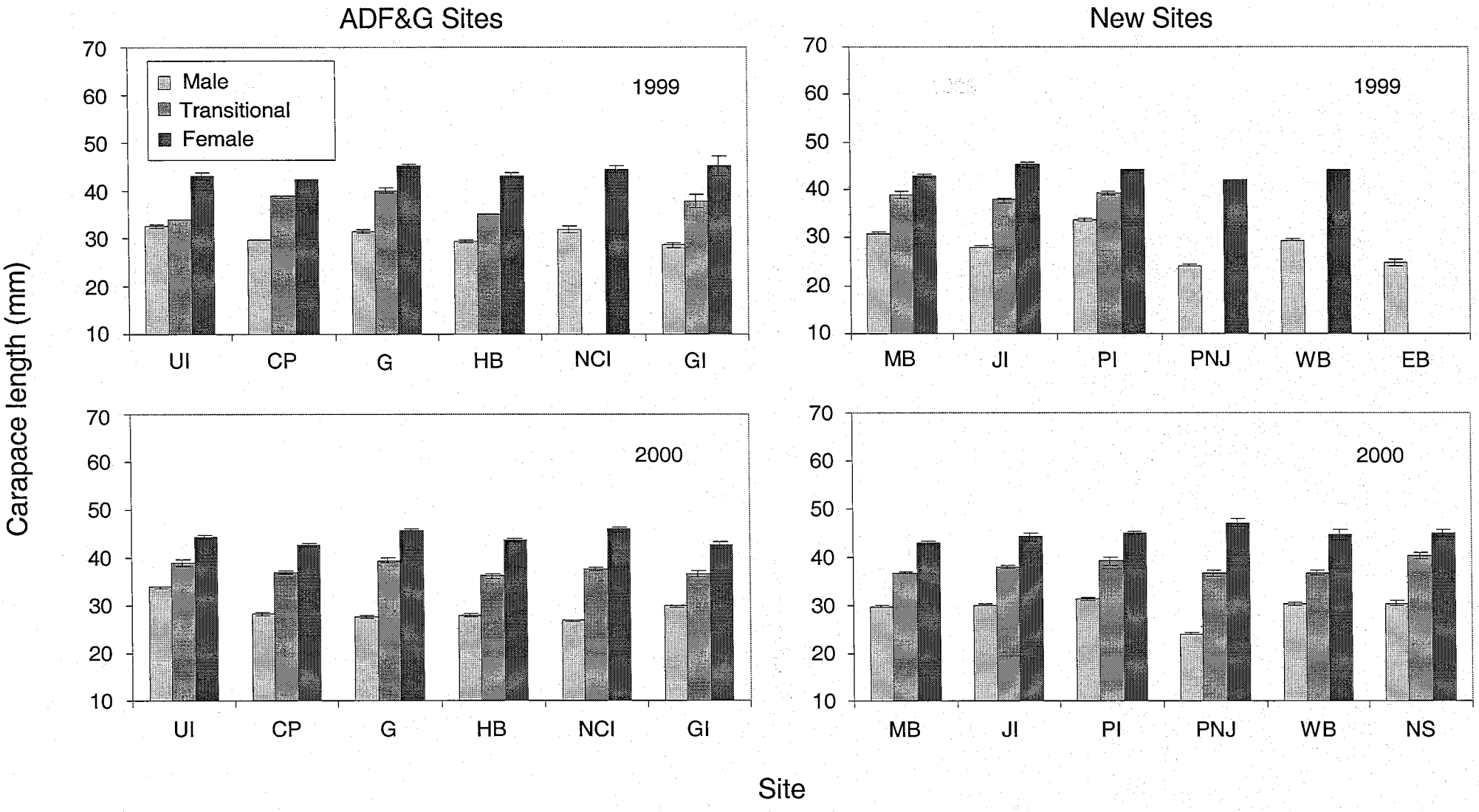


Figure 3. Mean carapace length of male, transitional and female spot shrimp at 12 sites in western Prince William Sound in October 1999 and 2000. Missing bars indicate that no shrimp of the appropriate life stage were caught at the site. Error bars are one standard error of the mean. Site abbreviations 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.

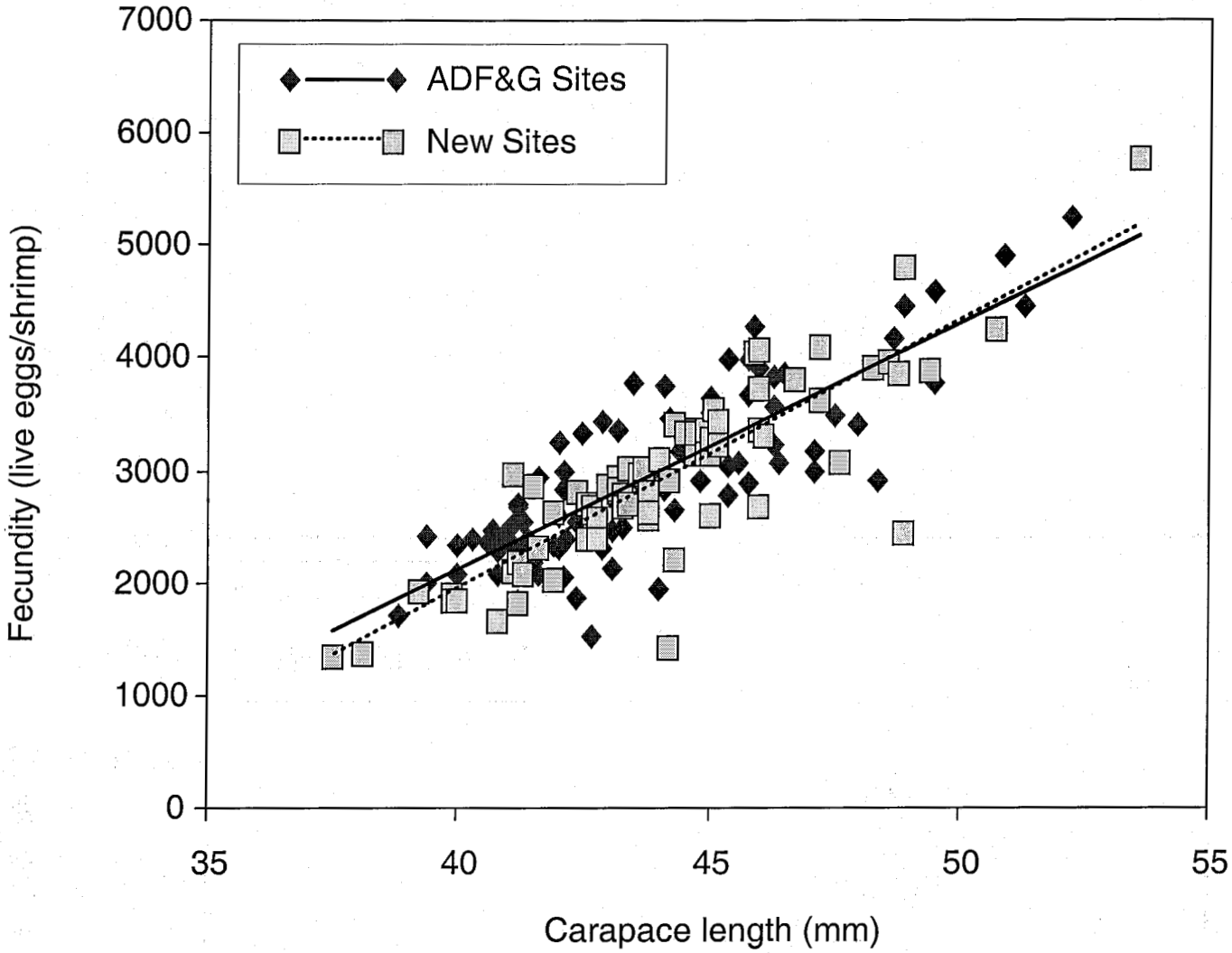


Figure 4. Relationship of fecundity to carapace length at traditional Alaska Department of Fish and Game sites and new sites (five sites each) in western Prince William Sound in 1999.

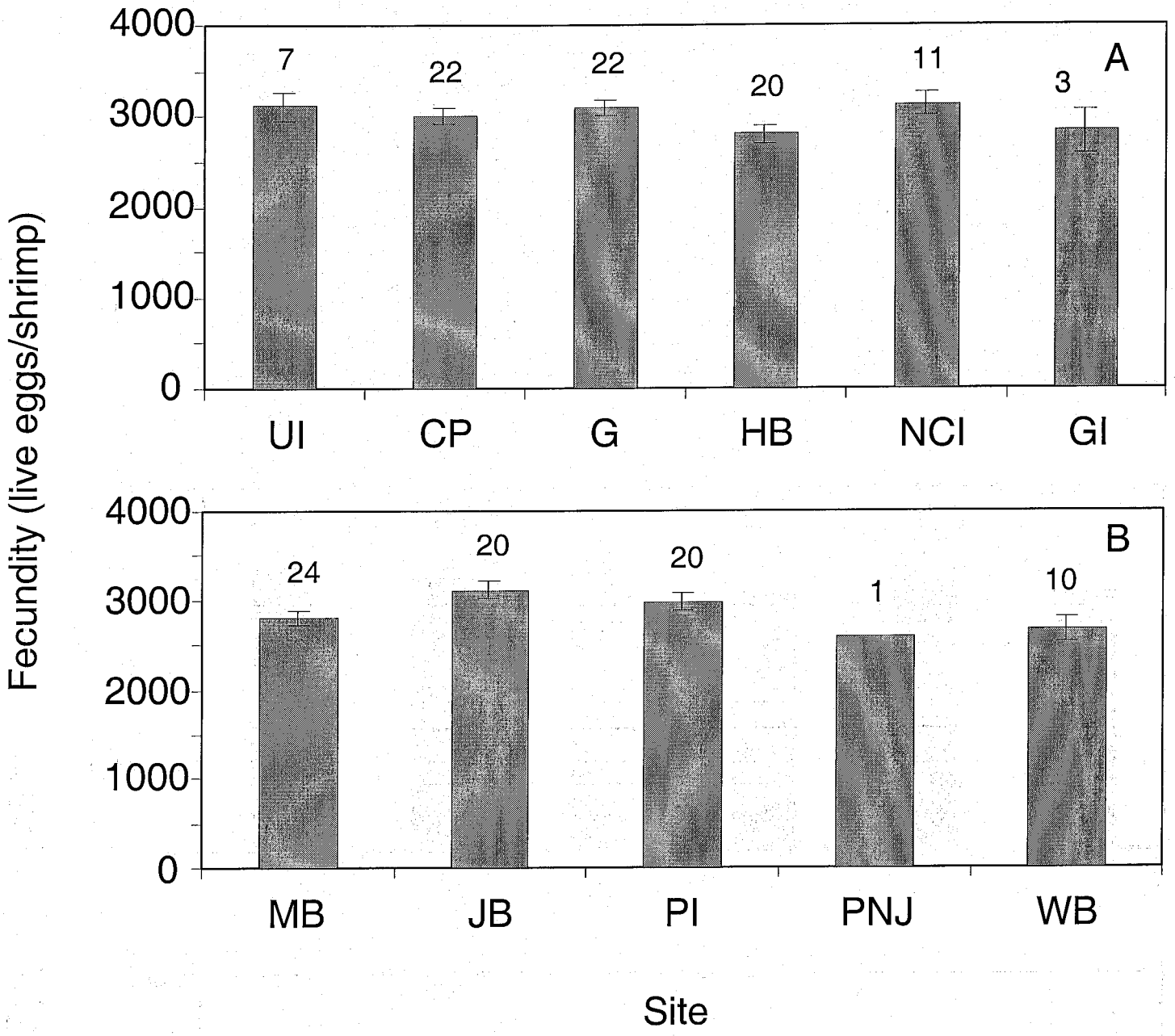


Figure 5. Adjusted mean fecundity (covariate, carapace length) of spot shrimp caught at six sites (A) traditionally sampled in the Alaska Department of Fish and Game annual survey and five new sites (B) in Prince William Sound in 1999. Means evaluated at carapace length = 44 mm. Numbers above the bars are the number of egg clutches used to estimate fecundity. 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.

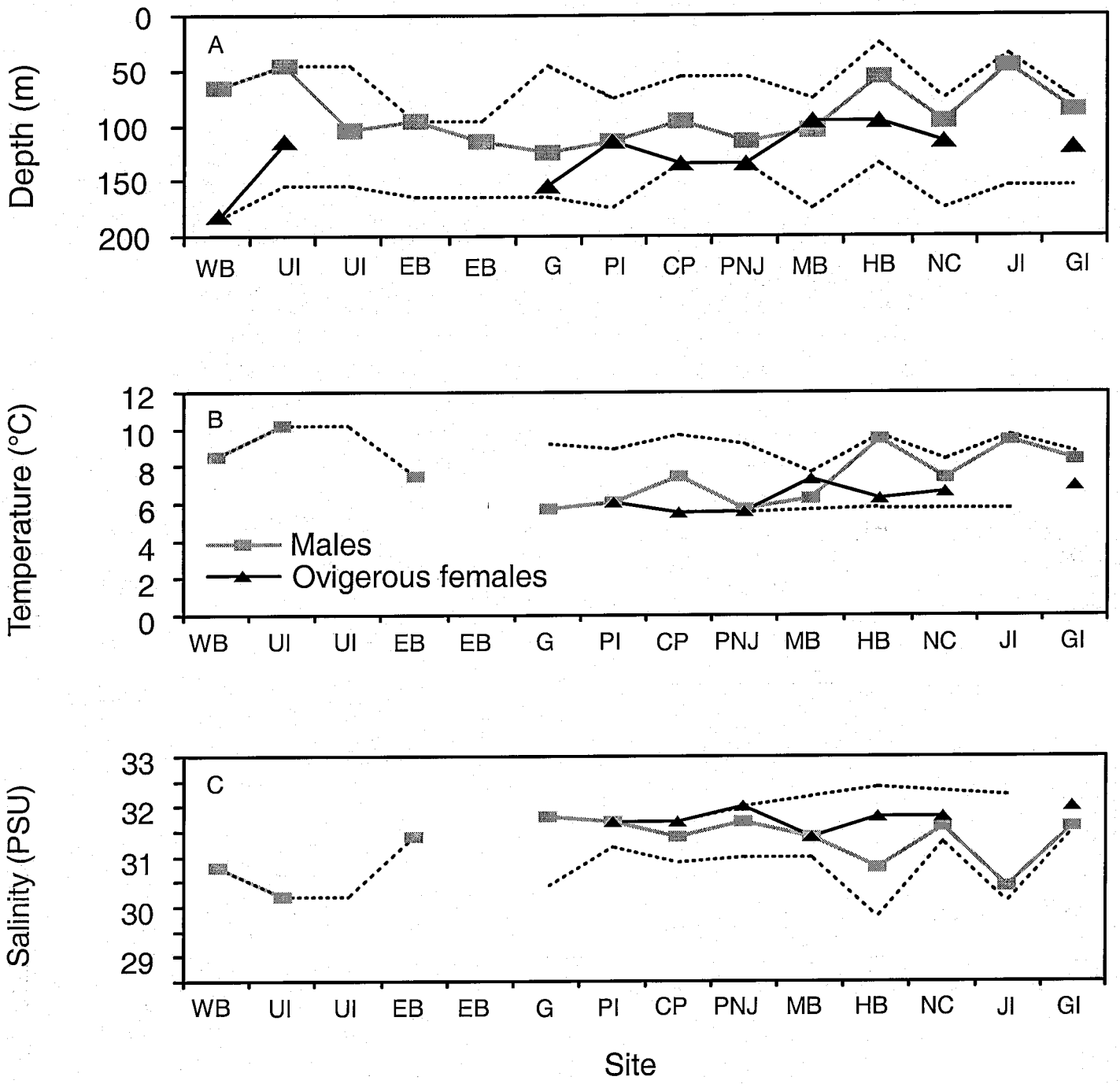


Figure 6. Mean depth (A), temperature (B) and salinity (C) of the modal CPUE in the distribution of spot shrimp with depth at 12 sites in western Prince William Sound in 1999. "Males" and ovigerous females are plotted separately. "Males" includes transitional, and nonovigerous female shrimp. Dashed lines 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.

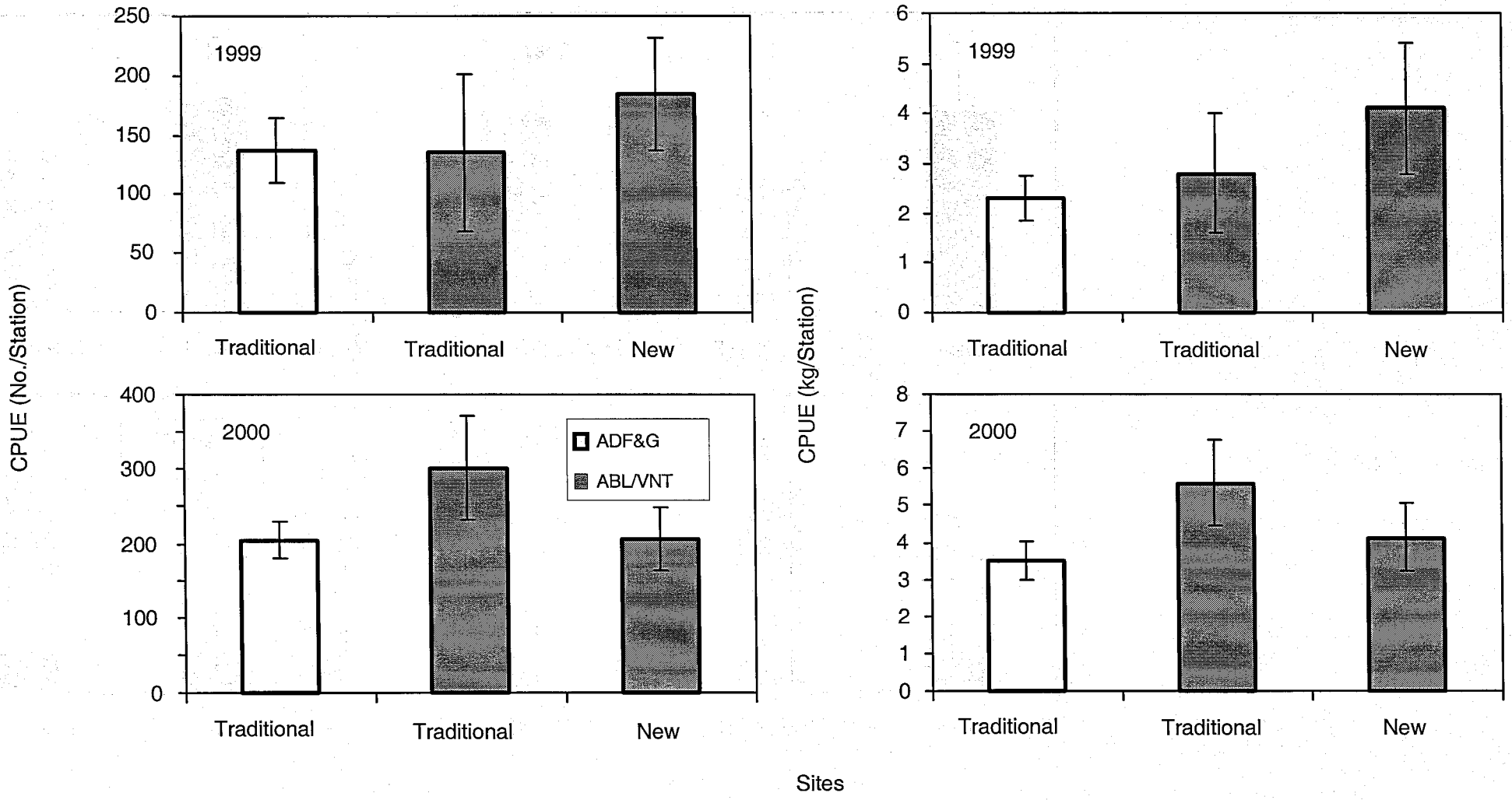


Figure 7. Catch (CPUE) expressed as no. per station (A) and as weight per station (B) of spot shrimp at Alaska Department of Fish and Game (ADF&G) traditional sites during the ADF&G annual survey in western Prince William Sound (WPWS) in October 1999 and 2000 compared with the CPUE at ADF&G traditional 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).

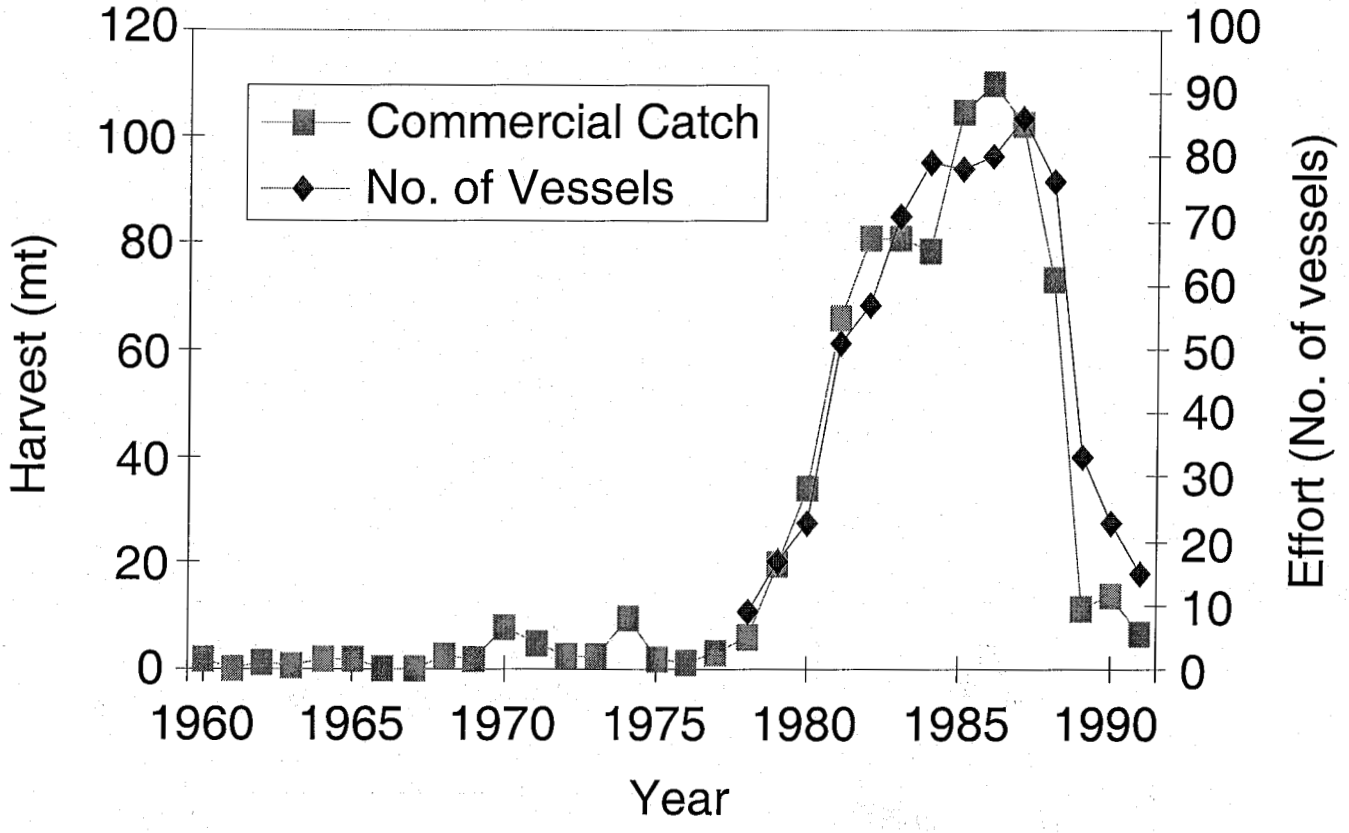


Figure 8. Commercial catch of spot shrimp and fishing effort in Prince William Sound from 1960 to 1991 [Data from Table 1 of Kimker et al. (1996)].

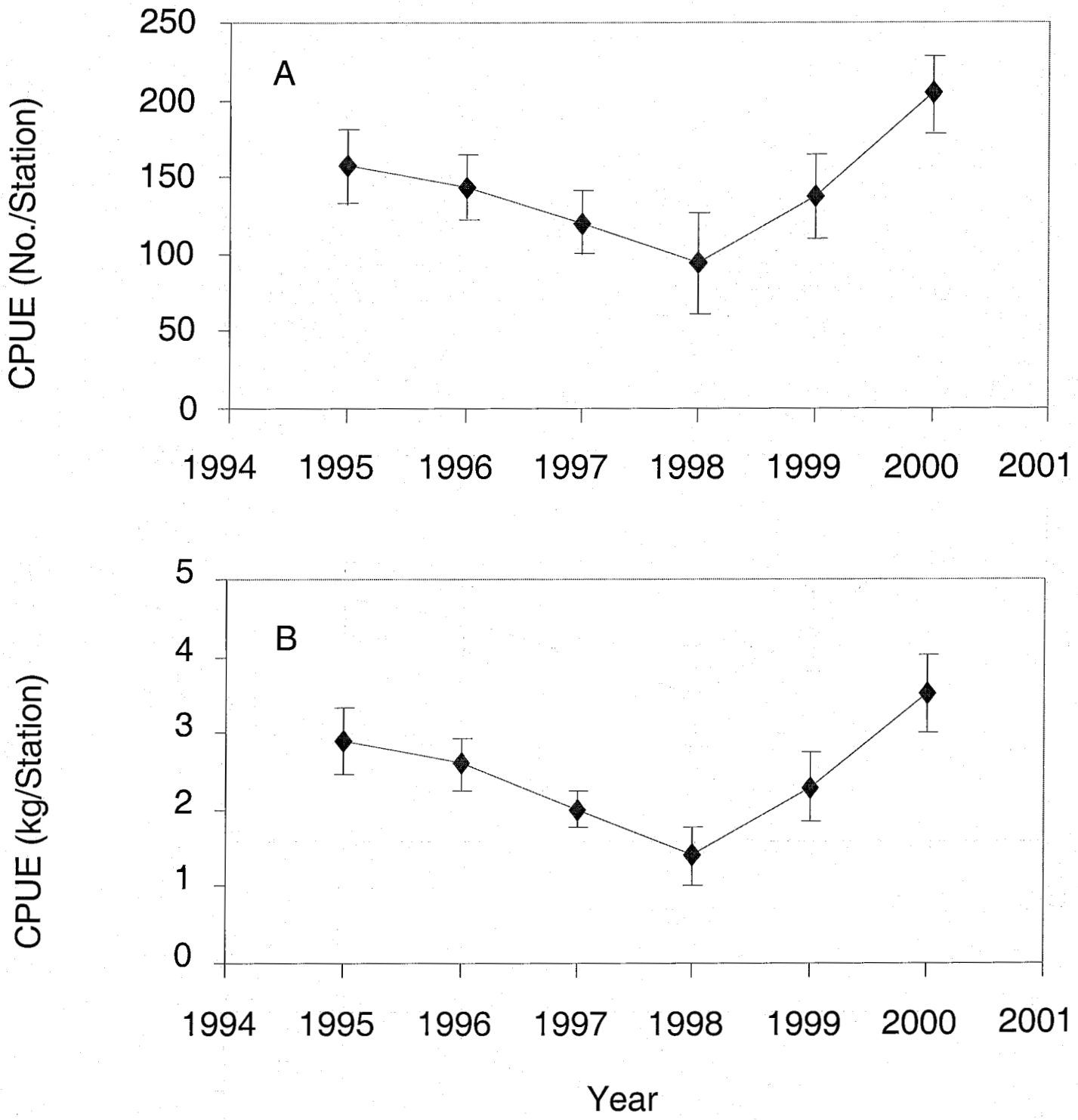
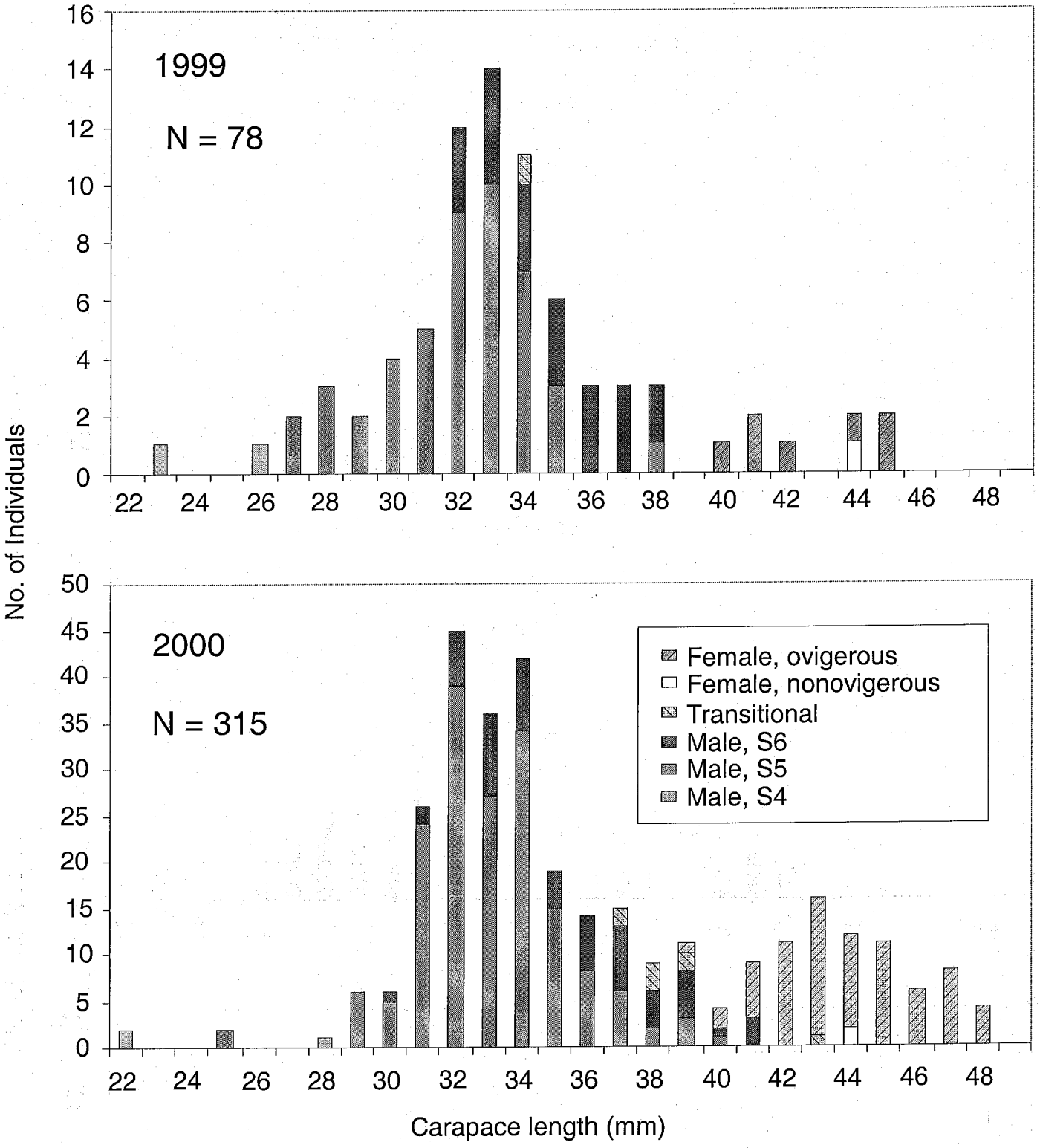


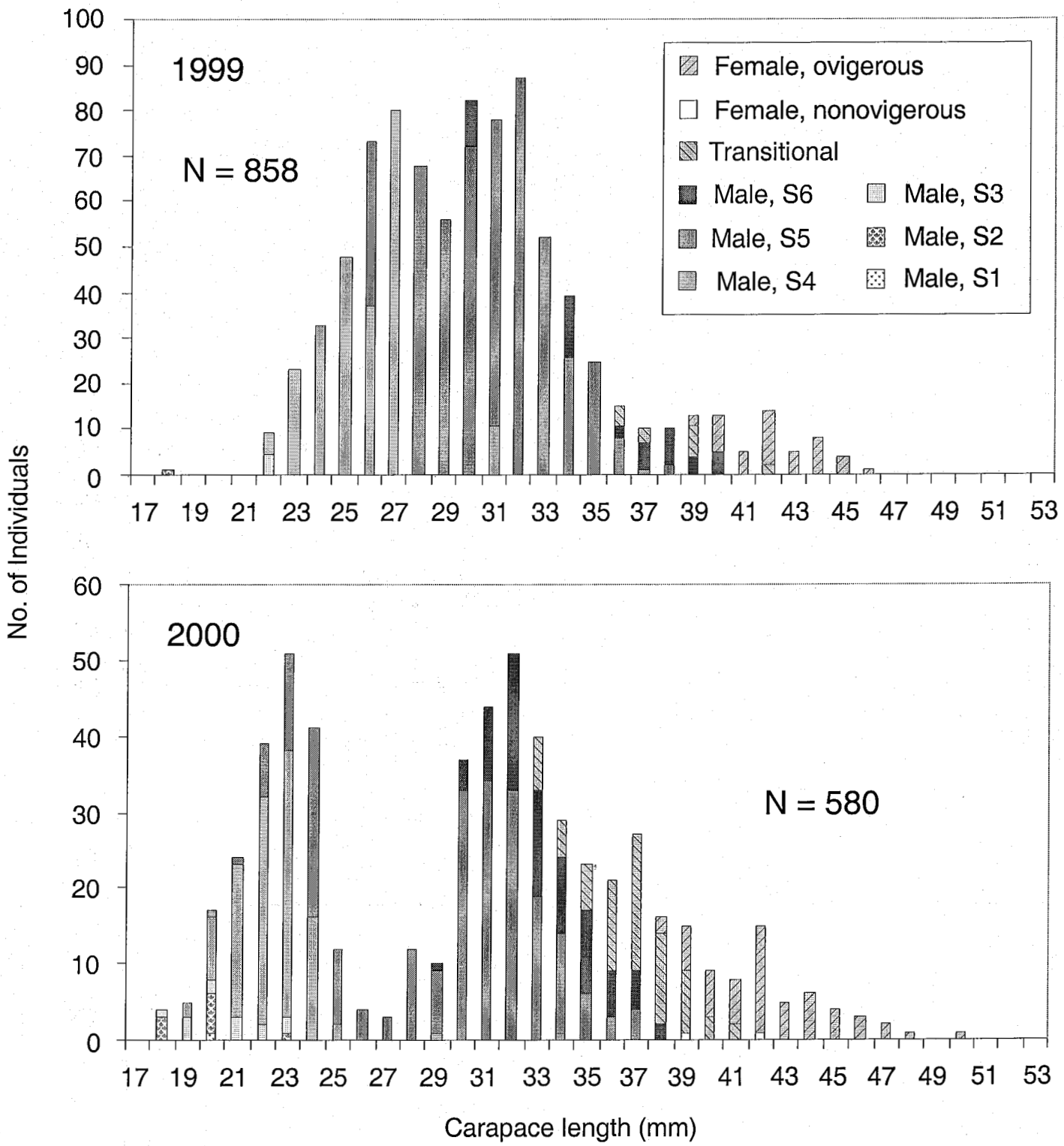
Figure 9. Mean catch per station (CPUE) of spot shrimp at sites traditionally sampled by the Alaska Department of Fish and Game (ADF&G) during ADF&G annual surveys in western Prince William Sound from 1995 to 2000. Error bars are one standard error of the mean. (Data provided by J. Brady and R. Berceli, ADF&G).

APPENDICES

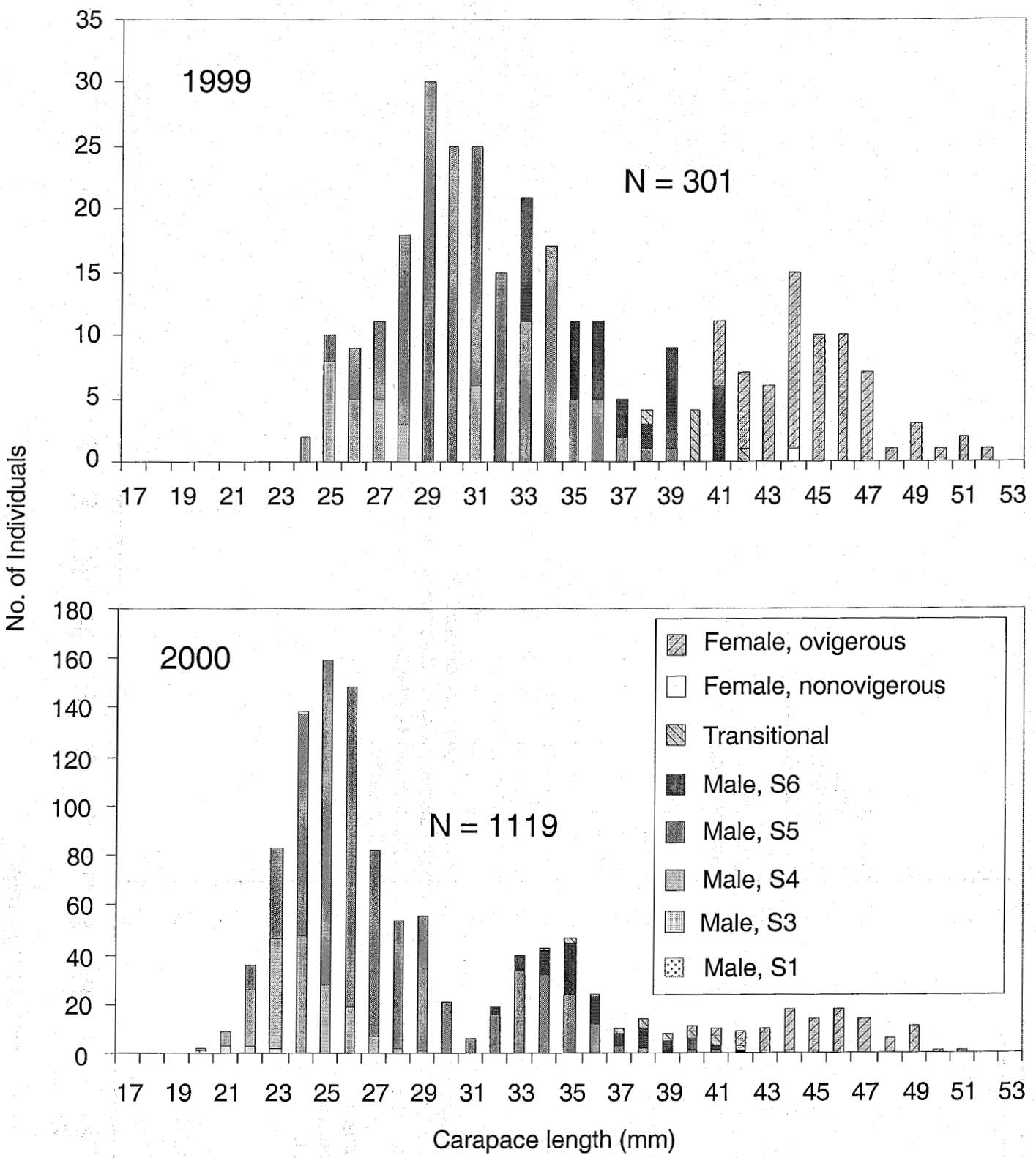
APPENDIX CONTENTS



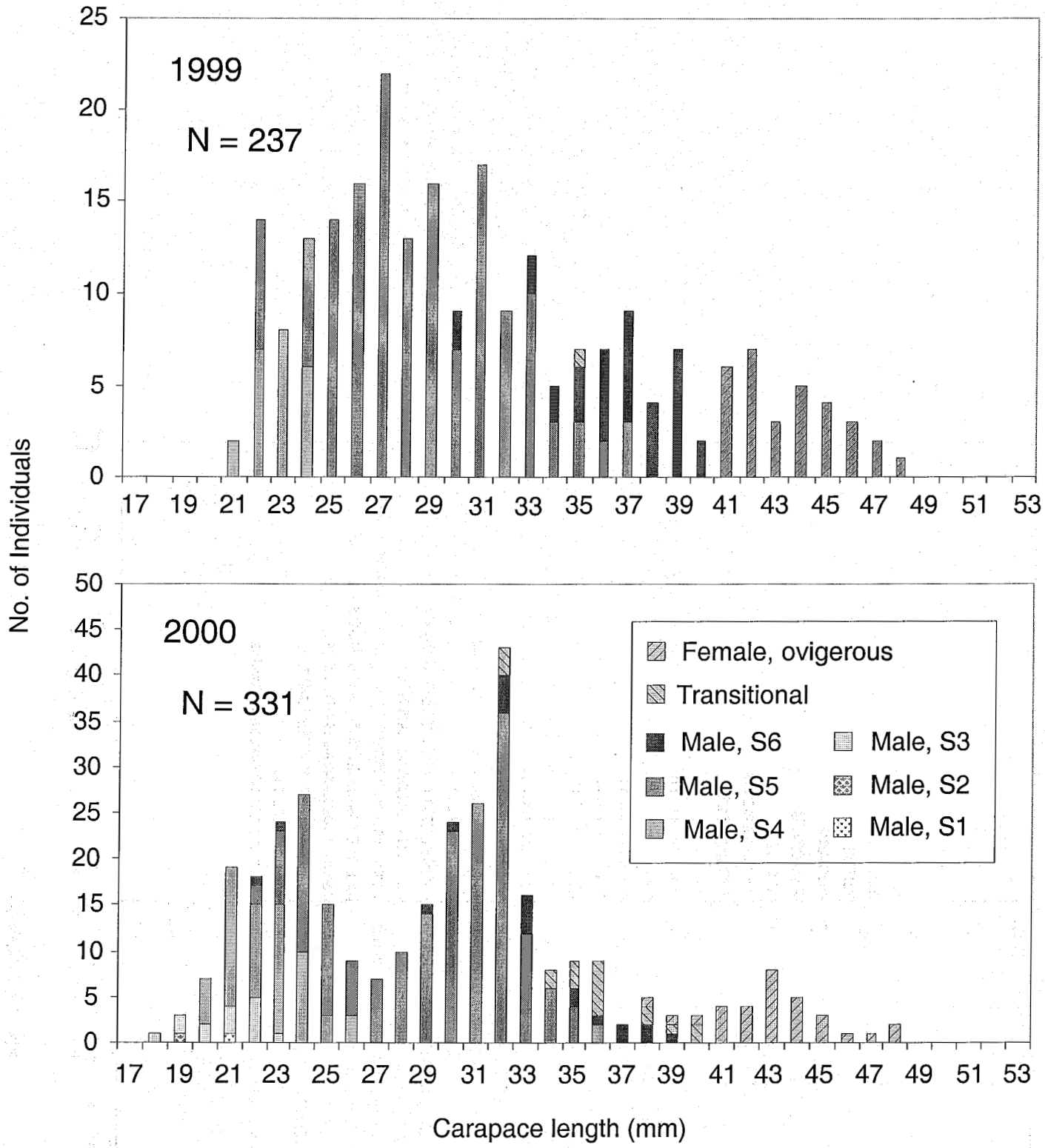
Appendix 1.1 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Unakwik Inlet, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



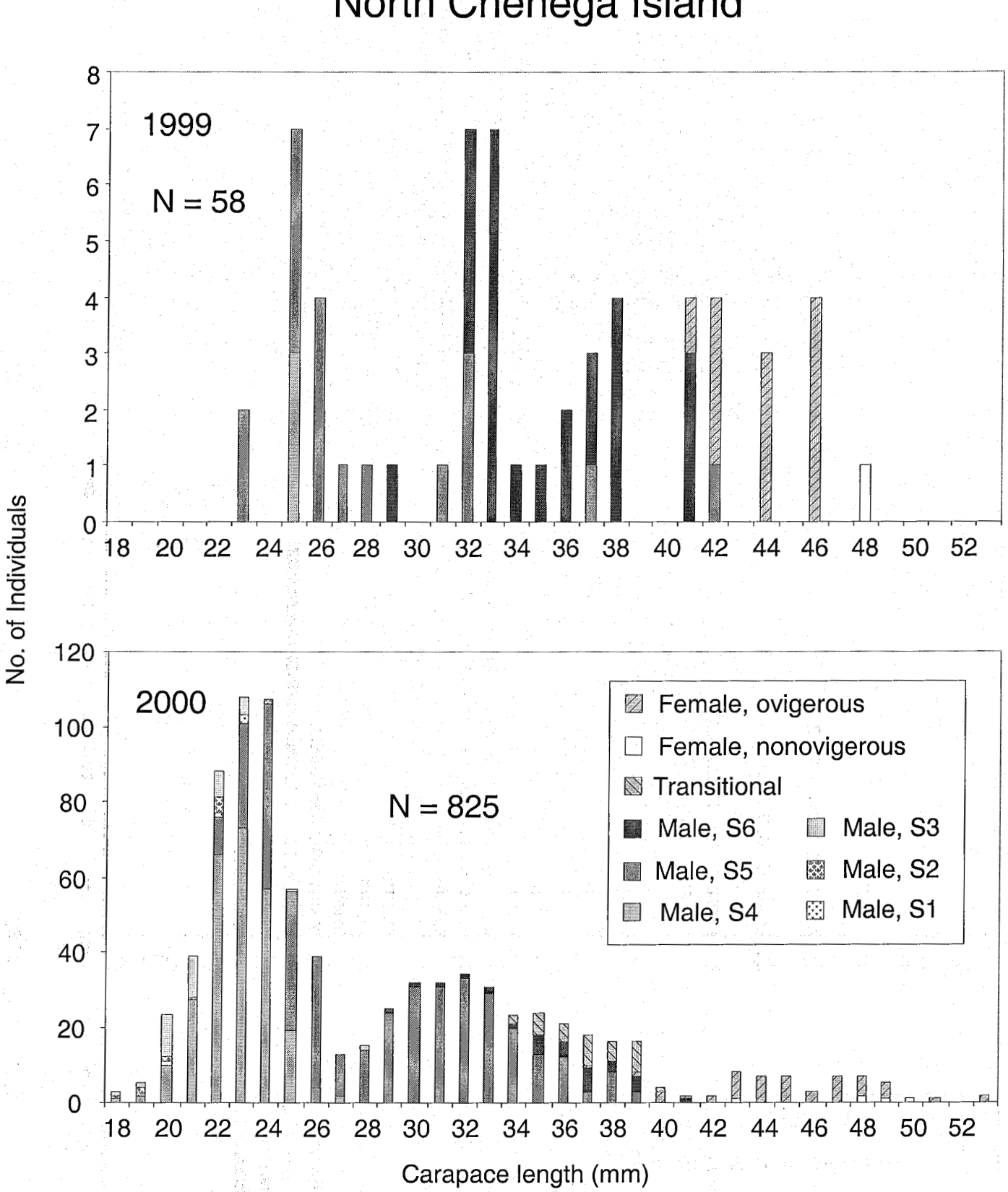
Appendix 1.2 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Culross Passage, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



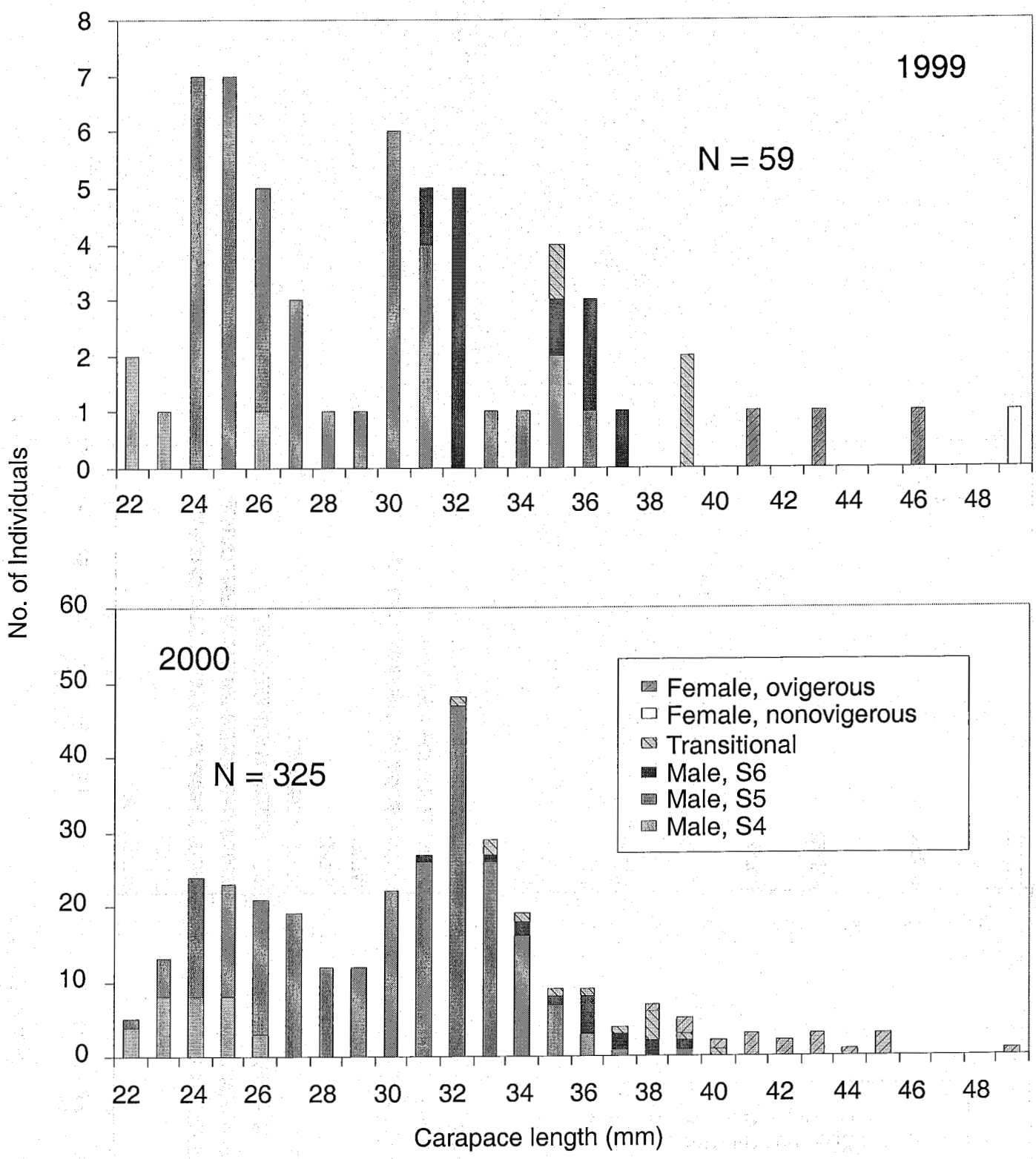
Appendix 1.3 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Golden, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



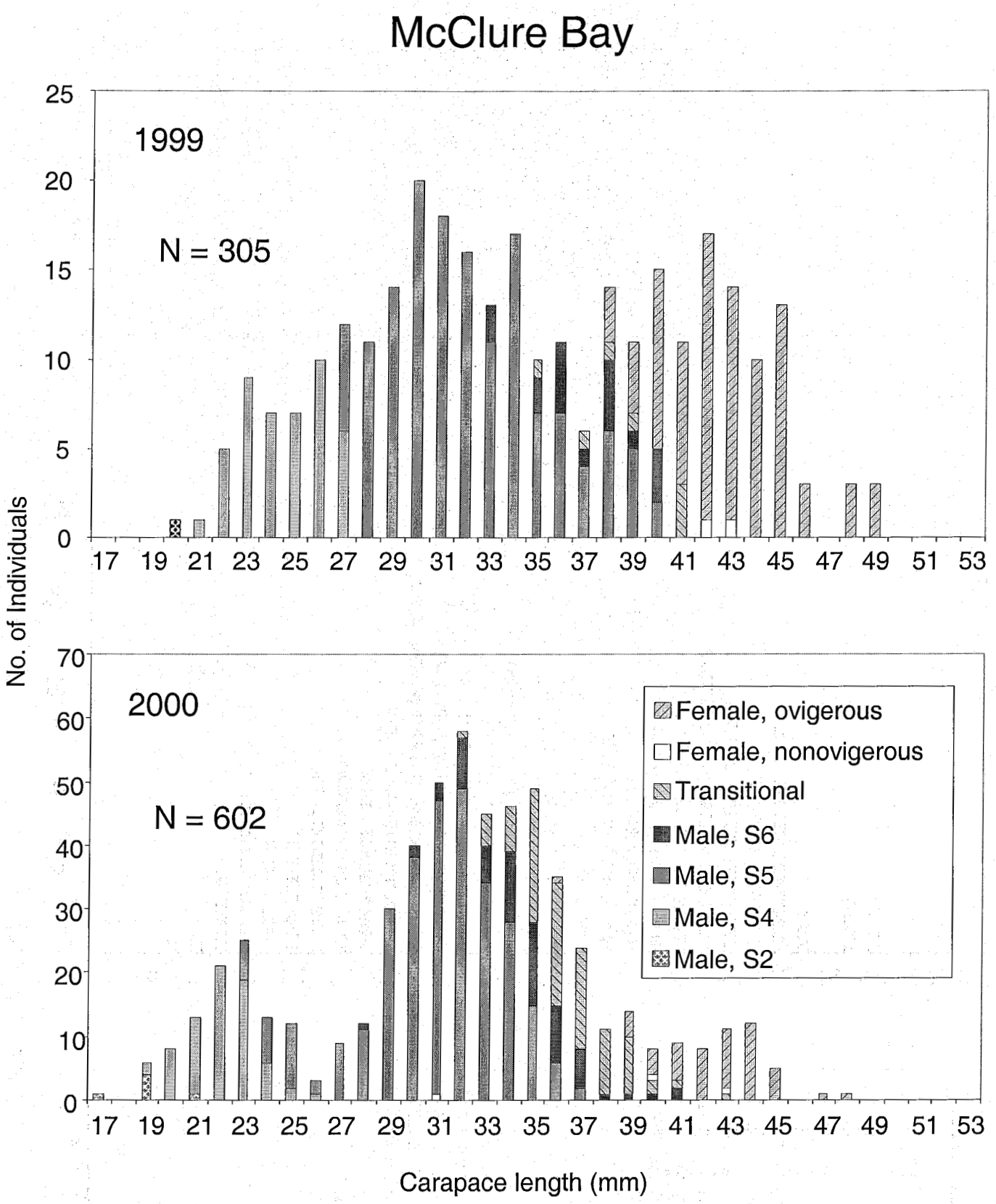
Appendix 1.4 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Herring Bay, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



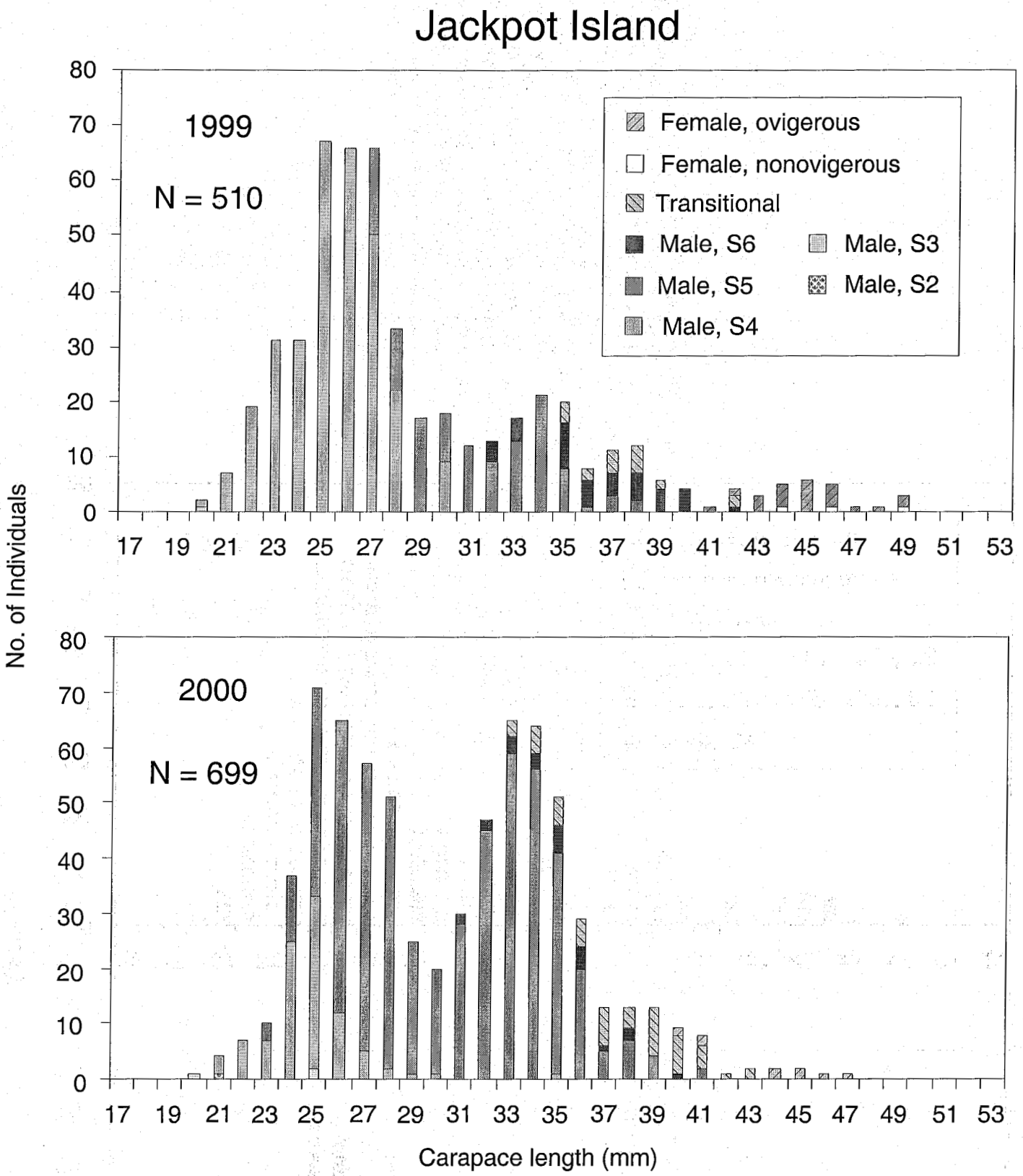
Appendix 1.5 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at North Chenega Island, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



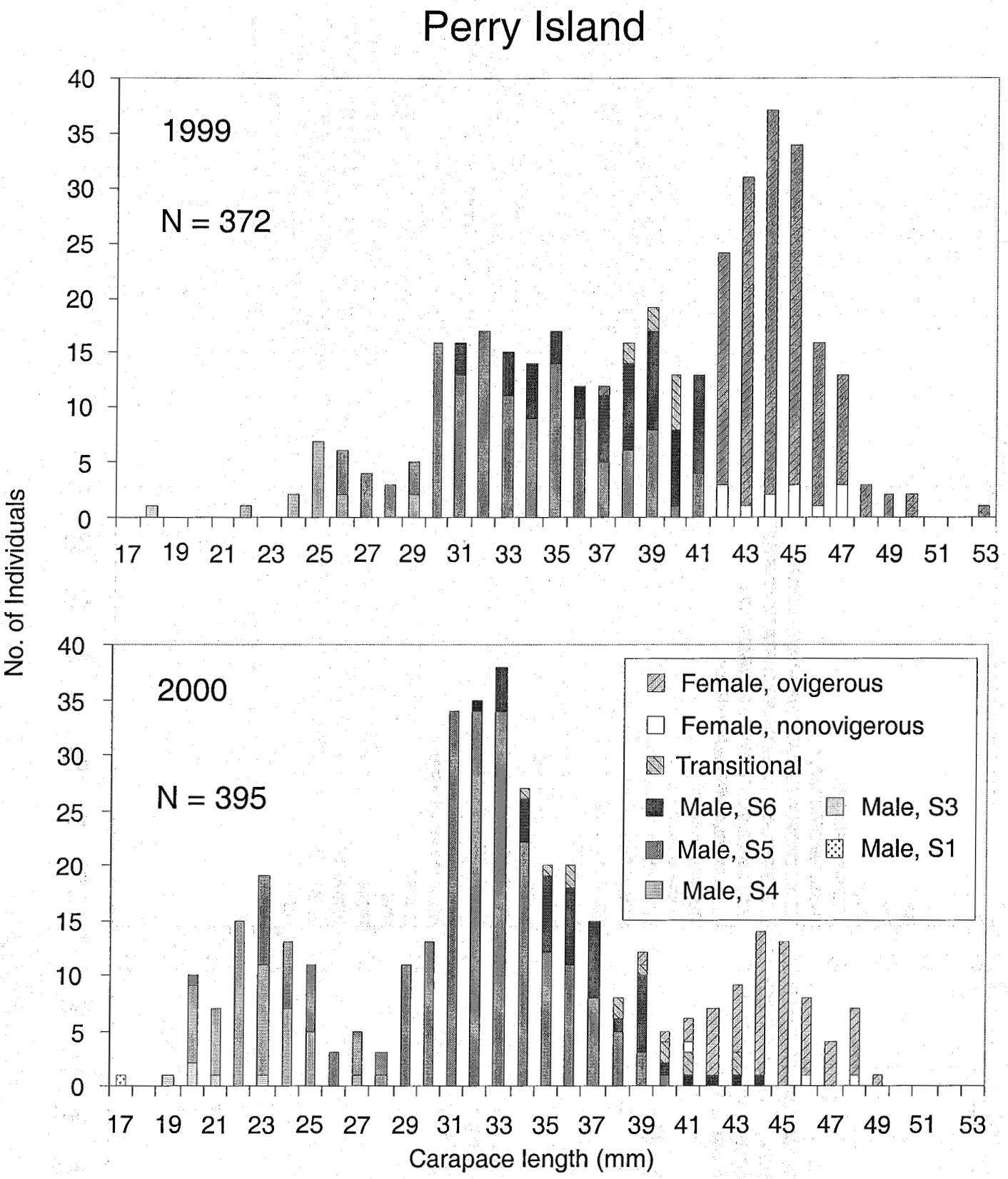
Appendix 1.6 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Green Island, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



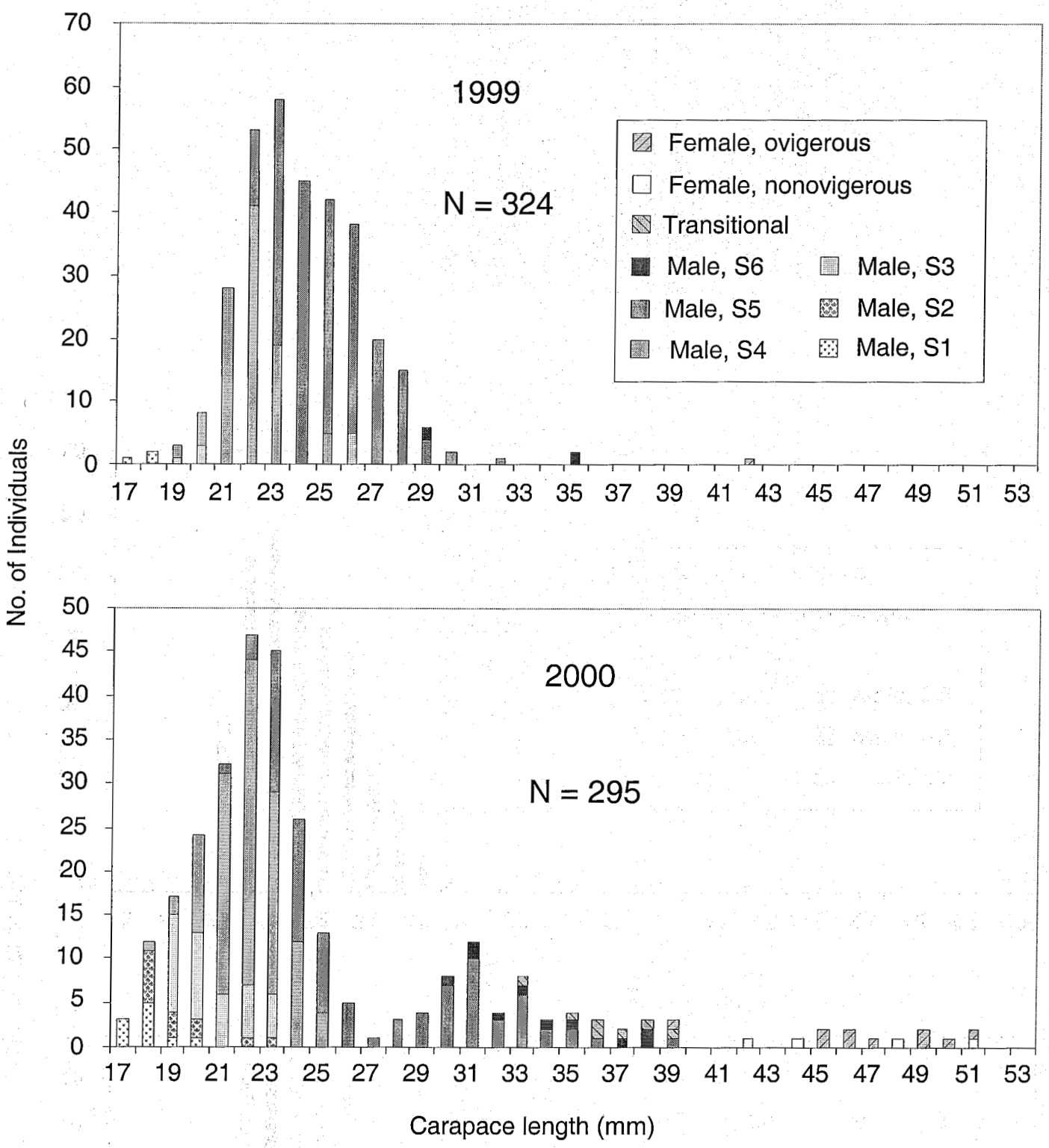
Appendix 1.7 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at McClure Bay, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



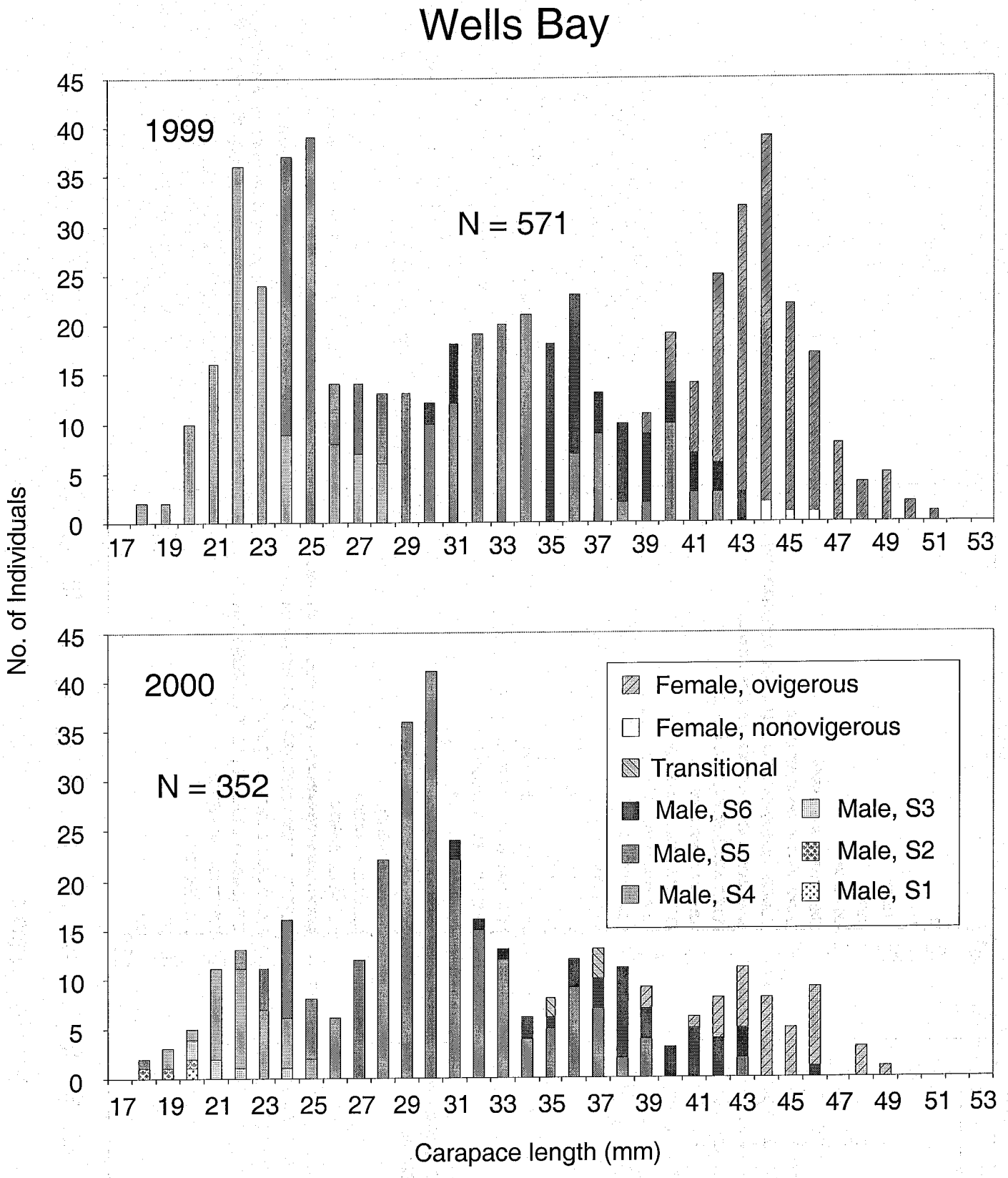
Appendix 1.8 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Jackpot Island, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



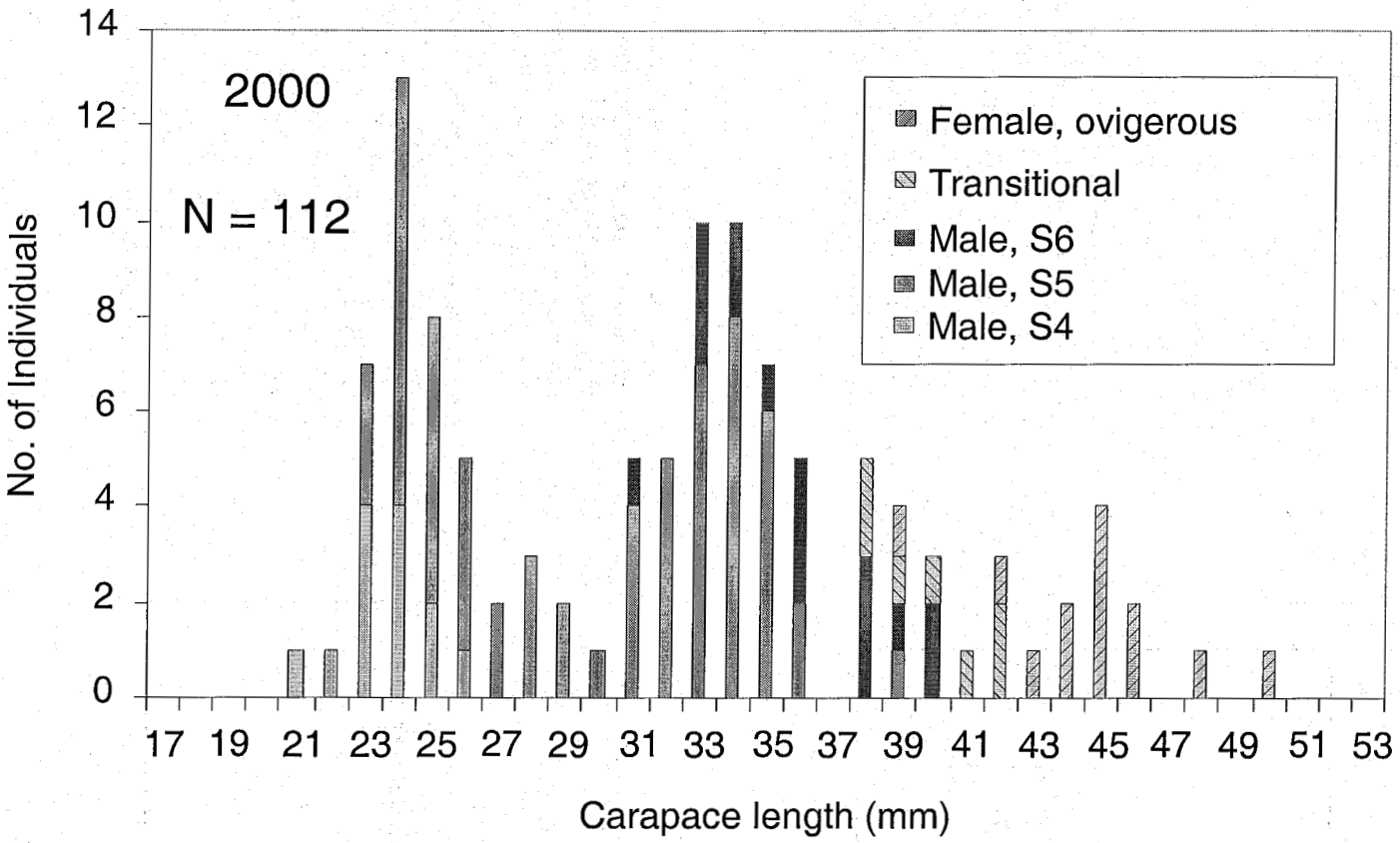
Appendix 1.9 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Perry Island, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



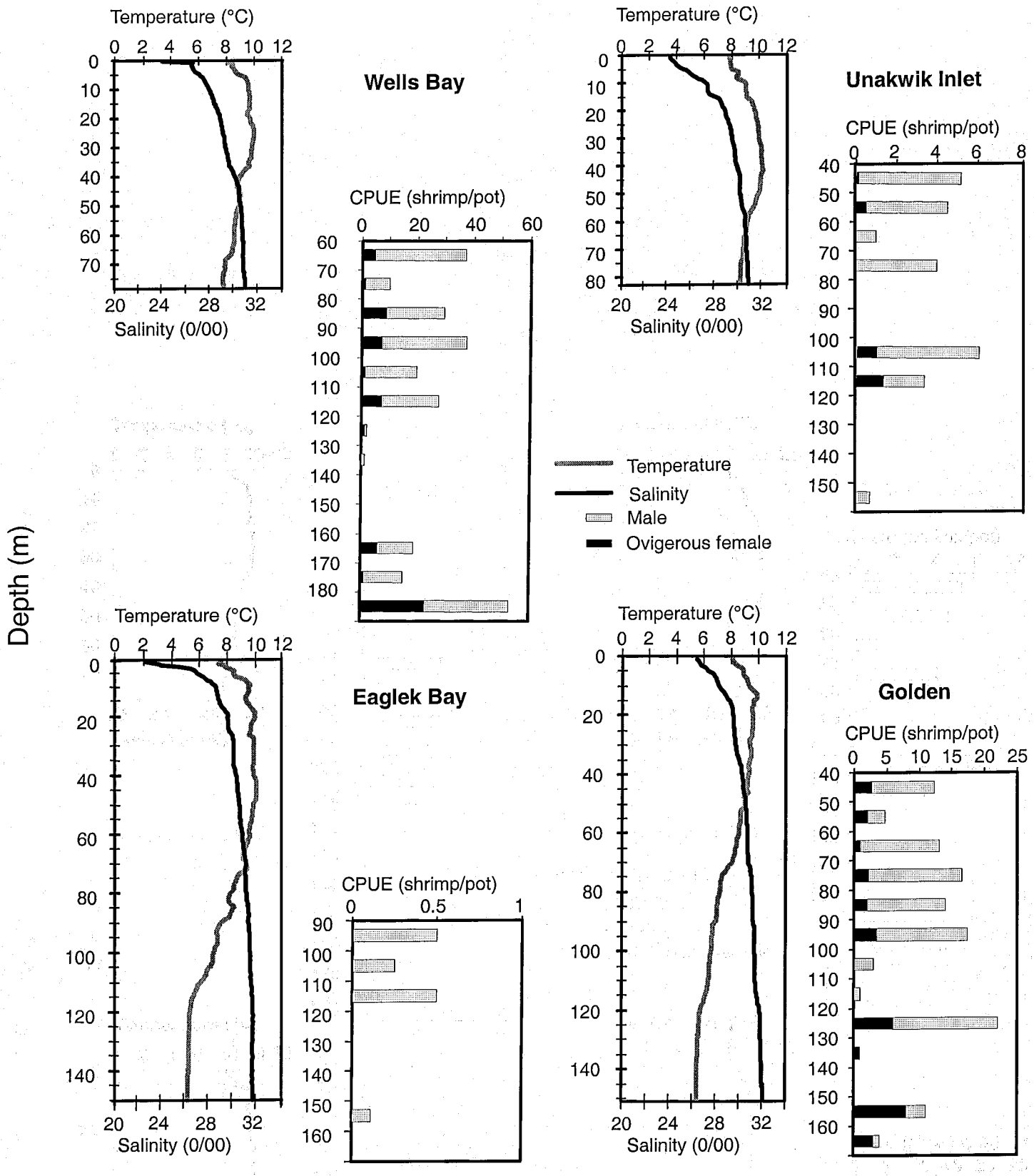
Appendix 1.10 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Port Nellie Juan, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



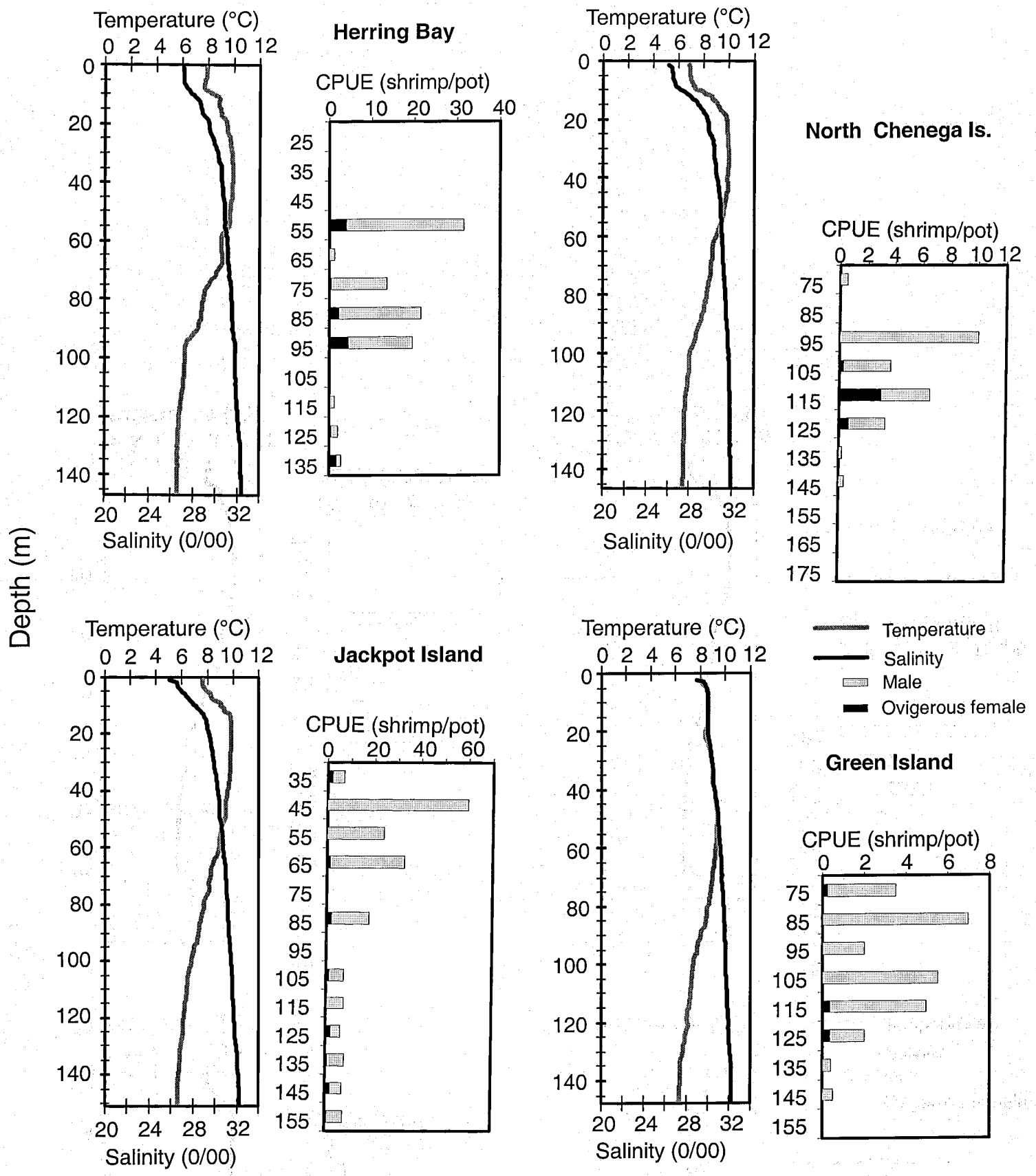
Appendix 1.11 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at Wells Bay, Prince William Sound in October 1999 and 2000. N = number of spot shrimp measured.



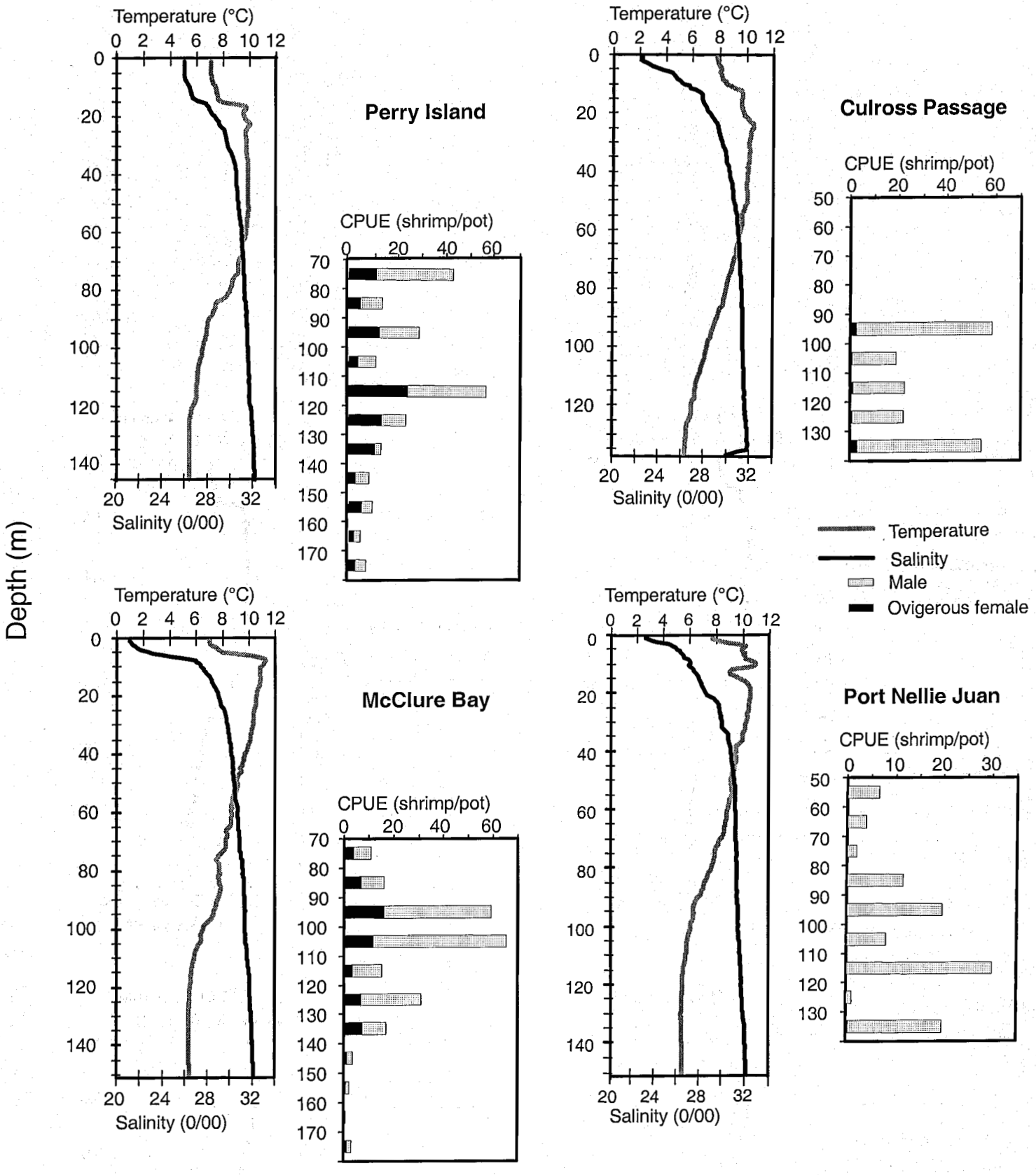
Appendix 1.12 Carapace length-frequency distributions of spot shrimp by sex, female reproductive condition and male stage from pot catches at North Squire Island, Prince William Sound in October 2000. N = number of spot shrimp measured.



Appendix 2.1 Water temperature and salinity profiles (left panel of each pair) and spot shrimp distribution with depth at Wells Bay, Unakwik Inlet, Eaglek Bay, and Golden, Prince William Sound in October 1999. CPUE = catch per unit effort.



Appendix 2.2 Water temperature and salinity profiles (left panel of each pair) and spot shrimp distribution with depth at Herring Bay, North Chenega Island, Jackpot Island, and Green Island, Prince William Sound in October 1999. CPUE = catch per unit effort.



Appendix 2.3 Water temperature and salinity profiles (left panel of each pair) and spot shrimp distribution with depth at Perry Island, Culross Passage, McClure Bay, and Port Nellie Juan, Prince William Sound in October 1999. CPUE = catch per unit effort.