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Estimates of Age, Growth, and Mortality of an Alaskan Stock of *Pandalus borealis* Kröyer

by

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ABSTRACT

Northern shrimp, *Pandalus borealis* carapace length-frequency data collected from shrimp surveys and commercial catches between 1972 and 1989 were studied to estimate age, growth, and mortality in Pavlof Bay, Alaska. Dominant size modes representing 1971 and 1975 year-classes were separated from carapace length-frequency distributions by the use of a maximum likelihood mode separation technique. The average growth rate for the 1975 year-class was significantly greater than that of the 1971 year-class. An inverse relationship of growth to within year-class strength was suggested, since the numerical abundance of the 1975 year-class was lower than that of the 1971 year-class. Age at sex transition appears to be related to year-class abundance or overall density since 1975 year-class shrimp completed transition at a younger age than that of 1971. Increases in natural mortality occurred after the 1971 year-class completed transformation to the female sex at age 6.4; and may indicate a combination of spawning stress and senescence or increasing abundance of the predator *Gadus macrocephalus*. A series of unsubstantial year-classes followed after 1979 exhibited much faster growth and higher ranging mortality rates.

INTRODUCTION

The Pavlof Bay (Fig. 1) population of *Pandalus borealis*, in the western Gulf of Alaska, was chosen for this study because it supported a major fishery and an extensive data base was available. The bay was a major producer accounting for over 13,000 mt of Pandalid landings in 1976 alone (Fig. 2). *Pandalus borealis*, made up anywhere from 11 to 97% of landings with variable quantities of *P. goniurus*, *P. hypsinotus*, and *Pandalopsis dispar* making up the remainder. Pavlof Bay shrimp populations have been surveyed annually by the National Marine Fisheries Service (NMFS) since 1972. Data collected from these surveys included carapace length-frequencies by sex and abundance estimates. The Alaska Department of Fish and Game (ADFG) has collected species and size composition data from commercial landings since the beginning of the fishery in 1968.

The *P. borealis* population in Pavlof Bay has been managed as a discrete stock by the ADFG. Vertical migrations, in concert with ocean currents, may act as a dispersal mechanism for pandalids (Barr,1970; Gotshall, 1972; Percy, 1970). But, in Pavlof Bay effects of ocean currents probably are minimized by barrier islands and shallow entrances which favor confinement and limit immigration (Fig. 1).

Since there are no known anatomical structures for aging *P. borealis*, researchers have used length-frequency analysis to estimate age and growth. For example, Rasmussen (1953) used dominant year-class modes to interpret growth and sex transformation of *P. borealis* in Norwegian stocks; and, Skúladóttir (1981) used the positive deviations from long term length-frequency distributions to identify average lengths-at-age for *P. borealis* from Icelandic fjords.

Dominant size modes representing year-classes were separated from the Pavlof Bay length-frequency distributions using the maximum likelihood technique of MacDonald and Pitcher (1979). Annually, calculated mean lengths and numerical abundance of year-classes were then used to estimate growth and mortality using methods similar to those of Fréchette and LaBonte (1981) and Anderson (1981). The present study expands on previous work by using modal analysis of length-frequencies from commercial catches to estimate fishing and natural mortality rates. Results from these analyses were used to examine year-class specific growth, mortality, and rates of sex transformation.

MATERIALS AND METHODS

Pavlof Bay was surveyed annually from 1972 to 1989 by trawling at randomly selected stations during August to mid- September (Table 1). During these months dense aggregations of *P. borealis* form in relatively deep water. Also, female growth slows because they molt into "breeding dress" in late summer and do not molt again until completion of the spring egg hatch (Allen, 1959). Early surveys had shown shrimp were concentrated in depths greater than 70 m (Ronholt, 1963). As a consequence all survey tows were restricted to depths greater than 55 m (Fig. 1). Each year, when possible, 10 to 13 stations were sampled with a 30 minute tow (approximately 1.8 km) during daylight using a 32 mm mesh (32 mm mesh codend liner) high-opening shrimp trawl with a 18.6 m headrope and footrope (Wathne, 1977). The mesh size and configuration of this trawl were similar to commercial fishing gear which allowed for direct comparison between survey and commercial data.

Carapace lengths (CL) were measured to the nearest 0.5 mm (eye socket to mid-posterior carapace edge) from approximately 300 specimens of *P. borealis* selected at random from each survey tow. The shape of the endopodites on the first two pleopods (Allen, 1959) was used to separate shrimp according to sex. Length-frequency data by sex from commercial catch samples were provided courtesy of the ADFG.

Estimating the Mean Size and Abundance of Year-Classes

The total number of *P. borealis* in a survey or commercial catch was estimated for each 0.5 mm CL group as:

$$\hat{N}_{ij} = n_{ij} \frac{C_j}{w_j} \tag{1}$$

where: $\hat{N}_{ij}$ = number of *P. borealis* in the ith size interval taken in th jth haul ($i = 1....q$; $j = 1....r$);

n_{ij} = number of *P. borealis* in the ith size interval sampled from the jth haul;

C_j = weight of *P. borealis* in the jth haul; and

w_j = sampled weight in the jth haul.

Estimates of each size group were summed for all tows annually to form length-frequency distributions (Fig. 3 and 4). Macdonald and Pitcher's (1979) technique was then used to differentiate and quantify year-class modes. Length was assumed to be normally distributed for a given year-class. The computer algorithm (Macdonald, 1980) requires starting values of parameters (mean, standard deviation, proportion) for each mode. Starting values for parameters were visually determined and the program iteratively computed maximum likelihood parameters for each mode (year-class).

The estimated number of shrimp of a given year-class ($\hat{N}k$) was calculated as :

$$\hat{N}_k = \hat{P}_k \; \hat{N}_{..} \quad \hat{B} \, / \sum_{j=1}^{r} C_j \qquad (2)$$

let: $\hat{P}_k$ = estimated proportion of the kth year-class in the sample population N..

$\hat{N}_{..}$ = estimated total number of shrimp captured in a survey period

$$\text{and: } \hat{B} = \frac{A}{r} \sum_{j=1}^{r} [\, C_j / a_j \,] \, q \qquad (3)$$

where: $\hat{B}$ = estimated biomass of *P. borealis*

A = total survey area (Pavlof Bay >55 m; 302 km^2)

a_j = area covered in tow j

q = catchability coefficient of the sampling gear

In the absence of better information, the catchability coefficient (q) in this analysis was set equal to 1.0. Strictly speaking, this only applies to sizes that are fully recruited to the sampling area and gear. Equation (3) is essentially that of Alverson and Pereyra (1969). Biomass estimates are conservative because small shrimp are not fully vulnerable to capture.

Finally, the number of *P. borealis* of a given year-class ($\hat{R}_k$) caught by the fishery between surveys was estimated as:

$$\hat{R}_k = \hat{P}_k \, N_{..} \, [\, L/W \,] \qquad (4)$$

where: $\hat{P}_k$ is calculated similarly to survey catches above.

N.. = total number of shrimp sampled from the commercial catch in a given year

L = total landed weight of *P. borealis* between surveys

W = total sample weight from which N.. was calculated.

Determination of Growth and Mortality

Growth rates were estimated by following individual year-classes, through a time series of length-frequency distributions (Fig. 3 and 4). Non-linear least-squares regression (Program BCG2, Abramson, 1971) were used to fit von Bertalanffy growth curves to average size-at-age data.

Annual instantaneous total mortality rates (Z) for a given year-class were calculated as:

$$Z_k = -\ln (N_{k,t+1} / N_{k,t}) \qquad (5)$$

where: t = one year and $N_{k,t}$ and $N_{k,t+1}$ represent the relative abundance of the k_{th} year-class in two consecutive years.

Fishing and natural mortality estimates were derived from estimated total mortality using Ricker's (1975) formula:

$$F_k = \hat{\mu} Z_k / (1 - e^{-Z_k}) \qquad (6)$$

where: $\hat{\mu}$ = is the ratio of estimated catch in numbers (Rk from equation 4) and estimated abundance (Nk from equation 2) of the 1971 and 1975 year-class.

RESULTS AND DISCUSSION

Estimates of age, growth, and mortality rates in this study were made for two dominant year-classes which could be followed through most of their life span. Assumptions underlying the estimates were that size modes represented a particular age group, that year-classes could be differentiated using length-frequency information, and that immigration and emigration of Pavlof Bay shrimp was minimal.

Identification of Year-Classes

The 1971 and 1975 year-class modes were identified and followed through 1981 in length-frequency plots (Fig. 3, Table 2). The size at which dominant modes are first identified is between 10 and 11 mm CL. *Pandalus borealis* of this size are approximately 1.4 years old if it is assumed that larvae hatch in April and early growth is similar to that reported by other investigators (Butler, 1964; Ivanov, 1970; Fox, 1972; Skúladóttir, 1981). The plots indicate a similar pattern as well as close agreement in location of dominant modes in both the survey and commercial data (Fig. 3 and Table 2).

Problems in identifying the age of the smallest modal group have been noted by other researchers (Fréchete and Parsons 1983). Entering year-class modes from survey data were assigned the age of 1.4. A smaller mode (mean of 6.5-7.5 mm CL; numbers not large enough to be depicted in Fig. 3) was designated age 0.4. Nunes (1984) reported laboratory reared *P. borealis* postlarvae reached 3.6 - 3.9 mm CL by about 110 days after hatch. Seasonal trawl sampling of Chiniak Bay, Alaska along with larval surveys showed juvenile young of the year reaching an average size of 7 mm CL by September for three consecutive years (E. Munk, personal communication). The mesh size in this study was 32 mm with a 32 mm cod end liner, which may have helped in the retention of young shrimp.

Abundance and Variability of Year-Classes

The abundance of *P. borealis* in Pavlof Bay peaked in 1977 and declined substantially in later years (Table 1). In response to reduced abundance the fishery was closed by the ADFG in 1979; and the population subsequently stabilized at a lower level. The decline in abundance of the 1971 year-class (Table 2) reflected that of the total population. The average number of *P. borealis* caught per survey tow steadily declined from approximately 199,000 in 1976 to 10,000 in 1981.

Extreme variability in year-class strength can mean the success or failure of the commercial fishery. The 1971 year-class was the predominant element of commercial catches in Pavlof Bay during at least five fishing seasons (Fig.3B). To calculate the contribution that dominate year-classes made to the commercial catch an average weight, calculated from Pavlof Bay *P. borealis* length-weight data $W = 0.00104\ CL^{2.70160}$ (Anderson, 1981), was multiplied by the estimated number caught in each year-class (Table 2). During the years 1974-1978 the 1971 year-class contributed about 70% and the 1975 year-class about 3% of the 12,384 metric tons of *P. borealis* harvested from Pavlof Bay. The *P. borealis* biomass in the bay underwent a substantial decline and the fishery was closed. Even though the commercial fishery was closed in Pavlof Bay from 1979-1989 little or no improvement in stock condition occurred. In Pavlof Bay it appears that the *P. borealis* fishery was largely supported by a single year-class. World-wide other *P. borealis* fisheries have experienced similar cycles of high and low abundance (Balsiger 1981) that characterized the rise and fall of western Gulf of Alaska fisheries in the 1970's. The decline of shrimp in Pavlof Bay was probably inevitable regardless of the presence of a fishery, since many adjacent areas lightly or seldom fished experienced similar population declines

(Anderson and Gaffney 1977). These declines may be directly attributable to the demise of a series of strong year classes. Since little is known about the parameters controlling shrimp natality and its relationship to subsequent recruitment, this probably deserves study, along with the effects of predation (Albers and Anderson 1985), ecological, and environmental parameters (Nunes, 1984).

Estimates of Growth

Separate von Bertalanffy growth curves were fit to average size-at-age data for the two dominant year-classes (Fig. 4 and 5). Parameters of the fitted relationship were L_∞ = 29.64, K = 0.16, t_0 = -1.30 for the 1971 year-class; and L_∞ = 26.31, K = 0.29, t_0 = -0.47 for the 1975 year-class. A Friedman two-way analysis of variance by ranks (Connover, 1971) showed that members of the 1975 year-class were significantly ($P > 0.001$) larger for a given age indicating a higher growth rate for this year-class. For example, the 1971 year-class attained average sizes of 16.47 and 21.75 mm of CL at ages 3.4 and 6.4 respectively whereas the 1975 year-class averaged 18.20 and 23.01 mm CL at these ages. Skúladóttir (1981) also detected large differences in growth rates between year-classes. In her study one slow growing year-class had a K = .15 and L_∞ = 28 which is similar to the parameters calculated for the 1971 year-class in this study. On the other hand, parameters calculated for the average of five fast growing year-classes in her study indicated a K = .23 which is lower than the K (0.29) calculated for the 1975 year-class in the present study.

While growth of *P. borealis* is probably not related to overall population density (Table 1) there is evidence to support an inverse relationship relative to within year-class strength (Table 2). Both the 1971 and 1975 year-classes hatched during periods of high overall population levels (Table 1), but the faster early growth of the 1975 year-class may be explained by its relatively lower numerical abundance (Table 2) and hence lesser competition for food during the juvenile phase. *Pandalus borealis* is an aggregating species that exhibits differential distribution by size, sex, age, and seasons (Shumway et al. 1985). Although most larvae are captured between 20-30 m in the water column (Haynes 1983), Wolotira et al.(1984) have reported finding a downward shift in vertical distribution with progressive stages of larval development. They thought the distributional differences reflected a possible change in diet or distribution of food items. Berkeley (1930) reported the apparent segregation of juveniles from the adult population. The effect of ecological separation of life history categories could then explain differing growth rates among year-classes even though overall population density was high.

Since 1979 the occurrence of small shrimp (< 12 mm CL) in survey samples has been much less than in previous years (Figs.3 and 6). Three possible explanations for the virtual disappearance of this size class are 1) small shrimp are only retained when overall catch rates are high like they were in 1972-1977 , 2) juvenile shrimp are not normally found within the same area as larger adult shrimp except when high population levels force them into the less preferred adult habitat and 3) faster growth of juvenile shrimp lead to entering year-classes growing beyond 10 mm CL to 13-15 mm CL since 1979. I believe the most plausible explanation for the disappearance of small shrimp from survey samples is faster growth of juveniles. Growth has been shown to be inversely related to year class strength in this study. The overall population decline of *P. borealis* in Pavlof Bay (Table 1) is attributed to the dying out of the relatively strong 1971 and 1975 year classes and a series of relatively weak entering year classes since 1979 (Figs. 3 and 6). The 1.4 year old group is now between 13.2-14.4 mm CL rather than the 10-11.8 mm CL that was observed for 1972-1979 survey samples (Table 3). Growth rates of *P. borealis* in Pavlof Bay since 1979 are now much higher than the previous estimates for the 71 and 75 year-classes with K in the range of 0.46 to 0.63 (Table 4). Growth is now similar to that reported for the Gulf of Maine by Haynes and Wigley (1969). Since sample sizes remained large (at about 5,000 shrimp per survey) the possibility of missing size modes in this recent data series is low.

Variability in growth rates of year-classes also causes variability in the age of full recruitment in survey sampling, owing to the size selectivity of our 32 mm mesh trawl. Recruitment was complete at age 5.4 and 3.4 (18.96 and 18.20 mm CL) for the 1971 and 1975 year-classes respectively. Likewise, selectivity experiments by Blott et al. (1983) showed complete vulnerability of 19 mm CL *P. borealis* in a 32 mm stretch mesh trawl. Fox (1972) reported full recruitment at age three (≈ 18.0 mm CL) in stocks of *P. borealis* from Kodiak Island, Alaska in which sampling was accomplished with trawls having a similar mesh size to those in the present study.

Sex Transformation

The rate of transformation from male to female was considerably different for the two dominant year-classes studied (Fig. 7). Some members of the 1971 year-class initiated transformation to female during their fourth year, however others transformed during either their fifth or sixth year. In contrast, all members of the 1975 year-class initiated and completed transformation during their fourth year. The age at and rate of sex change for a year-class also appears to be closely related to year-class size or overall population density. Charnov (1979, 1981) proposed a model in which high mortality rates lead to a shorter male phase. Charnov et al. (1978) also considered how natural selection might act to alter the sex ratio of pandalid shrimp in response to environmental influences. I feel that accelerated sex transition observed for the 1975 year-class in this study was influenced by short term phenomena and is evidence of the labile timing in sex change of this species. The occurrence in 1980 and again in 1984-1986 of the smallest ovigerous females ever sampled (13.0 mm CL) (Table 3) is further evidence that accelerated sex reversal may also be a possible mechanism which attempts to increase reproductive capacity in the face of decreasing density (Table 1). Charnov and Anderson (1989) reported on an analysis of Pavlof Bay *P. borealis* that demonstrated the size of sex change moves through time to track changes in the breeding size distribution.

Mortality Estimates

Total mortality estimates were based on year-class abundance after full recruitment to survey sampling (equation 5; Table 5). The age of full recruitment to survey sampling was identified as 5.4 for the 1971 year-class and 3.4 for the 1975 year-class based on the visual inspection of the catch curve (Fig. 8). Since the commercial fishery was closed prior to the 1979 survey, total mortality rates estimated for the 1975 year-class beyond age 4.4 are equivalent to natural mortality. Table 5 also presents annual exploitation, total and fishing mortality rates estimated for both year-classes (from equation 6). The 1971 year-class showed increasing natural mortality between age 5.4 and 8.4 while fishing mortality remained relatively stable during this period.

Catch curve analysis of 1971 year-class survey abundance estimates indicate increasing total mortality after full recruitment. Fishing mortality for the 1971 year-class remained fairly steady after full recruitment (Table 5). Increasing total mortality with age for this year-class is hence attributed to increasing natural mortality. Apparent increases in mortality could also be caused by emigration of older individuals from the Pavlof Bay population, but this seems unlikely since it has been demonstrated that larger (older) shrimp are less active in diel vertical migration (Barr, 1970) and would tend to be retained by the shallow entrance of Pavlof Bay. The observed higher natural mortality in this study may be the result of spawning stress or senescence since the 1971 year-class may have approached their maximum longevity. Predation by Pacific cod (*Gadus macrocephalus*) may have also contributed to the high mortality observed between age 6.4/8.4 when cod abundance increased from 10 to about 500 kg per nautical mile towed (Albers and Anderson, 1985).

The 1975 year-class showed highest calculated natural mortality between age 3.4/4.4 (Table 5), however mortality rates were subsequently lower. After closure of the fishery the total mortality rates for the 1975 year class beyond age 4.4 are equivalent to natural mortality. Albers and Anderson (1981) reported the significance of cod (*Gadus macrocephalus*) predation on *P. borealis* in Pavlof Bay. Cod abundance peaked in 1979 and declined to about one sixth of its former abundance by 1981. Lower observed natural mortality for the 1975 year-class beyond age 4.4 could be explained by decreasing cod predation.

Rapid growth of year-classes after 1979 made it difficult to estimate mortality owing to their rapid growth past the size of full recruitment and the uniform weakness of a series of entering year-classes (Figs. 3 and 4). It was possible to follow entering modes until problems of overlap obscured them. Results show uniform high rates of mortality in this recent data and a much shorter overall life span than were observed in the early to mid 70's year classes. No year-classes were identified nor could they be followed in length-frequency data sets after the age of 4.4 (Table 6, Fig. 4). Mortality estimates for this group were high ranging from 1.147 to 4.512 at age 2.4/3.4 to 1.900 to 6.890 at age 3.4/4.4. These rates range much higher than that observed for the dominant year-classes followed during the 1970,s and suggests that fundamental changes in biological or environmental factors that may effect survival have occurred in the Pavlof Bay stock.

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Table 1. Abundance estimates and commercial landings of *P. borealis* shrimp in Pavlof Bay, 1972 - 1989. (metric tons with 80% confidence intervals for abundance, catches removed prior to next survey)

Dates	# of Tows	Abundance[1]	Catch
9/7-9/10/72	10	8,310 (6,999-9,616)	177
9/13/73[2]	2	3,084 (3,062-3,107)	1,075
9/8-9/10/74	13	11,476 (10,406-12,546)	150
9/19-9/21/75	12	6,886 (5,597-8,174)	1,919
9/12-9/14/76	12	10,796 (9,086-12,501)	5,670
8/25-8/27/77	13	12,392 (9,462-15,318)	3,819
8/29-8/30/78	13	3,602 (2,880-4,323)	826
9/4-9/7/79	10	599 (367-830)	CLOSED
8/24-8/26/80	12	549 (376-721)	CLOSED
9/10-9/11/81	12	662 (485-839)	CLOSED
8/19-8/21/82	13	749 (485-1,014)	CLOSED
8/11-8/12/83	12	2,646 (2,094-3,197)	CLOSED
8/29-8/30/84	13	308 (176-463)	CLOSED
8/12-8/15/85	12	617 (397-838)	CLOSED
8/28-9/1/86[3]	13	2,315 (1,631-3,020)	CLOSED
8/5-8/8/87	13	286 (150-417)	CLOSED
8/10-8/15/88	22	68 (50-86)	CLOSED
8/18-8/20/89	21	172 (104-240)	CLOSED

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[1] Abundance estimates and confidence intervals were calculated by the "area swept" technique of Alverson and Pereyra (1969), using the equations developed by Smith and Bakkala (1982).

[2] Survey curtailed due to severe weather.

[3] A 3.2 mm mesh liner was used during this survey.

Table 2. Mean carapace length (CL) , standard deviation (SD), and estimated number in survey area or estimated number caught in millions (N) of dominant year-class components separated by the Macdonald and Pitcher method from Pavlof Bay trawl survey and commercial catch length-frequency samples.

	1971 Year Class						1975 Year Class					
	Survey			Commercial Catch			Survey			Commercial Catch		
	CL	SD	N	CL	SD	N	CL	SD	N	CL	SD	N
1972	10.06	0.79	388.48	10.24	0.75	0.78						
1973	14.28	0.55	561.33	14.16	0.79	98.30						
1974	16.47	0.73	2337.62	15.54	0.70	21.93						
1975	17.44	0.71	1252.43	17.65	0.72	450.55						
1976	18.96	0.87	1738.33	19.10	0.91	642.08	10.66	0.81	413.90	11.01	0.49	53.33
1977	21.75	0.99	1007.98	21.67	0.85	184.36	15.68	0.93	225.03	14.74	0.68	26.70
1978	22.98	0.84	177.96	22.17	0.48	21.56	18.20	0.90	317.99	17.17	0.56	71.44
1979	23.61	0.67	3.93				19.23	0.79	23.63			
1980							21.45	0.60	9.83			
1981							23.01	1.17	3.48			

Table 3. Mean size (CL) and standard deviation (SD) of 1.4 year old shrimp from 1972-1986 survey samples.

Survey Year	CL	SD
1972	10.06	0.79
1973	11.39	0.92
1974	10.62	0.92
1975	10.99	0.67
1976	11.84	1.98
1977	11.52	0.94
1978	11.72	0.70
1979	11.75	0.70
1980	13.21	0.83
1981	14.41	0.74
1982	13.70	1.12
1983	14.31	0.99
1984	13.97	1.24
1985	13.45	1.09
1986	13.24	1.04

Table 4. Growth parameter estimates L_∞ and K from the von Bertalanffy growth equation for year classes separated from Pavlof Bay length-frequency distributions 1980-1989.

Year Class	L_∞	K
1980	27.73	0.52
1981	26.81	0.54
1982	24.19	0.63
1983	27.60	0.48
1984	27.14	0.51
1985	28.18	0.46

Table 5. Annual exploitation (μ), total (Z), fishing (F), and natural(M) mortality rates for the 1971 and 1975 year-classes.

	1971 Year Class				1975 Year Class[2]			
Age[1]	μ	Z	F	M	μ	Z	F	M
3.4/4.4					0.225	2.600	0.632	1.968
4.4/5.4					0.000	0.877	0.000	0.877
5.4/6.4	0.369	0.545	0.478	0.067	0.000	1.038	0.000	1.038
6.4/7.4	0.183	1.734	0.385	1.349				
7.4/8.4	0.121	3.813	0.472	3.341				

[1] Ages of the 1971 year-class correspond with years 1974-1979; and 1978-1981 for the 1975 year-class (see Table 2).

[2] Fishery closed in 1979, thus μ and F are both zero.

Table 6. Mortality estimates (M) (calculated from equation 5) of fully recruited year classes separated from length-frequency distributions 1981-1989.

Year Class	Age	M
1980	3.4/4.4	6.890
1981	2.4/3.4	4.512
1982	2.4/3.4	3.774
1983	2.4/3.4	1.147
	3.4/4.4	2.219
1984	2.4/3.4	2.142
	3.4/4.4	3.642
1985	2.4/3.4	4.297
	3.4/4.4	1.900

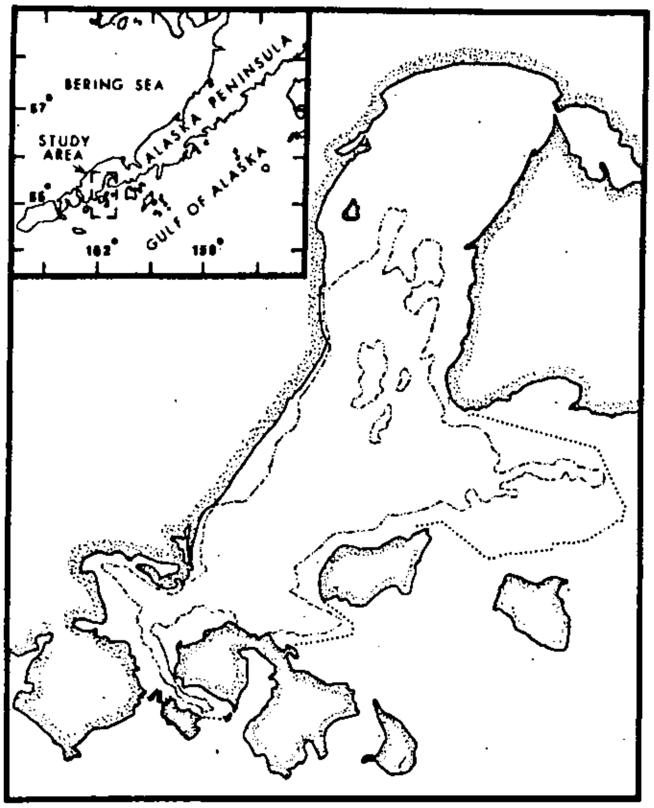


Figure 1. Pavlof Bay sampling area showing 55 m isobath (dotted/dashed line) and approximate location of the 20 m isobath (dotted).

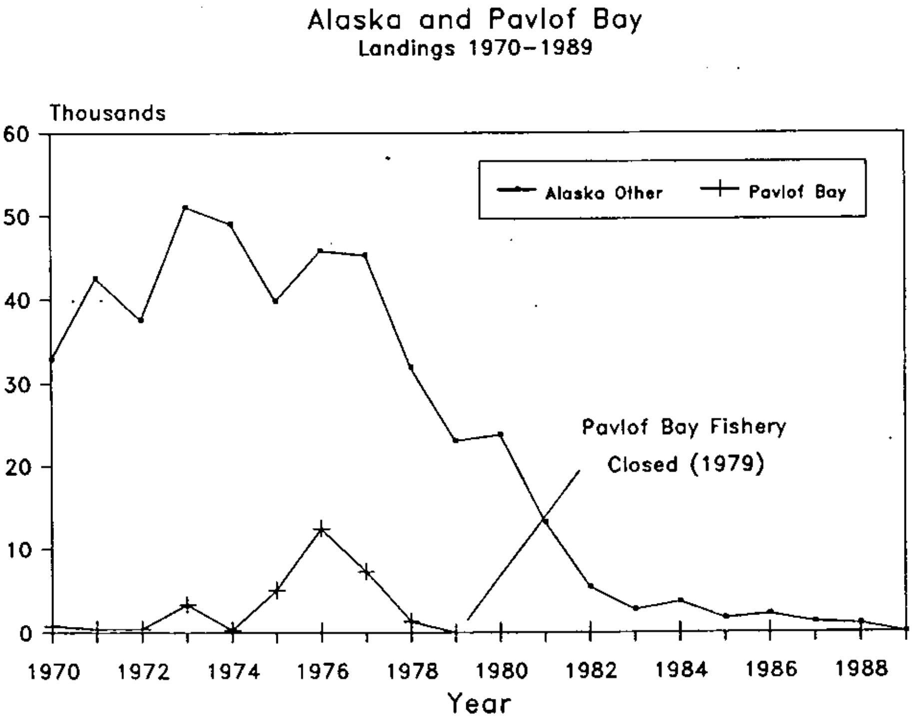
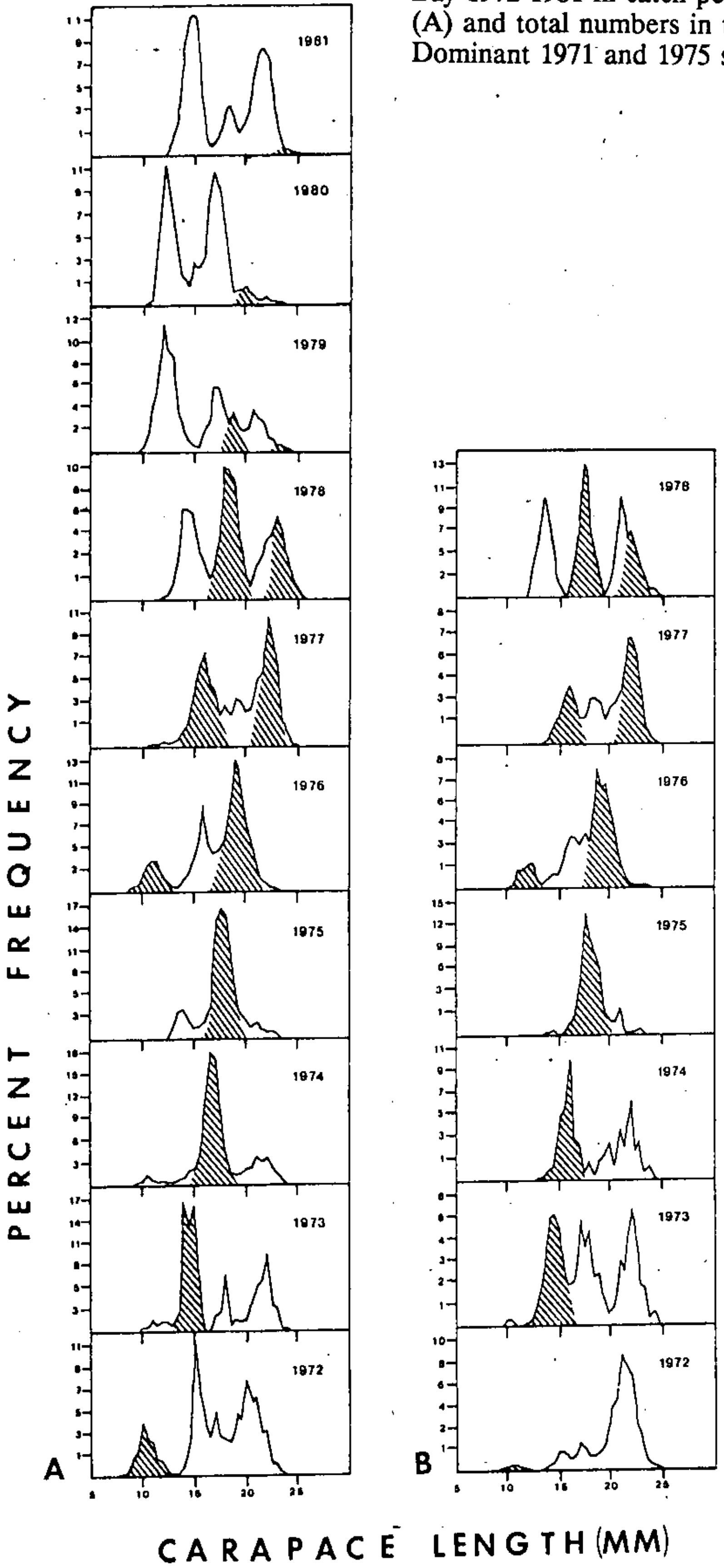


Figure 2. Alaska statewide and Pavlof Bay landings (metric tons) of Pandalid shrimp 1970-1989.

Figure 3. Size-frequency polygons of *P. borealis* from Pavlof Bay 1972-1981 in catch per kilometer from annual surveys (A) and total numbers in the commercial catch (B). Dominant 1971 and 1975 size modes shaded.



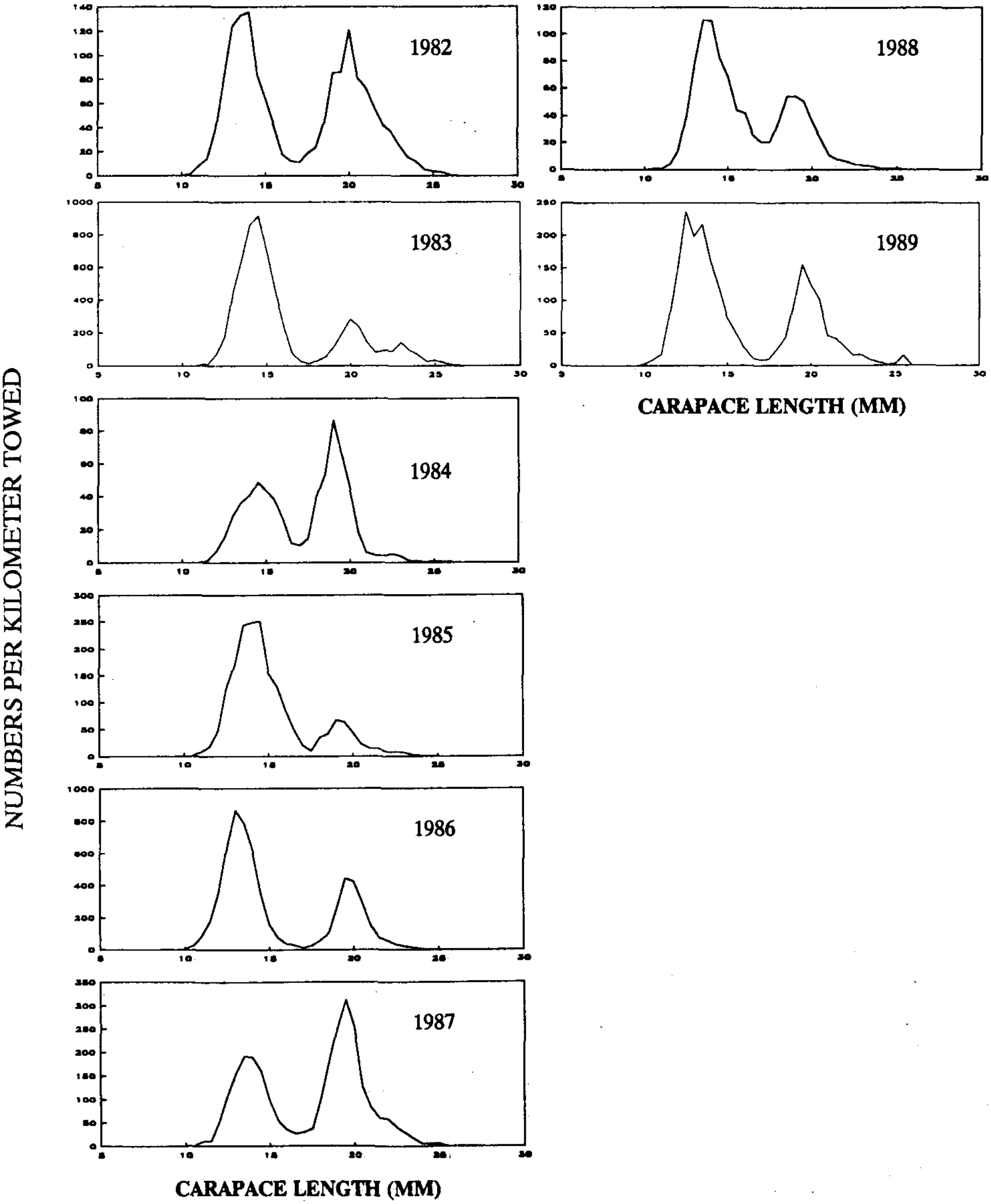


Figure 4. Size-frequency polygons of *P. borealis* from Pavlof Bay 1982-1989 in catch per kilometer from annual surveys.

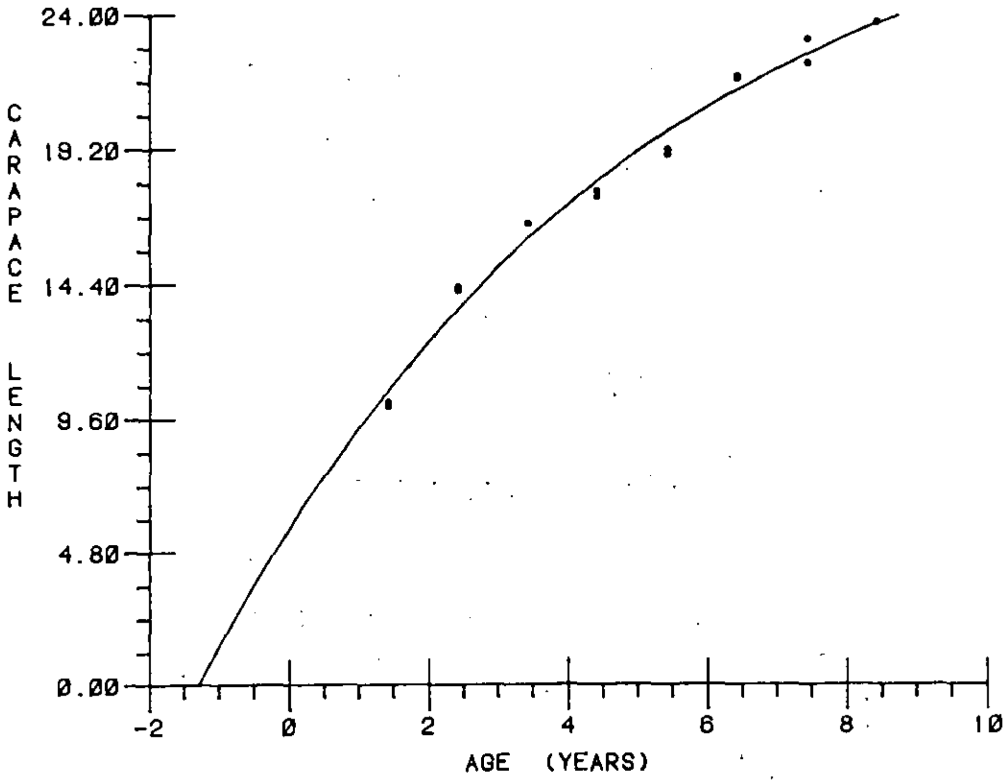


Figure 5. Von Bertalanffy growth curve generated from 1971 year class *P. borealis* mean size at age data from both survey and commercial catch data.

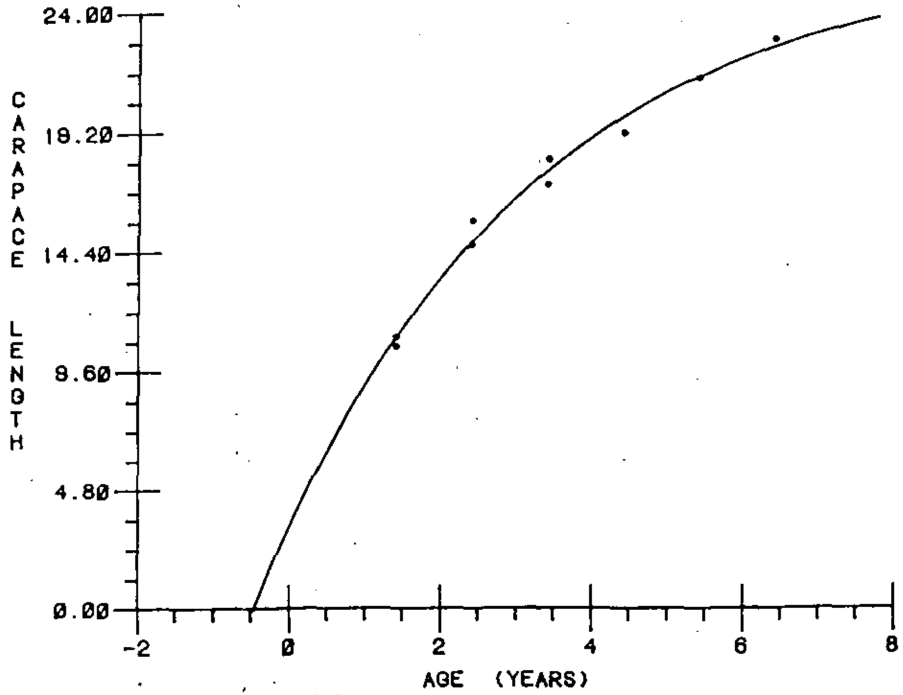


Figure 6. Von Bertalanffy growth curve generated from 1975 year class *P. borealis* mean size at age data from both survey and commercial catch data.

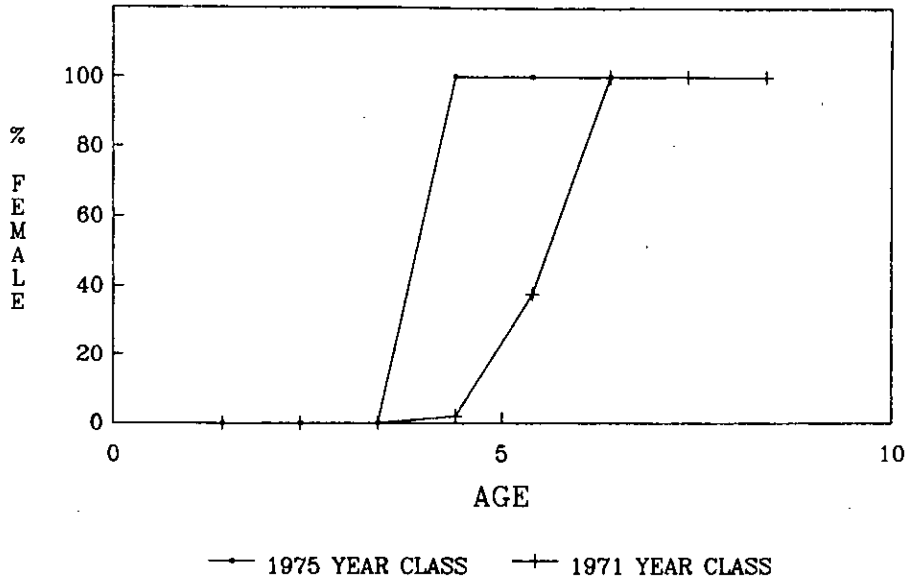


Figure 7. Percent Female of the 1971 and 1975 year classes at age (years), determined from survey length-frequency samples sorted by sex category.

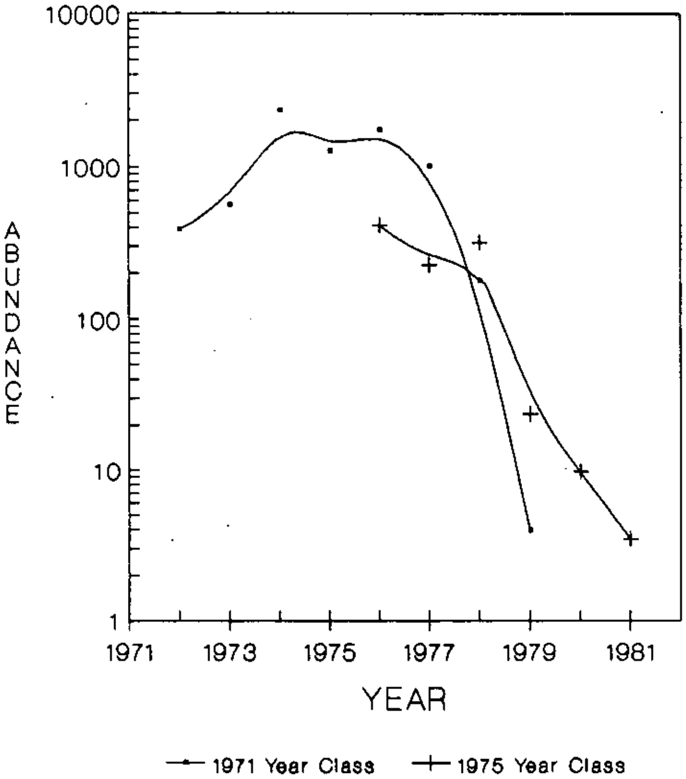


Figure 8. Catch curve (fitted by eye) of the 1971 and 1975 year classes from Pavlof Bay survey data.