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# Spot Shrimp Growth in Unakwik Inlet, Prince William Sound, Alaska

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ABSTRACT: Commercial shrimp harvests from the pot fishery in Prince William Sound, Alaska, averaged 2.9 metric tons (mt) annually prior to 1979. Catches increased rapidly after 1978, 110 mt being harvested in 1986. Little was known about adult spot shrimp *Pandalus platyceros*, which composed the bulk of these harvests. To obtain life history information the Alaska Department of Fish and Game marked 10,168 spot shrimp with streamer tags during 1983–1986. A total of 1,061 tags were recovered, 206 of these being repeat recoveries. The maximum time at liberty was 1,562 d, during which time the shrimp grew 11.5 mm. Mean annual growth was 3.1 mm for the 477 recoveries that molted between recaptures. Data on time at liberty and size at tagging and recapture for individual shrimp were fit to a von Bertalanffy growth equation. Results indicated that shrimp 28.5 to 41.5 mm carapace length were 3 to 7 years old, representing 5 age classes. Combined with previous studies that indicated the juvenile stage of spot shrimp lasts at least 2 years, lifespans of spot shrimp in Prince William Sound probably exceed 7 years. This longevity is much greater than previously assumed and emphasizes the need for more conservative management.

## INTRODUCTION

Commercial shrimp harvests from the pot fishery in Prince William Sound, Alaska, date back to the early 1960s (Table 1). Annual harvests averaged 2.9 metric tons (mt) from 1960 to 1978 but then increased rapidly from 19.8 mt in 1978 to 110 mt in 1986. Beginning in 1982 the relative harvest stability observed was attributed to more restrictive management measures, including closed seasons and catch limits. Spot shrimp *Pandalus platyceros* have historically composed 90% or more of the commercial harvest; coonstripe shrimp *Pandalus hypsinotus* composed the remainder. The productivity of these species has not been documented in Alaska.

To obtain life history information, the Alaska Department of Fish and Game (ADF&G) conducted a spot shrimp tagging program in Prince William Sound along the northern Gulf of Alaska (Kimker 1986). In a 1982 pilot study 926 spot shrimp at Green Island in Prince William Sound were marked with streamer tags, and 9 tags were recovered by the end of the year (unpublished ADF&G data). These results confirmed that streamer tags could be applied to spot shrimp and used to collect life history data. To improve both tagging and recovery opportunities, this tagging project was moved to Unakwik Inlet in 1983 (Figure 1), a major goal being to examine spot shrimp growth and longevity.

## METHODS

Tagging was conducted in Unakwik Inlet, Alaska, from late winter through early fall during 1983–1986. This inlet in northern Prince William Sound is a glacially influenced embayment characterized by a bottom sloping steeply to over 330 m (Figure 1).

We selected 18 tagging sites that varied from 79 to 197 m deep on steep, rocky substrate near Cannery Creek Hatchery (Figure 1). This area was selected because (1) spot shrimp were abundant; (2) it was protected from inclement weather, which maximized tagging and recovery opportunities; and (3) staff at the nearby hatchery were available to collect reliable tag-recovery data. Although exact replication of sample stations in successive capture periods was impossible due to the high-relief, steeply sloping substrate, Loran C coordinates and depth data indicated successive tagging stations were similar to each of the previous stations.

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Tagging operations were conducted from the ADF&G research vessel *Montague*. Shrimp were captured in (1) rectangular pots, 41 cm high x 41 cm wide x 102 cm long and covered with a vinyl perforated mesh, that had a tunnel on each end of the pot sloping to a 9-cm hole; and (2) square pots, 46 cm high x 91 cm wide x 91 cm long and covered by a vinyl perforated mesh, that had a single tunnel on top sloping to a 10-cm hole. Five rectangular pots were fished on a single longline, whereas the square pots were fished individually. All pots were retrieved approximately 24 h after being baited with chopped herring *Clupea* spp. contained in a 1.4-L perforated jar.

During tagging the pots were pulled aboard, bait jars were removed, and the shrimp were gently shaken out of the pot and into a 57-L plastic holding tank. The holding tank was continuously circulated with seawater pumped from 2.1 m below the ocean surface and allowed to overflow at the top of the tank. Shrimp were measured (nearest 0.5 mm) from the rear of the eye socket to the posterior midpoint of the carapace, tagged, and returned to the water in <30 s.

Tagging was eventually limited to shrimp 28.5–42.5 mm in carapace length. The integument of smaller shrimp appeared to tear excessively as the tag was inserted. Larger shrimp were not effectively tagged because the notched center of the tag, which aids retention, was less than the thickness of the abdomen (Figure 2). To minimize handling of the shrimp, sex was not determined.

Two types of streamer tags were used: a 4-mm-diameter yellow tag and a 6-mm-diameter black tag (Marullo et al. 1974; Somers and Kirkwood 1984; Wassenberg and Kerr 1990; Figure 2). The tags, 10 cm long with a 3-mm-wide notch, were attached to a slotted-eye needle. Needles were dipped in a 10% antibiotic-petroleum jelly mixture and manually inserted through the articular membrane between the first and second abdominal segments. The needle and tag were then pulled through the abdomen with pliers, after which the needle was detached from the tag.

Tag recoveries occurred during subsequent retagging efforts. In addition, shrimp fishing by commercial and recreational users in Unakwik Inlet provided some additional recoveries of tagged shrimp. Tag number and type, geographic location, and carapace length (nearest 0.5 mm) were obtained from tag recaptures. For purposes of this study, tags returned without shrimp had to be ignored. During ADF&G recaptures, tagged shrimp were returned to the water in <30 s.

Three approaches were used to calculate the annual growth of adult spot shrimp. The first method fit a von Bertalanffy growth curve to mark-recapture data

Table 1. Commercial harvest of shrimp from the Prince William Sound Management Area pot fishery, 1960–1986.

| Year | Harvest[a] (kg) | Vessels | Landings |
|---|---|---|---|
| 1960 | 1,889 | | |
| 1961 | 0 | | |
| 1962 | 1,354 | | |
| 1963 | 417 | | |
| 1964 | 1,609 | | |
| 1965 | 1,650 | | |
| 1966 | 0 | | |
| 1967 | 284 | | |
| 1968 | 2,600 | | |
| 1969 | 1,949 | | |
| 1970 | 7,490 | | |
| 1971 | 4,951 | | |
| 1972 | 2,632 | | |
| 1973 | 2,413 | | |
| 1974 | 9,461 | | |
| 1975 | 1,572 | | |
| 1976 | 913 | | |
| 1977 | 2,847 | | |
| 1978 | 5,858 | 9 | 17 |
| 1979 | 19,774 | 17 | 98 |
| 1980 | 34,098 | 23 | 155 |
| 1981 | 65,728 | 51 | 509 |
| 1982 | 80,971 | 57 | 397 |
| 1983 | 80,834 | 71 | 646 |
| 1984 | 78,509 | 79 | 513 |
| 1985 | 104,804 | 78 | 528 |
| 1986 | 110,079 | 80 | 540 |
| 1987 | 102,131 | 86 | 489 |
| 1988 | 72,888 | 76 | 433 |
| 1989 | 11,103 | 33 | 69 |
| 1990 | 13,914 | 23 | 59 |
| 1991[b] | 6,658 | 15 | 45 |

[a] Converted to "heads-on" or whole weight using a tail-to-whole weight multiplier of 1.67.

[b] Fishery closed in 1992 through 1995.

for individual shrimp by solving for $K$ and $L_\infty$ (Phares 1980) in:

$$l_2 = L_\infty - (L_\infty - l_1)\, e^{-K\Delta t},$$

where:

$l_1$ = length at tagging,
$l_2$ = length at recapture,
$\Delta t$ = time between tagging and recapture,
$K$ = a growth constant, and
$L_\infty$ = the estimated asymptote or maximum length of the tagged animals.

To minimize the influence of measurement error and shrimp exhibiting little growth due to limited time

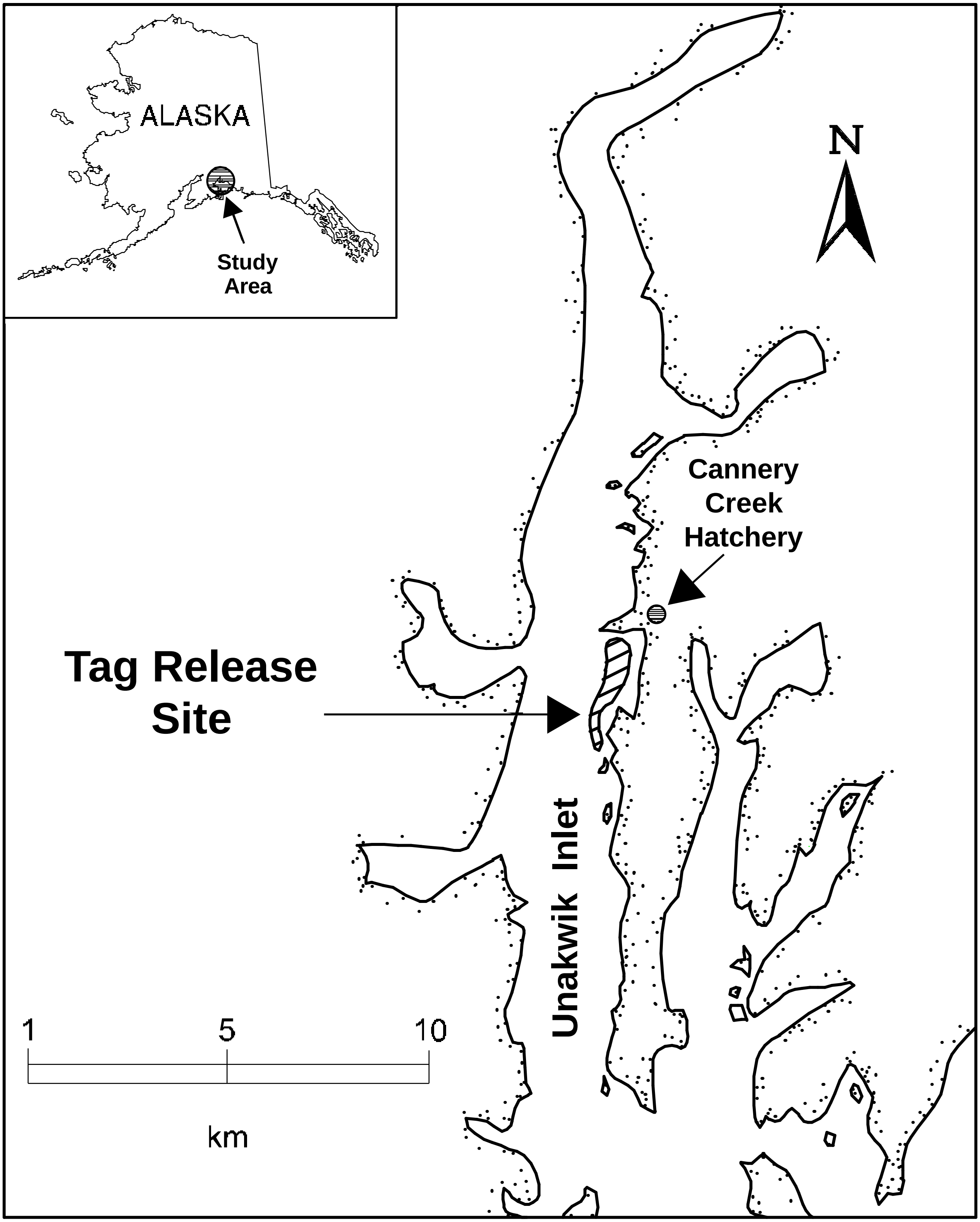


Figure 1. Study site for spot shrimp tagging study in Unakwik Inlet, Prince William Sound, Alaska, 1983 to 1986.

Table 2. Tag releases and recoveries from spot shrimp growth study in Unakwik Inlet, Prince William Sound, Alaska.

| Year | Application Month | Tags Applied | Tagged Shrimp Recaptures[a] | Shrimp Recapture Rate (%) | Tag Recoveries[a] | Tag Recovery Rate (%) |
|---|---|---|---|---|---|---|
| 1983 | February | 985 | 258 | 26.2 | 193 | 19.6 |
| | June | 985 | 235 | 23.9 | 168 | 17.1 |
| | September | 1,135 | 95 | 8.4 | 72 | 6.3 |
| | 1983 Total | 3,105 | 588 | 18.9 | 433 | 13.9 |
| 1984 | March | 1,194 | 96 | 8.0 | 78 | 6.5 |
| | June | 1,111 | 74 | 6.7 | 64 | 5.8 |
| | 1984 Total | 2,305 | 170 | 7.4 | 142 | 6.2 |
| 1985 | March | 1,469 | 170 | 11.6 | 160 | 10.9 |
| | June | 1,238 | 52 | 4.2 | 46 | 3.7 |
| | September | 1,067 | 42 | 3.9 | 39 | 3.7 |
| | 1985 Total | 3,774 | 264 | 7.0 | 245 | 6.5 |
| 1986 | February | 984 | 39 | 4.0 | 38 | 3.9 |
| Cumulative Total | | 10,168 | 1,061 | 10.4 | 858 | 8.4 |

[a] Because some shrimp were recovered more than once, the number of tags recovered is less than the number of shrimp recaptures.

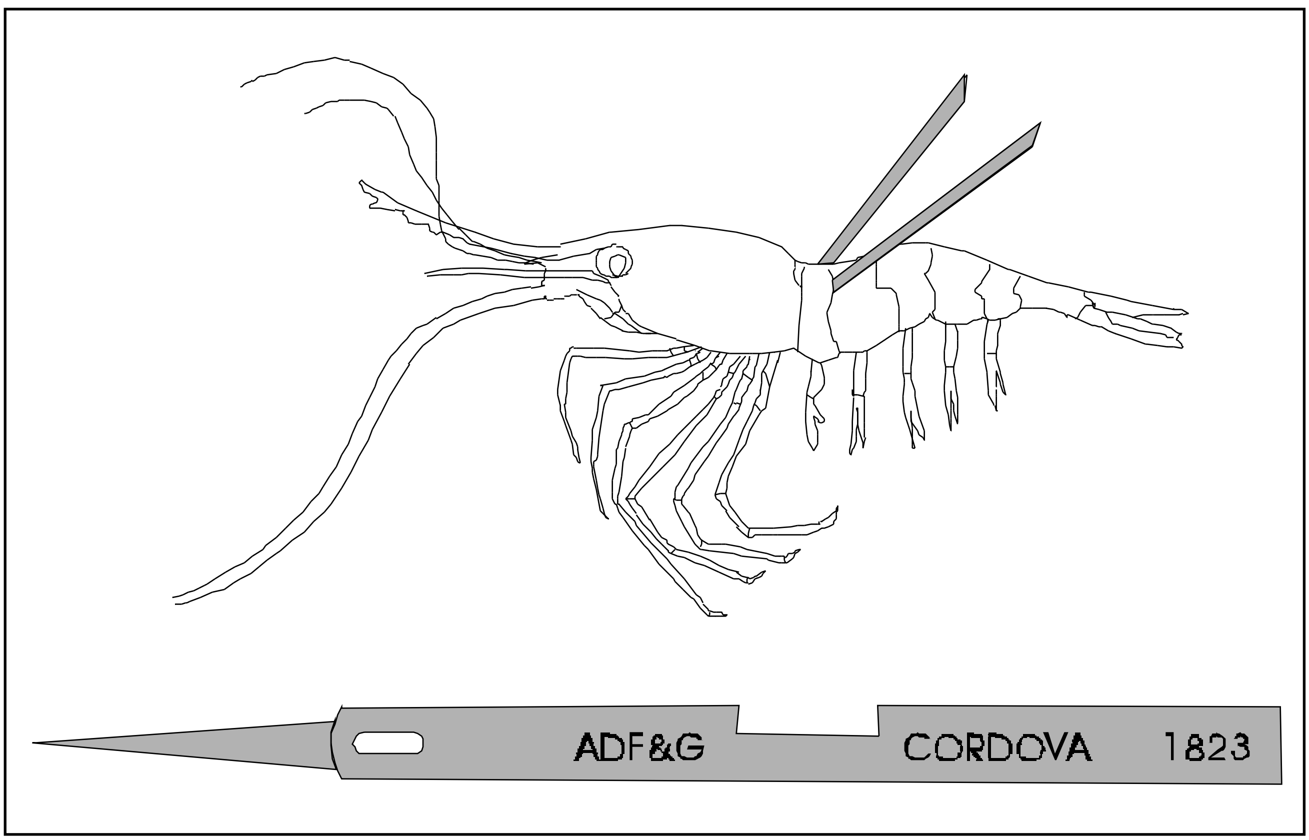


Figure 2. Example of streamer tag application to spot shrimp in Prince William Sound (not shown to scale).

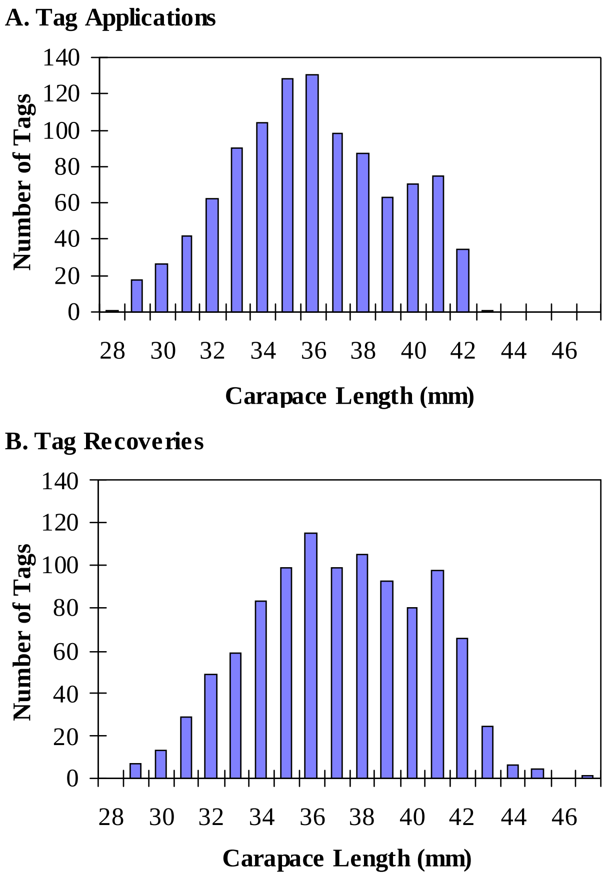


Figure 3. Distribution of carapace lengths collected during (A) the application and (B) the recovery of streamer tags to spot shrimp in Prince William Sound, Alaska, 1983 to 1986.

at liberty, the growth model input was restricted to shrimp that exhibited positive growth and were at liberty for at least 3 weeks. To obtain a realistic growth relationship, we also restricted $L_\infty$ to <100 mm.

The second method calculated an average annual growth rate based on all shrimp that grew ≥0.5 mm between captures. The third method, which assumed that spot shrimp in Unakwik Inlet molt at least once each year, restricted growth calculations to shrimp at liberty for >365 d.

## RESULTS

Between February 1983 and February 1986, 10,168 spot shrimp were tagged in Unakwik Inlet (Table 2). Successful applications included 6,467 black tags and 3,701 yellow tags. Between tagging and recaptures, carapace length distribution shifted to larger sizes but otherwise appeared similar (Figure 3). Shrimp tagged during the study initially ranged from 23.0 to 43.0 mm in carapace length and averaged 36.2 mm (SD = 3.2). Recaptured shrimp ranged from 29.0 mm to 47.0 mm and averaged 37.4 mm (SD = 3.3).

Although commercial and recreational fishing effort occurred throughout the fishable depths in the southern half of Unakwik Inlet and immediately outside the mouth of Unakwik Inlet (about 10 km from the tagging site), all tag recoveries were within 1.7 km of their release point. A total of 1,061 tagged shrimp were recovered between March 1983 and December 1986 (Table 2), but because multiple recoveries were observed for 203 individual tags (19% of all recoveries), the actual number of individual tags recovered was 858 (Table 2). Multiple recoveries included 122 tags recovered 2 times, 31 tags 3 times, 5 tags 4 times, and 1 tag 5 times. Of the 1,061 tag recoveries, 360 (34%) were not returned to the water, thereby greatly reducing the chances for multiple recoveries. Tag coloration did not affect the probability: 11% recovery rate (690 tags) for black tags and 10% recovery rate (371 tags) for yellow tags ($\chi^2 = 0.8518$, 1 df; Figure 4).

A total of 520 shrimp molted and grew between tagging and recapture. Individual growth ranged from 0.5 to 11.5 mm, and shrimp size generally increased with greater time at liberty (Figure 4). The 11.5-mm growth was for a shrimp at liberty for 1,562 d (4.3 years), the longest at-liberty period, during which time it grew from 30.5 to 42.0 mm. Many (123) shrimp grew 0.5 mm; they averaged 143 d at liberty and ranged from 1 to 579 d, although only 2 were captured after 300 d.

The von Bertalanffy growth model predicted an $L_\infty$ of 49.2 mm with a $K$ parameter of 0.29 ($n$=520). Plotting the von Bertalanffy with the estimated $L_\infty$ and $K$ parameters and plausible $L_0$ values (a model parameter for length at time zero) of -10.0, 0.0, and 10.0 had little effect on the overall results (Figure 5). Based on the von Bertalanffy growth curve, the adult shrimp sampled in this study ranged from 3 to 7 years in age.

For the 520 shrimp growing 0.5 mm or more between captures, the average growth rate was calculated as 3.45 mm (SD=2.58) per year; 107 of these were at liberty for >1 year and were estimated to have grown 3.02 mm (SD=1.46) annually. These results provided reasonable agreement both with each other and with the von Bertalanffy equation. Therefore, it appears that average growth was approximately 3.2 mm per year for shrimp between 28.5 and 42.5 mm.

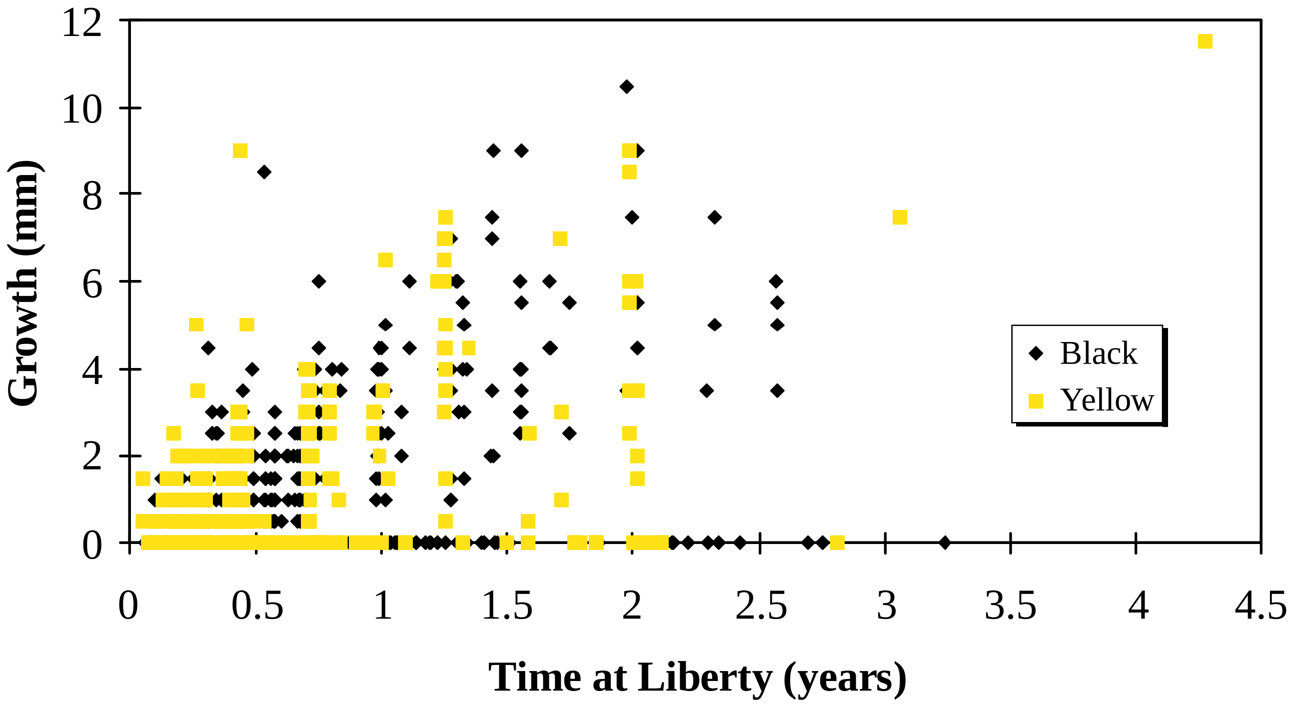


Figure 4. Growth in spot shrimp carapace length as a function of time at liberty.

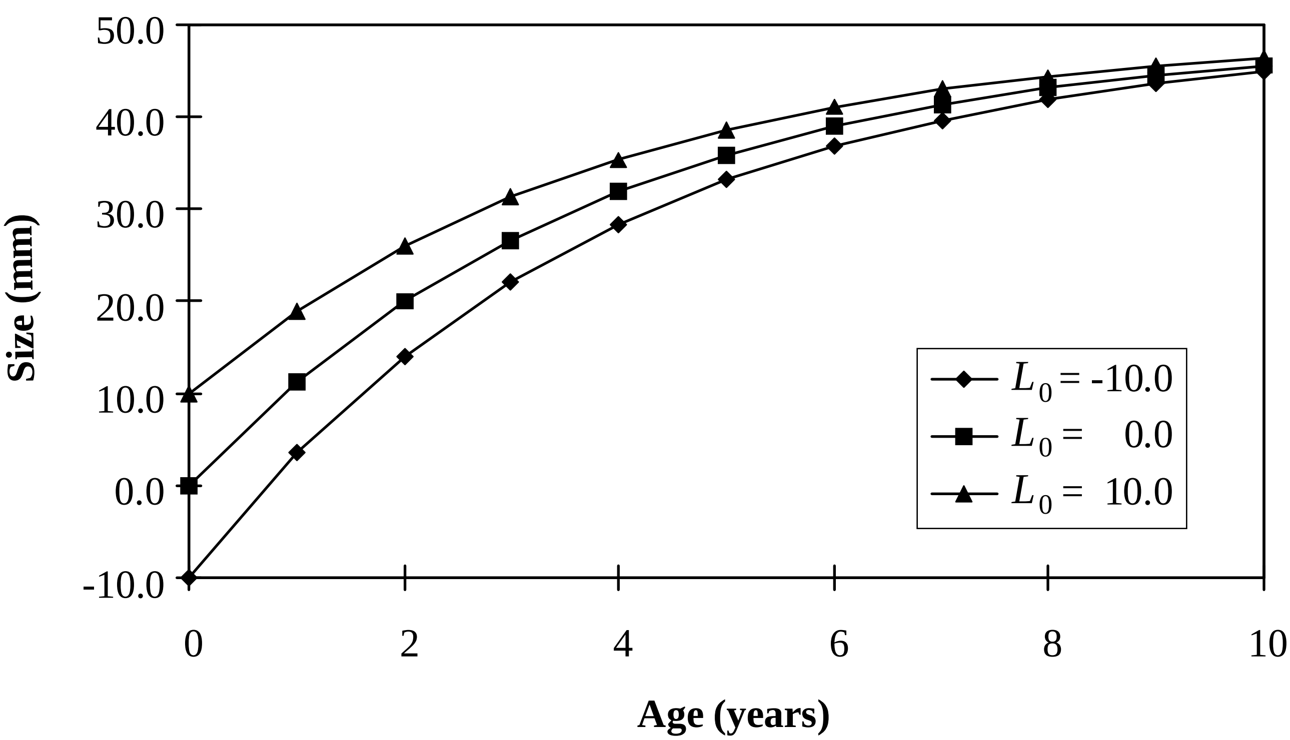


Figure 5. Potential size-at-age projections for spot shrimp based on a von Bertalanffy curve using $L_\infty$ = 49.2 mm, $K$ = 0.29, and $L_0$ values of -10.0, 0.0, and 10.0.

## DISCUSSION

Growth of some pandalid species varies annually within the same geographic area. For example, juvenile spot shrimp reared in Howe Sound, British Columbia, showed growth variation between year classes (Marliave and Roth 1995).

Over 500 of the shrimp recovered in our study failed to grow between tagging and recapture (Figure 4). While a portion of this may be attributed to measurement error, many of these shrimp were recovered within several weeks of tagging. This short a time interval might have been insufficient or at the wrong time of year for a molt; that is, molting in Prince William Sound is believed to occur primarily in spring and fall (unpublished data).

The shrimp we tagged were almost all 28.5 to 42.5 mm long, a range of 14 mm. Given an average growth rate of 3.2 mm per year for all shrimp showing growth between tagging and recapture, the 14.0-mm range in size represents 5 years longevity. Thus, combining the 2-year juvenile period (Barr 1973) with our estimated adult period of 5 years, the minimum life cycle for spot shrimp in Prince William Sound is 7 years. This life span is significantly longer than the 4-year life cycle identified by Butler (1964) for spot shrimp in the more temperate waters of southern British Columbia. Greater longevity has also been found in the northern distribution of other pandalid species. For example, Anderson (1991) calculated the life cycle of pink shrimp *Pandalus borealis* in Pavlof Bay on the Alaska Peninsula to vary from 5 to 8 years, whereas Butler estimated 3 years for the same species in British Columbia.

Both longevity and maximum growth may be substantially greater than that predicted by this study. The $L_\infty$ of 49.2 mm was less than the maximum size of spot shrimp the authors had previously observed in Prince William Sound, and greater size would presumably represent greater longevity. Francis (1988) discussed the potential discrepancies between growth parameters estimated from tagging, such as in this study, and age-growth data. Although age-at-length estimates outside of the range observed in our study should be viewed with some uncertainty, the model provides a reasonable fit for spot shrimp growth based on time at liberty and size at tagging and recapture (Figure 5). Changes of $L_0$ values for the von Bertalanffy yield relatively minor changes in the predicted size-at-age.

Pandalid shrimps are protandrous hermaphrodites, an evolutionary strategy providing some resilience to population perturbations (Charnov et al. 1978; Charnov 1979). This study indicated that spot shrimp in Prince William Sound exhibit greater longevity than was previously suspected, which implies that annual productivity will be less than for shorter-lived populations or species (Leaman and Beamish 1984). Although further studies are needed to refine these preliminary findings, long-term yield of the spot shrimp resource in Prince William Sound should be reexamined because it may require more conservative management approaches. In fact, shrimp harvests began to decline in 1987, and low stock size effected partial closure of the fishery in February 1989, just prior to the *Exxon Valdez* oil spill. The areas closed and showing weak stock size were the areas the fishery had originated in and historically targeted. After the March 1989 oil spill, the effects of harvest policies on the shrimp stocks were masked by the possible effects of the oil spill. The catch data (Table 1), however, do indicate a likelihood of overharvest.

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