FACTORS CONTROLLING GROWTH AND SURVIVAL OF CULTURED SPOT PRAWN, *PANDALUS PLATYCEROS*, IN PUGET SOUND, WASHINGTON

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ABSTRACT

Environmental factors affecting growth and survival of juvenile and yearling spot prawns, *Pandalus platyceros*, were studied at two sites in Puget Sound, Washington. It was thought that higher water temperatures at the southern site would promote increased growth rates, but intense plankton blooms and rapid fluctuations of water temperature induced high mortalities. Moribund prawns recovered quickly when placed in epibenthic cages that received cooler, relatively plankton-free water.

Although the cooler central Puget Sound site was judged suitable for prawn culture, fluctuations in temperature and plankton abundance caused moderate mortalities here as well.

Since 1970, several commercial marine aquaculture projects utilizing floating net pens for the culture of Pacific salmon, *Oncorhynchus* spp., (Mahnken 1975) have been developed in the Pacific Northwest. Development of companion crops to be grown in net pens with the salmon would enable growers to diversify and increase the return on their investments. The spot prawn, *Pandalus platyceros* Brandt, (herein referred to as prawn) may be a potential companion crop for several reasons: 1) it is adaptable to the sides as well as the bottom of net pens; 2) it can reproduce in captivity (Rensel and Prentice 1977); 3) it grows more rapidly and reaches a larger size than other pandalids (Butler 1964); 4) it consumes a variety of foods including dead fish; 5) it is gregarious and is normally not cannibalistic; and 6) it can be cultured in the laboratory (Wickins 1972; Kelly et al. 1976; Prentice[3]).

The objective of the present study was to determine the effects of environmental factors on growth and survival of juvenile and adult prawns held separately but near to salmon rearing pens at two differing salmon aquaculture sites. It was hypothesized that higher water temperatures at the more southern site would produce increased growth rates.

METHODS

Two sites were utilized for the experiments, Clam Bay and Henderson Inlet, both in Puget Sound, Wash. (Figure 1). At the National Marine Fisheries Service (NMFS) laboratory at Clam Bay, floating net pens for salmon research were situated at the end of a pier. Depth under the pens ranged from 9 to 14 m, depending on the stage of the tide. Data collected over several years indicated that the site had good water exchange with tidal currents reaching 0.4 kn at maximum flood and 1.0 kn at maximum ebb. The growth rate of prawns cultured previously at the site (Rensel and Prentice 1978) approximated that found in a wild population (Butler 1964).

The Henderson Inlet site (Figure 1) was at the location of a commercial log rafting operation. In 1973, a pilot-scale salmon aquaculture project was initiated by the Weyerhaeuser Company and the Washington Sea Grant Office at the site, and hydrographic data were collected (Snyder et al.[4]). Because of the inlet's shallow depth (10 m mid-channel), configuration, and location, seawater exchange is more restricted and tidal currents less

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[3]Prentice, E. F. 1975. Spot prawn culture: status and potential. *In* C. W. Nygaard (editor), Proceedings of a seminar on shellfish farming in Puget Sound, Oct. 7, 1975, Poulsbo, Wash. Processed Rep., 11 p. Wash. State Univ. Coll. Agric., Coop. Ext. Serv., Pullman, WA 99163.

[4]Snyder, B. P., A. J. Didier, Jr., and E. O. Salo. 1974. The culture of salmon at Willapa Bay, Grays Harbor, and Henderson Inlet in southern Puget Sound. Final Report Jan. 1973 to Feb. 1974. Univ. Wash., Coll. Fish., Fish. Res. Inst., Seattle, WA 98195, 211 p.

Manuscript accepted December 1979.
FISHERY BULLETIN: VOL. 78, NO. 3, 1980.

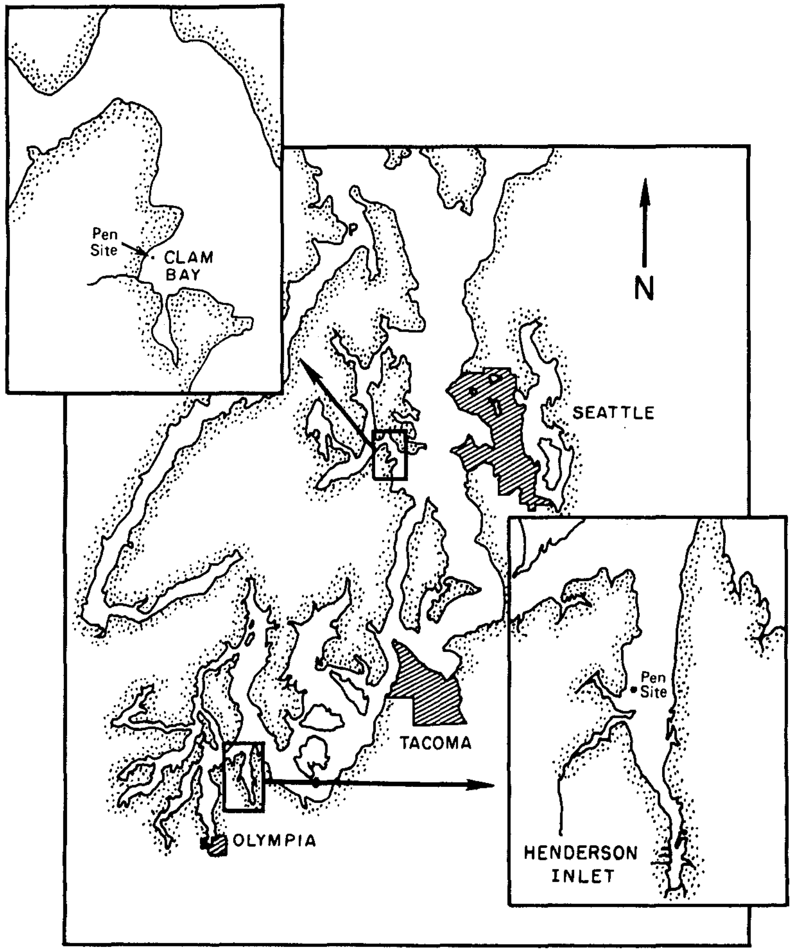

FIGURE 1.—Puget Sound, Washington, with sites of spot prawn studies at Henderson Inlet and Clam Bay.

than at Clam Bay. Surface water at the inlet was warmer and more turbid, but dissolved oxygen and salinity were similar to Clam Bay.

Five-month-old juvenile prawns, reared at the NMFS Clam Bay laboratory, were used in the study. The prawns were transferred to net pens and cultured from July to November 1974 at Henderson Inlet and from July 1974 until March 1975 at Clam Bay. Initial carapace lengths (distance from the base of the eyestalk to the posterior middorsal edge of carapace) of the juvenile prawns averaged 5.3 mm (n = 135 at each site, SD = 1.70) for all experimental lots. Weight of the prawns was not initially determined. We obtained wild prawns from commercial fishermen on Hood Canal (Puget Sound) in May 1974 and held them in a common pen for 3 wk at each site prior to distribution to rearing pens. The culture period was from June 1974 to March 1975. At the start of the experiment, the average carapace length was 25.8 mm (n = 336, SD = 1.68), and the average weight was 11.1 g (SD = 2.25). These prawns are referred to as yearlings as defined by the weight and length range (6.4-15.4 g, 21.2-28.5 mm) reported by Butler (1964) for a wild population.

Juvenile prawns were cultured in rectangular, knotless nylon net pens (stretched measure 6.7 mm), 2.16 m square × 1.8 m deep. Weights were attached externally to the corners of the pens to maintain their shape. Covers made of black plastic sheeting were placed over the pens to reduce light and discourage bird predation. Each pen was divided into three equal chambers by vertical net panels. The total immersed net area was 6.3 m^2/chamber. Each chamber was stocked with 45 prawns for an initial density of 7.1 prawns/m^2.

Pens used for the yearling prawns were also covered with plastic sheeting. These pens were the same overall size and depth as the pens for the juveniles but were made of a larger mesh size (stretched measure, 9.0 mm) and not divided into chambers. Polyvinyl chloride pipe frames were placed in the pen bottoms to maintain the pen's shape. The total immersed substrate available to the prawns was 11.5 m^2/pen. Each pen was stocked with 112 prawns for an initial density of 9.7 prawns/m^2.

The prawns were divided into treatment groups based on age and diet. Juvenile prawns were fed raw meat of the blue bay mussel, *Mytilus edulis*. Yearling prawns were divided into two diet treatments. A "clam-fed" diet consisted of frozen processing waste from the geoduck, *Panope generosa*, which was fed without limit every other day after old food was removed. In a second treatment, "unsupplemented," the prawns were not fed but foraged on organisms growing on or drifting into the net pens. Dead prawns and exuviae were collected from each treatment every other day. All treatments were replicated three times at both test sites.

All surviving prawns were measured for length and weight except juveniles whose weights were estimated from carapace lengths using the formula $\log W = 2.93148 \log L = 3.07787$, where: L = length in millimeters and W = weight in grams (Butler 1964). Initially, the carapace of each juvenile prawn was measured to the nearest 0.1 mm with an ocular micrometer. Carapace length of yearlings was measured with calipers to the nearest 0.5 mm. Starting in October, the juvenile prawns were also measured with calipers. A top loading balance was used to obtain individual wet weights (nonblotted) of the prawns to the nearest 0.01 g.

RESULTS AND DISCUSSION

Environmental Data

Salinity at Henderson Inlet and Clam Bay ranged from 28.4 to 31.0‰, being within the range reported by Butler (1964) for wild prawn populations. Dissolved oxygen (DO) peaked in May (11.0 ppm at Henderson Inlet and 9.0 ppm at Clam Bay) and gradually fell to a minimum (5.0 ppm) in September at both sites. This low value at both sites only lasted a few hours during some tidal cycles. We believe these DO levels, because of their short duration and lack of stress on salmon in adjacent net pens, were adequate for the prawns and never caused stress. Bottom temperatures at Henderson Inlet were always higher than those at Clam Bay (Figure 2).

Light influences the growth of crustaceans. Forster (1970) reported significantly higher growth rates for juvenile prawns, *Palaemon serratus*, held in total darkness when compared with those held in other light conditions. A similar phenomenon has been reported with the American lobster, *Homarus americanus* (Conklen 1975). In our study, juvenile and yearling prawns avoided brightly illuminated areas and stopped feeding when the black covers were removed. This sudden increase in light intensity and the presence of an observer could have affected growth and survival, but no quantitative information was obtained.

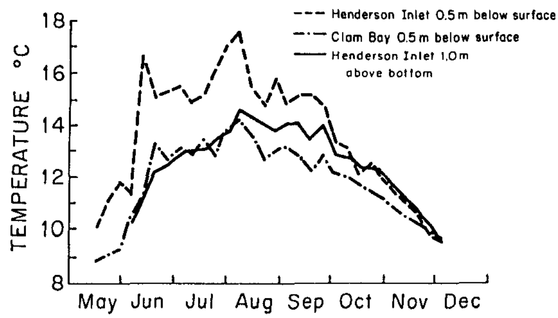

FIGURE 2.—Weekly mean water temperatures for Henderson Inlet and Clam Bay.

At Henderson Inlet, maximum water transparency, as measured with a Secchi disc, was from 0.5 to 4.2 m (5-d mean) less than at Clam Bay (Figure 3). Seasonal fluctuation in water transparency at both sites was caused by plankton blooms and runoff.

Growth and Survival of Juveniles

Between-site comparison of juvenile prawn growth was terminated in late November when Clam Bay juveniles were significantly heavier (t = 3.61, df = 2,147, P<0.001) (Figure 4) and longer (t = 3.35, df = 2,147, P<0.002) than those at Henderson Inlet. Growth monitoring continued at Clam Bay until March 1975.

Water temperature is an important factor affecting the growth of the spot prawn, and Wickins (1972) indicated that the optimum was at 18° C in the laboratory. During the period from July to September the maximum water temperatures at

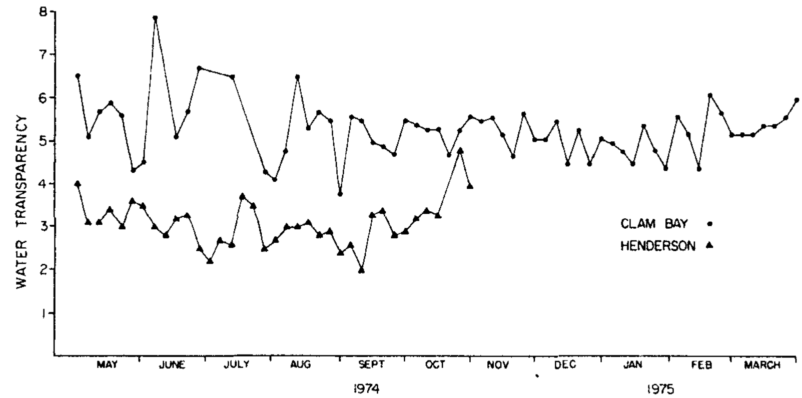

FIGURE 3.—Water transparency (5-d averages) at Henderson Inlet and Clam Bay as measured with a Secchi disc for the period May 1974 to March 1975.

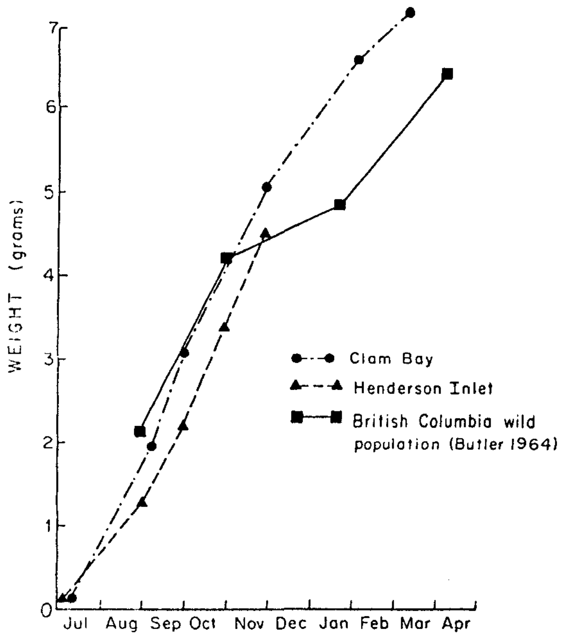

FIGURE 4.—Mean weights of juvenile spot prawns reared in net pens at Clam Bay and Henderson Inlet compared with a wild population in British Columbia (Butler 1964).

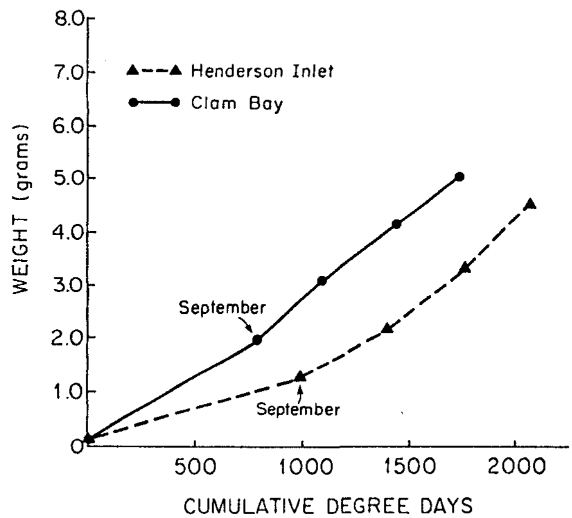

FIGURE 5.—Average weight of juvenile spot prawns as a function of cumulative degree days in the rearing experiments July to December 1974.

Henderson Inlet and Clam Bay were 19.0° and 16.5° C. Daily fluctuations up to 4° C were seen at both sites and the daily surface water temperatures at Henderson Inlet averaged 2.5° higher than at Clam Bay. The weekly mean temperatures never exceeded the optimal 18° C value at either site (Figure 2).

To evaluate the effect of temperature on the growth of juvenile prawns, the mean weight of the prawns was plotted against cumulative degree days (Figure 5). If temperature were the primary variable controlling growth within the prawns' zone of anabolism, then the curves (Figure 5) would be similar; however, this is not the case, as growth was depressed at Henderson Inlet. The slopes of both curves parallel each other after September, indicating that temperature had become the major factor affecting growth. Beginning in September there was a general decrease in water temperature at both sites (Figure 2).

To evaluate the growth of our prawns relative to the growth of wild populations, we compared our data with those of Butler (1964) who studied growth of a wild population in British Columbia. The data indicate the growth rate (increase in weight over time) of the cultured prawns was similar to that of the wild population up to the end of October (Figure 4). After October, the cultured prawns continued to increase in weight at a relatively constant rate until the termination of the study. The wild population showed a decrease in growth rate during the period of late October to the end of January which was followed by a growth rate which approximated that of the cultured group. Water temperature and decreased availability of food are among the many factors which could account for the decreased growth in the wild populations.

At termination of comparative testing in November, total mortality of juvenile prawns was significantly greater ($\chi^2 = 67.2$, df = 1, $P<0.05$) at Henderson Inlet than at Clam Bay (Figure 6). The experiment at Clam Bay was continued to 10 March 1975, when survival was 79%.

We partially attribute the high mortality rate and the reduced growth of juvenile prawns at Henderson Inlet from July to September to plankton blooms. At the time of stocking in early July, water transparency was depressed by a plankton bloom (Figure 3). A 20% mortality occurred during the first 2 wk of July followed by a decrease in the mortality rate after the bloom subsided (Figure 6). During the same period prawns at Clam Bay showed an estimated 2% mortality as determined from semidaily pen examination.

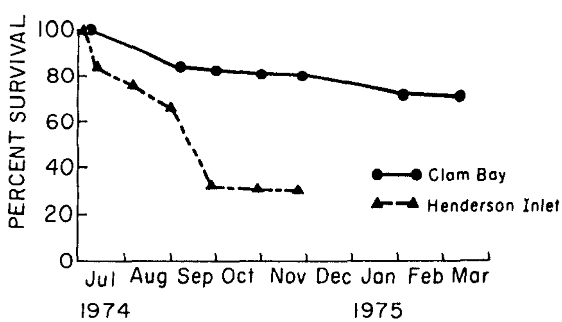

FIGURE 6.—Survival of juvenile spot prawns from July 1974 to March 1975 at Henderson Inlet and Clam Bay.

The mortality of juvenile prawns at Henderson Inlet increased again in early September during blooms of the dinoflagellates, *Ceratium* sp. and *Peridinium* sp. Salmon mortalities also increased in adjacent net pens during this period. Prawn mortalities at Henderson Inlet decreased with the end of the intense plankton blooms in the fall (Figures 3, 6).

Substantial mortalities of Pacific salmon reared in net pens in British Columbia have also been associated with algae blooms. Kennedy et al.[5] suggested that the algae promoted the production of suffocating mucus or physically damaged gills through contact with sharp diatom spicules. At Henderson Inlet the prawns' gills were noticeably blackened and had unidentifiable matter on the lamellae that may have been mucus or deteriorated dinoflagellates.

At Henderson Inlet, during the first 2 wk only, several dead prawns had single lesions—dark in the center and often surrounded by an area of reddish tissue. These lesions were not observed on the prawns at Clam Bay. Lightner and Lewis (1975) found the cuticular injuries from handling of penaeid shrimp resulted in bacterial septicemic diseases. Handling could partly explain the lesions and initial losses of juvenile prawns at Henderson Inlet because the net pens were pulled to the surface frequently to remove old food and dead prawns. This procedure was not followed at Clam Bay where water transparency allowed examination of the prawns in place.

Growth and Survival of Yearlings

No yearling prawns at Henderson Inlet survived in either dietary treatment after the first 2.5 mo (Figure 7). In early June, maximum surface temperatures increased from 11.8° to 21.9° C in 1 wk,

[5]Kennedy, W. A., C. T. Shoop, and W. Griffioen. 1975. Preliminary experiments in rearing Pacific salmon (1973 parr). Environ. Can., Fish. Mar. Serv., Tech. Rep. 541, 17 p. Pac. Biol. Stn., Nanaimo, B.C. V9R 5K6.

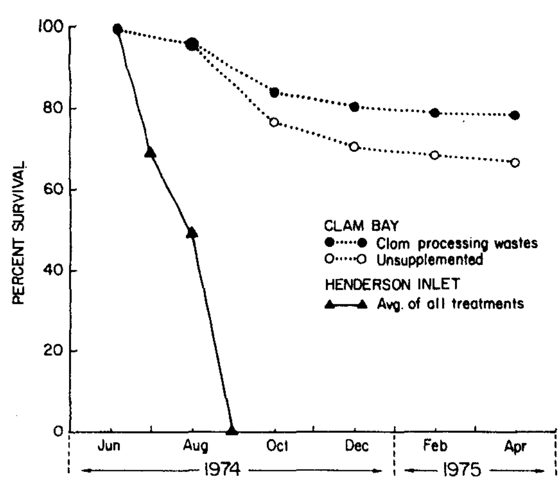

FIGURE 7.—Survival of yearling prawns held in floating net pens at Henderson Inlet and Clam Bay.

and the weekly mean rose about 5° C. As mentioned previously, a plankton bloom also occurred during this period. The rapid rise in water temperature and the onset of plankton blooms were the primary factors associated with the rapid rise in mortality rate of the yearling prawns. Abnormalities in appearance and behavior of the prawns were noted soon after their arrival at Henderson Inlet in June. The prawns became covered with fouling organisms, particularly the hydroid, *Obelia* sp., and the suctorian protozoan, *Ephelota gemmipara*. Heaviest fouling occurred on periopods and ventral edges of the cephalothorax, but the gills were unaffected. Within 2 wk many prawns were dying while survivors seemed lethargic and did not feed or molt. The entire stock was given a formaldehyde/malachite green dip (25 to 0.1 ppm ratio for 8 h), but beneficial effects lasted only a few days.

On 2 July, 49 surviving yearling prawns from one clam-fed replicate at Henderson Inlet were removed from the experiment and placed in a vinyl coated wire mesh cage (0.9 × 0.9 × 0.5 m) that was placed on the bottom of the Inlet, into water that was colder (Figure 2), less lighted, and out of the influence of the surface plankton bloom. Within 2 d the prawns became active and began molting although many still had some fouling organisms. By September, only four mortalities had occurred in the cage (92% survival), while prawns in the surface net pens had suffered 100% mortality. Colder water, reduced light, and the possibility of being out of the surface plankton bloom could explain this increase in survival. There are no natural populations of prawns in the shallow inlets of southern Puget Sound (i.e., those inlets to the west of Henderson Inlet). Berkley (1930) noted that late larval and postlarval prawns in British Columbia were commonly found inshore at depths of 3.7-5.5 m. The adverse conditions encountered in surface waters during this study produced extensive mortalities and could explain the absence of natural prawn populations in the shallow inlets of southern Puget Sound.

Survival of yearling prawns at Clam Bay after 10 mo (5 June 1974-28 March 1975) was 78.6% for clam-fed treatments and 66.7% for unsupplemented dietary treatments (Figure 7). The difference in survival was significant (χ^2 = 9.48, df = 1, P<0.005).

Temperature fluctuations and plankton blooms at Clam Bay were associated with increases in mortality. Over half of the total mortalities occurred in a 2-mo period (August-September) in which the weekly mean temperature rose to a high for the year (14.2° C) and the lowest transparency value occurred (Figures 2, 3). In general, yearling prawn mortality coincided with rapidly decreasing water transparency and increasing water temperature and not the absolute value of Secchi disc readings.

Both treatment groups at Clam Bay grew at essentially the same rate during the June to August period. Thereafter the clam-fed prawns were significantly heavier (t = 10.98, df = 2,539, P<0.00) and longer (t = 3.17, df = 2,539, P<0.001) than the unsupplemented prawns (Figure 8).

Despite the fact that no food was given, the unsupplemented group had a positive growth rate throughout the experiment and a fairly high survival (66.7%). About 60% of prawns sampled at the termination of the experiment had materials in their stomachs, including unidentifiable brown matter, various algae (brown filamentous forms and diatoms, particularly *Riddulphia* sp.), and fragments of exoskeleton from either the prawns' exuviae or naturally occurring crustaceans in the net pens. The prawns had apparently maintained themselves on net fouling and/or pelagic organisms and through consumption of dead prawns or molted exuviae.

Net fouling organisms were preyed upon by prawns in both treatment groups. Commonly seen net fouling organisms (mussels, tunicates, and bryozoans) were noticeably absent from the nets containing prawns after 10 mo of immersion. The only major fouling organisms remaining were hydroids, *Obelia* sp., and small entroprocts (both

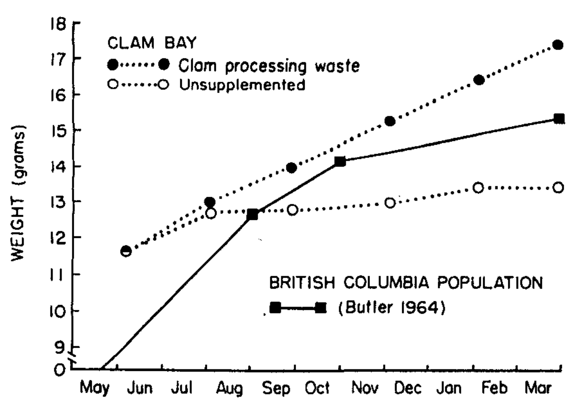

FIGURE 8.—Seasonal mean weight of yearling spot prawns reared at Clam Bay compared with a British Columbia wild population (Butler 1964).

restricted to the top 10 cm of the net). By feeding on net fouling organisms, the prawns not only make use of a free food supply, but they also provide net cleaning services that would reduce pen maintenance.

Molting

The yearling prawns held at Clam Bay showed five major molting peaks. At each peak, a higher percentage of clam fed prawns molted than unsupplemented prawns, but periods of peak molting generally coincided for each group (Figure 9). Two major molting peaks occurred in the summer about 50 d apart. By winter (November-February), the peaks were about 75 d apart, and by spring the intermolt periods were once again shortened to nearly 50 d. A pattern emerged with molting peaks occurring at either 1.6- or 2.5-mo intervals, depending on season. Rickards (1971) found a highly significant relationship between temperature and frequency of molting for tank-reared, juvenile pink shrimp, *Penaeus duorarum*. In the present study, the percentage of prawns molting appears related to temperature (Figure 9), but molt frequency is not related since it increases in late winter while water temperatures are still depressed. A previous study of juvenile prawns concludes that molt frequency decreases with age (Wickens 1972); however, there is no published account for molt frequency of older prawns. Kamiguchi (1971) reported that molt frequency of sexually immature *Palaemon pauciden* decreased with size until maturity when a constant interval between molting peaks was the rule.

In the present study, molting patterns may have been affected by changing photoperiod (Aiken 1969) and maturation as the prawns became functional males midway through the experiment.

In conclusion, surface waters of Henderson Inlet were unsuitable for prawn culture due to intense plankton blooms and rapid fluctuations of water temperature. These factors outweighed the growth stimulating effects of elevated water temperatures. Clam Bay was suitable for prawn culture although moderate mortalities were associated with plankton blooms and increases of water temperatures.

ACKNOWLEDGMENTS

This work was supported in part by the Washington Sea Grant Office and the Weyerhaeuser Company.

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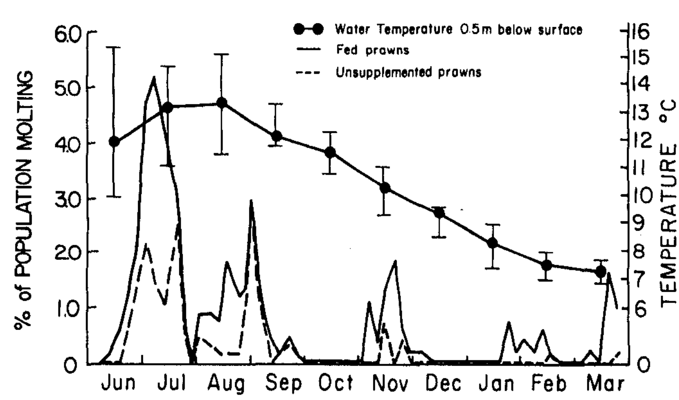

FIGURE 9.—Yearling spot prawn molting cycle 5-d means) and monthly means and ranges of surface water temperatures at Clam Bay.

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