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STANDING STOCK OF JUVENILE BROWN SHRIMP, *PENAEUS AZTECUS*, IN TEXAS COASTAL PONDS

The increased demand for timely information concerning management of shrimp stocks has renewed interest in developing reliable methods of predicting brown shrimp, *Penaeus aztecus*, crop size for the offshore Gulf of Mexico fishery. Advance information regarding shrimp abundance would also enable elements of the shrimp industry to prepare for a potentially good or poor harvest. Studies exploring the feasibility of predicting the annual abundance of brown shrimp off the Texas coast, initiated in 1960 (Baxter 1963), are based on the premise that postlarval and juvenile shrimp abundances are proportionally related to the subsequent commercial harvest (Berry and Baxter 1969).

A "good" predictor is one that is precise, timely, and cost effective. The abundance of postlarval shrimp as they move from the Gulf of Mexico into coastal bays is determined from semiweekly collections made by the National Marine Fisheries Service, Galveston, at the entrance to Galveston Bay between late February and early May (Baxter 1963). The postlarval shrimp index gives the earliest but least reliable indication of potential harvest. A more accurate but less timely prediction is derived from landings of the bait shrimp fishery. Statistics for bait shrimp landings since 1960 provide the basis for a predictive model developed by K. N. Baxter (Klima et al. 1982) defining the relationship between the bait abundance index and subsequent offshore catch. However, this prediction is not available until mid-June, just prior to the seasonal opening, because recruitment of brown shrimp into the bait fishery does not begin until May (Chin 1960). A third possible indicator is the standing stock size of juvenile shrimp in estuarine nursery areas measured before shrimp emigrate and become vulnerable to the bait fishery. This would provide an estimate earlier in the season than the bait index and may be a more accurate predictor than the postlarval abundance. Predictive capability increases with each successive life stage because of the decreased time span between the estimate and subsequent commercial harvest.

To examine the relationship between juvenile brown shrimp standing stock and offshore harvest, and to determine the suitability of juvenile brown shrimp abundance as a predictor, we conducted a mark-recapture study in Galveston Bay, TX, during the first week of June 1983. In this report we summarize the results of our study, compare estimates obtained by mark recapture and an alternative drop sampler method, and discuss previously unreported results of 1970-71 studies (Welker and Baxter[1]).

Methods

Sydnor Bayou is a shallow coastal tidal pond in Galveston Bay (Fig. 1). The site was chosen because the single narrow entrance could be blocked easily with netting, thus preventing immigration and emigration of shrimp during the experiment, and because Sydnor Bayou was the site of a similar study in 1970.

The pond covers 32.4 to 36.4 ha, depending on the tide, is about 0.9 km long and 0.2 km at its widest point, narrowing to 6 m at the mouth. Maximum depth is about 1.5 m at high tide, with a 0.25 m tidal difference. Average salinity during the marking was 20.5 ppt and mean surface temperature was 28°C.

Weekly sampling of Sydnor Bayou with a 3 m otter trawl (25 mm stretched mesh) began 25 April 1983 to monitor the size of the juvenile shrimp. By 23 May 1983, most shrimp caught in the trawl were larger than the 40 mm TL (total length) minimum needed for tagging, and we decided to begin the mark-recapture experiment the next week.

Sydnor Bayou was blocked at dawn on 31 May 1983 across bridge B-1 (Fig. 1) with a 45.7 m net having a 6 mm mesh. The net was anchored to the bottom and remained in place for the duration of the experiment.

A 1.8 m diameter, 0.8 m deep round tank with continuous water flow and two 147 L aerated ice chests were set up on shore to hold shrimp during the marking process. Shrimp were caught in 49 5-min trawl hauls and transported to the marking site in aerated 45 L ice chests. To minimize marking mortality, only shrimp 40 mm TL and larger were marked and held in the large tank. Marking was accomplished by injection with pink fluorescent pigment as described by Klima (1965). Representative length-frequency, species-composition, and sex ratio information was obtained from shrimp captured in one trawl haul.

Marked shrimp were released within the hour after the target number (4,100) had been marked. Shrimp were scattered along the shallow grassy shoreline from moving skiffs. No dead or moribund shrimp were released, and release operations ceased whenever shore birds were attracted.

Four 61 cm × 61 cm × 20 cm wire cages, each containing 25 marked and 25 unmarked shrimp, were set out in the pond and remained submerged through all tidal stages. After 24 h, cages were raised and all shrimp, dead and alive, were counted, measured, and recorded for an estimate of marking mortality.

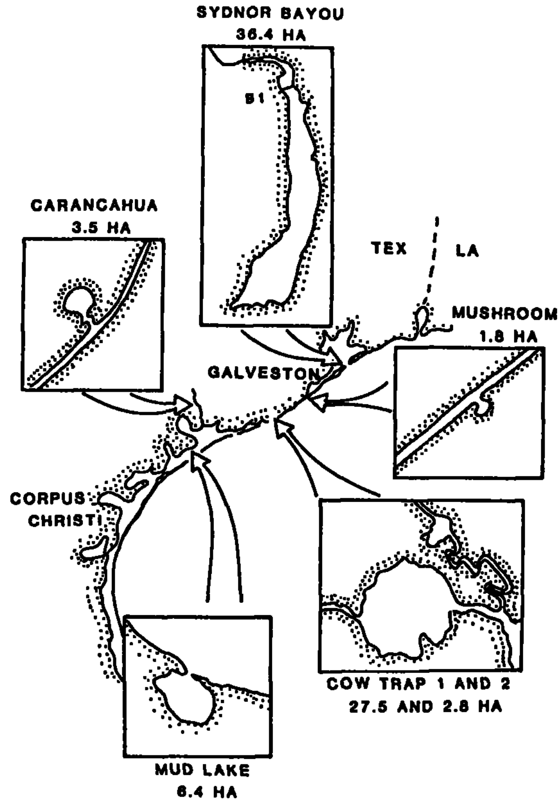

FIGURE 1.—Texas ponds selected for brown shrimp mark-recapture studies: Sydnor Bayou (1970 and 1983); Cowtrap, Mushroom, Carancahua, and Mud Lake (1971).

Recapture trawling began 18 h later, allowing marked shrimp time to distribute themselves in the unmarked population. For three consecutive days, all trawlable bottom was sampled by 5-min trawl hauls. Shrimp were returned to the laboratory where marked shrimp were identified under ultraviolet light. All marked and up to 100 unmarked recoveries were measured per tow. Length-frequency distributions for releases, marked recoveries, and unmarked recoveries are shown in Figure 2.

We estimated an initial population of juvenile brown shrimp using Bailey's (1951) modification of the Petersen formula

[1]Welker, W., and K. N. Baxter. Juvenile brown shrimp population estimates in Texas tidal marsh ponds. Unpubl. manuscr., 8 p. Southeast Fisheries Center Galveston Laboratory, National Marine Fisheries Service, NOAA, 4700 Avenue U, Galveston, TX 77550.

$$N = M \frac{(C + 1)}{R + 1}$$

where M = number of marked shrimp released, corrected for marking mortality,
C = number of shrimp examined for marks,
R = number of recaptured marked shrimp in the sample.

The 95% confidence limits for the true population were estimated using the standard error of the large sample variance formula (Bailey 1951)

$$V(N) = \frac{M^2 (C + 1)(C - R)}{(R + 1)^2 (R + 2)}.$$

Application of this method is justified under the following conditions (Ricker 1975):

1) Marked shrimp suffer the same natural mortality as unmarked.
2) Marked and unmarked shrimp are equally vulnerable to fishing.
3) Marked shrimp do not lose their mark.
4) Marked shrimp become randomly distributed among unmarked.
5) All marks are recognized and reported on recovery.
6) There is not emigration or immigration occurring in the catchable population.

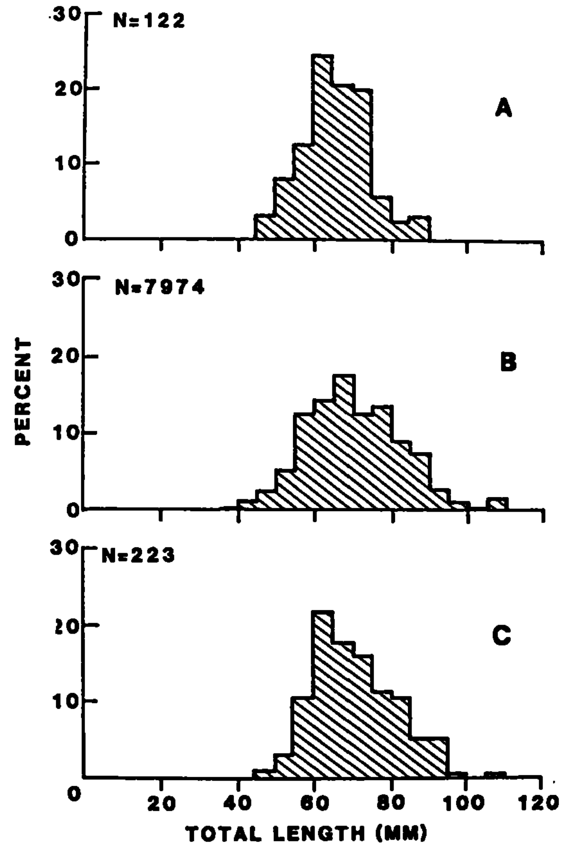

FIGURE 2.—Length-frequency distribution of brown shrimp in Sydnor Bayou, June 1983: A) representative sample of shrimp collected during marking; B) unmarked shrimp caught during recapture operations; and C) marked shrimp caught during recapture operations.

Results and Discussion

Overall marking mortality was 9%. One cage had unusually high mortality. Nineteen of 25 marked shrimp were alive at the end of 24 h, and the only evidence of the other 6 marked shrimp was pieces of exoskeleton. They apparently molted and were cannibalized. Holt (1982) suggested that the condition of shrimp prior to tagging dictates the survival of the tagged animals. When stressed animals were tagged, mortality more than doubled. Howe and Hoyt (1982) hypothesized that tags and marks may indirectly cause mortality by attracting predators. Farmer and Al-Attar (1979) found shrimp marked with subcutaneous pigment suffered high mortality (compared with controls) only when held with unmarked conspecifics. Clark and Caillouet (1973), however, found negligible marking mortality in a mark-recapture experiment with white shrimp, *P. setiferus*, when 50 marked and 50 unmarked control shrimp were held in a large pen in a pond rather than in several small cages. Costello and Allen (1962) stated that stained shrimp may be expected to survive at essentially the same rate as unmarked shrimp, regardless of presence of predators. To avoid overestimating marking mortality, we did not include the counts in the high cage in the calculation. The resulting 4% (3 dead marked shrimp out of 75) was similar to the marking mortalities of past studies in Sydnor Bayou, Mud Lake, and Mushroom (Welker and Baxter fn. 1).

1983 Population Estimate

A total of 223 marked shrimp were among 12,304 shrimp caught in 94 recapture tows. Tides during the recovery period were low in the morning, approaching high tide in the afternoon. Areas along the shore and the south end of the bayou were shallow for trawling in the mornings, but could be adequately sampled in the afternoon. Distribution of marked shrimp was random (one-sample runs test, $P = 0.960$; Siegel 1956).

The population estimate of 207,786 shrimp determined from mark-recapture data compared favorably with the results of a concurrent drop sampler experiment (Table 1). Shrimp densities were obtained using a 2.8 m^2 drop sampler at high tide. Detailed methodology has been described by Zimmerman et al. (1984). Drop samples were taken in two sets, four pairs each, in vegetated and nonvegetated areas, divided between the south and north ends of the bayou. Vegetated habitat was sampled along the bayou margins, while nonvegetated area sampling was in open waters of the bayou. Numbers of shrimp within the sampler were extrapolated to represent the shrimp population in the vegetated, nonvegetated, and total areas of Sydnor Bayou. Confidence intervals for the drop sampler were much wider than those for Petersen estimate because drop sampler estimates were based on a small number of samples. The drop sampler estimate for 36 ha was higher by about 92,000 shrimp. One reason for this difference is that the mark-recapture estimate reflects only that part of the population >40 mm TL, while the drop sampler measures density of small (<40 mm) shrimp more effectively, and these small shrimp are included in the estimate (Table 2). We calculated the drop sampler population estimate using only shrimp larger than 40 mm TL (Table 1). A chi-square test shows a significant difference between the drop sampler and mark-recapture size-frequency samples, categories 41-50 mm and higher ($\chi^2 = 109.45$, df = 6, P very small). The high chi-square value is due mainly to the greater number of 41-50 mm shrimp and the lower number of larger shrimp (81-90 mm), which may avoid the sampler, in the drop sample. Length-frequency composition of the drop sampler catch indicates that 23% of the 103 shrimp taken were smaller than 40 mm TL, while no shrimp smaller than 40 mm were captured by the otter trawl.

TABLE 1.—Sydnor Bayou brown shrimp population estimates determined by mark-recapture and drop sampler methods, June 1983.

Method	Estimated population	95% C.I.
Mark-recapture[1]		
32.4-36.4 ha	207,786	180,884-234,688
Drop sampler		
32.4 nonvegetated ha	185,000	41,900-479,000
4.0 vegetated ha	115,000	49,000-248,000
36.4 total ha	300,000	90,800-727,000
Drop sampler[1]		
32.4 nonvegetated ha	157,000	113,000-423,000
4.0 vegetated ha	88,000	53,500-183,000
36.4 total ha	245,000	166,000-606,000

[1]Estimate of shrimp population >40 mm TL.

TABLE 2.—Length-frequency composition of Sydnor Bayou brown shrimp samples taken with the otter trawl (N = 8,197) and drop sampler (N = 83), 1-3 June 1983.

Length (mm)	Otter trawl (%)	Drop sampler (%)
<20	0.0	9.7
21-30	0.0	1.9
31-40	0.0	11.7
41-50	3.8	19.4
51-60	17.3	19.4
61-70	32.2	22.3
71-80	25.7	12.6
81-90	16.0	1.9
91-100	4.2	0.0
>100	0.6	0.8

1970-71 Population Estimates

Our methodology for conducting a Petersen single census mark-recapture experiment with juvenile brown shrimp was developed during June and July 1971 studies of five Texas coastal ponds (Fig. 1). All ponds ranged from 0.3 to 0.9 m in depth during a normal summer tidal cycle. Cow Trap 1 and 2 had considerable emergent vegetation along their shorelines and were part of a large marsh complex. Extensive flooding of the marsh surrounding these ponds at flood tide greatly increased the area accessible to shrimp, but this shallow, vegetated area could not be sampled. Shrimp could move from pond to pond via flooded marsh and ditches, rendering block nets ineffective. Evidence of this movement was the netting of marked shrimp released in Cow Trap 1 and recaptured in Cow Trap 2. These problems precluded reasonable population estimates for the Cow Trap ponds, and large marsh complexes were avoided for future studies of this type.

Mud Lake, Carancahua, and Mushroom had generally well-defined shorelines, even during flood tide, and were not contiguous with other ponds or ditches. Mark-recapture methods were essentially the same as described for the 1983 study. Marking and holding operations were conducted on a portable barge rather than from shore (Emiliani and Marullo 1973). Population estimates determined by Bailey's (1951) formula ranged from 7,490 to 17,119 brown shrimp per hectare (Table 3). The lowest estimate was recorded in Mud Lake, where the highest percentage of total catch was <40 mm TL, while the highest estimate was for Carancahua. The density in Mushroom was close to that in Carancahua.

Although marking methods differed, a 1970 mark-recapture study in Sydnor Bayou provided a population estimate for comparison. Marking was accomplished by spraying shrimp >40 mm TL with granular fluorescent pigment (Benton and Lightner 1972). Data analysis was as described for the 1983 Sydnor Bayou study. The average density of shrimp in Sydnor Bayou during the 1983 study was 37% of the May 1970 density and was the lowest per hectare estimate of any pond previously sampled (Table 3).

We believe that juvenile brown shrimp population density, determined by the mark-recapture method, may prove to be a good predictor of offshore production as we compile a longer term data base. Although the drop sampler (area-density method) may measure shrimp density more accurately, the Peterson mark-recapture method gives a more precise (having less variance) population estimate.

Acknowledgments

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TABLE 3.—Summary of juvenile brown shrimp population studies in Texas coastal ponds.

Location	Start date	Number 5-min tows	Number shrimp caught	Percent <40 mm	Number marked and released	Percent released and recovered	Percent marking mortality	40+ mm population per hectare	95% confidence interval[1]
Sydnor Bayou									
32.4 ha	5/31/83	49	5,188	0.3	3,994	5.9	4.0	6,412	5,583-7,244
36.4 ha								5,709	4,970-6,448
Sydnor Bayou									
32.4 ha	5/21/70	32	8,045	—	7,718	1.7	4.0	17,933	14,198-20,042
36.4 ha								15,238	12,637-17,839
Mud Lake									
6.4 ha	6/3/71	27	6,750	20.0	6,120	10.8	4.0	7,490	6,956-8,025
Carancahua									
3.5 ha	6/7/71	26	6,301	7.0	4,574	9.8	8.0	15,697	11,815-17,087
Mushroom									
1.8 ha	7/2/71	24	8,348	6.0	4,142	28.8	4.0	14,375	13,628-15,120

[1]Bailey (1951) large sample variance.

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A POSSIBLE LINK BETWEEN COHO (SILVER) SALMON ENHANCEMENT AND A DECLINE IN CENTRAL CALIFORNIA DUNGENESS CRAB ABUNDANCE

Dungeness crab, *Cancer magister*, are taken commercially along the west coast of the contiguous United States from Avila, CA, to Destruction Island, WA (Fig. 1). During the early years of the California Dungeness crab fishery, effort was concentrated on the central California population which produced most of the state's landings (Fig. 2). The northern population subsequently became the major contributor to California's landings after an expansion of the fishery there during the 1940's.

Northern California landings (Fig. 2) generally have followed a fluctuating pattern similar to one expressed in Oregon and Washington; however, landings from the relatively isolated central California population failed to recover from a coastwide low during the early 1960's. The lower landings reflect a long-term reduction in abundance which has been variously attributed to egg predation by a nemertean worm *Carcinonemertes errens* (Wickham 1979) and to the effects of a long-term change in oceanic conditions (Wild et al. 1983).

The failure of the central California population to recover from the coastwide period of low abundance also occurred about the time coho salmon, *Oncorhynchus kisutch*, reared in Oregon and Washington hatcheries began to make a significant contribution to the west coast salmon fishery (Oregon Department of Fish and Wildlife 1982). The effect of salmonid predation on commercially important marine crustaceans has received little attention, although it is suspected that predation by salmonids introduced into a number of both small and large freshwater lakes (Nilsson 1972; Morgan et al. 1978) has substantially altered the abundance and species composition of their planktonic crustacean communities. Since numerous salmonid food habit studies (Heg and Hyning 1951; Petrovich 1970; Reilly 1983a) show that planktonic Dungeness crab megalops are a major component of the coho salmon diet, it is conceivable that an increase in the coho predation rate associated with an influx of hatchery coho into the central California region is at least partially responsible for the prolonged decline in Dungeness crab landings.

In this paper I first present evidence showing that a large portion of the coho salmon ultimately caught each summer off the west coast are in California waters during spring, the period Dungeness crab megalops are most abundant. I then compare and contrast survival indices to determine if the temporal variation in survival of both species is consistent with the predator-prey hypothesis.

Oregon Production Index Area Coho

Each spring and summer, a single coho salmon brood (year class) is recruited to the commercial salmon fishery off California, Oregon, and southern Washington, an area collectively referred to as the Oregon Production Index area or O.P.I. area (Oregon Department of Fish and Wildlife 1982). These fish entered the ocean to feed in May and June of the previous year, after having spent about 18 months in freshwater. Coho caught in the O.P.I. area before 1961 (Fig. 3) were predominately wild stocks. These stocks had declined to extremely low levels by 1960; however, the successful introduction of Oregon and Washington hatchery-reared coho resulted in a return to historical landing levels during the 1960's and 1970's. Much of the hatchery fish responsible for the increased landings are derived from early return Toutle River coho, which tend to enter fisheries south of their stream of origin (Hopley 1978).

Coho salmon made up only 10% or less of California's ocean salmon catch prior to the development of Oregon and Washington enhancement programs (Fry 1973). Most of these wild coho originated in the streams and rivers of Oregon and Washington (Allen 1965) and were landed primarily in the northern California ports of Crescent City and Eureka. The recruitment of hatchery fish increased the average annual coho contribution to 25% of the total ocean salmon catch, with the central California ports of San Francisco and Fort Bragg accounting for a considerably larger portion of the total coho catch.