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[Management Brief]

Spatial Allocation of Shrimp Catch Based on Fishing Effort: Adjusting for the Effects of the Texas Opening

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Abstract.—Estimates of fishing effort for the Gulf of Mexico penaeid shrimp fishery depend on the ability of National Marine Fisheries Service port agents to accurately assign fractional catches within a fishing trip to 5-fathom-depth bins within 21 Gulf of Mexico statistical areas. In previous studies, we showed that the method used for assigning landings was inaccurate and developed an algorithm for assigning landings based up observer and captain's logbook data on fishing effort and catch. The resulting algorithm explained over 92% of the variance in actual catch. Results of regression analyses of new observer data collected for over 7,700 tows confirm that the algorithm provides reliable estimates of fractional catches associated with the different subareas fished within a trip (adjusted $r^2 = 0.96$ when 11 outliers are removed from 1,845 observations). Nine of the 11 outliers occurred within a month of the Texas opening, a period when catches are initially high but then decay rapidly. Here, we have incorporated this decay as part of the allocation algorithm for this period. The agreement of expected and actual shrimp catch declined slightly from the regression with outliers removed (adjusted $r^2 = 0.95$). Nevertheless, we suggest that data from this period should be modeled separately to better evaluate the consequences of management actions that might be taken during the Texas opening time frame.

In cooperation with the National Marine Fisheries Service (NMFS) and the Gulf and South Atlantic Fisheries Foundation (GSAFF), Gallaway et al. (2003a) developed a simple electronic logbook (ELB) that uses global positioning satellite technology to map the location and amount of fishing effort for selected vessels in the Gulf of Mexico (Gulf) offshore penaeid shrimp fishing fleet. As described in Gallaway et al. (2003a), these data enable one to assign shrimp catch to the areas fished (e.g., statistical area and 5-fathom-depth bins) and calculate the corresponding catch per unit effort (CPUE) values. These data can be used to calculate more accurate estimates of total fleet fishing effort and to allocate catches to subareas for comparison with similar estimates obtained with the historical methodology.

Historically, NMFS port agents have allocated penaeid shrimp effort and catches to specific depth zones or cells within standard statistical areas (Patella 1975), based on limited interviews with shrimp fishermen and personal knowledge of fishing patterns (Nance 1992; Gulf of Mexico Fishery Management Council [GMFMC] 1994). Comparison of the two methods showed that the historical system was inadequate for describing the temporal/spatial patterns of shrimp fishing effort and the corresponding catches in the Gulf (Gallaway et al. 2003b). The historical method provides a single estimate of effort for each geographic cell but does not allow for estimates of error. When compared with observer data, the results of the ELB method of catch allocation more accurately reflected the distribution and magnitude of effort and catch in subareas of the Gulf. On the basis of these results, the NMFS and the GMFMC adopted the ELB approach and NMFS funded a 5-year program to refine and implement the ELB methodology.

Gallaway et al. (2003a) used paper logbook data and a limited amount of NMFS-sponsored observer data gathered in 1999 and 2000 to demonstrate that penaeid shrimp catch in a statistical area–depth zone combination within a trip could be reliably predicted by multiplying the effort within any specific zone by the mean CPUE for the overall trip. When the 139 observer data trip and zone combinations of actual catch were regressed against the predicted or expected catch by the proposed model, the results were significant ($P < 0.0001$), the intercept was not significantly different from 0 ($P = 0.86$), the slope was approximately equal

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to 1, and the adjusted r^2 value was 0.9212. Similar results were observed from analyses of the paper logbook data. Despite the apparent good agreement between actual and predicted catches, however, some viewed the algorithm with skepticism. Testing the hypothesized algorithm required new data, as all available data had been used in the initial analyses.

The ELB was not designed to record the fractional catch per tow within a trip (Gallaway et al. 2003a). However, the total pounds of penaeid shrimp landed from each trip are obtained from dealers and recorded by NMFS port agents. These trip landings can be matched with the corresponding ELB records for that trip. Our hypothesis is that vessels spend more time in zones with greater catch rates than in zones with lower catch rates. If this is true, then the portion of the total landing taken in each zone within any single trip should be directly proportional to the time fished within each zone. If reasonable agreement is obtained between the actual catches recorded within zones and the corresponding estimated catches based on time fished and total catch alone, the inexpensive ELB can be used to allocate landings reliably to statistical area and depth zones and to calculate area CPUEs.

Beginning in 2000, NMFS expanded both their observer studies and those they sponsored in conjunction with the GSAFF. These studies have produced a considerable body of new data (total records include observations for over 7,700 tows from 330 trips), thereby enabling us to test the catch allocation algorithm with this additional information. The expanded data set also includes records from 29 trips that began on or during the Texas opening, a time when shrimp catches are exceptionally high for a short period. This article provides the results of the expanded analyses.

Methods

Data from all of the NMFS-sponsored observer programs were obtained from the NMFS Galveston Laboratory. These files included data from 10 different studies and contained 7,721 tows for which location (latitude and longitude), duration (hours fished), and shrimp catch (pounds of tails) were recorded. Some of the records included penaeid shrimp catch for each of the nets towed, whereas some recorded catch for a subset or combination of the nets towed. Data were standardized to catch per net per hour. When these values were multiplied by effort for each tow and summarized within trip by zone fished, the data constituted the "actual-catch" data set.

The "expected-catch" data set was calculated by multiplying the effort in each zone by the overall CPUE for the trip (Gallaway et al. 2003a):

$$\text{expected zone catch} = \Sigma \text{ trip effort in zone} \times (\text{total landings on trip}/\text{total effort on trip})$$

Actual catch was then regressed on expected catch. A combination of standardized residuals, difference-from-fitted-values statistic (DFFITS), and Cook's distances (Draper and Smith 1998) were examined to identify and remove outliers and very high leverage points that unduly influenced the observed relationships. Observations that had standardized residuals greater than 5 or less than −5 were treated as outliers.

Of the 11 identified outliers, 9 represented tows on trips that had started in Texas waters within a month of the opening of the Texas penaeid shrimping season. Accordingly, a model was developed specifically for this time frame in an attempt to improve the overall algorithm. This model was based on the observation that remarkably high CPUE at the opening of the Texas shrimping season was followed by an exponential decay in catch rate over the first 30 d of fishing.

The observed exponential decay in daily CPUE was modeled according to Venables and Ripley (2002) and Krebs (1998) with use of a reciprocal transformation (1/[day number + 2]). The model coefficients, along with overall trip catch rate and trip length, were used to calculate the CPUE for each day fished on the trip. For the 29 trips starting at or within a month of the Texas opening, the daily CPUE was multiplied by the number of hours fished for each tow made on that day to yield expected catch by statistical/depth zone. These values were summed by zone fished for each trip. For the other 301 trips, we used the method of Gallaway et al. (2003a) and multiplied the hours fished in each zone by the overall trip CPUE (see equation).

Analyses were performed with the statistical program R, an open-source version of S-Plus, available under the GNU Public License (R Development Core Team 2004).

Results and Discussion

At the time of these analyses, the observer database contained information from 7,721 tows made over the course of 330 trips (Table 1). These observations reduced to a total of 1,845 trip–zone combinations, of which 216 (11.7%) were made on trips that started within 1 month after the Texas opening.

The regression of actual catch on expected catch, based on all 1,845 data pairs, was significant ($P < 2 \times 10^{-16}$), with an adjusted r^2 of 0.928. The intercept was not significantly different from 0 and the slope was approximately 1 (0.997). The analysis detected 11 outlier observations. When these were removed, the adjusted r^2 for the resulting regression increased to 0.962 (Figure 1). Again, the resulting intercept was not

TABLE 1.—Summary of observer information (trips, tows, and trip–zone combinations) made during two time periods. The Texas opening period includes data within 30 days of the opening and the rest of the year is included in the non–Texas opening period (335 days).

Period	Trips	Tows	Trip–zone combination
Texas opening	29	1,013	216
Non–Texas opening	301	6,708	1,629
Total	330	7,721	1,845

significantly different from 0, and the slope was 1.01. With or without inclusion of the outliers, the regression results confirm that the original algorithm (Gallaway et al. 2003a) provides reliable estimates of the fractional catches associated with the different areas fished within a trip.

Nine of the 11 observations identified as outliers occurred on trips that began on or within 30 d of the Texas opening. The Texas opening is a major event in the penaeid shrimp fishery of the Gulf. Both federal and state waters offshore the Texas coast are closed to shrimping from mid-May to early to mid-July. This allows shrimp that are migrating from estuarine nursery areas to offshore habitats to attain larger sizes of greater economic value before being harvested (Nance et al. 1989, 1990, 1994; Nance 1996). When these waters are opened to shrimping in July, a high proportion of the entire Gulf shrimp fishing fleet moves into Texas waters to reap the benefits of high densities of relatively large shrimp. However, the initial high

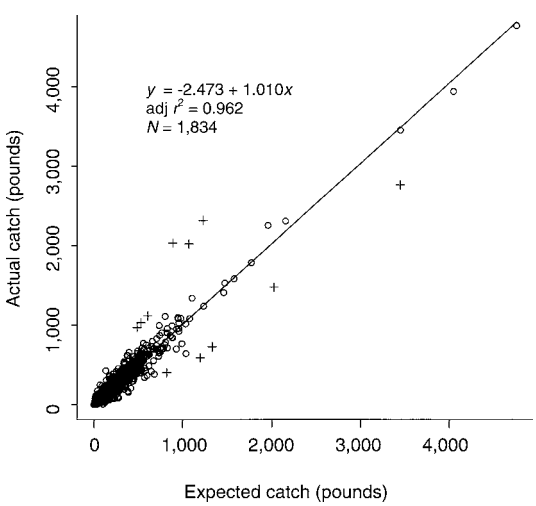

FIGURE 1.—Regression of actual catch on expected catch with no adjustment for Texas opening. The + symbol represents extreme outlier values identified by standardized residual values greater than 0.5 or less than −0.5.

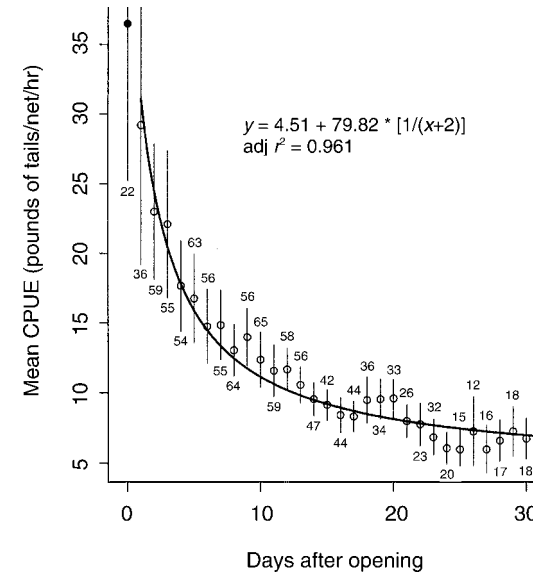

FIGURE 2.—The decay in catch per unit effort (CPUE) values (pounds of tails/net per hour) after the opening of the Texas shrimping season versus the number of days after the opening. The mean catch and 95% confidence intervals are shown by the open circle and vertical lines; the numbers reflect the number of tows on which the mean is based. The filled circle represents an outlier removed from the analysis because of undue leverage (Cook's distance > 8).

densities decrease rapidly, as evidenced by a plot of the mean daily catch rates based on the observer data collected during this period (Figure 2). The model describing these data had an adjusted $r^2 = 0.961$; the intercept was 4.51 (SE = 0.267) and the slope was 79.82 (SE = 2.669).

Using this model, we estimated the expected catch for 216 of the total 1,845 observations for trips that began on or during the first 30 d of the opening; the expected catch for the remaining 1,629 observations was estimated with the base model. When actual catch was regressed on expected catch by using the combination of the two models (Figure 3), the adjusted r^2 was 0.947, the regression had a slope near 1 (0.989) and the intercept (0.035) was not significantly different from 0 ($P = 0.98$).

Because the original algorithm used to assign fractional catch levels to individual zones explains over 92% of the observed variance in catch, and the adjusted r^2 can be improved to over 96% by removing a small number of outliers (11 of 1,845 observations), why should one model the brief Texas opening period as a separate entity? The brief period following the Texas opening is characterized by the highest annual catch rates and the highest total catches that will occur

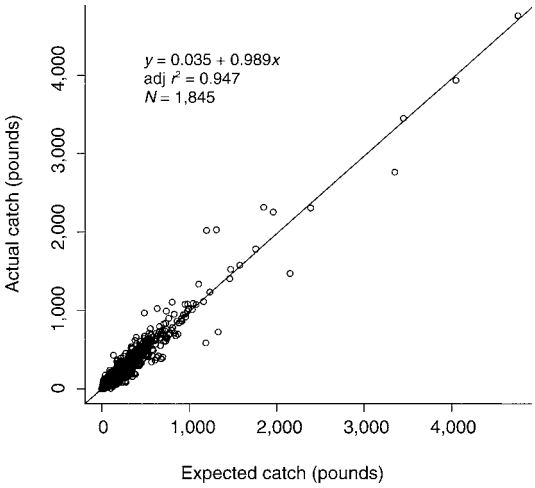

FIGURE 3.—Regression of actual catch on expected catch according to the model adjusted for the Texas opening.

at any time during the course of a given year. The success of the season and the annual economics of the fishery are highly influenced by what occurs during this 1-month period. Further, a substantial fraction of the entire Gulf penaeid shrimp fishing fleet is consolidated in Texas offshore waters during this period. This aggregation may result in an increase in bycatch offshore Texas, but a corresponding decrease in bycatch would be expected in other areas. Given these considerations, and the corresponding importance of any management actions that might be proposed for this time or region, we deem prudent to maintain as much realism in the model as possible.

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