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Species Composition and Seasonality of the Smallest Size Class of Shrimp in the Tortugas Fishery of Florida

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Shrimps from the smallest commercial size class (68 or more heads-off shrimp per 454 g) were analyzed from samples collected at the Tortugas fishing grounds from March 2002 through March 2004. Pink shrimp *Farfantepenaeus duorarum* and yellow roughneck shrimp *Rimapenaeus similis* occurred together in 90% of the samples, comprising 65.4% and 27.2% of individuals, respectively. Estimates of the proportion and seasonality of both species in the shrimp samples were combined with an analysis of the smallest size class in the Tortugas landings data. Our analysis suggested that yellow roughneck shrimp make up 23.6% by number of the smallest shrimp catch and constitute 6.6% by weight of total shrimp landings, very similar results to those from 1959. Results also indicated that there was a significant difference in the seasonality of each species during the collection period. A follow-up study of this unreported yellow roughneck shrimp is recommended to ensure sound data and good management for this important fishery.

The Tortugas shrimp fishery covers approximately 10,000 km^2 between Key West, FL, and the Dry Tortugas in the Gulf of Mexico. The fishery began in 1949 and soon became a major industry. Landings have been valued at as much as $35 million annually (Nance and Patella, 1989). Monthly shrimp landings from the Tortugas fishery (which is typically seasonal) have ranged from 0.6 million kg to less than 0.1 million kg (Klima and Patella, 1985). The Tortugas shrimp fishery is directly dependent on the recruitment of young shrimp that migrate from the main nursery grounds of Florida Bay and the lower southwest Florida mangrove estuaries onto the fishing grounds (Costello and Allen, 1966). In 1981 the Gulf of Mexico Fishery Management Council (GMFMC) established the Tortugas Shrimp Sanctuary, closing a portion of the fishing grounds from trawling to protect small-size shrimp (Klima and Patella, 1985; Roberts, 1986). In the mid 1980s the Tortugas fishery experienced a severe decline in catch-per-unit-effort (CPUE) and landings (Sheridan, 1996). CPUE, although variable, has been stronger since then; however, landings have decreased recently because of decreased effort (Hart, 2008).

Since the early 1960s the Fishery Information Management Division at the National Marine Fisheries Service (NMFS) Southeast Fisheries Science Center Fisheries Service of the National Oceanographic and Atmospheric Administration (NOAA) has maintained a shrimp fishery database. Those shrimp landing statistics are classified in terms of the number of heads-off shrimp (''tails'') counted to 454 g (1 pound) and so categorized in eight ''size-count'' categories (Kutkuhn, 1962b; Klima et al., 1986). Higher counts indicate that more (and therefore, smaller) shrimp make up a given weight. The weighted average of the number of pink shrimp per 454 g has been used as a descriptive parameter when analyzing data for the fishery (e.g., Klima and Roberts, 1986; Ehrhardt and Legault, 1999).

The Tortugas shrimp fishery has been managed as a single-species fishery for the pink shrimp *Farfantepenaeus duorarum*. However, other shrimp genera and species enter the commercial catch. These include the yellow roughneck shrimp *Rimapenaeus similis* (formerly *Trachypenaeus similis*) and its congener the roughneck shrimp *Rimapenaeus contrictus*; three species of rock shrimp, *Sicyonia dorsalis*, *Sicyonia typica*, and *Sicyonia brevirostris*; and the oceanic shrimp *Solenocera atlantidis* (Eldred, 1959a; Ingle et al., 1959). Roughneck shrimp species are seldom the object of a directed commercial fishery in the Gulf of Mexico because of their small size, although some Indo-Pacific species support a commercial fishery (Dall et al., 1990).

Roughneck shrimp species resemble pink shrimp in body shape and color, but can be easily distinguished on the basis of morphological features (Pérez-Farfante, 1969; Williams, 1984; Pérez-Farfante, 1988; Pérez-Farfante and Kensley, 1997). Prior studies on the Tortugas fishery indicated that yellow roughneck shrimp made up 23% of the total number of shrimp caught (Eldred, 1959a; Ingle et al., 1959). Examination of frozen shrimp samples from the Tortugas grounds packed in Tampa indicat-

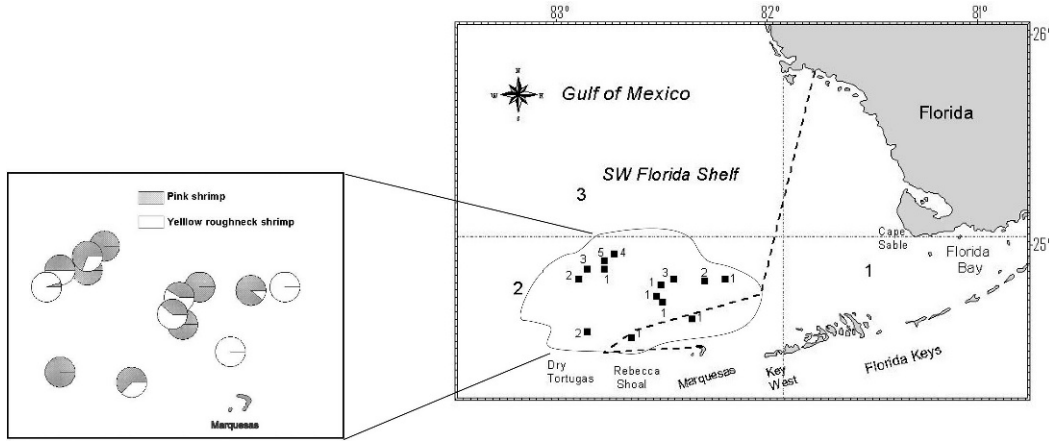

Fig. 1. Map of the study area showing the Tortugas fishing grounds (enclosed area in continuous line) within the NMFS shrimp statistical subareas 1–3; the area lying between the coastline and the long dash lines represents the Tortugas Shrimp Sanctuary; dark rectangles are locations where shrimp of the smallest size class were collected by commercial vessels from March 2002 through March 2004 with the number of samples collected at each location above the rectangles; pies in the blowup map represent percentages of pink shrimp and yellow roughneck shrimp at each location.

ed that the proportion of yellow roughneck shrimp was 25% (Eldred, 1959b). Furthermore, Eldred (1959b) found that roughneck shrimps (i.e., both species) were nearly as abundant as pink shrimp from Jan. through March 1959.

Despite the demonstrated occurrence of *Rimapenaeus* species in the Tortugas fishery, that genus historically has not been differentiated from pink shrimp in commercial markets or in fishery statistics. When the GMFMC established a plan for management of the Tortugas fishery in 1980, no species-specific regulations were included (GMFMC, 1980). The purposes of this study were i) to examine the species composition of shrimp from samples of the smallest commercial size class of the Tortugas fishery to compare with and update older published research; and ii) to estimate seasonality and proportions of pink shrimp and yellow roughneck shrimp in samples of the smallest size class of shrimp and in the Tortugas shrimp landing data and then to evaluate whether the fisheries data for the smallest size class might be compromised by the unnoted inclusion of another species.

Materials and Methods

Penaeid shrimp that would fall within the smallest commercial size class (''small shrimp'') of 68 or more heads-off shrimp per pound (454 g) were examined for this study. Small shrimp were the focus of our study because they are the only size category where the yellow roughneck shrimp, because of its small maximum size, could be expected to be found (Eldred, 1959a; Ingle et al., 1959). Shrimp were acquired from routine trawling operations of four vessels, *Carol Jean*, *Miss Ashley*, *Equalizer*, and *Sea Island Lady*, fishing within the historical limits of the Tortugas fishery, statistical subarea 2 (Fig. 1) of the NMFS shrimp database. The commercial shrimp trawlers used standard otter trawl nets (mesh size ~3.8 cm). Crew members visually sorted the catch into commercial size classes as part of their usual on-deck routine and reserved a sample from the smallest size class for our analysis. Our samples were subjected to the same sorting on the vessel that is applied to all the shrimp in the fishery. The fishery-dependent database and stock assessments are likewise entirely dependent upon that same manner of sorting.

The samples were held onboard (by freezing, or packed in ice) until the vessel unloaded at the dock. The NMFS port agent picked up the samples and sent them to the NMFS laboratory at Miami. Information from the captain on date and latitude and longitude of capture were included with all samples. Although pink shrimp are often graded into commercial size categories on the basis of heads-off weight, small shrimp are usually marketed ''heads-on.'' Hence, the shrimp we examined were intact, and the heads had not been removed by the crews. A total of 28 samples containing between 20 and 150 shrimp each was collected monthly from March 2002 through March 2004. In June 2002, April 2003, and March 2004 more than one sample was collected per month. Only one sample was collected from each trip, although more than

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TABLE 1. Species composition, abundance, size, and weight of the smallest commercial size class of shrimp collected at the Tortugas fishing grounds from March 2002 through April 2004 by commercial vessels. Abundances are given in number of females (♀), males (♂), and percentages (%). Total length (TL), carapace length (CL), and total weight (TW) are mean ± SD.

Species	Abundance		TL (mm)	CL (mm)	TW (g)
	Number	%			
Pink shrimp (*Farfantepenaeus duorarum*)	517♀, 878♂	65.4	102.8 ± 16	25.3 ± 5.2	6.9 ± 4.8
Pink spotted shrimp (*Farfantepenaeus brasiliensis*)	4♀, 5♂	0.4	147 ± 34	36.6 ± 8.4	29.5 ± 16
Yellow roughneck shrimp (*Rimapenaeus similis*)	580♀, 0♂	27.2	68.7 ± 8.1	18.6 ± 2.7	2.6 ± 0.9
Roughneck shrimp (*Rimapenaeus constrictus*)	13♀, 0♂	0.6	63 ± 9.7	19.5 ± 6.4	1.5 ± 0.2
Oceanic shrimp (*Solenocera atlantidis*)	90♀, 46♂	6.4	57 ± 11	14.4 ± 3.0	1.3 ± 0.4

one trip was made to some of the same locations (Fig. 1).

Shrimp were identified to species following morphological descriptions and keys available in the literature (Eldred and Hutton, 1960; Pérez-Farfante, 1969; Williams, 1984; Pérez-Farfante, 1988). Shrimp of each species were counted and sexed, and the presence of spermatophores (sperm-bearing structures) and sperm plugs (structures inserted after the sperm is deposited) were recorded.

To determine the length-to-weight relationship of the two shrimp species from the smallest size class, 360 pink shrimp and 307 yellow roughneck shrimp were randomly selected from the samples. Shrimp were measured for total length (TL), carapace length (CL), and whole weight. Measurements were examined for normality and homogeneity of variance. The main trend of data satisfied the normality assumption (Shapiro–Wilk test, $P > 0.8$). Separately, 50 yellow roughneck shrimp were randomly weighed whole and with the head removed to establish a tail-to-whole-weight relationship for this species. A linear regression was used with the least-square method.

A generalized least-square model with maximum likelihood solution (S-PLUS, 2005) was used to determine the seasonality of the proportions of pink shrimp and roughneck shrimp in our samples. The significance of the model was determined from type III sums of squares analysis of variance (ANOVA) (Sokal and Rohlf, 1998).

The proportion of pink shrimp (P_p) in each quarter was

$$P_p = \text{Backtrans}\,(Y),$$

where Y was the arcsine of the proportion of pink shrimp in each sample.

The proportion of yellow roughneck shrimp (P_y) in the samples was

$$P_y = 1 - P_p.$$

To examine the incidence of the yellow roughneck shrimp within the smallest commercial size class of the Tortugas shrimp catch, landings data of statistical subarea 2 from the NMFS database (F. Patella, unpubl. data) were analyzed for the 2-yr period April 2002 through March 2004. Data were analyzed by quarter of the year to determine the 2-yr total catch of small shrimp for each quarter and to compare the relative magnitude of this catch among quarters.

To estimate the incidence of pink shrimp (C_p) and that of yellow roughneck shrimp (C_y) within landings of the size category of small shrimp we calculated the product of the proportion of pink shrimp (P_p) and yellow roughneck shrimp (P_y), respectively, in our samples, multiplied by the catch of small shrimp by quarter of the year (C_Q):

$$C_p = P_p C_Q, \text{ and } C_y = P_y C_Q.$$

The proportion of yellow roughneck shrimp in the total catch (all sizes) was determined as the sum of C_y for all four quarters divided by the sum of the total shrimp catch for all four quarters.

RESULTS

A total of 2,133 penaeid shrimp belonging to three genera and five species was identified in our samples (Table 1). Pink shrimp was the most abundant species, comprising 64% of the specimens examined. Its congener, the pink spotted shrimp *Farfantepenaeus brasiliensis*, comprised only 0.4% of all specimens. Yellow roughneck shrimp comprised 27.2% of the total specimens, and roughneck shrimp only 0.6%. All *Rimapenaeus* shrimp examined from both species were females. The oceanic shrimp, *S. atlantidis*, was found in 6.4% of our samples.

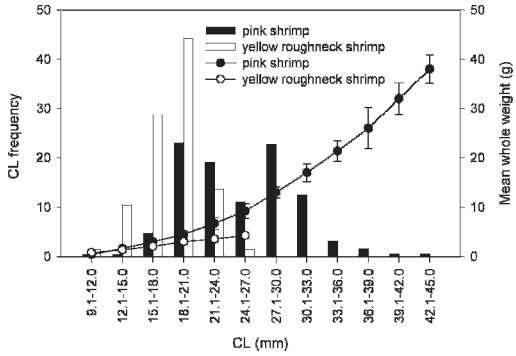

Fig. 2. Size frequencies of carapace length (bars) and mean whole weight ± SD (curves) of pink shrimp and yellow roughneck shrimp estimated from shrimps of the smallest commercial size class collected at the Tortugas fishing grounds between March 2002 and March 2004.

As an indication of reproductive periodicity, two pink shrimp females (TL = 102–104 mm, CL = 22.4–24.5 mm) collected in June 2003 had spermatophores attached to their thelyca. Seven yellow roughneck shrimp (TL = 55.0–57.0 mm, CL = 13.3–15.4 mm) collected in Jan. 2003 had sperm plugs inserted in their thelyca. Although the sample size was small, the pink shrimp finding is supported by the reported large influx of pink shrimp postlarvae to western Florida Bay nursery grounds in July and Aug. (Criales et al., 2006), and for yellow roughneck shrimp the reproductive season is reported during winter months (Eldred et al., 1959a,b; Ingle et al., 1959).

Pink shrimp and yellow roughneck shrimp occurred together in 90% of the samples (Fig. 1). This suggests that the two species inhabit the same areas of the fishing grounds. Yellow roughneck shrimp comprised a higher proportion of the samples from the relatively shallow, inshore locations near the Tortugas Shrimp Sanctuary than they did in the offshore samples. More specific conclusions on the spatial distribution of the shrimp species on the Tortugas grounds would be tenuous given the relatively small number of samples.

For small shrimp, the frequency distribution patterns of CL and body weight of pink shrimp differed from that of yellow roughneck shrimp (Fig. 2). Although at lengths between 9.1 and 27.0 mm CL and total weights of 0.4 and 25.0 g, both species followed a comparable pattern of incidence; however, that pattern diverged at larger lengths and weights. The largest peak in the size distribution for yellow roughneck shrimp was at 18.1–21.0 mm CL, coinciding with the second peak in the length frequency of pink shrimp. At the larger peak of the length frequency distribution of pink shrimp (27.1–30.0 mm CL), yellow roughneck shrimp was absent. Thus, it is likely that yellow roughneck shrimp are normally not to be found in samples, or in landings, of shrimp belonging to size categories that contain fewer than 68 shrimp per pound heads off.

The slope of the tail-weight-to-whole-weight ratio for pink shrimp (Kutkuhn, 1962a) was 0.625 ± 0.002 (mean ± SD) assuming an intercept value of zero (Table 2). The slope of the like ratio for yellow roughneck shrimp (this study) was 0.534 ± 0.005 assuming an intercept value of zero. Thus, the ratio of tail weight to whole weight is lower in yellow roughneck shrimp than in pink shrimp.

The species composition of small shrimp sampled at different times of the year suggests a significant seasonal difference in the proportion of pink shrimp vs yellow roughneck shrimp (df 3, F = 4.95, $P = 0.008$, from ANOVA). The highest quarterly mean proportions of pink shrimp in our samples were April–June and July–Sep., 98% and 94%, respectively (Fig. 3A). The highest quarterly mean proportions of yellow roughneck shrimp were in Jan.–March and Oct.–Dec., 59% and 57%, respectively.

The small shrimp size class comprised a large proportion of the total commercial catch. These made up as much as 41% by weight of quarterly landings for the Tortugas fishery (Fig. 3B). During the period April 2002 through March 2004, small shrimp comprised 28% of the 1,429-metric-ton total shrimp catch. For the smallest size class there was a significant difference

TABLE 2. Linear regression equations of the tail-to-whole-weight relationship for pink shrimp and yellow roughneck shrimp: $Y = a + bX$; Y is the head-off (tail) weight, X is the whole weight, a is the intercept, and b is the slope. Values of slope are given with the 95% confidence limits. The equation for the yellow roughneck shrimp was calculated from the smallest commercial size class of the Tortugas fishery, and the one for pink shrimp was estimated by Kutkuhn (1962a) from the Tortugas fishery and Biscayne Bay (Florida).

Species	n	Intercept	Slope, a ≠ 0	Slope, a = 0	Study
Pink shrimp	1,617	0.31	0.614 ± 0.03	0.625 ± 0.002	Kutkuhn (1962a)
Yellow roughneck shrimp	50	0.08	0.504 ± 0.04	0.534 ± 0.005	This study

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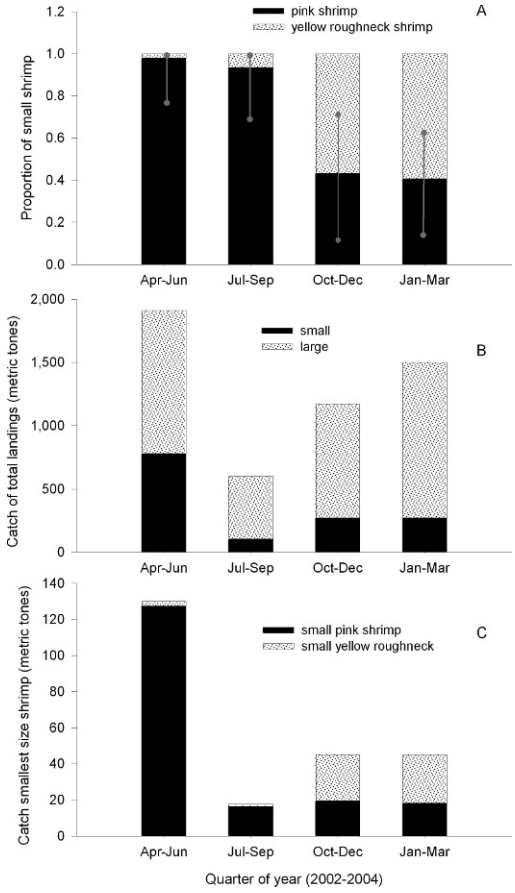

Fig. 3. (A) Predicted proportions of pink shrimp and yellow roughneck shrimp calculated by quarter of the year (April 2002–March 2004) from 28 shrimp samples of the smallest size class collected in Tortugas shrimp fishery statistical subarea 2; predictions used a generalized least-square model; vertical lines represent 95% confidence intervals. (B) Total commercial shrimp landings separated into large (less than 68 heads-off shrimp per 454 g) and small (68 or more heads-off shrimp per 454 g) size class of shrimp, by quarter of the year (April 2002–March 2004) from the Tortugas shrimp fishery statistical subarea 2. (C) Estimated catch of pink shrimp and yellow roughneck shrimp by quarter of the year in the smallest commercial size class from the Tortugas shrimp fishery statistical subarea 2.

among quarters in magnitude of the reported catch, by weight, for the period April–June 2002 through Jan.–March 2004 (df 3, F = 3.05, P = 0.053). The highest landings occurred in April–June when the proportion of yellow roughneck shrimp in our samples was low (Fig. 3C). On the basis of the seasonal proportions of yellow roughneck shrimp in our samples and the seasonal catches of the small shrimp, we estimated that the total catch of yellow roughneck shrimp during the 2-yr period (April 2002–March 2004) was about 337 metric tons, equaling 23.6% by weight of the catch of smallest size class and 6.6% by weight of the total shrimp catch.

Discussion

Studies conducted at the start-up of the Tortugas shrimp fishery (Eldred, 1959a; Ingle et al., 1959) reported that yellow roughneck shrimp made up 23% of the total number of shrimp caught and 6.6% of the total weight of the pink shrimp fishery. This information was calculated from a sample of 360 head-off shrimp sorted from 6,000 roughneck shrimp collected from Nov. 1957 through Oct. 1958. No information was provided about the method used to estimate the percentage of this species in relation to the pink shrimp data. However, these data are strikingly similar to the numerical abundance and estimate weights of the catch that we developed from 2002–2004 sampling.

The catch of small shrimp in the Tortugas fishery has been highly variable in the past 20 yr (Hart, 2008). This high variability was also reflected in our data; therefore this analysis from a 2-yr period (2002–2004) should be interpreted cautiously. During the 1980s–1990s small shrimp became a larger component of the Tortugas fishery than previously because a profitable market had developed for heads-on individually quick-frozen small shrimp. Starting in 2002, escalating prices for fuel influenced fishers to switch back to targeting larger shrimp, which were now providing a more favorable return on trawling effort (Hart, 2008; E. Little, pers. obs.). Therefore, it is likely that the proportion of yellow roughneck shrimp in the Tortugas fishery was substantially larger between 1980 and 2001, when the small shrimp were the target of the Tortugas fishing effort, than during the period in which our samples were collected 2002–2004. In spite of the high variability of the small shrimp catch in the history of the fishery, the percentages of yellow roughneck shrimp in the Tortugas fishery estimated in this study and 50 yr ago (Eldred 1959a; Ingle et al., 1959) remain stable (27% vs 23% in number of shrimp and 6.6% in weight for both studies).

Recruitment of small pink shrimp to the Tortugas fishery usually occurs in the fall (Sep.–Oct.) and the spring (March–April). These two peaks vary from year to year in magnitude and timing (e.g., Nance and Patella, 1989; Browder et al., 2002; O'Connor and Matlock, 2005). When summarized by quarters of the year, our data indicated that the abun-

dance of yellow roughneck shrimp was low in April–June and July–Sep., quarters for which the incidence of pink shrimp was greatest. Conversely, the greatest abundance of yellow roughneck shrimp was recorded in Jan.–March and Oct.–Dec. These results suggest that a large proportion of the recruitment to the Tortugas fishery occurring within the Oct.–March time frame may consist of roughneck shrimp. In several recent years, there has been a strong fall recruitment peak (Hart, 2008). At times such as these, the yellow roughneck shrimp might conceivably make up a larger component of the catch of small shrimp than suggested by our results.

Roughneck shrimp are abundant in the Gulf of Mexico and ecologically important as members of coastal shelf habitats (Eldred, 1959a; Joyce, 1965; Bauer and Lin, 1994). Despite their great abundance and ecological importance basic information on their life history is very limited. The location of the spawning and nursery grounds of the yellow roughneck shrimp at the Tortugas grounds has not been established. Gravid females have been collected between Marquesas and Dry Tortugas (Eldred et al., 1959a,b; Ingle et al., 1959; this study) and early settlement stages are abundant in western Florida Bay (Criales et al. unpubl.). However, it is unknown whether yellow roughneck shrimp from these two locations belong to the same population. Historical and present data (Eldred, 1959a; Ingle et al., 1959) indicate that the yellow roughneck shrimp has been a bycatch of the Tortugas shrimp fishery in the past 50 yr. Data also indicate that the percentage of yellow roughneck shrimp in the fishery has remained relatively stable, suggesting no serious impacts on this species yet. This stability occurs despite the fact that shrimp included in the fishery are mainly reproductive females because the largest size class is represented only by females because of a disparity in sizes by sex (Joyce, 1965; Anderson, 1970; this study).

Our analysis shows that yellow roughneck shrimp may constitute a substantial portion of the catch of the smallest size class of shrimp in the Tortugas fishery. Yet, the presence of a species that does not grow to contribute to the weight and number of shrimp in the larger size categories might compromise any direct use of small-shrimp CPUE as an index of recruitment. Year-to-year variation in the proportion of yellow roughneck shrimp among the catch of small shrimp might cause erroneous conclusions about trends from CPUE time series. Follow-up research to confirm or refute our findings should be based on a larger number of samples and more powerful statistical analysis. Such a study would also promote a better knowledge of the biology of the species that comprise the fishery and good management and conservation of the entire shrimp resource.

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