VI. DISCUSSION AND CONCLUSIONS

Historical Investigations

Bycatch weight averaged about 65% of the total catch per tow for the commercial bait shrimpers that were observed during Bessette's research in Galveston Bay. Bycatch species taken during shrimping activities in Galveston Bay differ by area and season. This is to be expected, since general species abundance also differs between bay areas and season, as documented by fishery independent studies of TPWD (Rice et al. 1988, Dailey et al. 1991).

Atlantic croaker, gulf menhaden and sand seatrout were among the dominant bycatch species reported by Lamkin (1984) during 1981-82 and Bessette (1985) for May-November 1984. The low occurrence in the bycatch of other special interest fish, such as southern flounder, red drum and spotted seatrout was demonstrated by both Bessette and Lamkin. Matlock (1982) reported that bycatch of southern flounder by bait and commercial shrimpers in Galveston Bay was less than that for any other Texas bay system except Upper Laguna Madre. The TPWD study reported largest flounder catch of the Galveston Bay system to be in a sample from a Trinity Bay bait dealer; largest flounder catches reported by Bessette also came from that area (Table 6).

Only one shrimper from West Bay consistently appeared to harvest more shrimp than bycatch. This fisherman's 27.2% monthly bycatch, as determined by Lamkin in 1981-82, approximates the 31.3 % determined by Zein-Eldin and Bessette for the 1984 season in West Bay. However, Lamkin identified 52 species of finfish and 4 invertebrates compared with 30 fish and 3 invertebrate species listed by Bessette for West Bay. Annual variation in species numbers within the bays have been documented by TPWD (Rice et al. 1988, Dailey et al. 1991). However, a severe freeze in late December 1983 and early January 1984 caused a massive fish kill, with resulting decreases in several species in the spring of 1984 (Rice et al. 1988). Although these species declines may be the major cause of the reduced number of species recorded by Bessette, it must be pointed out that Lamkin examined samples from three times more tows in West Bay than Bessette (62 vs. 18 by Bessette). Thus, with more intensive sampling in this area, Lamkin may have simply encountered more finfish species (including uncommon species) in his study than Bessette did in her research.

The shrimping methods of the West Bay fisherman mentioned above may be worth investigating in more detail. It would be useful to determine whether his methods would reduce bycatch in other bay areas as well. The relatively low levels of bycatch observed in samples collected from West Bay are possibly due to the fact that the West Bay fisherman utilized a "bottomless" net. The "bottomless" net has an unusually long footrope (leadline) which trails a long distance behind the headrope. A large portion of the net webbing has been removed from the underside of the trawl. These features give the net it's "bottomless" appearance except for the presence of mesh located on the underside of the cod end (at the trailing portion of the net). The net has been primarily used in estuarine areas of the middle and lower Texas coast which have extensive oyster reefs or shell bottoms (Gary Graham, TAMU Marine Extension Service, personal communication). Removing the webbing from the bottom of the net allows shrimpers to drag across reefs or areas with hard shell substrate without damaging the trawl net. Although no specific examination of bycatch magnitude was conducted for testing the bottomless net, further investigation of this gear type has merit.

1992 Sampling

Two hundred ninety-six samples were collected in the Galveston Bay system. Of these, seven samples were not used in analyses due to problems with data collection (i.e., gear failure, mis-identification of samples, etc.). The sampling design, which followed historical trends in shrimping effort, initially called for 280 samples to be collected in the three 'fishing zones' (Trinity Bay = 101, Upper/East Bay = 117, Lower/West Bay = 62). The actual distribution of samples taken in each area deviated from the original work plan because of high freshwater inflow and low catch rates in Trinity Bay. Few, if any fishing vessels were working in Trinity Bay. This occurrence was verified by TPWD enforcement agents. The samples which were to be taken in Trinity Bay were allocated proportionately to the other two fishing areas. Thus, only 34 samples were collected in Trinity Bay. The work plan also called for collection of 10% of all samples during the December-April period. Because only a few bait shrimp vessels were fishing during this period (the commercial fishery did not open until mid-May), most of the samples for this period were collected in April (30 of 35). Distribution of samples collected in other parts of Galveston Bay system was extensive except for the Galveston ship channel (Pelican Island bridge to U.S. Coast Guard station). Numerous attempts were made to contact fishermen working the Galveston channel but none were interested in participating in this study. A significant portion of the fishery exists in this area, especially during periods of extreme environmental conditions (temperature, wind, sea state). Therefore, the characterization data presented here may not be representative of trawl bycatch in the Galveston ship channel.

Overall, bycatch within the Galveston bay system is temporally and spatially variable. During 1992 sampling efforts, bycatch weight ranged between 2% and 98% of total trawl catch (avg. =71%). Highest levels of bycatch (relative to total catch) were observed during March and April when shrimp catches were low in number and biomass. A total of 134 different species was identified from trawl subsamples (85 finfish, 49 invertebrates). Analyses of individual sites within each 'fishing zone' may provide better information on areas of high and low bycatch rates. Preliminary analyses indicate lower bycatch CPUE's from tows in Lower Galveston and West Bays, near the Galveston causeway and Offats Bayou. This parallels the low bycatch rates observed by the West Bay fisherman as reported in the Lamkin (1984) and Bessette (1985) studies. Samples taken in 1992 were collected on vessels without the 'bottomless net' which was employed by the fisherman utilized in the Lamkin (1984) and Bessette (1985) studies. Therefore, it appears that bycatch CPUE in this area is lower than that observed for other portions of Galveston Bay, although more detailed analyses are warranted.

Most of the bycatch, up to 80% by number and weight, is dominated by less than ten species. Of these, Atlantic croaker, gulf menhaden, spot, cutlassfish and sand seatrout were the most abundant. Dominance of these species in trawl bycatch may affect commercial or recreational landings. Fish of special interest such as southern flounder, red drum, black drum and spotted seatrout were captured infrequently. The presence of individual species among bycatch in Galveston Bay during specific time periods probably coincides with the timing of life history events such as spawning activity, etc. Most flounder were captured within a limited time period during the fall when they aggregated in deep channels after water temperatures decreased. Temperature decreases in the fall (Oct.-Nov.) stimulate the spawning run in which flounder migrate to offshore waters to spawn (Sabins and Truesdale 1974; Reagan and Wingo 1985; Gilbert 1986).

Overall, white shrimp CPUE's (number and biomass) were greater than for brown shrimp. The size of white shrimp were generally larger than brown shrimp. For both species, size appears to increase with distance from the Gulf. The small size of brown shrimp is one of the reasons cited by individual fishermen participating in this study for the drastic reduction of effort in Trinity Bay during 1992. Postlarvae enter the bay through 3 passes (Rollover pass, Galveston/Houston ship channel, San Luis Pass). Shrimp in the upper reaches of the bay probably endure longer residence times. We hypothesize that heavy freshwater inflow during the early portion of the shrimp season is partly responsible for the prevalence of smaller brown shrimp. Heavy rainfall during March-June resulted from unusual weather patterns because of the "El Niño" phenomenon in the Pacific Ocean. Low salinity conditions in Galveston Bay may limit the availability of optimal habitat for shrimp. Other effects of high freshwater inflow are not entirely quantified, but freshwater conditions may negatively impact food sources utilized by shrimp. Shrimp feed on detritus and benthic organisms and high freshwater inflow may alter the abundance of shrimp prey items. Low salinity conditions may also modify habitat utilization for some finfish, thus affecting predation rates and mortality of shrimp. Nevertheless, preliminary analyses indicate positive correlation of increased white shrimp abundance in TPWD survey during "El Niño" years (Anne Walton, TPWD, Resource Protection Division, personal communication). The long term impacts of high freshwater inflow are not known. Low salinity conditions in Galveston Bay also occurred during the spring of 1990 and 1991; heavy precipitation in the Galveston Bay watershed led to freshwater conditions over a large portion of the bay, especially in upper Galveston Bay and Trinity Bay.

Spatial differences in size were also observed for finfish species. Generally, larger individuals of cutlassfish, spotted seatrout, red drum were observed in upper Galveston and East bays. However, the low occurrence of spotted seatrout and red drum in all samples does not provided conclusive evidence of spatial differences in length of these species. Samples from lower Galveston Bay indicate larger individuals of gulf menhaden, sand seatrout, southern flounder and black drum. Spatial differences in size of individual species may also be related to optimal habitat and natural geographic distributions within the bay. Salinity is a major factor in determining the distribution of many estuarine finfish in the same manner as it affects penaeid shrimp distribution in Galveston Bay. Juvenile forms of gulf menhaden, spot and Atlantic croaker are abundant in polyhaline and euryhaline areas (Monaco et al. 1989). Adult sand seatrout and Atlantic croaker are also abundant in these areas. All life forms (eggs, larvae, juveniles, adults) of hardhead catfish, are also abundant in polyhaline and euryhaline areas of Galveston Bay (Monaco et al. 1989). Generally, fewer species are found in freshwater portions of the bay (Monaco et al. 1989). Nevertheless, large numbers of individual freshwater species were (blue catfish, shad, Ohio shrimp, etc.) were captured in trawls sampled from Trinity Bay during April-May, 1992. Spotted seatrout and southern flounder are not usually found in freshwater areas (Monaco et al. 1989). However, 1992 data show that both of these species were captured in tows from Trinity Bay (1992) when salinity was measured at 0 ppt.

The scope of this study did not include a thorough examination of bycatch mortality. Magnitude of bycatch reported here represents only fish that were captured during trawling operations, therefore, mortality levels are impossible to determine from the data available. Since bycatch levels during the 1992 season were estimated at 3.7 million kg of finfish and 548,000 kg of invertebrates, mortality rates are important in assessing impacts on population structures of individual bycatch species. It is also important to consider that most fishermen (18 out of 19) which participated in new sampling efforts utilized culling tanks on their vessels. The catch is released from the net into the culling tanks. Bycatch is removed and returned the water; shrimp are retained in a separate holding tank or in partitioned section of the culling tank. Compared with catch which is dumped on deck prior to sorting, the use of a culling tank may significantly increase survival of bycatch organisms.

The proportion of bycatch returned to the water in good condition was not specifically examined in this study or in historical studies previously reviewed in this document. Injured or dead bycatch items may have ecological importance in the bay system as part of the food web and nutrient recycling. No attempt was made in the studies reviewed here to do more than weigh the bycatch and consider its species composition.

Debris items were not categorized by individual type (i.e., plastic, paper, etc.) but they were among the top 15 items (based on weight) captured in shrimp trawls. No detailed analysis could be conducted for the large species captured (sharks, stingrays, alligator gar, etc.) although their presence was recorded. These species remain a part of overall bycatch in shrimp trawls and must be considered as such.

Comparison With TPWD Fishery Independent Survey

Few conclusions can be drawn from the statistical comparisons between the TPWD fishery-independent and the NMFS fishery-dependent data. The length-frequency (Kolmogorov-Smirnov) analyses showed significant differences in all monthly length distributions for 4 of the 14 species (brown shrimp, roughback shrimp, spot, and white shrimp). For brown and white shrimp, the directed species, differences in size composition among the two data sets were detected for each month. Tests for three other species (Atlantic croaker, Atlantic brief squid, and hardhead catfish) yielded significant differences in all but one month. Only 2 species (pink shrimp and spotted seatrout) produced no significant differences for any month. However, these were two rare species in terms of catch abundance. Length distributions of the last five other species (bay anchovy, blue crab, cutlassfish, gulf menhaden, and sand seatrout) were significantly different in some months and not in other months. Consequently, there did not appear to be any discernible trends from analyses of species-specific length distributions.

Similarly, statistical analyses of CPUE values (Student t-test), of most species found during two or more months were significantly different some months and not for other months. Mean CPUE values for four species were significantly different during all months, while CPUE values for 15 species were not significantly different during all months. Generally, significant differences in CPUE and size composition were not observed for some species but only during specific months. There appeared to be no discernible trends produced from the analysis of the species-specific monthly mean CPUE values.

The results of the regression analysis indicate that bycatch ratios from TPWD survey trawls and NMFS trawl samples (collected on commercial shrimp vessels) are not comparable. Significant differences in bycatch ratios were observed for all three fishing zones ($\alpha = 0.05$, $p > 0.1$; Table 22). Consequently, based on the information collected by NMFS in 1992 (and subsequent analyses presented here) it appears that fishery independent collections conducted by TPWD are not sufficient for development of an index which will estimate the magnitude and size composition of organisms taken during fishery dependent activities (based on 1992 samples).

General Discussion and Conclusions

The issue of bycatch in fisheries is rapidly becoming one of the most important problems facing the fishing industry and fishery managers alike. Tillman (1993) reports three primary reasons for the current concerns about bycatch: 1) user conflicts, 2) legislative mandates and 3) public ethics and attitudes toward waste. Fishery managers are faced with the responsibility of protecting living marine resources and ensuring the viability of future fishery stocks. Regardless of the actual impacts, bycatch has become a resource management problem because it is perceived as such by the public (Murray et al. 1992). Increased environmental awareness worldwide has focused attention on impacts of fishing techniques regardless of whether damages incurred are actual or perceived. The bycatch issue came to the forefront in the U.S. during the middle and late 1980's when shrimp trawling was seen as one of the causes for a decline in red snapper stocks and capture of threatened or endangered sea turtles in the Gulf of Mexico (Henwood and Stuntz 1987, Goodyear and Phares 1990, Goodyear 1991). Shrimp landings comprise the most important fishery in the U.S. in terms of value (Thompson 1983, 1984, 1985, 1986, 1987; O'Bannon 1988, Holliday and O'Bannon 1992); however, the economic importance of the shrimp fishery will not be enough to mediate the concerns of fishery managers, environmentalists and other interests with respect to bycatch. From the perspective of the fisherman, the primary goal is to maximize catch of shrimp and minimize bycatch. Bycatch adds to sorting and processing time. Consequently, the quality of shrimp produced suffers from prolonged exposure to high temperatures (Nelson 1993). Elimination or reduction of bycatch in trawls (and other gear types) would reduce sorting time and discards while improving the quality of the product.

Galveston Bay maintains the highest abundance of fish populations relative to all other Texas estuaries (Monaco et al. 1989). Abundance of fish in Galveston Bay is estimated at more than 6,000 fish per hectare (annual mean; Monaco et al. 1989). The magnitude and composition of bycatch in shrimp trawls is extremely variable with respect to time and area. This variability was evident in data recorded historically (Lamkin 1984, Bessette 1985) and also in recent samples taken from new sampling efforts. Since trawl nets usually do not select for individual species, temporal and spatial variability in bycatch may be a reflection of community structure within the bay system. In 1992, species diversity was highest during June-July and in the Upper and Lower reaches of Galveston Bay. The variability in bycatch (and abundance of individual species) is probably regulated by many complex, interacting factors. Abundance of estuarine species during a specific year are not only be influenced by present environmental conditions; conditions in previous years which impacted the magnitude of parent stocks or affected reproductive success may also be reflected in abundance of individuals during successive years. TPWD has examined trends in populations of living marine resources (based on trawl surveys) as a means of analyzing long term changes in individual stocks. As temporal changes in population structures are identified, further analyses may provide insight or clues to cause-effect relationships. The long term trends indicate that only blue crab and white shrimp stocks in Galveston Bay were in chronic decline during 1982-1990 (Osborn et al. 1992). However, white shrimp stocks appear to have rebounded in 1991 and 1992 based on TPWD survey data (Anne Walton, TPWD Resource Protection Division, Austin, TX; personal communication).

Generally, bycatch is dominated by several species. Atlantic croaker, gulf menhaden, sand seatrout, spot, bay anchovy, and hardhead catfish account for the majority of bycatch in terms of numbers and biomass. Although slight differences in ranking of individual species were observed by both Lamkin (1984) and Bessette (1985), the same species made up the bulk of bycatch reported historically. Anecdotal reports from commercial fishermen in Galveston Bay indicate that these species generally dominate bycatch composition each year. Atlantic croaker, sand seatrout and spot are listed among the top recreational species landed by anglers fishing in Galveston Bay (Campbell et al. 1991). Menhaden accounted for the largest quantity of commercial fishery landings in the United States during 1982-87 (Thompson 1983, 1984, 1985, 1986, 1987; O'Bannon 1988). The menhaden fishery was second in the U.S. in terms of commercial quantities landed during 1991; gulf menhaden accounted for 60% of all menhaden landings (~550 million kg; Holliday and O'Bannon 1992). Monaco et al. (1989) report that gulf menhaden is one of the most abundant species in Galveston Bay (> 1000/hectare). Atlantic croaker and spot in Galveston Bay are classified as moderately abundant (40-800/hectare; Monaco et al. 1989). Thus, abundance of these species in bycatch from shrimp trawls may be important when considering impacts on recreational or commercial landings. However, it appears that trawling operations in Galveston Bay are not significantly impacting individual populations of these species. Based on TPWD long term trend analyses, the abundance of Atlantic croaker, sand seatrout and bay anchovy captured in trawls increased during 1983-1990 (Osborn et al. 1992). Despite a slight decrease during 1987-1990, trawl catch of gulf menhaden increased between 1983-1990 (Osborn et al. 1992). The fact that these species are among the dominant catches of both recreational and commercial fisheries attests to their abundance. Whitaker et al.

(1989) concluded that commercial shrimp trawling in South Carolina's sounds and bays does not significantly impact estuarine finfish species. Additional monitoring is required because it is difficult to determine the overall impacts based on the data presented here.

Cutlassfish and hardhead catfish were dominant bycatch species observed in 1992 samples. However, cutlassfish was not among the most abundant species in tows taken by bait shrimpers in previous studies (Lamkin 1984, Bessette 1985). Cutlassfish CPUE in TPWD surveys was extremely low in comparison with 1992 data (all months). Blue crab was a major species listed by Lamkin (1984) but was not among the dominant species listed by Bessette (1985) or in the 1992 NMFS study. Blue crab CPUE's measured in TPWD trawl surveys during 1992 were generally lower than those observed during new sampling efforts.

Special interest fish, such as southern flounder, red drum and spotted seatrout were captured infrequently in samples taken by both Bessette (1985) and Lamkin (1984). Similar results were observed during the 1992 sampling efforts conducted by NMFS as well as the fishery independent surveys of TPWD. Red drum, spotted seatrout, black drum and southern flounder are common (< 40/hectare) but not abundant in Galveston Bay (Monaco et al. 1989). Natural populations of red drum, spotted seatrout and black drum have been augmented by TPWD through the release of hatchery-reared individuals. However, red drum and spotted seatrout are among several estuarine-dependent species whose stocks were believed to be in decline (Osborn et al., 1992).

More species were captured during 1992 (>130) in comparison other studies (Lamkin 1984, 56 species; Bessette 1985, 74 species; 1992 TPWD survey, 79 species). Differences in sampling effort and intensity are probably responsible for the variance among these data. Overall, bycatch ranged between 27% (Lamkin 1984) and 71% (1992 data) of total catch. Finfish : shrimp biomass ratios were equally variable among all studies. Bessette (1985) and Zein-Eldin and Bessette (in prep.) report an overall ratio of 4.1 kg of bycatch per kg of shrimp landed. The overall ratio during 1992 was approximately 3 to 1 (2.64 kg of fish and 0.39 kg of invertebrates captured per kg of shrimp). Monthly ratios were highest during March-April when abundance of shrimp in Galveston Bay is low. However, only live-bait fishing is permitted during these months and only a small portion of the total effort from Galveston Bay is exerted during this period. Numerical ratios for TPWD survey data (biomass data not available) were generally higher than those observed in the NMFS study; however, monthly trends were similar. The higher ratios in the trawl survey may be due to less samples collected and smaller sample sizes; the TPWD surveys are limited to 10 minute tows.

Survival of discards was not specifically measured during 1992 sampling efforts. Mortality of bycatch is dependent on numerous factors (tow duration, total catch size, sorting/processing catch, etc.). Air and water temperature and the presence of predators may affect survival rates of individuals returned to the bay waters. Temperature and salinity in the bay (and in culling tanks) affects oxygen saturation of water and biophysical demands of estuarine species. As temperature increases throughout the day, water temperatures in culling tanks may exceed optimal levels. This, along with the high density of animals released from the net, increases stress on bycatch species and can lead to higher mortality. Individuals returned to the water soon after being caught are generally in good condition. However, field observations indicate that organisms which endured prolonged periods in the trawl net or culling tanks generally exhibited higher mortality rates. Generally, tow times among commercial bay trawlers are longer than for bait shrimpers. Commercial shrimping in the bay is limited to 2 seasons (May-July, August-December) and no trawling is permitted after 2:00 pm during the spring open season (May-July). Bait shrimping occurs year-round; the magnitude of bait shrimping effort (seasonally) depends on market demand, shrimp catch and weather conditions. Bait shrimpers must maintain at least 50% of total shrimp catch in a live condition. A review of Texas shrimp fishery regulations is provided in Appendix 2.

Several studies in other coastal areas have provided evidence on the importance of environmental factors in regulating survival rates. Mortality of bycatch from inshore trawl fisheries in Florida was variable. In St. John's River, mortality of bycatch from 30 minutes tows was low in February and high in July (Snyder et al. 1993). The differences were probably due to the magnitude of bycatch caught, handling techniques and water temperature (David Snyder, Continental Shelf Associates, Inc., Jupiter, FL; personal communication). In Pine Island Sound, Florida, very low mortality occurred among bycatch from 8 minute tows in both summer and winter trials (Snyder et al. 1993). The extremely short tow time is probably a factor because the total catch should be smaller; bycatch organisms spend less time in the net, sorting time is proportionately decreased and stress on individuals is minimized. In Australian coastal waters, observations indicate that mortality is high (Wassenberg and Hill 1989, Kennelly 1993). Mortality of some species were attributed to drowning, being crushed in the net or stung by venomous bycatch (Kennelly 1993).

Some species are less hardy and more vulnerable to the stresses of trawling and processing (sorting). It is not uncommon for some species to die up to several weeks after any form of handling (Kennelly 1993). Trawling and sorting may only cause superficial damage but the possibility of infection may remain long after organisms are returned to the water. In Galveston Bay, field observations provide an indication that squid, anchovies and spotted seatrout may be less tolerant to trawling than crabs, croaker, drum and many other species. Low mortality rates may be a reason for apparently low impacts of bycatch on Atlantic croaker populations. Differences in survival have been observed even within a single genus; Wassenberg and Hill (1990) reported >60% survival among one species of flounder while <20% of another species in the same genus survived (Australian coastal waters).

Shorter tow times among bait shrimpers may reduce mortality rates. Rayburn (1993) observed that due to restrictions already imposed on the Texas bait shrimp fishery, much of the bycatch is returned to the estuary in a live condition and, "while it may not survive due to predation by seabirds or other scavengers aggregating around the vessel, the overall impact to the stock should be minimal." Other restrictions on the fishery may have reduced total bycatch in recent years by decreasing overall fishing effort (Rayburn 1993).

In a worst case scenario with 100% mortality, ~3.7 million kg of finfish (estimated; see Table 17) would be killed by shrimp trawling. By comparison, bycatch in the

Galveston Bay recreational fishery affects 1.2 - 3.5 million fish (no biomass estimates provided; Saul et al. 1992). Assuming that smaller fish are captured in trawls (due to differences in selectivity of trawls vs. hook-and-line gear), the number of individuals affected by trawling is much greater than those impacted by the recreational fishery. However, we do not expect comparable mortality rates among the two fisheries and variability of mortality within each fishery should be extremely variable (and probably much less than 100%).

Studies examining other causes of mortality found that >32 million organisms (~234,000 kg) per year (projected) would be impacted by impingement mechanisms at four of five power generating stations operated by Houston Lighting and Power Company (HL&P) on Galveston Bay (Palafox and Wolford 1993). HL&P stations utilize large amounts of water from Galveston Bay as coolant during power generating operations. Impingement refers to the diversion or removal of debris and live organisms from cooling water when they encounter small mesh screens at water intakes. The relatively low biomass of impinged organisms suggests that affected animals are primarily made up of early life stages and juvenile forms. Mortality of organisms which pass through impingement screens is variable, but survival decreased when organisms were exposed to high water temperatures (Palafox and Wolford 1993). Only one other industrial facility on Galveston Bay (other than power generating stations) was found that could have major impacts on fisheries stocks but no impingement data are available for this site (Palafox and Wolford 1993). Once water passes through the cooling system, it re-enters Galveston Bay as thermal effluent. The effects of thermal effluent on living marine resources In Galveston Bay remain controversial and unresolved. Other human-induced activities (point and non-point source discharges, etc.) have resulted in the death of an estimated 175 million fish over the last twenty years (Palafox and Wolford 1993). However, no information on biomass or species composition were available.

With respect to long term impacts, local resource managers hypothesized that, "many fish and shellfish populations were already in a state of reduced abundance" in Galveston Bay (Osborn et al. 1992). The instability of living resources in Galveston Bay (and other aquatic systems) may be impacted further if bycatch is a major factor in determining stock variation. Synergistic effects are likely related to other factors such as declines in the abundance of viable habitats and changes in water quality. Whitaker et al. (1989) conclude that estuarine-dependent finfish abundance is primarily regulated by changes in environmental conditions (water temperature, salinity) and that adverse impacts of commercial trawling in estuaries is minimal. However, many discarded fish (alive or dead) fall prey to seabirds, dolphins, sharks or other finfish which follow trawlers (Wassenberg and Hill 1990, Kennelly 1993, Wassenberg and Hill 1993). Discards that reach the benthic area are scavenged primarily by crabs (Wassenberg and Hill 1989, 1990, 1993). Trawling bycatch may be categorized within two groups (Wassenberg and Hill 1993). The impacts are more damaging for those species that are injured or do not survive trawling and handling; other species benefit by scavenging discards (Wassenberg and Hill 1993) or through removal of predator and competitors.

The effects of reducing or eliminating trawl bycatch on shrimp predator-prey relationships is not completely quantified. Sheridan et al. (1981) utilized a modeling technique to estimate that reducing discards in the offshore shrimp fishery by 50%

would decrease shrimp stocks by 25%. In the model, the effect of discards is through re-assimilation of bycatch and/or nutrients into the shrimp population (Sheridan et al. 1981). In Galveston Bay, predation by estuarine dependent finfish is a primary cause of mortality of juvenile shrimp in nursery areas (Minello et al. 1989). The main predators of juvenile penaeid shrimp in nursery areas include southern flounder, spotted seatrout, red drum, gulf killifish, pinfish and, to a lesser extent, spot (Minello et al. 1989). Removal of predators (or competitors) may benefit shrimp populations and ultimately, fishery production. Spot are regularly captured in shrimp trawls while southern flounder, spotted seatrout, red drum and pinfish occur infrequently among bycatch species. Divita et al. (1983) reported that penaeid shrimp emigrating from Texas estuaries (into the Gulf of Mexico) are a major prey item for silver seatrout, sand seatrout, southern kingfish, rock sea bass, dwarf sand perch, southern hake and lane snapper. Most of these species were captured in 1992 trawls sampled; sand seatrout was among the dominant bycatch species. De Diego (1984) reported that only 5 of 17 species (Atlantic sharpnose shark, Atlantic croaker, ladyfish, spotted seatrout and bighead searobin) captured with gill nets around the Galveston ship channel contained shrimp in their stomachs. Data collected by De Diego (1984) indicated low predation rates on shrimp; only 2.4 % (11 fish) of all fish collected had eaten penaeid shrimp; however, the small sample size may have confounded the results.

Rayburn (1993) observed that, "it is incumbent on the state to insure that the parameters of the public trust are adequately considered to insure that the bycatch does not negatively impact other resource users, that ecosystem balance is not being substantially undermined, that endangered or threatened species are being protected and that adequate rent is being extracted from the harvested resources to cover the costs of management and negative impacts." The use of time/area management is being considered as a possible method for dealing with the bycatch problem. This involves the closure or restriction of fishing in specific 'problem' areas during periods when bycatch is a problem (i.e., when juvenile finfish are resident in a specific fishing area). In Australia, scientists would recommend geographic and temporal closures to minimize impacts on bycatch species (Kennelly et al. 1993). There has already been precedent established for time/area management in North American fisheries. Provisions in the Gulf of Alaska Groundfish Fishery Management Plan (approved in 1985) allow for closure of the groundfish fishery when an annual quota of halibut bycatch has been attained (Blackburn and Davis 1992). However, Whitaker et al. (1989) reported that the relative abundance of fish in areas closed to commercial fishing in South Carolina were no different from those areas where trawling effort and bycatch are high.

Gear modifications such as fish excluder and bycatch reduction devices show some promise towards reduction of trawl bycatch. Utilization of the 'bottomless net' by a single fisherman in West Bay (Lamkin 1984, Bessette 1985) resulted in lower bycatch. However, more analyses are required to determine if lower bycatch was related to other factors; preliminary analyses from 1992 data indicate below average bycatch rates in the same fishing area. In fact, some fishermen have voluntarily utilized some types of bycatch reduction devices for many years. Individual fishermen utilize the gear and techniques with which they are most familiar and which best apply to specific conditions they encounter. The most common is some form of a 'cannonball shooter' which is used during times of high abundance for 'cannonball' or cabbage head jellyfish (*Stomolophus* spp.). 'Fish eyes' are used for periods or areas with high finfish abundance. Use of TED's (Turtle Excluder Devices) in inshore waters was mandated by NMFS at the end of 1992. Certain exemptions apply for some vessels which limit gear size and tow times; however, exemptions only appear to be applicable through 1994. Utilization of TED's should help in reducing overall bycatch. There are many different designs for TED's and bycatch reduction devices which are being used or tested in the Gulf of Mexico (review Fowle and Bierce 1992, Jones 1993). The number of TED's certified for use in offshore waters has increased in recent years because no individual gear modification is applicable or useful for general use. The applicability of excluder/reduction devices in bays and estuaries has not been thoroughly examined; bay trawlers utilize smaller vessels with less power than offshore boats. Bay fisherman are limited to one net (smaller than those used offshore) and different restrictions for net size apply during the spring and fall commercial seasons (see Appendix 2). The variety of complex habitats and trawlable bottom in estuarine systems will further preclude the use of any single gear modification that will achieve satisfactory bycatch reduction while preventing loss of production. Extensive testing of gear modifications would be required for effective implementation of bycatch reduction devices in estuaries.

We recommend additional monitoring of bycatch to examine long term trends in magnitude and composition of bycatch (and associated effects) prior to implementation of specific management schemes. The highly variable nature of the data collected during new sampling efforts require additional sampling if trends and spatial/temporal variations in bycatch are to be addressed. The fishing industry is unwilling to accept regulatory mandates based on inadequate data and limited knowledge of the impacts of bycatch on the ecosystem (Nelson 1993). Future studies in Galveston Bay also need to be specifically designed to address ecological issues associated with shrimp trawl bycatch. Differences in fishing techniques and gear types used by commercial vs. live bait shrimpers may affect magnitude of bycatch as well as survival of discards. Effect of tow depth and speed may be important in explaining differences in species composition or capture of various life stages (size classes). Water clarity, salinity, temperature, tidal patterns and physiological/behavioral characteristics of finfish and invertebrates may also explain differences in abundance and distribution of individual species. Salinity appears to be especially important; the bycatch species observed during 1992 included a number of freshwater species throughout Trinity Bay and the upper reaches of Galveston Bay. The presence of several marine species in the lower bay area provides evidence of the influences of tidal effects. Additional analyses of the present database may determine the importance of these and other factors on bycatch magnitude, composition and fate. Investigations which are designed to answer specific questions regarding effects of bycatch on ecological niches, community structures, predator-prey interactions and nutrient cycling are critical to understanding the overall impacts of shrimp trawling operations. There is evidence that removal of individual bycatch species during trawling can have ecological implications (review Freeberg 1992). Impacts on forage species, although difficult to quantify, should have been realized long ago, given the long term existence of commercial trawling. Nevertheless, we recommend that future investigations also focus on bycatch mortality and its impact on community structure, predator-prey interactions, nutrient dynamics, etc. In future years, the impact of TED utilization toward mitigating bycatch will also need to be quantified. The use of more efficient TED's or other bycatch reduction devices in the future may negate any adverse impacts of shrimp trawling with respect to bycatch. All of this information will be a prerequisite to effective management measures. Additionally, economic impacts of management measures on the fishing industry are being more closely scrutinized, especially during recent times of recession and a stagnant economy. Implementation of management measures to reduce/eliminate bycatch may have economic impacts on the shrimp fishery itself as well as other businesses which serve the fishery (fuel, supplies, distributors, etc.).

Finally, the success of the 1992 characterization was largely due to the participation of individual fishermen. Without their assistance, and that of the industry advisory panel, the data collected would be lacking in quantity and quality. Future efforts to characterize, address or resolve issues regarding bycatch should include input from the fishing industry if productive investigations and viable solutions are expected.