Reader:

Please note the following erratum for this article.

Page 400, left column, last four lines

The sentence “For each species, probit analysis was conducted on untransformed data to determine the time at which 50% of the test animals exposed to the test salinity died (LE_{50}) (Sokal and Rohlf, 1981)” should read

“For each species (48 hour), probit analysis was conducted on untransformed data to determine the time at which 50% of the test animals exposed to the test salinity died (LE_{50}) (Sokal and Rohlf, 1981).”

Effect of the salt-box catch-bycatch separation procedure, as used by the Texas shrimp industry, on short-term survival of bycatch

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Abstract—Experiments were conducted to determine the effect of the salt-box catch-bycatch separation procedure, as used by the Texas shrimp industry, on short-term survival of bycatch. Bioassays were conducted on five economically important bycatch species: spotted seatrout (*Cynoscion nebulosus*); red drum (*Sciaenops ocellatus*); Atlantic croaker (*Micropogonias undulatus*); southern flounder (*Paralichthyes lethostigma*); and blue crab (*Callinectes sapidus*). Red drum were most affected by hypersalinity, requiring 17 minutes exposure to a 70‰ salt water solution to kill 50% of the test specimens within 48 hours. For samples collected from commercial boats and Texas Parks and Wildlife (TPW) trawl samples, we found that neither initial nor final percent survival was significantly different for bycatch removed with or without the aid of a salt-box. Bycatch mortality was high regardless of the method used to separate bycatch from the target catch. At the conclusion of catch separation, bycatch survival averaged 76% (±22%) for commercial samples and 48% (±40%) for TPW trawl samples separated with salt-boxes. Survival at the conclusion of catch separation without a salt-box averaged 56% (±35%) for commercial samples and 43% (±39%) for TPW trawl samples. Bycatch survival 21–27 h after catch separation averaged 13% (±6%) for commercial samples and 5% (±9%) for TPW trawl samples separated with salt-boxes and 34% (±29%) for commercial samples and 10% (±19%) in TPW trawl samples separated without a salt-box. Mortality rates (*M*) for bycatch separated with a salt-box averaged 0.08 (±0.03) for commercial samples and 0.10 (±0.04) for TPW trawl samples. For bycatch separated without the salt-box, *M* averaged 0.48 (±1.23) for commercial samples and 0.10 (±0.05) for TPW trawl samples. Results of an exploratory analysis with stepwise multiple regression suggested that final percent survival of bycatch was most affected by trawling time. The salt-box had little or no effect on bycatch survival; therefore, regulating the use of salt-boxes in shrimp trawling operations is not necessary.

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Shrimp (*Penaeus* spp.) are the most important commercial seafood product in Texas, accounting for more than 80% by weight and 93% of the value of all Texas commercial fisheries landings (Robinson et al., 1996). Texas shrimp landings from 1986 through 1995 were about 32,000–44,000 metric tons (t) annually. About 6400–8000 t of the annual catch during the 10-year period came from Texas bays. Texas bay shrimpers are reported to catch 2.4–6.8 kg of nontarget species (bycatch) for each kg of shrimp landed (Fuls and McEachron, 1998). Removal of the bycatch is time consuming and thus costly to fishermen. To reduce the time spent removing bycatch, Texas bay shrimpers frequently use salt-boxes to assist in rapid separation of bycatch from shrimp (Bumguardner and Colura, 1997). Salt-boxes are onboard tanks that hold a hypersaline solution of seawater and food-grade salt. The catch is placed in the solution, where most fish species float and shrimp sink. Floating bycatch is skimmed from the surface and discarded. Shrimp are then dipped from the tank and any remaining bycatch removed and discarded. Although use of salt-boxes is known to fisheries managers, the effect of its use on the survival of discarded organisms is unknown.

The objectives of our study were to assess the effects of the use of the salt-box on bycatch survival. This was accomplished by first conducting bioassays to determine the exposure time to hypersaline conditions that would affect survival of five economically important species known to occur as a part of the bycatch (Fuls and McEachron, 1998). The combined effects of trawling and exposure to hypersaline conditions in the salt-box were evaluated by comparing survival and mortality rates of bycatch (all species) and three major components of the bycatch (Atlantic croaker*, Micropogonias undulatus,* sand seatrout*, Cynoscion arenarius*, and spot, *Leiostomus xanthurus*) separated with and without the aid of a salt-box. This comparison was made for a series of samples collected from Texas bay shrimp fishermen and a series of samples collected during control experiments conducted by Texas Parks and Wildlife (TPW) personnel using experimental trawls. The TPW control experiments were conducted to remove some of the variation caused by the differing fishing methods used by each bay shrimper (i.e. different lengths of time the trawl was fished).

Materials and methods

Bioassays

Bioassays were conducted on spotted seatrout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellatus*), Atlantic croaker, southern flounder (*Paralichthys lethostigma*), and blue crab (*Callinectes sapidus*). The species were selected because of their importance to Texas' recreational or commercial fisheries, or both (Weixelman et al., 1992; Robinson et al., 1996) and because they are known to occur as a portion of the bycatch (Fuls and McEachron, 1998). Red drums and blue crabs were col-

Table 1

Exposure times, salinity, temperature, and number of individuals per replicate used in high-salinity exposure bioassays. Three replicates were used at each exposure time.

Species	Exposure times (min)	Salinity (‰)	Temperature (°C)	Bay water salinity (‰)	Fish/ replicate
Red drum	4, 8, 16, 32, 64, 128	70	24	19	10
Atlantic croaker	4, 8, 16, 32, 64, 128	70	23	16	5
Spotted seatrout	4, 8, 16, 32, 64[1]	69	26	24	5
Southern flounder	4, 8, 16, 32, 64, 128	71	27	18	5
Blue crab	4, 8, 16, 32, 64, 128	70	26	24	5

[1] Specimens did not survive to 128 min of exposure.

lected from TPW hatchery ponds; Atlantic croaker and southern flounder were collected from Matagorda Bay with a trawl; spotted seatrout were collected form East Matagorda Bay with a bag seine. Fish were held 7–10 days in 1850-L tanks at ambient bay salinities and temperatures and fed frozen brine shrimp or chopped shrimp (or both) three times daily. Blue crabs were placed in holding tanks for one day prior to bioassay initiation. Juvenile blue crabs molt at frequent intervals and because of their aggressive nature, any soft crabs in a common tank are almost immediately cannibalized. Therefore, blue crab trials were held before substantial mortality occurred in holding tanks and without an initial acclimation period.

Bioassay trials were conducted at salinities of 70‰ (±1‰) and temperatures from 23 to 27°C. A salinity of 70‰ was selected on the basis of salinities observed in salt-boxes on commercial shrimping vessels (Bumguardner and Colura, 1997). Trials were conducted over a geometric sequence of times up to 128 minutes with three replicates for each time (Table 1). Either 5 or 10 individuals were exposed for each replicate, depending on size and availability. Test animals were placed in 4-L all-glass aquaria that had been washed with acid and alcohol and filled with about 3-L of 70‰ salt water. Air was continuously bubbled through the water from a 1-mL disposable pipette attached to an air blower. High-salinity water was obtained by adding salt (Mortons Ship n Shore®) purchased from a fishing supply store to water taken from Matagorda Bay. Salinity levels of bay water for each trial are presented in Table 1. Animals were removed from test aquaria at the end of the specified exposure time, high-salinity water was discarded, the aquarium was refilled with bay water, and animals were replaced in the aquaria. So that control animals were treated similarly, they were placed in the aquaria containing bay water and held for 60 minutes, after which these animals were removed, the bay water replaced with new bay water, and the control animals returned to the aquaria. The number of live individuals was recorded for each replicate immediately after high-salinity exposure, 24 hours after exposure, and 48 hours after exposure. For each species, probit analysis was conducted on untransformed data to determine the time at which 50% of the test animals exposed to the test salinity died (LE_{50}) (Sokal and Rohlf, 1981). A no-observed-effect exposure (NOEE) (Rand and Petrocelli, 1985) for each species was calculated by using a multiple goodness-of-fit comparison of log-likelihood ratio G values (Sokal and Rohlf,1981).

Effect of salt-box use on bycatch survival: samples from the bay shrimp industry

Thirty samples of bycatch were collected from May through October 1995 from bay shrimpers working in Matagorda, San Antonio, and Aransas bays. Fifteen samples were separated with a salt-box (SB) and the remaining 15 samples were separated without the aid of a salt-box (NSB). For each sample the following data were collected:

1 Length of time that trawl was fished;
2 Time that catch was removed from water;
3 Time that separation procedure began;
4 Time that bycatch was returned to water;
5 Bay temperature;
6 Bay salinity; and
7 Salinity in salt-box.

Total catch weight was not measured because bay shrimpers do not weigh individual catches and we did not want to change their shrimping practices more than necessary to collect the samples. To collect bycatch samples, an individual boarded the boat and waited until the bycatch was discarded. A 1–2 kg sample was randomly removed from the bycatch with a dip net or plastic scoop and placed into a 60-cm diameter × 60-cm deep holding pen. Pens were constructed from a bag of 15-mm stretch-mesh knotless nylon net secured to a life ring. The opening in the life ring served as the opening of the pen. After the sample was placed in the pen, the opening was covered with 6-mm stretch-mesh netting. The pen was then placed overboard where TPW personnel in another boat recovered it. The samples, when brought aboard the TPW boat, were immediately placed in separate 89-L transport tanks (ice chests fitted with plastic tubing and commercial aquarium air stones, through which compressed oxygen was supplied to the tanks). Dead organisms were removed from samples immediately after placement in the transport tanks.

All moribund specimens were classified as dead. Samples were transported to the Perry R. Bass Marine Fisheries Research Station (PRB) located near Palacios, Texas, where they were transferred to separate 60-cm diameter × 60-cm deep holding pens placed in an aerated 1500-L holding tank. Water in the holding tank was maintained within 2°C and 2‰ salinity of the bay temperature and salinity from which the samples were taken. Samples were checked at least hourly during transport to PRB. After having been placed in the holding tank, organisms were checked at least every three hours, except from 2300 to 0700 hours, when they were checked once. Each time samples were checked, beginning when the samples were placed in transport tanks, all dead organisms were removed, labeled to identify sample, their time and date of collection were recorded, and the organisms were preserved on ice for later examination. At approximately 1200 hours on the day following collection of the sample (about 21–27 h after collection), the remaining organisms were removed, their condition identified (living or dead), and the sample identification number and time and date of collection were recorded. All organisms collected in the sample were then identified, enumerated, and their total length (TL) was measured.

The effect of salt-box use was evaluated for all bycatch species and for Atlantic croaker alone. Three measurements were used for the evaluation: percent survival of bycatch organisms when separation of catch was completed (initial survival), percent survival of bycatch organisms at completion of sample observations (final survival), and mortality rate (M) of bycatch. Mortality rate was the absolute value of the slope of the regression of the natural log of living organisms +1 as a function of time. Time was measured from the time the catch was removed from the water to completion of sample observation. Because the three measurements had unequal variances, even when data were transformed, nonparametric procedures were used to compare the two separation methods and to examine relationships. Wilcoxon signed rank test was used to determine if initial survival, final survival, M, number of specimens collected, and TL of specimens differed significantly between the two separation methods. The Spearman correlation coefficient and the probability that the coefficient was significantly greater than 0 were used to examine relationships among all variables. For the correlation analysis, the use of a salt-box was coded as 1 and non-use as 0.

Stepwise multiple regression analysis was used as an exploratory procedure to examine the effect of 1) length of time trawl was fished; 2) catch separation time (total time bycatch was onboard the vessel); 3) bay temperature at the time of collection; 4) bay salinity at time of collection; and 5) effect of use or non-use of a salt-box on initial survival, final survival, and M of bycatch. For the regression analysis, coding of the use and non-use of a salt-box was the same as that for the correlation analysis. The significance level of the independent variable to enter and stay in the model was $P \leq 0.05$. Statistical analyses were performed by using the Statistical Analysis System (SAS Institute, 1990). All statistical tests were considered significant at the $P=0.05$ level.

Effect of salt-box use on bycatch survival: control experiments

Fourteen samples were collected from Matagorda Bay between 16 May and 25 October 1995, with a 6.1-m wide trawl constructed of 3.8-cm stretched nylon multi-filament mesh (Kana et al., 1993) equipped with a 6-mm stretch-mesh liner in the codend. The trawl was towed for 15 minutes. The catch was removed from the trawl and placed on a 0.67 × 1.0 m table. The catch was allowed to sit on the table for seven minutes to simulate the time the catch sits on deck while commercial shrimpers re-initiate trawling operations. The 7-min period was selected on the basis of a preliminary survey that we conducted of Texas bay shrimp fishing practices. The catch was then divided into approximately two equal portions: one half was placed in a salt-box and the bycatch was removed by skimming floating organisms from the surface; the remaining half of the catch remained on the table and shrimp were removed by hand, leaving the bycatch on the table. The salt-box was a 185-L fiberglass tank, half filled with bay water to which was added about 7.5 kg of food-grade salt. All bycatch removed from the salt-box was immediately placed in a separate 89-L transport tank filled with bay water and supplied with compressed oxygen. In the hand separation process, shrimp were removed and the bycatch remaining on the table was placed in a separate 89-L transport tank filled with bay water and supplied with compressed oxygen. Dead organisms were removed from samples immediately after they were placed in transport tanks. Samples were then transported to the PRB where they were treated in the same manner as previously described for samples collected from commercial shrimpers. The effect of the salt-box on the bycatch (all species), and on Atlantic croaker, spot, and sand seatrout (each species separately) was evaluated. Analyses were identical to those used to analyze samples collected from bay shrimpers.

Results

Bioassays

Probit analysis indicated LE_{50} for the five species ranged from a low of 17 min for red drum to 67 min for blue crab (Table 2). Southern flounder was the most tolerant of the fishes with an LE_{50} of 58 min. Comparison of log-likelihood ratio G values indicated that NOEE ranged eight min for Atlantic croaker and red drum to 64 min for blue crab. Southern flounder had the greatest NOEE (32 min) of the four fishes tested.

Effect of salt-box use on bycatch survival: samples from the bay shrimp industry

All commercial fishermen resumed fishing operations before beginning the catch separation procedure. Therefore, for descriptive purposes, catch separation time can be divided into two periods: 1) time the catch remains on deck or table while fishing is resumed and 2) time the catch is

Table 2

Results of high salinity bioassays and mean total length (TL) of experimental animals. LE_{50} = time required for 50% of experimental animals to die, NOEE = no-observed-effect from exposure time.

Species	*n*	LE_{50} (min)	NOEE (min)	Mean TL (mm)
Atlantic croaker	210	19	8	65 ±11.7
Red drum	105	17	8	28 ±2.7
Spotted seatrout	90	35	16	72 ±15.5
Southern flounder	105	58	32	131 ±23
Blue crab	105	67	64	45 ±4.8[1]

[1] Carapace width for blue crabs = TL.

Table 3

Mean (±SD) trawling time (h), catch separation time (min), bay salinity (‰), salinity in the salt-box (‰), and bay temperature (°C) for bycatch samples collected from the commercial fishery and separated with (*n*=15), or without (*n*=15), the aid of a salt-box and results of Wilcoxon signed rank tests comparing the means.

Variable	Salt-box	No salt-box	*Z*	*P*
Trawling time	1.5 ±0.62	1.2 ±0.79	0.634	0.526
Separation time	9.9 ±3.1	16.5 ±21.5	–0.605	0.550
Bay salinity	21.0 ±4.7	22.3 ±2.7	–1.045	0.296
Salt-box salinity	77.0 ±6.4			
Bay temperature	26.7 ±0.7	28.7 ±1.8	–3.887	<0.001

sorted. The mean time that catch remained on deck while fishing resumed was 11.7 min (±18.9 min) for fishermen not using a salt-box and 7.8 min (±4.2 min) for fishermen using a salt-box. Time the catch remained on the deck was statistically similar for the two methods (Z=0.6251, P=0.9502). The catch separation procedure with a salt-box began when fishermen used a large scoop to transfer the catch from the boat deck to the salt-box. Fishermen not using a salt-box spread the catch on the boat deck or a table and began removing shrimp. Once the catch separation procedure began, fishermen using a salt-box required 1.7 min (±1.4 min) to separate the catch, whereas fishermen not using a salt-box required 7.0 min (±12.0 min) to separate the catch; mean time required was statistically similar between the methods (Z=–1.44571, P=0.1483). Time required to separate the catch once the procedure began appeared to depend upon size of the catch, but we had only the captain's estimate of the size of the catch. Trawling time, catch separation time (total time bycatch was out of the water), and bay salinity at the time samples were collected did not differ significantly for samples collected by each method (Table 3). Mean bay temperature at the time of collection differed significantly between samples collected with the salt-boxes and those collected with no salt-box. Bay temperature averaged 28.7° (±1.8°)C when NSB samples were collected and 26.7° (±0.7°)C when SB samples were collected.

Thirty-three species (30 fishes and 3 invertebrates) were collected (Table 4). Atlantic croaker (*n*=536) was the most common organism and was present in 27 of the 30 samples. Other fishes frequently observed were spot (*n*=278), sand seatrout (*n*=90), Gulf menhaden (*Brevoortia patronus*, *n*=198), and bay anchovy (*Anchoa mitchilli*, *n*=45). The most frequently observed invertebrates were brown shrimp (*Penaeus aztecus*, *n*=46) and blue crab (*n*=34). Remaining species generally averaged <1 per sample. Some differences were observed in the frequency and length of some of the bycatch species that composed the NSB and SB samples. However, differences were generally small and were probably biologically insignificant. Atlantic croaker, bay anchovy, hardhead catfish (*Arius felis*), and brown shrimp were found in significantly greater numbers in SB samples than in NSB samples (Table 5). Bay whiff (*Citharichthys spilopterus*), bluntnose jack (*Hemicaranx amblyrhynchus*), Atlantic spadefish (*Chaetodipterus faber*), and inshore lizardfish (*Synodus foetens*) were found in significantly greater numbers in NSB samples than in SB samples, although they were rare in NSB samples. Mean number of specimens collected for all other species were similar in both sample types. Mean length of Atlantic croaker, Gulf menhaden, spot, sand seatrout, and pinfish (*Lagodon rhomboides*) were significantly greater in NSB samples (Table 5). Blue crabs collected in SB samples had a significantly greater mean carapace width than those collected in NSB samples. Mean lengths of all other species were similar in both sample types.

In general, all three measures of salt-box effect on bycatch were highly variable (Table 6). Mean (±SD) initial

Table 4

Species collected from bycatch of Texas bay shrimpers and in Texas Parks and Wildlife (TPW) samples. X indicates that the species was collected.

Common name	Species	Bay shrimpers	TPW
Vertebrates			
Atlantic bumper	*Chloroscombrus chrysurus*	X	
Atlantic croaker	*Micropogonias undulatus*	X	X
Atlantic cutlassfish	*Trichiurus lepturus*	X	X
Atlantic midshipman	*Porichthys plectrodon*	X	X
Atlantic spadefish	*Chaetodipterus faber*	X	X
Atlantic stingray	*Dasyatis sabina*	X	
Atlantic threadfih	*Polydactylus octonemus*		X
bay anchovy	*Anchoa mitchilli*	X	X
bay whiff	*Citharichthys spilopterus*	X	X
bighead searobin	*Prionotus tribulus*	X	X
blackcheek tonguefish	*Symphurus plagiusa*	X	X
bluefish	*Pomatomus saltatrix*	X	
bluntnose jack	*Hemicaranx amblyrhynchus*	X	X
gafftopsail catfish	*Bagre marinus*	X	X
gulf butterfish	*Peprilus burti*		X
gulf menhaden	*Brevoortia patronus*	X	X
hardhead catfish	*Arius felis*	X	X
harvestfish	*Perprilus alepidotus*	X	X
hogchoker	*Trinectes maculatus*	X	X
inshore lizardfish	*Synodus foetens*	X	X
least puffer	*Sphoeroides parvus*	X	X
lookdown	*Selene vomer*	X	
pinfish	*Lagodon rhomboides*	X	X
sand seatrout	*Cynoscion arenarius*	X	X
silver jenny	*Eucinostomus gula*		X
silver perch	*Bairdiella chrysoura*	X	X
skipjack herring	*Alosa chrysochloris*	X	
southern flounder	*Paralichthys lethostigma*	X	X
southern kingfish	*Menticirrhus americanus*	X	
spot	*Leiostomus xanthurus*	X	X
spotted seatrout	*Cynoscion nebulosus*	X	
star drum	*Stellifer lanceolatus*	X	
threadfin shad	*Dorosoma petenense*	X	
Invertebrates			
Atlantic brief squid	*Lolliguncula brevis*	X	X
blue crab	*Callinectes sapidus*	X	X
brown shrimp	*Penaeus aztecus*	X	X
white shrimp	*Penaeus setiferus*		X

survival rates were 76.1% (±21.7%) and 55.5% (±35.1%), respectively for SB and NSB samples. Final survival rates were 12.9% (±6.0%) for SB samples and 34.5% (±28.9%) for NSB samples. Means of initial and final survival were not significantly different. Average (±SD) M of organisms separated by use of a salt-box (0.08 [±0.03]) were significantly lower than M of bycatch separated without the aid of a salt-box (0.48 [±1.23]).

For individual species, comparison of the effect of use and non-use of a salt-box on M, and on initial and final survival variables could only be determined for Atlantic croaker. Other species were either found infrequently in individual samples, or in insufficient numbers within the sample type. Estimates of initial and final survival for Atlantic croaker were obtained from 19 samples (6 NSB samples and 13 SB samples). Estimates of M were obtained from 16 samples (4 NSB samples and 12 SB samples). Samples not used had too few Atlantic croaker (i.e. only one or two specimens in the sample or no deaths) to make estimates of percent survival or M. Means of the three estimates used to compare the two separation techniques were highly variable for Atlantic croaker (Table 6). Means

Table 5

Species which differed significantly in either mean numbers or total length (mm) from comparative samples collected from the commercial fishery and separated with or without the aid of a salt-box, and results of Wilcoxon signed rank tests used to compare means.

	Salt-box		No salt-box			
Species	Mean ±SD	*n*	Mean ±SD	*n*	*Z*	*P*
Number of specimens						
bay anchovy	2.7 ±4.9	15	0.3 ±0.6	15	3.159	0.002
Atlantic croaker	28.8 ±14.5	15	6.9 ±5.0	15	4.030	<0.001
hardhead catfish	2.5 ±3.3	15	0.7 ±1.4	15	2.150	0.032
bay whiff	0.1 ±0.3	15	1.3 ±1.4	15	–3.097	0.002
bluntnose jack	0	15	1.3 ±1.7	15	3.440	0.001
Atlantic spadefish	0	15	0.5 ±0.9	15	–2.366	0.018
inshore lizardfish	0	15	0.4 ±0.8	15	–2.073	0.038
brown shrimp	2.0 ±1.8	15	1.1 ±1.8	15	3.397	0.001
Total length						
Atlantic croaker	120 ±15	419	104 ±19	93	8.129	<0.001
gulf menhaden	110 ±47	120	119 ±22	57	3.460	<0.001
spot	98 ±23	157	109 ±20	60	3.910	<0.001
sand seatrout	103 ±30	45	129 ±25	44	4.830	<0.001
pinfish	75 ±13	9	89 ±20	82	–3.348	0.001
blue crab	82 ±23	60	66 ±28	16	–2.268	0.023

Table 6

Means of bycatch (all species) and Atlantic croaker initial percent survival, final percent survival, and mortality rate (*M*) and results of Wilcoxon signed rank tests comparing the means. All samples were collected from Texas bay shrimpers and separated with or without the aid of a salt-box.

	Salt-box		No salt-box			
Variable	Mean ±SD	*n*	Mean ±SD	*n*	*Z*	*P*
Bycatch						
initial survival	76.1 ±21.7	15	55.5 ±35.1	15	1.763	0.078
final survival	12.9 ±6.0	15	34.5 ±28.9	15	–1.389	0.093
M	0.08 ±0.03	15	0.48 ±1.23	15	2.605	0.009
Atlantic croaker						
initial survival	74.4 ±25.7	13	81.8 ±25.1	6	0.746	0.046
final survival	28.6 ±19.9	13	62.3 ±30.7	6	2.330	0.020
M	0.23 ±0.12	12	0.26 ±0.19	4	0.364	0.716

of *M* were similar between separation techniques. Means of initial (81.8% [±25.1%]) and final (62.3% [±30.7%]) survival of fish separated without a salt-box were significantly greater than initial (74% [±25.7%]) and final (28.6% [±19.9%]) survival of those separated with a salt-box.

By examining Spearman correlation coefficients that were significantly greater than 0, we found a relationship between the three measurements and factors other than use or non-use of a salt-box (Table 7). Initial and final survival estimates were negatively correlated to trawling time and catch separation time, whereas *M* was positively correlated to the two variables. Only estimates of *M* (r_s=0.488) were found to be related to the use or non-use of a salt-box. Final estimates of survival and *M* were also associated with some bycatch species. *M* was positively correlated to numbers of Atlantic croaker (r_s=0.526) and sand seatrout (r_s=0.458) in the samples, whereas final survival was inversely correlated to the two species (Atlantic croaker r_s=–0.391, sand seatrout r_s=-0.564). Other species to which *M* and final survival were associated occurred in fewer than half the samples or averaged <1 specimen per sample. Initial survival estimates were not related to

Table 7

Spearman correlation coefficients (r_s) and probability (P) that the coefficient values were greater than 0, of variables that demonstrated relationships with mortality rate (M), initial percent survival, and final percent survival for bycatch (all species) and Atlantic croaker. Samples were collected from the catch of Texas bay shrimpers and separated with or without a salt-box. A space indicates the probability that the variables r_s value was greater then 0 was >0.05.

	M		Initial survival		Final survival	
Variable	r_s	P	r_s	P	r_s	P
Bycatch						
separation time	0.638	<0.001	–0.586	0.001	–0.749	<0.001
trawling time	0.650	<0.001	–0.414	0.023	–0.665	<0.001
bay temperature	–0.459	0.011				
bay anchovy	0.477	0.008				
Atlantic croaker	0.526	0.003			–0.391	0.033
gulf menhaden	0.445	0.014			–0.461	0.010
sand seatrout	0.458	0.011			–0.564	0.001
pinfish	–0.434	0.017				
bighead searobin	–0.368	0.046				
gafftopsail catfish					–0.398	0.029
bay whiff					0.379	0.039
Atlantic cutlassfish					–0.373	0.042
salt-box	0.488	0.006				
Atlantic croaker						
separation time	0.637	0.008	0.459	0.016		
least puffer	0.994	<0.001				
hardhead catfish					–0.592	0.001
blue crab					–0.463	0.015
brown shrimp					–0.566	0.002
harvestfish			0.401	0.038	0.400	0.038
Atlantic brief squid	–0.833	0.039				
salt-box					–0.629	0.004

Table 8

Independent variables that entered stepwise multiple regression models describing bycatch (all species), initial percent survival, final percent survival, and mortality rate (M), and Atlantic croaker M resulting from Texas bay shrimpers separating them from shrimp with or without the aid of a salt-box. Included are y-intercepts±SE, coefficients±SE of the selected independent variables, partial r^2 of each variable in parenthesis, and model r^2. A space indicates the variable did not enter the model.

		Independent variable				
Dependent variable	y-intercept	Separation time	Trawl time	Bay temperature	Salt-box	Model R^2
Bycatch						
initial survival	217.4 ±65.3	–120.5 ±21.8 (0.52)				0.52
final survival	60.0 ±6.9		–20.2 ±4.1 (0.48)		–15.5 ±5.8 (0.11)	0.59
M	2.3 ±1.2	5.1 ±0.4 (0.79)	–0.3 ±0.1 (0.03)	–0.1 ±0.04 (0.03)		0.85
Atlantic croaker						
final survival	51.2 ±10.1	61.9 ±27.0 (0.11)			–31.22 ±10.0(0.38)	0.49

any bycatch species. The initial survival (r_s=0.459) and M (r_s=0.637) of Atlantic croaker were related to catch separation time. Atlantic croaker final survival (r_s=–0.629) was negatively correlated to use of a salt-box.

Stepwise multiple regression identified four variables, which explained most of the variation associated with the three measurements (Table 8). Catch separation time (total time that bycatch was on the vessel), trawling time, and

Table 9

Species collected from samples of bycatch separated with or without the aid of a salt-box in control experiments whose mean total length (mm) differed significantly and results of Wilcoxon signed rank tests used to compare the means.

	Salt-box		No salt-box			
Species	Mean total length ±SD	*n*	Mean total length ±SD	*n*	*Z*	*P*
Bay anchovy	50 ±11	191	53 ±13	219	–2.977	<0.001
Spot	94 ±18	138	89 ±24	194	2.818	0.005
Silver perch	72 ±37	4	111 ±22	18	–2.605	0.009
Atlantic brief squid	82 ±39	53	58 ±39	63	4.177	<0.001

bay temperature explained 85% of the variation associated with estimates of bycatch *M*. Catch separation time was the most important of the three, explaining 79% of the variation. Catch separation time explained 52% of the variation observed in initial survival and was the only variable to meet the $P \leq 0.05$ significance level required for entry into the model. Trawling time explained 48% of the variation observed in bycatch final survival and use or non-use of a salt-box explained the remaining 11%. For the dependent variable, Atlantic croaker final survival, the use or non-use of a salt-box explained 38% of the variation explained by the model and catch separation time explained an additional 11%. The five independent variables did not meet the $P \leq 0.05$ significance level required to enter or stay in stepwise regression models for Atlantic croaker initial survival and *M*.

Effect of salt-box use on bycatch survival: control experiments

Twenty-eight species were collected for the control experiments: 24 fishes and 4 invertebrates (Table 4). Bay anchovy (n=3794), Atlantic croaker (n=2048), spot (n=949), sand seatrout (n=291), and Gulf menhaden (n=148) were the most numerous organisms and were observed in more than half the samples collected. Remaining fishes averaged <1 individual per sample. Brown shrimp (n=494) and Atlantic brief squid (*Lolliguncula brevis*, n=133) were the most numerous invertebrates caught. By species, no significant differences were found between numbers of individuals in SB and NSB samples. Bay anchovy, spot, silver perch (*Bairdiella chrysoura*), and Atlantic brief squid collected in NSB samples were significantly larger than those collected in SB samples, but differences for the most part were small or the organism was present in small numbers (Table 9). Remaining species were similar in size in both NSB and SB samples. Catch separation time averaged 12 min (±6 min) for SB samples and 18 min (±18 min) for NSB samples and was significantly different (Z=2.05399, P=0.04). At the time samples were collected, bay temperature averaged 26.0° (±3.1°)C, bay salinity, 18,0‰. (±7.2‰), and salt-box salinity 66‰ (±8‰).

Survival rates and mortality rates were highly variable for bycatch separated by both methods. Mean initial survival rates were 48.4% (±39.7%) and 43.6% (±39.3%), respectively for SB and NSB samples. Final survival rates were 5.4% (±8.9%) for SB samples and 9.5% (±18.7%) for NSB samples. Mortality rates averaged 0.1 (±0.04) for SB samples and 0.1 (±0.05) NSB samples. All estimates of survival and mortality were statistically similar (Table 10). By species, estimates of initial survival, final survival, and *M* for Atlantic croaker, spot, and sand seatrout were also highly variable and were statistically similar between the two methods of bycatch separation.

Spearman correlation coefficients significantly greater than 0 demonstrated a relationship between bycatch (all species) catch separation time and the variables initial survival (r_s=0.445) and M(r_s=0.522). (Table 11). Initial survival was found to have an inverse relationship with temperature. All three measurements of the effect of salt-box use on bycatch were associated with the frequency of occurrence of some species in the bycatch. The variable *M* was positively correlated to Atlantic croaker (r_s=0.765), spot (r_s=0.681), and sand seatrout (r_s=0.792) numbers. Initial survival was positively correlated to Atlantic croaker (r_s=0.630), spot(r_s=0.530), and blue crab (r_s=0.494) numbers and was inversely related to the numbers of bay anchovy (r_s=–0.795) and Gulf menhaden (r_s=–0.466). Final survival was positively correlated to blue crab (r_s=0.631) numbers and inversely related to bay anchovy numbers (r_s=–0.655). Other species to which *M*, and initial and final survival were related occurred in fewer than half the samples and averaged <1 organism per sample. Atlantic croaker *M* was related to bay temperature (r_s=0.828), bay salinity (r_s=–0.513), and to the presence of Atlantic brief squid (r_s=–0.833). Neither Atlantic croaker initial nor final survival estimates were correlated to other variables. Spot and sand seatrout *M*, initial survival, and final survival were not correlated to any variable.

For all species, stepwise multiple regression identified catch separation time, bay salinity, and bay temperature at the time of sample collection as significant variables which explained some of the observed variation in *M* and final survival (Table 12). The salt-box variable did not enter any model. Catch separation time explained 27% of the variation that was accounted for by the model for the dependent variable *M*, and an additional 11% was explained by bay salinity at time of sample collection. Bay temperature and salinity at the time of collection explained 34% of variation observed in the final survival model. No variable met the $P \leq 0.05$ significance level for entry into regression models

Table 10

Mean (±SD) of initial percent survival, final percent survival, and mortality rate (*M*) and results of Wilcoxon signed rank tests used to compare the means of bycatch (all species), Atlantic croaker, spot, and sand seatrout from bycatch samples collected in control experiments and separated with or without the aid of a salt-box.

	Salt-box		No salt-box			
Variable	Mean ±SD	*n*	Mean ±SD	*n*	*Z*	*P*
Bycatch						
initial survival	48.4 ±39.7	14	43.6 ±39.3	14	–0.460	0.643
final survival	5.4 ±8.9	14	9.5 ±18.7	14	–0.322	0.748
M	0.10 ±0.04	14	0.10 ±0.05	14	–0.277	0.782
Atlantic croaker						
initial survival	41.1 ±38.2	8	56.0 ±40.1	8	0.790	0.430
final survival	18.3 ±24.1	8	16.8 ±34.1	8	–0.373	0.709
M	0.41 ±0.77	8	0.82 ±1.27	8	0.105	0.916
Spot						
initial survival	70.9±30.3	12	71.7 ±27.3	12	–0.206	0.837
final survival	24.9±34.8	12	21.5 ±36.4	12	–0.695	0.519
M	1.30±2.71	12	2.07 ±3.26	12	0.799	0.424
Sand seatrout						
initial survival	85.7 ±28.8	11	72.3 ±26.7	11	–1.242	0.214
final survival	29.2 ±38.0	11	14.1 ±20.0	11	–0.774	0.439
M	3.58 ±6.31	11	4.27 ±6.38	11	0.417	0.677

Table 11

Spearman correlation coefficients (r_s) and probability (*P*) that the coefficient values were greater than 0, of variables which demonstrated relationships with bycatch (all species) mortality rate (*M*), initial percent survival and final percent survival and Atlantic croaker *M*. Samples were collected in Texas Parks and Wildlife trawls and separated from shrimp with or without the aid of a salt-box during control experiments. A space indicates the probability that the variables r_s value was greater then 0 was >0.05.

	M		Initial survival		Final survival	
Variable	r_s	*P*	r_s	*P*	r_s	*P*
Bycatch						
separation time	0.522	0.004	0.445	0.018		
Atlantic croaker	0.765	<0.001	0.630	<0.001		
spot	0.681	<0.001	0.530	0.004		
sand seatrout	0.792	<0.001				
least puffer	0.692	0.039				
bay temperature			–0.4249	0.025		
salt-box salinity			–0.680	<0.001	–0.635	0.015
bay anchovy			–0.795	<0.001	–0.655	<0.001
gulf menhaden			–0.466	0.012		
bay whiff			0.444	0.018		
brown shrimp			0.433	0.021		
brief squid			–0.588	0.001		
blue crab			0.494	0.008	0.631	<0.001
silver perch			–0.386	0.042	–0.480	0.010
bluntnose jack			–0.568	0.002		
Atlantic croaker						
bay temperature	0.829	0.042				
bay salinity	–0.514	0.028				
Atlantic brief squid	–0.833	0.039				

Table 12

Independent variables which entered stepwise multiple regression models describing bycatch (all species), Atlantic croaker, spot, and sand seatrout short-term final percent survival, or mortality rate (*M*) (or both) resulting from their separation from shrimp with or without the aid of a salt-box during controlled experiments. Included are *y*-intercepts (±SE), coefficients (±SE) of the independent variables, partial R^2 of each variable in parenthesis, and model R^2. A space indicates the variable did not enter the model.

		Independent variable			
Dependent variable	*y*-intercept	Separation time	Bay salinity	Bay temperature	Model R^2
Bycatch					
final survival	216.59 ±58.069		–2.71 ±0.88 (0.13)	–4.68 ±2.08 (0.21)	0.34
M	0.12 ±0.03	0.09 ±0.03 (0.27)	–0.002 ±0.001 (0.11)		0.38
Atlantic croaker					
M	–5.36 ±203	2.25 ±0.45 (0.75)		0.21 ±0.08 (0.08)	0.83
Spot					
M	–1.44 ±1.41		0.18 ±0.07 (0.20)		0.20
Sand seatrout					
final survival	213.31 ±67.36			–7.08 (0.29)	0.29
M	–39.75 ±12.90			1.61 ±0.47 (0.37)	0.37

for the dependent variable initial survival. Time required to separate catch accounted for 75% of the variation observed in Atlantic croaker *M*, whereas bay temperature at time of sample collection accounted for the remaining 8% variation explained by the model. Bay salinity at time of sample collection explained 20% of the variation observed in *M* of spot. Bay temperature at time of sample collection explained 37% and 29%, respectively, of the dependent variables *M* and initial survival of sand seatrout. No variable met the $P \leq 0.05$ significance level for entry into models to explain initial survival of Atlantic croaker, spot, or sand seatrout, or final survival of Atlantic croaker or spot.

Discussion

Use of a salt-box to separate bycatch, as practiced by Texas shrimpers, had little or no effect on short-term survival of bycatch. Measurements of bycatch (all species) initial and final survival were not significantly different for the bycatch separation methods in samples collected from bay shrimpers and from TPW trawls. Significant differences between SB and NSB Atlantic croaker initial and final survival of samples collected from the commercial fishery were not corroborated by the results of the TPW control experiments. Exposure time to hypersaline conditions in a salt-box is short, generally less than two min, and the no-observed-effect exposure for selected species suggests that longer exposure (at least eight min for red drum and Atlantic croaker) would probably be required to significantly affect survival of most bycatch species. For these reasons, regulation of salt-box use as currently practiced by Texas bay shrimpers is unnecessary.

The use of a salt-box had little impact on bycatch *M*, and initial or final survival. Salt-box use was correlated to *M*, for samples collected from the fishery, but not to initial or final survival. Salt-box use was not correlated to any of the three variables for bycatch in the control experiments. Atlantic croaker final survival was negatively correlated to the presence of a saltbox in samples collected from the fishery but the correlation was not present in the control experiments. The salt-box variable entered the final survival regression models for combined catch and Atlantic croaker from the fishery but entered no other regression models.

Environmental factors at the time of sample collection played a role in determining survival of bycatch, although not as great as other variables associated with bycatch separation. Both bay temperature and salinity at the time of sample collection affected survival and *M* variables in the control experiments as demonstrated by the correlation and regression analyses. Bay temperature also explained a small portion of the variation (3%) associated with *M* in trials conducted on samples collected from the fishery. For individual species, bay temperature and salinity, either individually or combined, explained part of the variation associated with the regression models for *M* of Atlantic croaker, spot, and sand seatrout, and for final survival of sand seatrout. The effect of temperature on *M* in samples taken from the fishery and survival and *M* in control experiments suggest there may be a seasonal effect on survival of bycatch. Failure to observe a greater effect in trials with the fishery samples probably is due to the effect of other factors associated with the fishery, such as long trawl times and catch separation times that mask the effect of environmental factors.

Catch separation time was one of the most important variables associated with bycatch survival. It was correlated to *M*, initial survival, and final survival for samples collected from the fishery and to *M* and initial survival in the control experiment. The variable entered multiple regression models for the variables *M* and initial survival of bycatch in experiments conducted with samples collected from the fishery. It also entered multiple regression models for the dependent variable *M* of bycatch and Atlantic croaker in the control experiments. The use of the salt-box significantly reduced catch separation time in control experiments, suggesting that the use of the salt-box could possibly reduce *M* by speeding catch separation time. The importance of reducing catch separation time has been corroborated by Ross and Hokenson (1997) who reported a positive correlation between mortality and on-deck sorting time for three species of bycatch (American plaice, *Hippoglossoides platessoides*; witch flounder, *Glyptocephalus cynoglossus*; and pollock, *Pollachius virens*) associated with the Gulf of Maine northern shrimp (*Pandalus borealis*) fishery.

Trawling time was also an important variable affecting *M* and survival. It was correlated to *M*, initial survival, and final survival of bycatch and entered the final survival regression model for bycatch from the fishery. This variable may affect survival in several ways. Longer trawl times in general result in larger catches. This would presumably increase catch separation time thus contributing to increased bycatch mortality. Long trawl times would also increase the time bycatch is in the net, thus increasing the chance of fatal injuries.

In the absence of a satisfactory method to reduce the catch of nontarget species, survival of bycatch could probably be improved by limiting the time a trawl is fished and by requiring the catch to be separated prior to resumption of fishing. These variables were the only ones found in our study that had significant impact on bycatch survival and that could easily be altered to improve survival. Enforcement of either of these proposals, however, would be difficult.

Use of percent survival estimates at the conclusion of the observation periods in our study to predict long-term survival of bycatch released into the bay is not recommended. Stress in fishes is characterized by hypersecretion of epinephrine, norepinephrine, and corticosteroids. These hormones induce secondary effects resulting in changes in metabolism, osmoregulation, and the immune systems (Mazeaud et al., 1977) that last for several days and can result in increased susceptibility to disease (Wedemeyer and McLeay, 1981). Furthermore, stress can lead to behavioral changes (Wedemeyer, 1974) that might make the fish more susceptible to predation. Specimens can be maintained under identical conditions (in the laboratory or field) to compare survival and mortality rates of individuals treated differently at capture. However, it would be speculative to project survival estimates of specimens maintained in any form of captivity to those released into the wild because it is impossible to account for predation and possibly disease.

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