Effectiveness of four industry-developed bycatch reduction devices in Louisiana's inshore waters

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Abstract.—Trawling was conducted in three areas of coastal Louisiana during the two inshore shrimp seasons of 1992 to evaluate the effectiveness of four industry-developed bycatch reduction devices (BRD's). Each BRD (Authement-Ledet excluder, Cameron shooter, Lake Arthur excluder, and Eymard accelerator) was towed alongside a control net 72 times; tows were equally divided between areas and seasons. The Authement-Ledet excluder, Cameron shooter, and Lake Arthur excluder BRD's caught fewer fish (–36%, –51%, and –21%, respectively), but also fewer shrimp (–18%, –16%, and –24%) than corresponding control nets. Biomass catch differences were –42%, –33%, and –21% for fish and –14%, –14%, and –17% for shrimp. The Eymard accelerator caught 26% more fish numerically, 19% less fish biomass, and more shrimp (38% in numbers, 26% in biomass) than control nets. Differences between catches obtained with BRD nets and those with control nets depended upon the organisms present in an area. Abundances and size distributions of many species differed between areas; thus BRD's may have to be selected for the area where they are intended to be used.

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The inshore shrimping area of Louisiana is typically the waters landward of the barrier islands and the general Gulf of Mexico shoreline. The Louisiana inshore shrimp fishery is managed as three geographic zones (Fig. 1) and has two inshore shrimping seasons. Brown shrimp, *Penaeus aztecus*, dominate spring catches, whereas white shrimp, *P. setiferus*, dominate fall catches, although both species are caught during each season. In 1992, nearly 101 million kg of shrimp, valued at about $389 million, were landed commercially in the Gulf of Mexico (National Marine Fisheries Service, 1993). From 1986 to 1989, 40% of the total commercial catch in Louisiana was caught inshore (Baron-Mounce et al.[1]).

Although fishing gears and areas fished have varied, a survey in 1987 (Keithly and Baron-Mounce[2]) characterized Louisiana's commercial inshore shrimpers as follows. The average vessel size was 10.2 m for full-time shrimpers, 6.1 m for part-time shrimpers. Smaller boats tended to be constructed of fiberglass and powered by outboard motors. About 75% to 80% of the commercial inshore shrimpers participated in the fishery on a part-time basis. State law limited the size of each trawl to a headrope of 7.6 m length when two trawls were towed in inshore waters, except for Breton and Chandaleur Sounds. The inshore shrimp fleet was not highly mobile between management zones; only about 10% of the full-time shrimpers with boats in the 20–30 ft range and 2% of the part-time shrimpers fished in more than one zone during either season. The estimated inshore shrimping effort in 1987 by management zone was 18% (zone 1), 73% (zone 2), and 9% (zone 3)(Keithly and Baron-Mounce[2]).

The otter trawl has been the primary gear used by the inshore shrimp fishery in Louisiana (Keithly and Baron-Mounce[2]), although butterfly (wing) nets, cast nets, and skimmer (bay sweepers) nets have

[1] Baron-Mounce, E., W. Keithly, and K. J. Roberts. 1991. Shrimp facts. La. Sea Grant Coll. Prog., Communications Office, Louisiana State Univ., Baton Rouge, LA, 22 p.

[2] Keithly, W. R., Jr., and E. Baron-Mounce. 1990. An economic assessment of the Louisiana shrimp fishery. Final report to NMFS NA88WC-H-MF179. Coastal Fisheries Institute, Louisiana State Univ., Baton Rouge, LA, 129 p.

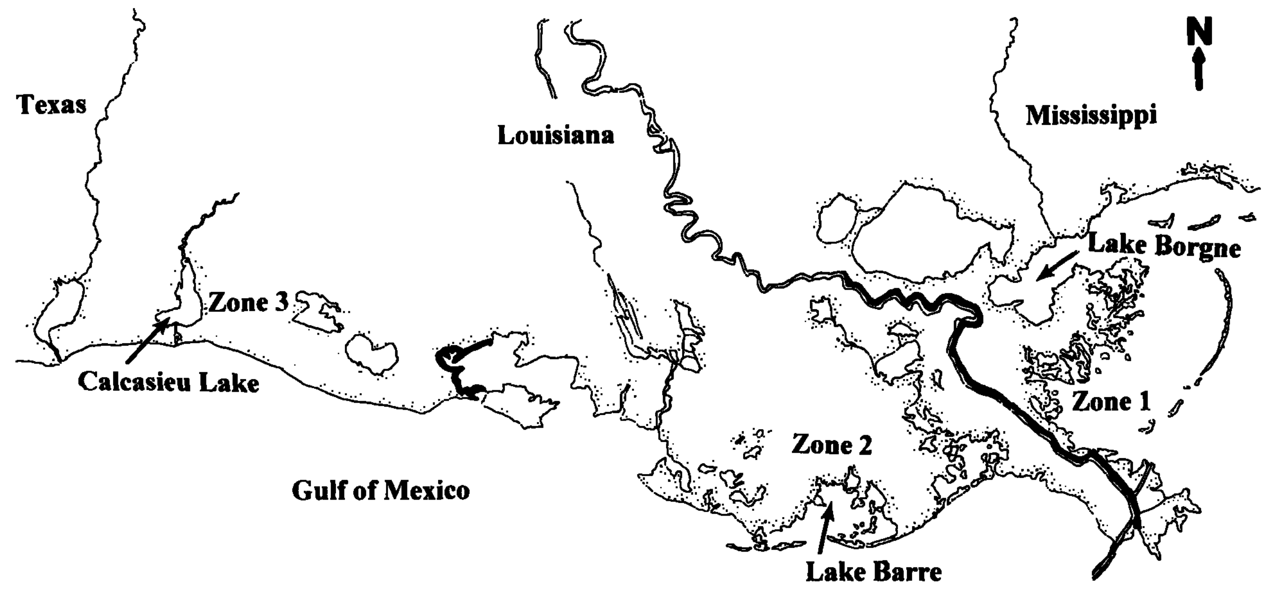

Figure 1
Map of the Louisiana coastline with locations of the three study areas and the three shrimp management zones (east-west zone boundaries are denoted by dark lines).

also been used. The minimum legal stretch mesh size at the time of the present study was 3.2 cm; however, shrimpers often use larger mesh to reduce the catch of small shrimp and nontargeted (bycatch) organisms.

Some methods that shrimpers have used to reduce bycatch have included relocating to areas of lower fish concentrations, cutting openings in nets, reducing tow speeds before haulback, and modifying nets in various ways. Heightened pressure by environmental organizations and pending legislation to reduce bycatch has furthered the development of shrimp trawls equipped with bycatch reduction devices (BRD's) to reduce the catch of nontargeted organisms. Previous research on BRD designs tested in the United States has been summarized by Watson and Taylor.[3]

Some of the BRD designs used successfully in other shrimp fisheries have proven ineffective in Gulf of Mexico waters. For example, a horizontal separator panel yielded a 75% reduction in bycatch but lost 30% of the shrimp (Seidel, 1975). Seidel (1975) tested six modifications of the Pacific Northwest shrimp separator trawl, which has a vertical separator panel and several chutes for fish escapement. Shrimp losses ranged from 9.1% to 63.5%, and fish reduction ranged from 37% to 83.5%; however, the modification with the best fish reduction had a shrimp loss of 63.5%. The lowest attainable shrimp loss (6%) from a trawl with vertical separator panels of varying mesh had a 45% bycatch reduction (Watson and McVea, 1977).

The Gulf has a high diversity of bycatch species, many of which are similar in size to shrimp; shrimp, however, may represent as little as 10% of the total catch (Seidel, 1975). Prior to this study, most evaluations of BRD's in the Gulf had been conducted in offshore waters. Inshore organisms are often smaller than those caught offshore, inshore trawls and vessels are typically smaller, and trawling conditions, such as water depth and turbidity, may differ. Because of these differences, the present study was designed to determine the performance of four BRD's in inshore waters of Louisiana.

Materials and methods

Bycatch reduction devices

To gather regional expertise on trawling and BRD design, an advisory committee of shrimpers, net makers, and fishery-related agency personnel was

[3] Watson, J. W., and C. W. Taylor. 1990. Research on selective shrimp trawl designs for penaeid shrimp in the United States: a review of selective shrimp trawl research in the United States since 1973. Proceedings ASMFC Fisheries Conservation Engineering Workshop, Narragansett, RI, April 1990, 21 p.

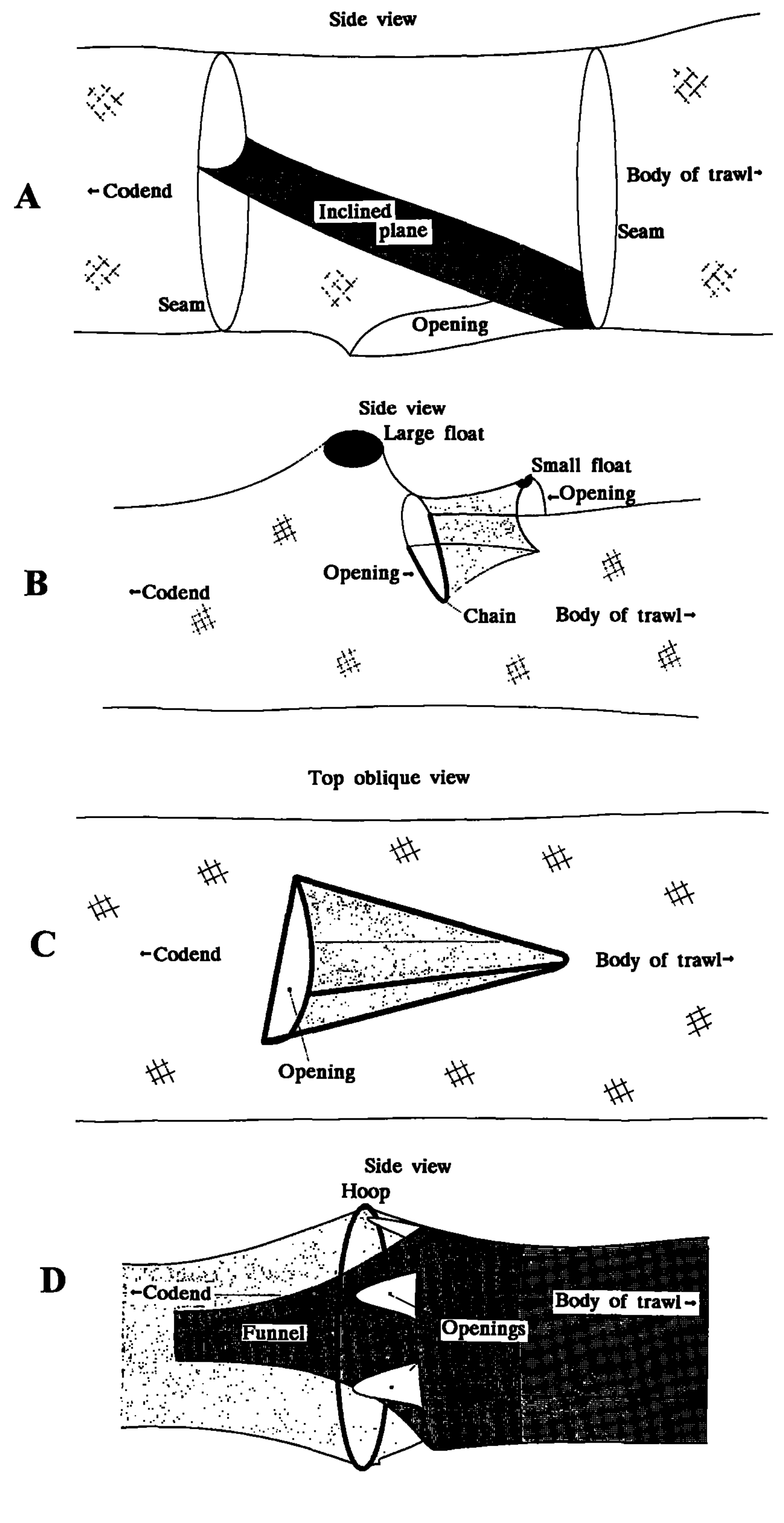

Figure 2

Diagrams of the bycatch reduction devices used in this study: (**A**) Authement-Ledet excluder; (**B**) Lake Arthur excluder; (**C**) Cameron shooter; and (**D**) Eymard accelerator.

organized. The industry committee members recommended basic trawl specifications and sampling areas. BRD's were selected from a pool of 14 industry- and NMFS-developed BRD and turtle excluder device (TED) designs suggested by members of the committee. Four industry-developed BRD designs were selected: Authement-Ledet excluder, Lake Arthur excluder, Cameron shooter, and Eymard accelerator (Fig. 2). The Cameron shooter, and very similar designs, such as the fisheye and Florida fish excluders, have had the widest use among commercial shrimpers along the U.S. Gulf of Mexico and Atlantic coasts. The other devices have been used on a limited basis in inshore and offshore waters of Louisiana, primarily in certain management zones: Eymard (zone 1), Authement-Ledet (zone 2), and Lake Arthur (zone 3).

Seven identical four-seam, nylon semiballoon trawls with 6.1-m headrope length were constructed; three were used as control nets and four were randomly selected for BRD installation. Each net had 3.5-cm stretch mesh in the body (no. 7 twine) and in the codend (no. 15 twine).

The Authement-Ledet excluder (Fig. 2A), constructed of 3.5-cm stretch mesh polyethylene webbing, was 35 meshes long and contained an inclined plane that was angled 20° from the net bottom to guide the catch upwards. The inclined plane was 18 meshes wide at the front and 30 meshes wide at the back; the back of the inclined plane was attached 18 meshes from the top seam of the trawl net. Fishes swimming forward from the codend were guided by the inclined plane to exit through the 18-mesh-wide, 40-mesh-long bottom opening.

The Lake Arthur excluder (Fig. 2B) was constructed by cutting 22 meshes across the top of the trawl net beginning 30 meshes from the tail. A 3-mm chain was attached to the forward edge of this opening and a 10-mesh × 12-mesh long cover was attached to the rear edge of this opening. Half of a 3.8 × 7.6 cm float ("small float" in Fig. 2B) was attached under, and a 4.5-mm rope was threaded along, the forward edge of this cover. A 13 × 28 cm conical float ("large float" in Fig. 2B) was attached 10 meshes behind the opening. The chain and floats created the escape opening.

The Cameron shooter (Fig. 2C) was a 30-cm wide, 45-cm long, 15-cm deep half cone of 12.7-mm aluminum round stock. A 30-mesh opening was cut in the top of the trawl net, and the forward edge of the cone was inserted into the codend, 20 meshes back from the body of the trawl. The semicircular frame opening faced the codend and protruded inside the trawl net.

The Eymard accelerator (Fig. 2D) had a polyethylene-webbing accelerator funnel, 45 meshes in diameter and 24 meshes long surrounded by six 10 × 10 × 10 mesh triangular openings. A 60-cm hoop of rubber coated cable was attached to pull the trawl net away from the funnel after initial dive tests indicated that the funnel blocked the escape openings.

Personnel from the National Marine Fisheries Service (NMFS) Harvesting Systems Branch examined the trawls several times by using scuba equipment, and adjustments were made to the trawl rigging and the BRD's. Dye was injected into various parts of the nets around the devices to observe water flow, and the behavior of escaping fish was documented.

Sampling

A 6.7-m Boston whaler, powered by twin 115-hp outboard motors and equipped with a single-drum winch and double boom, was used to tow twin trawls off the stern (Harrington et al., 1988); one trawl contained a BRD, the other a bare control net. The nets were equipped with tickler chains, connected to an aluminum dummy door, and spread by two 0.6 × 1.07 m pinewood trawl doors. Although twin trawls are not typically towed behind commercial vessels in Louisiana, the use of twin trawls to replace single large trawls off outriggers is increasing, particularly in the Gulf of Mexico (Watson et al., 1984). Smaller inshore vessels in Louisiana, without outriggers, typically tow a single larger net behind the boat. Our twin-trawl rigging configuration was approved by the committee to ensure that the nets sampled an area as closely as possible, given the patchy nature of many species. Nets were towed for 20 minutes (time at towing speed); the speed over ground was maintained between 2.0 and 2.5 knots (2.2 kn, average) by using a Global Positioning System, as recommended by the committee. Tows were made during daylight hours, near commercial shrimp boats whenever possible. Average water depth and the salinity were recorded for each trawl tow.

The four BRD's were evaluated in each inshore shrimp zone (Fig. 1). Eighteen two-day sampling trips were made, three trips to each area during each season. Each BRD net was towed 72 times over the year. Tows were divided among the areas and seasons. The towing order and trawl side for each BRD were initially selected randomly, although the same nets were not used on consecutive tows owing to the time taken to empty the nets. The three control nets were numbered and alternated to ensure equal pairing with a particular BRD net throughout the study. Sampling was conducted during the 1992 inshore shrimp seasons, although the short spring season necessitated sampling the week before the season opened in zone 1 and a few days after the season in zone 3. This schedule was approved by the advisory committee.

Samples were tagged and placed in mesh bags in ice and water. In the laboratory, organisms in each sample were identified, counted, and the biomass of each species in a sample was weighed to the nearest 0.1 g. When numerous, individuals of a species within a sample were subsampled and the total number estimated by weight. Standard lengths of most fishes, carapace widths of crabs, and total lengths of penaeid shrimp were measured. Organisms were measured in 5-mm length increments, designated by the lower end of the length range (e.g. 10-mm class=10.0 to 14.9 mm).

Statistical analysis

Residuals were examined for univariate normality and homogeneity of variances prior to accepting the analysis of variance model. Normality was tested with the Wilk-Shapiro test, and a modified Levene test was used to test for homogeneity of variances. These tests indicated that the raw data were not distributed normally and variances were not homogeneous. The transformation ln(catch+1) was used to create a new variable that met the criteria of being approximately normally distributed with homogeneous variances. This transformed variable was used in the analysis of variance (ANOVA). Statistical analysis was performed by using the Statistical Analysis System (SAS).

Control nets The transformed catch (both numbers and biomass of abundant species) of the three control nets was used as the dependent variable in an ANOVA with season, area, and season-by-area terms and with the interaction of these terms with the control net number, with tow as the experimental unit. Length-frequency distributions of abundant organisms collected by the control nets in each area were visually examined.

BRD's versus control nets Catches of shrimp, fish, and the nine most abundant species were analyzed. An ANOVA model was used to compare the difference between control and BRD net catches between areas and seasons. ANOVA was also used to detect differences caused by towing a BRD on the port or starboard side of the twin trawl.

The number of individuals and biomass of each species (or group) caught in a BRD net was compared with the number caught by the control net by using a univariate paired *t*-test. The univariate procedure is appropriate if one can assume that the probability of one species being retained within the net is independent of another species being retained. The short tow duration contributes to the chance that this assumption is valid. Paired *t*-tests were conducted on untransformed and log-transformed differences between BRD- and control-net catches. Percent catch differences of untransformed data were calculated to compare device nets:

$$\frac{\textit{Percentage catch}}{\textit{difference}} = \frac{\textit{Device net} - \textit{Control net}}{\textit{Control net}} \times 100.$$

Percent catch difference values could range from −100 to infinity.

Differences between areas and seasons

A univariate paired *t*-test was also used to compare differences between a BRD net and the control net within each area. This test had less power because the sample size was reduced by two-thirds and because the test was not able to detect as small a difference as the test with the areas combined. A similar analysis was conducted to examine device performance in each season.

For all analyses, differences between means with an alpha of 0.05 or less were considered significant. However, the exact probabilities are presented in the tables.

Results

Control nets

The control nets collected 88 species of fishes and invertebrates; fewer species were collected in the spring than in the fall in all areas (Table 1). More than 64% of the 84,919 organisms collected in the control nets were caught during the spring. Nine species represented nearly 89% of the total control-net catch. Bay anchovy, white shrimp, and hardhead catfish catches were higher in the fall, but the other

Table 1

Numbers of most abundant organisms collected in the control nets in inshore waters of Louisiana during the spring and fall of 1992.

		Spring				Fall				
		Area				Area				
Species		Borgne	Barre	Calcasieu	Total	Borgne	Barre	Calcasieu	Total	Combined total
Brown shrimp	*Penaeus aztecus*	2,842	5,375	10,593	18,810	400	481	245	1,126	19,936
Atlantic croaker	*Micropogonias undulatus*	597	8,346	5,162	14,105	240	207	2,015	2,462	16,567
Bay anchovy	*Anchoa mitchilli*	712	976	1,106	2,794	1,011	2,387	2,166	5,564	8,358
White shrimp	*Penaeus setiferus*	47	51	732	830	1,954	3,425	1,752	7,131	7,961
Hardhead catfish	*Arius felis*	423	363	2,638	3,424	1,087	1,432	1,864	4,383	7,807
Spot	*Leiostomus xanthurus*	846	2,059	1,603	4,508	180	161	339	680	5,188
Sand seatrout	*Cynoscion arenarius*	353	196	2,097	2,646	153	689	408	1,250	3,896
Blue crab	*Callinectes sapidus*	149	1,610	154	1,913	111	907	13	1,031	2,944
Gulf menhaden	*Brevoortia patronus*	86	278	1,533	1,897	54	68	623	745	2,642
Other species		273	2,108	1,152	3,533	1,263	2,273	2,551	6,087	9,620
Total		6,328	21,362	26,770	54,460	6,453	12,030	11,976	30,459	84,919
Number of species		38	51	53	66	47	65	57	82	88

six species were much more abundant in the spring. The catches from Lake Borgne were typically much smaller than catches from the other areas. Brown shrimp, hardhead catfish, sand seatrout, and gulf menhaden were most abundant in Calcasieu Lake, whereas Atlantic croaker and blue crab were most abundant in Lake Barre. Penaeid shrimp constituted 36% of the catch in the spring and 27% of the catch in the fall.

The numbers of organisms collected by the three control nets did not differ significantly. Control-net catches did not differ significantly with respect to the excluder with which they were paired. Length-frequency distributions of the abundant species differed between areas (Fig. 3).

The side of the trawl on which the control or BRD net was towed did not significantly affect catches of the abundant species. Each BRD was towed equally on each side of the twin trawl.

BRD's versus control nets

Fish All BRD nets had significantly different catches of fish from those of the control nets. Numerically, the Cameron BRD had the highest overall reduction of fish (–51%) compared with the catch of the control nets (Table 2). The Eymard BRD caught 26% more fish than the control nets. In terms of biomass, the Authement-Ledet BRD had the highest reduction (–42%), and the Eymard BRD had a 19% lower catch than the control nets.

The Authement-Ledet, Lake Arthur, and Cameron BRD nets caught fewer fish than the control nets in all size categories (Fig. 4). The Cameron BRD, in particular, had the highest reduction of small fish (≤75 mm). The Eymard BRD caught more small fish (≤85 mm) and fewer large fish than the control net.

The Cameron BRD had the best reduction in numbers of Atlantic croaker (49%), and the Authement-Ledet the best reduction in biomass (39%) (Table 3). The Authement-Ledet and Eymard BRD's caught 50% or fewer spot in terms of numbers and biomass; in contrast, the Cameron had very poor reductions for spot. Both the Cameron and Authement-Ledet BRD's caught 50% or fewer hardhead catfish than the control nets. The Cameron BRD caught 75% fewer bay anchovy than the control net, and the Authement-Ledet and Lake Arthur reduced bay anchovy by 37%. For most bycatch species, the Eymard BRD caught more than the control nets, although catches of the bay anchovy were markedly higher (83% numbers, 86% biomass).

Shrimp The catch of shrimp with all BRD nets differed significantly from the control net catch. The Cameron, Authement-Ledet, and Lake Arthur BRD's caught fewer shrimp than the control nets; shrimp catch with the Eymard was higher (38% numbers, 25% biomass) (Table 2). Numerically, the Cameron BRD had 16% fewer shrimp, and both the Cameron and Authement-Ledet had 14% lower shrimp biomass than the control nets.

Most of the catch difference between the BRD nets and corresponding control nets appeared to be smaller (≤85–90 mm) shrimp (Fig. 5). Catch differ-

Table 2

Comparison of numbers and biomass of fish and shrimp collected in bycatch reduction nets and corresponding control nets in selected inshore waters of Louisiana in 1992. SD is the standard deviation of the difference. Significance levels are 0.01 (**) and 0.05 (*). n=72. Superscripted letters denote significance levels of paired t-tests on log-transformed data: 0.01 ([a]). BRD = bycatch reduction device.

Type of catch and BRD	Numbers: Mean catch/tow Control	Numbers: Mean catch/tow Device	Numbers: Percent catch difference	Numbers: SD	Numbers: $P>t$-value	Biomass (g): Mean catch/tow Control	Biomass (g): Mean catch/tow Device	Biomass (g): Percent catch difference	Biomass (g): SD	Biomass (g): $P>t$-value
Fish										
Authement-Ledet	170.5	109.0	–36	102.6	0.01**[a]	2,541.8	1,464.1	–42	1,363.1	0.01**[a]
Lake Arthur	171.4	134.7	–21	124.9	0.01**[a]	2,904.4	2,282.6	–21	1,616.5	0.01**[a]
Cameron	181.7	88.3	–51	109.8	0.01**[a]	3,068.5	2,068.1	–33	1,233.3	0.01**[a]
Eymard	190.4	239.7	26	167.6	0.01**[a]	2,980.3	2,406.3	–19	2,059.8	0.02*[a]
Shrimp										
Authement-Ledet	84.8	69.3	–18	58.1	0.03*[a]	483.1	417.5	–14	240.7	0.02*
Lake Arthur	93.2	70.9	–24	57.5	0.01**[a]	514.0	425.0	–17	218.1	0.01**[a]
Cameron	110.9	93.0	–16	77.7	0.05*[a]	579.3	500.3	–14	220.5	0.01**[a]
Eymard	98.9	136.4	38	97.4	0.01**[a]	517.2	645.3	25	340.1	0.01**[a]

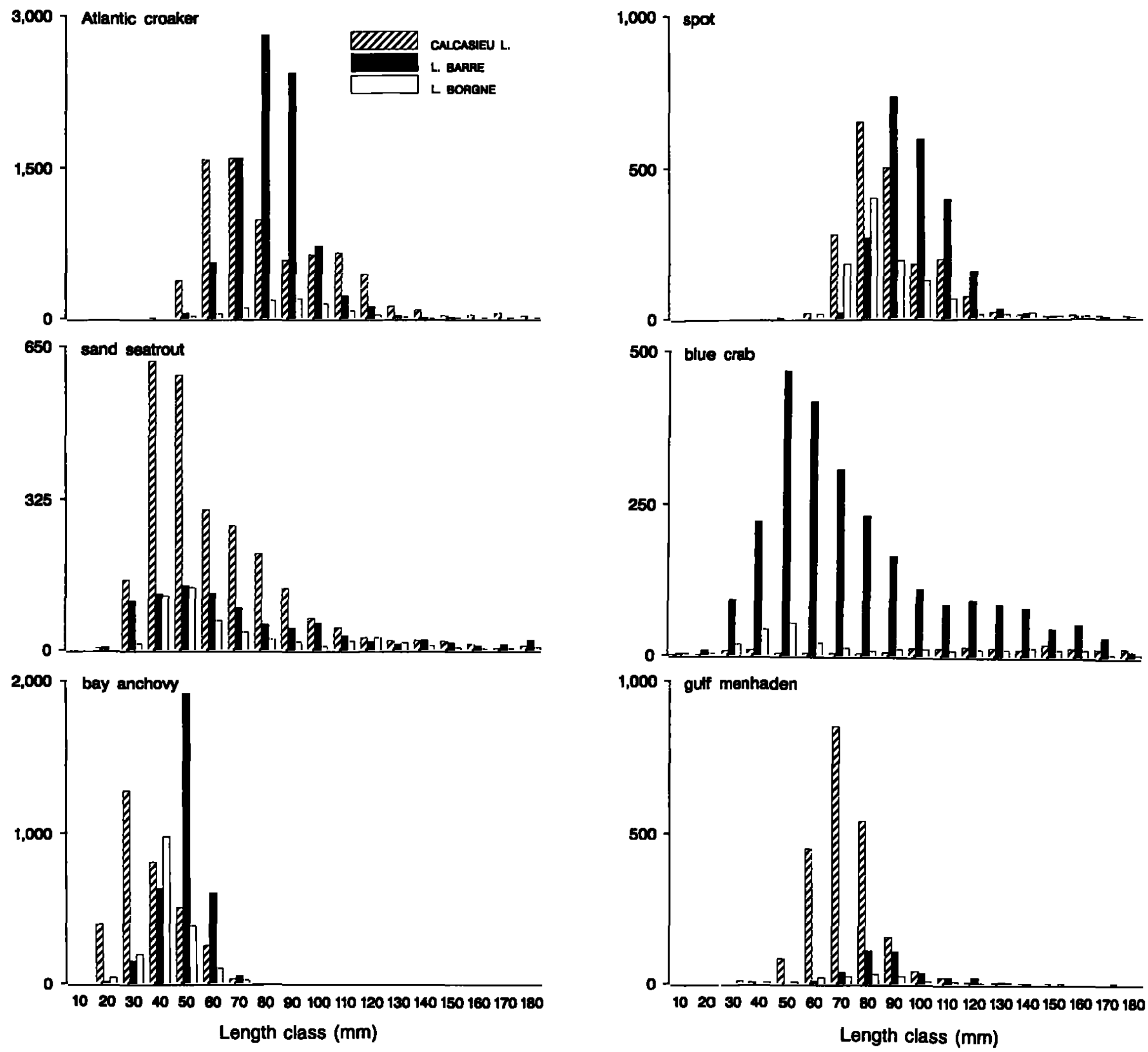

Figure 3
Length-frequency distributions of abundant species collected in control nets for the different areas. Note that length-class data are in mm, except those for catfish, which are in cm.

ences of brown shrimp and white shrimp differed for the BRD's (Table 3); fewer brown shrimp tended to be caught with the BRD nets.

Differences between areas and seasons

Although the Authement-Ledet BRD caught 18% fewer shrimp than the control nets overall, losses in Lake Barre were low and statistically nonsignificant (Table 4). Fish reduction was consistent across the areas for this BRD. The Lake Arthur BRD had a fairly consistent reduction of shrimp and fish across all areas but had the lowest shrimp catch difference in Lake Borgne and had poorer fish reductions in Calcasieu Lake. The Cameron BRD had the highest fish reduction in Lake Borgne; however, this was accompanied by the highest shrimp loss. This BRD lost the fewest shrimp in Lake Barre. The Eymard BRD caught more shrimp than the control net in all areas and reduced fish biomass in all areas, by as much as 35% in Lake Borgne.

Mean water depths and salinities differed between Lake Borgne and the other two areas. Lake Borgne (2.7 ±0.64 m) was slightly deeper than Lake Barre (1.9 ±0.34 m) and Calcasieu Lake (1.5 ±0.27 m). Mean salinities during sampling were 9.6 ±2.9‰ (Lake Borgne), 22.5 ±2.8‰ (Lake Barre), and 20.6 ±5.2‰ (Calcasieu Lake).

There were some slight differences in BRD performance between seasons (Table 5), reflecting differ-

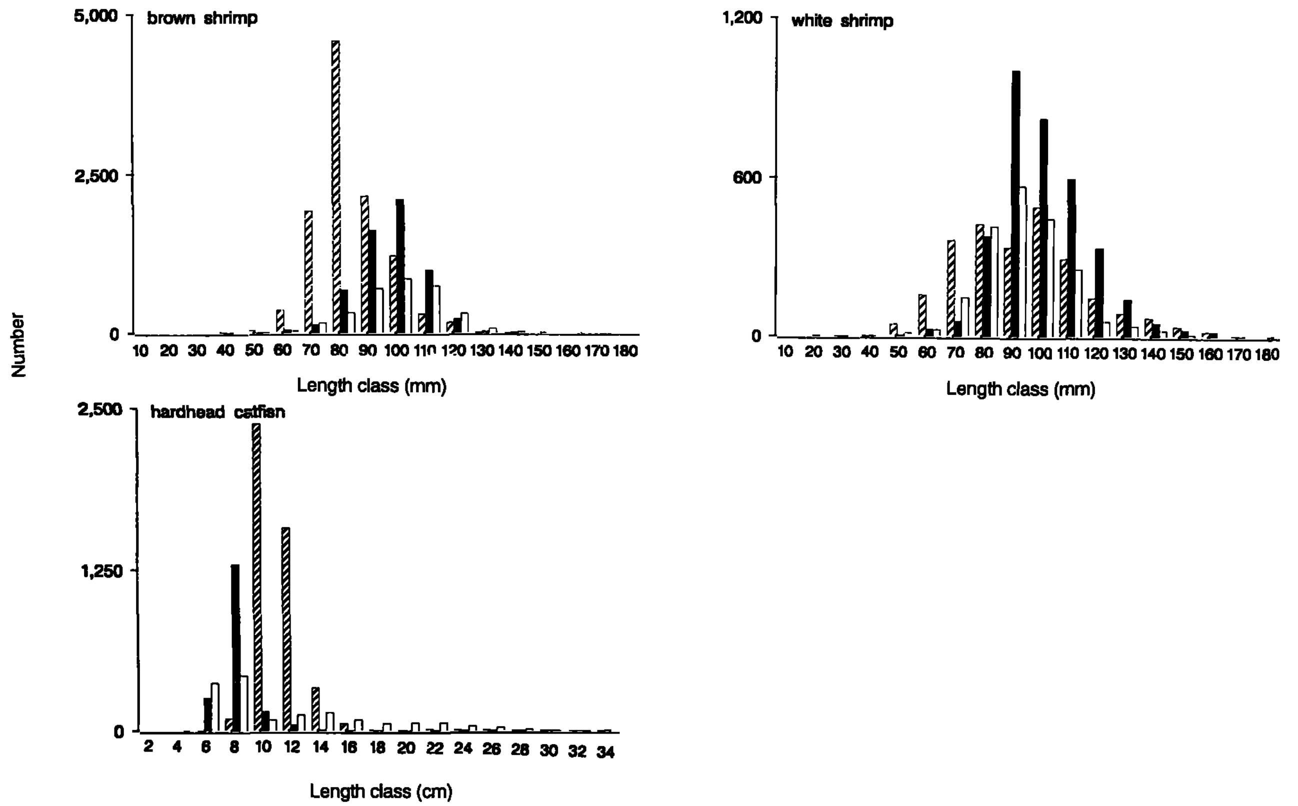

Figure 3 (continued)

ences in species composition and length-frequency distributions.

Discussion

The Authement-Ledet, Lake Arthur, and Cameron BRD's significantly reduced bycatch, but also the catch of shrimp. Excluded shrimp were primarily in the smaller size classes. The Eymard BRD caught significantly more fish and shrimp than the corresponding control nets.

The Lake Arthur and Cameron BRD's were designed with a similar opening, but the Lake Arthur BRD did not release as many fish. Because the weight of the aluminum frame of the Cameron BRD caused the device to sink slightly, the bottom of the Cameron opening was only about 15 cm from the bottom of the trawl net. In contrast, the floats of the Lake Arthur BRD raised the opening to about 30 cm above the trawl bottom. A design somewhat similar to the Lake Arthur BRD and placed 1.7 m from the end of the net did not significantly reduce bycatch in inshore waters of Alabama (Wallace and Robinson, 1994).

Reductions with the Cameron BRD (16% shrimp, 51% fish) were similar to those found by Watson et al. (1993) for the fisheye top position excluder in offshore waters (17% shrimp, 70% fish). Inshore fish are typically smaller and less able to escape by swimming; this may account for the lower reductions with the Cameron BRD. This BRD also released shrimp of most size classes; Watson and McVea (1977) found that the fish escape device, a somewhat similar device, also lost shrimp over the entire size range. Changing the location of the Cameron shooter may affect performance, although Watson et al. (1993) noted that the top position appeared to have the best effectiveness for fish reduction and shrimp retention. A bottom-mounted Florida fish shooter, placed 1.7 m from the end of a 4.9-m trawl, reduced bycatch 26% by weight and 46% by number and caught 14% fewer shrimp than an unmodified net (Wallace and Robinson, 1994). McKenna and Monaghan[4] reported that the efficiency of the Florida fish excluder depended on the size of the escape opening, placement of the excluder in the net, and the number of devices installed.

[4] McKenna, A., and J. P. Monaghan Jr. 1993. Gear development to reduce bycatch in the North Carolina trawl fisheries. Completion report to Gulf and South Atlantic Fisheries Development Foundation Cooperative Agreement No. NA90AA-H-SK052. North Carolina Div. Mar. Fish., Morehead City, NC, 79 p.

The Eymard BRD was developed to reduce the catch of larger hardhead catfish, particularly in Louisiana waters east of the Mississippi River. Hardhead catfish reductions were 6% in terms of numbers, but 51% in biomass, resulting from the loss of larger catfish. Overall, the Eymard BRD caught 26% more fish, but fish biomass was 19% less than that caught by the control net. This finding was the result of the BRD catching more fish smaller than 80 mm and fewer large fish than the control nets. The Eymard BRD caught significantly more numbers and biomass of shrimp, particularly smaller shrimp. The Eymard BRD design contained a webbing funnel, designed to carry shrimp and fish into the codend with accelerating water flow (Watson[5]). Because swimming speed of a fish is a function of size (Blaxter and Dickson, 1958), smaller fishes may not be able to swim in increased water flow, with the result that fewer shrimp and small fish can escape from the Eymard BRD than from a control net. However, dye released into the Eymard indicated that the water flow was not perceptibly increased by the funnel, probably because the funnel diameter was only slightly smaller than the net diameter. However, the Eymard BRD had a 21.6-cm greater net spread than that of the control net; this greater net opening may have resulted in the higher catches of many species. Because the nets were otherwise constructed identically, we suspect this difference was most likely due to the presence of the hoop. The polyethylene webbing may have increased the incidence of anchovy being gilled, particularly during haulback. Numerous small bay anchovies were found, upon retrieval, to be gilled in the polyethylene webbing of the Eymard BRD, and the device caught 83% more bay anchovy than the control net. In a subsequent study, a polyethylene net caught 245% more anchovies than a nylon net (Rogers et al.[6]).

Fish were observed escaping from several of the BRD's during diver evaluations in Florida. Divers observed several large juvenile pinfish (*Lagodon rhomboides*) escaping from the bottom openings of the Eymard BRD and numerous juvenile pinfish escaping the Authement-Ledet BRD

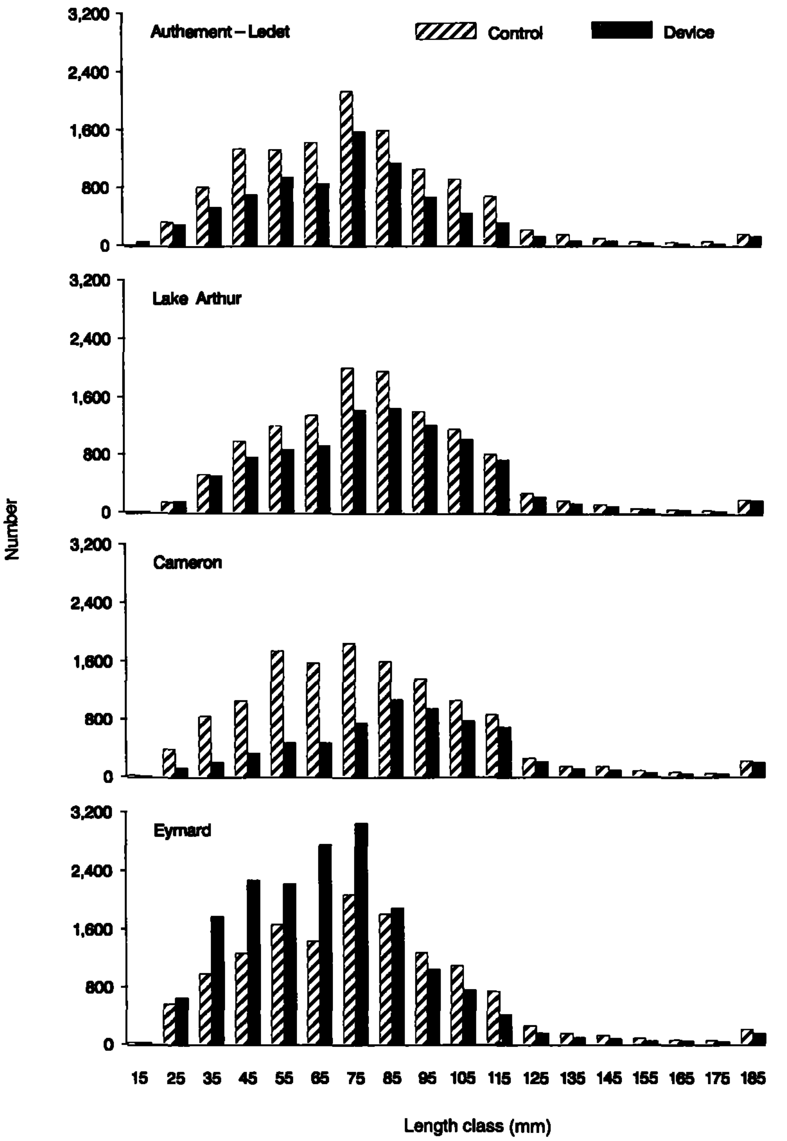

Figure 4

Length-frequency distribution of fish collected by the four devices and corresponding control nets. The 185-mm category includes all individuals greater than or equal to 180 mm.

[5] Watson, J. W. 1988. Fish behaviour and trawl design: potential for selective trawl development. *In* S. G. Fox and J. Huntington (eds.), Proceedings of the world symposium on fishing gear and fishing vessel design, p. 25–29. Newfoundland and Labrador Institute of Fisheries and Marine Technology, St. John's, Newfoundland.

[6] Rogers, D. R., B. D. Rogers, J. A. de Silva, and V. L. Wright. 1994. Evaluation of shrimp trawls designed to reduce bycatch in inshore waters of Louisiana. School of Forestry, Wildlife, and Fisheries, Louisiana State Univ. Agricultural Center. Final report submitted to NMFS, St. Petersburg, FL. NOAA Award No. NA17FF0375-01, 230 p. Available from LSU library.

Table 3

Comparison of numbers and biomass of the most abundant species collected in bycatch reduction device (BRD) nets and corresponding control nets. SD is the standard deviation of the difference. Significance levels are 0.01 (**) and 0.05 (*). n=72. Superscripted letters denote significance levels of paired t–tests on log–transformed data: 0.01 ([a]), 0.05 ([b]).

Species and BRD	Numbers: Mean catch/tow Control	Numbers: Mean catch/tow BRD	Numbers: Percent catch difference	Numbers: SD	Numbers: $P>t$–value	Biomass (g): Mean catch/tow Control	Biomass (g): Mean catch/tow BRD	Biomass (g): Percent catch difference	Biomass (g): SD	Biomass (g): $P>t$–value
Atlantic croaker										
Authement–Ledet	58.0	38.0	–34	67.9	0.01**[a]	832.9	509.8	–39	711.1	0.01**
Lake Arthur	56.8	41.6	–27	63.4	0.05*[b]	783.6	627.8	–20	450.9	0.01**[a]
Cameron	58.5	29.6	–49	64.8	0.01**	859.8	570.2	–34	524.7	0.01**
Eymard	56.9	83.6	47	117.6	0.06[b]	789.7	871.3	10	907.3	0.45
Spot										
Authement–Ledet	12.2	5.6	–54	12.4	0.01**[a]	294.4	110.7	–62	318.0	0.01**[a]
Lake Arthur	25.3	15.2	–40	52.3	0.10	575.5	372.7	–35	1,121.1	0.13
Cameron	12.0	9.8	–18	6.7	0.01**	322.5	269.4	–16	221.4	0.05*
Eymard	22.6	11.2	–50	49.4	0.05*[a]	562.0	234.0	–58	1,137.9	0.02*[a]
Sand seatrout										
Authement–Ledet	14.1	8.8	–38	26.3	0.09[b]	101.0	63.5	–37	114.9	0.01**
Lake Arthur	9.8	8.5	–13	9.6	0.27	132.1	110.5	–16	138.8	0.19
Cameron	13.3	4.8	–64	14.5	0.01**[a]	119.8	69.5	–42	105.5	0.01**[a]
Eymard	17.0	20.1	19	21.7	0.22[b]	165.5	160.1	–3	209.1	0.83
Hardhead catfish										
Authement–Ledet	22.3	11.0	–51	24.0	0.01**[a]	625.5	244.9	–61	596.6	0.01**[a]
Lake Arthur	26.2	20.8	–21	31.2	0.14[a]	729.6	548.4	–25	380.4	0.01**[a]
Cameron	35.3	14.4	–59	61.7	0.01**[a]	960.0	549.1	–43	784.2	0.01**[a]
Eymard	24.6	23.2	–6	51.3	0.82	802.0	393.7	–51	1,045.0	0.01**
Bay anchovy										
Authement–Ledet	29.3	18.3	–37	34.6	0.01**	40.1	22.1	–45	45.1	0.01**[b]
Lake Arthur	23.3	14.7	–37	30.2	0.02*[b]	35.3	25.0	–29	49.3	0.08[b]
Cameron	27.8	7.0	–75	31.2	0.01**[a]	36.7	9.5	–74	41.8	0.01**[a]
Eymard	35.8	65.4	83	67.4	0.01**[a]	43.4	80.8	86	79.8	0.01**[a]
Gulf menhaden										
Authement–Ledet	12.8	10.0	–22	18.5	0.20	135.2	110.8	–18	170.0	0.23
Lake Arthur	7.8	8.5	9	14.2	0.67	96.0	106.7	11	161.7	0.57
Cameron	7.6	7.1	–7	12.5	0.71	82.1	82.0	0	126.3	0.99
Eymard	8.5	12.1	42	22.8	0.19	96.0	109.7	14	173.0	0.50
Blue crab										
Authement–Ledet	9.9	9.0	–9	6.9	0.25	430.3	352.1	–18	353.3	0.06
Lake Arthur	9.0	6.4	–28	7.6	0.01**	378.6	295.9	–22	326.0	0.03*
Cameron	11.4	9.3	–19	15.8	0.24	571.0	457.2	–20	888.7	0.28
Eymard	10.5	9.3	–12	6.3	0.09	574.4	410.0	–29	647.9	0.03*
Brown shrimp										
Authement–Ledet	60.0	46.7	–22	52.0	0.03*[b]	332.4	270.7	–19	197.7	0.01**
Lake Arthur	64.3	48.2	–25	54.6	0.01**[a]	333.8	268.8	–19	181.7	0.01**[b]
Cameron	78.5	64.0	–19	72.4	0.09	375.6	315.6	–16	170.2	0.01**
Eymard	73.4	99.1	35	85.8	0.01**	356.3	438.6	23	273.4	0.01**
White shrimp										
Authement–Ledet	24.6	22.3	–9	22.9	0.40	150.3	146.3	–3	116.5	0.77
Lake Arthur	28.7	22.7	–21	20.9	0.02*[a]	179.6	156.2	–13	137.4	0.15[a]
Cameron	32.0	28.8	–10	24.6	0.28	202.9	184.5	–9	124.1	0.21
Eymard	25.4	37.0	46	47.5	0.04*[b]	160.8	206.2	28	209.1	0.07

opening while the nets were being towed. Few fish were observed escaping from the Cameron and Lake Arthur BRD openings during these tests.

Although each BRD net contained escape openings, smaller species, such as the bay anchovy, could have escaped through the codend meshes. The devices may have affected escape rates through the meshes by altering the shape of the codend. The percentage of fish and shrimp that escaped during trawling, as opposed to escaping during haulback, is also unknown. Watson et al. (1993) reported that most species escaped through escape openings during trawl haulback or when fish were crowded near the openings. Further diver evaluations are necessary to identify methods by which fish and shrimp escape.

Differences in catch rates of brown and white shrimp observed for many of the BRD's may have been due to species-specific behavior or size differences (or both). White shrimp swim more actively than brown shrimp during the day (Wickham and Minkler, 1975). The white shrimp caught by the control nets were larger, on average, than the brown shrimp, a finding that is typical for Louisiana catches (Keithly and Baron-Mounce[2]). In addition, the white shrimp caught in the spring were substantially larger than those in the fall.

These data are derived from a fishery-independent study; results from commercial shrimping could differ. Had the Eymard BRD been used in a larger trawl and without a hoop, the results might have been quite different. Many fish and shrimp may have been lost during haulback and although we had mechanical retrieval, a larger commercial vessel may have had faster retrieval. Although we trawled near shrimp boats whenever possible, at times no shrimp boats were present in a sampling area. When this was the case, we began trawling in an area where shrimp had been caught previously; if few or no shrimp were caught, we moved to another area. Moving short distances (one or two km) could result in very different catches. Because of time and fuel limitations, however, movements of very long distances were not feasible. Provided that shrimp were being caught, we did not relocate if large quantities of fishes or crabs were also present. In this situation, a shrimper would most likely relocate in an attempt to find more shrimp or cease shrimping until conditions in the area become more favorable. We found higher ratios of fish to shrimp when shrimp catches were low. Other studies have reported that bycatch ratios depend on shrimp abundance; when few shrimp are present, fishing times are longer and result in high catches of bycatch species (Adkins[7]). The 20-minute tows used in our study were three to six times shorter than those typically used in commercial operations. Longer tows would have necessitated decreasing the number of

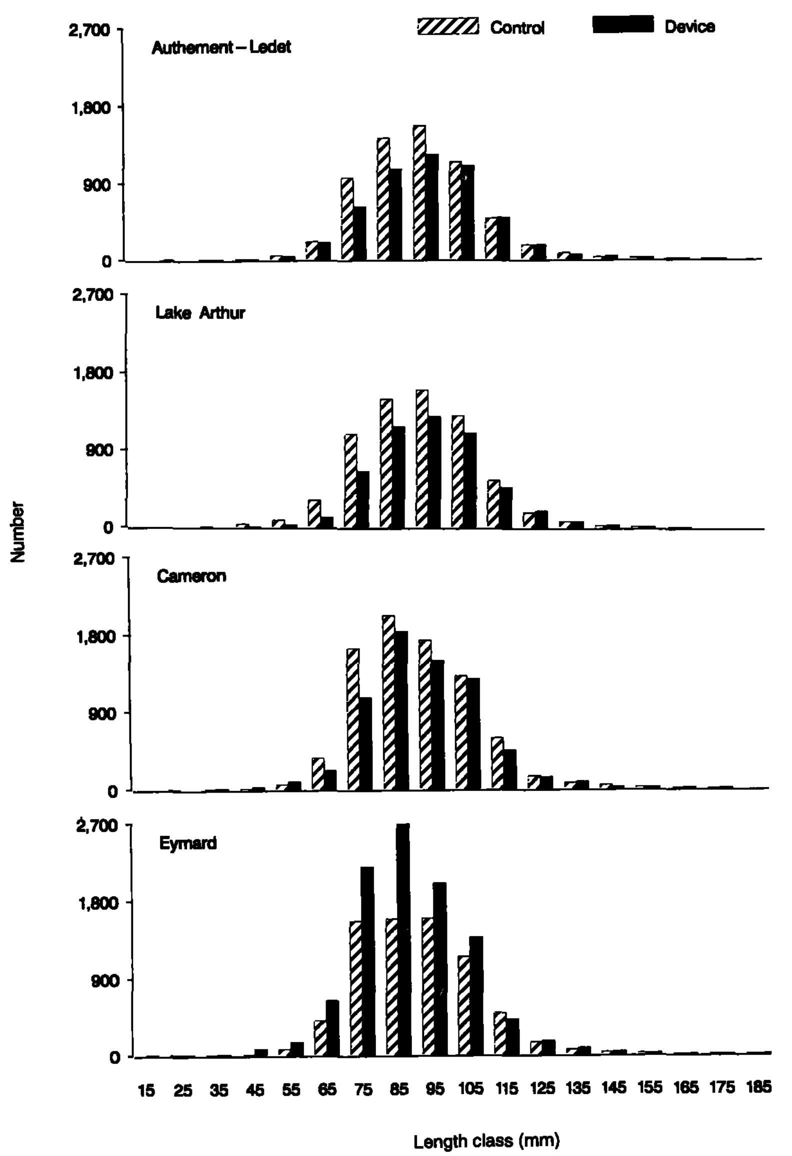

Figure 5
Length-frequency distribution of shrimp collected by the four devices and corresponding control nets.

[7] Adkins, G. 1989. A comprehensive assessment of bycatch in the Louisiana shrimp fishery. Final report to NMFS NA89WC-H-MF006. La. Dep. Wildlife Fish., Bourg, LA, 75 p.

Table 4

Comparisons of numbers and biomass of fish and shrimp collected by the four bycatch reduction device (BRD) nets and corresponding control nets in the three areas. SD is the standard deviation of the difference. Significance levels are 0.01 (**) and 0.05 (*). n=24. Superscripted letters denote significance levels of paired t-tests on log-transformed data: 0.01 (^{a}), 0.05 (^{b}).

		Numbers					Biomass (g)				
BRD and type of catch	Area	Mean catch/tow Control	Mean catch/tow Device	Percent catch difference	SD	$P>t$-value	Mean catch/tow Control	Mean catch/tow Device	Percent catch difference	SD	$P>t$-value
Authement-Ledet											
Fish	L. Borgne	64.6	38.4	–41	45.7	0.01^{**a}	1,119.9	732.7	–35	588.1	0.01^{**a}
	L. Barre	202.7	134.8	–34	122.6	0.01^{**a}	2,425.2	1,458.9	–40	1,302.6	0.01^{**a}
	Calcasieu L.	244.0	153.8	–37	114.7	0.01^{**a}	4,080.2	2,200.8	–46	1,584.7	0.01^{**a}
Shrimp	L. Borgne	49.0	35.8	–27	21.3	0.01^{**}	381.7	285.4	–25	178.1	0.01^{**}
	L. Barre	90.5	86.7	–4	40.1	0.64	613.6	579.7	–6	233.9	0.49
	Calcasieu L.	115.1	85.5	–26	89.4	0.12^{b}	454.1	387.5	–15	300.6	0.29
Lake Arthur											
Fish	L. Borgne	65.4	47.0	–28	36.4	0.02^{*b}	1,365.2	1,072.9	–21	638.6	0.03^{*}
	L. Barre	215.3	151.3	–30	149.3	0.05^{*}	3,046.8	2,263.0	–26	2,441.9	0.13
	Calcasieu L.	233.4	205.6	–12	152.9	0.38	4,301.0	3,511.9	–18	1,235.3	0.01^{**a}
Shrimp	L. Borgne	57.0	47.0	–18	20.1	0.02^{*a}	389.1	350.6	–10	142.5	0.20^{a}
	L. Barre	95.3	70.3	–26	39.5	0.01^{**a}	649.4	509.4	–22	239.9	0.01^{**a}
	Calcasieu L.	127.4	95.4	–25	89.4	0.09	503.5	415.1	–18	252.1	0.10
Cameron											
Fish	L. Borgne	89.8	32.5	–64	113.0	0.02^{*a}	1,987.7	1,170.2	–41	1,361.9	0.01^{**a}
	L. Barre	188.9	98.6	–48	75.1	0.01^{**a}	2,693.3	1,776.4	–34	869.6	0.01^{**a}
	Calcasieu L.	266.5	133.9	–50	125.9	0.01^{**a}	4,524.6	3,257.7	–28	1,402.8	0.01^{**a}
Shrimp	L. Borgne	59.8	45.0	–25	23.6	0.01^{**a}	419.8	338.2	–19	145.7	0.01^{**b}
	L. Barre	108.2	97.5	–10	42.8	0.23	719.6	655.1	–9	225.8	0.18
	Calcasieu L.	164.8	136.6	–17	126.7	0.29^{b}	598.4	507.7	–15	278.4	0.12
Eymard											
Fish	L. Borgne	81.6	114.4	40	83.9	0.07^{a}	1,970.0	1,288.0	–35	1,394.5	0.03^{*}
	L. Barre	201.8	301.0	49	193.1	0.02^{*a}	2,724.3	2,554.9	–6	2,158.8	0.70
	Calcasieu L.	287.8	303.7	6	195.7	0.69	4,246.5	3,376.1	–20	2,493.5	0.10^{b}
Shrimp	L. Borgne	52.7	84.1	60	79.2	0.06^{a}	365.2	510.4	40	343.3	0.05^{*}
	L. Barre	97.5	120.6	24	34.1	0.01^{**a}	672.8	730.8	9	166.2	0.10^{b}
	Calcasieu L.	146.5	204.5	40	145.4	0.06^{a}	513.5	694.8	35	450.7	0.06^{a}

trips or evaluating fewer BRD's. Increasing the trawl-tow duration decreases the ability of a fish to maintain swimming speed (Bainbridge, 1960). Reductions over longer tow periods may differ; if most reduction occurs during haulback, fish may be too exhausted to escape. Longer tows also increase the chances of catching large quantities of fish and shrimp that may clog the net and cause organisms to be released from the BRD.

In terms of abundances and size distributions, bycatch varied between the areas and seasons; some species were very abundant in one or two areas. The capability of a BRD to reduce fish or shrimp depends on the species assemblage present in an area. A BRD may work well in one area under certain conditions but perform poorly in another area owing to assemblage differences. Species-specific size selectivity has been reported in other studies (e.g. Rulifson et al., 1992). Of the four BRD's, the Cameron had the best overall fish reduction. However, if spot and gulf menhaden were the most abundant species in an area, the Authement-Ledet may be a better choice. Bycatch reduction devices may have to be selected for particular areas or seasons, depending on the type and size distributions of predominant bycatch species, because a particular device may not be as effective in all areas or at all times of the year.

The high shrimp losses from the BRD's evaluated in this study would most likely be unacceptable for commercial operations. However, further modifications to these devices, such as altering the size or location of escape openings, could reduce these losses.

Table 5

Comparison of numbers and biomass of fish and shrimp collected by the four bycatch reduction device (BRD) nets and corresponding control nets for the different seasons. S_D is the standard deviation of the difference. Significance levels are 0.01 (**) and 0.05 (*). n=36. Superscripted letters denote significance levels of paired t-tests on log-transformed data: 0.01 (^{a}), 0.05 (^{b}).

BRD and type of catch	Season	Numbers: Mean catch/tow Control	Numbers: Mean catch/tow Device	Numbers: Percent catch difference	Numbers: SD	Numbers: $P>t$-value	Biomass (g): Mean catch/tow Control	Biomass (g): Mean catch/tow Device	Biomass (g): Percent catch difference	Biomass (g): SD	Biomass (g): $P>t$-value
Authement-Ledet											
Fish	spring	218.3	137.8	–37	127.7	0.01^{**a}	2,895.3	1,667.1	–42	1,374.2	0.01^{**a}
	fall	122.6	80.2	–35	65.5	0.01^{**a}	2,188.3	1,261.2	–42	1,354.2	0.01^{**a}
Shrimp	spring	116.6	92.1	–21	73.2	0.05^{*b}	650.3	556.6	–14	288.7	0.06^{b}
	fall	53.1	46.5	–12	36.4	0.29^{b}	316.0	278.5	–12	180.4	0.22
Lake Arthur											
Fish	spring	216.1	165.2	–24	157.1	0.06	3,459.1	2,761.7	–20	2,119.1	0.06^{b}
	fall	126.7	104.2	–18	80.9	0.10^{b}	2,349.6	1,803.6	–23	893.6	0.01^{**b}
Shrimp	spring	124.8	96.5	–23	75.4	0.03^{*b}	642.3	541.1	–16	244.8	0.02^{*b}
	fall	61.7	45.3	–27	31.0	0.01^{**a}	385.7	308.9	–20	190.3	0.02^{*a}
Cameron											
Fish	spring	203.1	106.5	–48	101.5	0.01^{**a}	3,296.6	2,229.1	–32	1,187.8	0.01^{**a}
	fall	160.3	70.2	–56	118.9	0.01^{**a}	2,840.4	1,907.1	–33	1,290.5	0.01^{**a}
Shrimp	spring	157.9	134.9	–15	104.4	0.19^{a}	773.1	677.9	–12	252.8	0.03^{*a}
	fall	64.0	51.2	–20	35.8	0.04^{*}	385.4	322.8	–16	184.8	0.05^{*}
Eymard											
Fish	spring	233.8	301.1	29	197.3	0.05^{*a}	3,386.9	2,773.0	–18	2,029.4	0.08^{b}
	fall	147.1	178.3	21	131.7	0.16^{b}	2,573.8	2,039.7	–21	2,117.8	0.14
Shrimp	spring	145.1	199.8	38	119.5	0.01^{**a}	716.1	883.0	23	380.7	0.01^{**a}
	fall	52.6	73.0	39	65.9	0.07^{a}	318.2	407.7	28	294.3	0.08

The BRD nets tested here did not appear to slow water flow in the trawl net. Other studies, however, have indicated that flow rate around and through the BRD may be a key factor in fish and shrimp escapement. Watson et al. (1993) found that juvenile fish could exit a BRD at flow rates between 0.2 and 0.5 m/sec. However, shrimp accumulated in areas of reduced flow and crawled along the webbing against the flow to escape some devices (Watson et al., 1993). Devices can be designed to create a 0.2 to 0.5 m/sec flow rate, but debris can alter the flow rate and affect BRD performance. The ability to sustain swimming appears to be related to length, but this relationship often differs for each species (Bainbridge 1960). Further testing is necessary to acquire escape flow rates for the major species of concern.

Reduction rates for numbers and biomass of many species differed for the four BRD's, reflecting size-dependent selectivity. Escape rates of different species also varied considerably owing to differences in size and behavior. These differences, coupled with the high variability in organisms between areas, indicate that the performance of BRD's should be evaluated at the species and size level.

Future studies should continue to involve members of the industry. The advisory committee provided suggestions and valuable insight that greatly enhanced the success of this project and the acceptability of the results. Other studies have reported successful industry involvement (Rulifson et al., 1992; McKenna and Monaghan[4]). The design and construction of BRD's should be a dynamic process which will benefit from the cooperation of industry, research, and management personnel.

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Literature cited

Bainbridge, R.
1960. Speed and stamina in three fish. J. Exp. Biol. 37:129–153.

Blaxter, J. H. S., and W. Dickson.
1958. Observations on the swimming speeds of fish. J. Cons. Cons. Int. Explor. Mer 24:472–479.

Harrington, D. L., J. W. Watson, L. G. Parker, J. B. Rivers, and C. W. Taylor.
1988. Shrimp trawl design and performance. Ga. Sea Grant Coll. Prog., Univ. of Georgia, Athens, Mar. Ext. Bull. No. 12, 41 p.

National Marine Fisheries Service.
1993. Fisheries of the United States, 1992. U.S. Dep. Commer., NOAA, NMFS, Curr. Fish. Stat. 9200, 115 p.

Rulifson, R. A., J. D. Murray, and J. J. Bahen.
1992. Finfish catch reduction in South Atlantic shrimp trawls using three designs of by-catch reduction devices. Fisheries (Bethesda) 17(1):9–20.

Seidel, W. R.
1975. A shrimp separator trawl for the southeast fisheries. Proc. Gulf Caribb. Fish. Inst. 27:66–76.

Wallace, R. K., and C. L. Robinson.
1994. Bycatch and bycatch reduction in recreational shrimping. Northeast Gulf Sci. 13(2):139–144.

Watson, J. W., and C. McVea Jr.
1977. Development of a selective shrimp trawl for the southeastern United States penaeid shrimp fisheries. Mar. Fish. Rev. 39(10):18–24.

Watson, J. W., I. K. Workman, C. W. Taylor, and A. F. Serra.
1984. Configurations and relative efficiencies of shrimp trawls employed in southeastern United States waters. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 3, 12 p.

Watson, J., I. Workman, D. Foster, C. Taylor, A. Shah, J. Barbour, and D. Hataway.
1993. Status report on the potential of gear modifications to reduce finfish bycatch in shrimp trawls in the southeastern United States 1990–1992. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SEFSC-327, 131 p.

Wickham, D. A., and F. C. Minkler III.
1975. Laboratory observations on daily patterns of burrowing and locomotor activity of pink shrimp, *Penaeus duorarum*, brown shrimp, *Penaeus aztecus*, and white shrimp, *Penaeus setiferus*. Contrib. Mar. Sci. 19:21–35.