4.0 RESULTS

4.1 Water Intake Survey

Nineteen questionnaires were sent to selected TWC water rights permittees. Twelve permittees responded, and their responses appear in Appendix F. Seven permittees currently use their water rights permits and two responded with "not applicable." The purposes of water use (Table 4.1) included industrial cooling (Mobil Oil Corporation dba Mobil Mining and Minerals Company and Sterling Chemicals), and equipment washing (ARMCO), fire training and emergencies (Ethyl Corporation), municipal and industrial water supply (City of Houston), maintenance of a salt water control structure (Trinity Bay Conservation District), irrigation and municipal use (Chambers-Liberty Counties Navigation District), municipal use (Trinity River Authority), fish culture (Mr. William S. Edwards), and grain barge cleaning (Cooper's Marine Service).

For the remainder of this section, all permittees using water for municipal uses (i.e., City of Houston and Trinity River Authority) and/or irrigation (i.e., Chambers-Liberty Counties Navigation District) will not be considered as they either withdraw water a long distance from Galveston Bay and/or they use fresh water and impingement and entrainment of estuarine species would be minimal to nonexistent.

The frequency and volume of water used varied with the use. Frequency and amount used included eight hours in 1991 (720,000 gallons) by Ethyl Corporation, a maximum of three times per week (0.4 acre-ft or 130,340 gallons per year) for Cooper's Marine, twice per year in the fall and winter (2.6 million gallons per year) for Mr. Edwards' fish culture operation, and daily use (24.4 billion gallons per year) by Sterling Chemical (Table 4.1).

Intake devices also varied. Of the seven permittees currently using their water rights permits, five had some sort of intake device. These intake devices included a rotating screen (3/8-inch mesh), sucker rods (six inches apart), a grill (3/4-inch iron rods, two inches apart), a 1/4-inch mesh screen, and a debris screen for large objects only. No studies have been conducted in regard to the survival rate of fish in any of the respondents' facilities (Table 4.1).

4.2 Impingement and Entrainment

4.2.1 P.H. Robinson Generating Station

TABEL 4.1
SUMMARY OF RESPONSE RECEIVED FROM SURVEYED WATER RIGHTS PERMITTEES[1]

COMPANY	*RESPONSE* *YES*	*NO*	*Q1*	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*
Mobil Oil Corporation dba Mobil Mining & Minerals Company P.O. Box 3447 Pasadena, TX 77501 003989	X		No	This water system has not been used since the mid 1970's	N/A	Industrial Cooling	N/A	N/A	No
Phillips 66 Company D S Turner ET UX HCR 33, Box 522 Uvalde, TX 78801-1905 003991		X							
Ethyl Corporation Environmental Department P.O. Box 472 Pasadena, TX 77501 003992	X		Yes	Variable - 8 hrs in 1991	720,000 gallons in 1991	Fire training & Emergenci es	21000 gpm-max; 46.67 cfs-max	pump screen is #4 mesh (1/4" openings)	No
City of Houston Water Division Department of Public Works 105 Sabine ST/M Slaughter Houston, TX 77007 004261	X		Yes	Daily	In 1991, 119, 485 million gallons	Municipal and Industrial water supply	avg. 330 mgd at Trinity pump station. Intake velocity unknown	debris screens for trash - can only keep out large fish	No
Charles T. Jones, et al. P.O. Box 198 Winnie, TX 77665 004304		X							

TABEL 4.1
- CONTINUED -

COMPANY	*RESPONSE* *YES*	*NO*	*Q1*	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*
Trinity Bay Conservation District P.O. Box 580 Anahuac, TX 77514 004307 (409)267-3111	X		Yes	N/A	N/A	N/A	N/A	N/A	N/A
ARMCO, Inc. Greens Port Ind. Park P.O. Box 96120 Houston, TX 77213 003990 (713)960-5100	X		No	N/A	N/A	Cooling water for Industrial Equipment	N/A	N/A	No
Mr. Bob Gaddis Phillips 66 Company Adams Terminal 149 Phillips Building, Annex Bartlesville, Oklahoma 74004 003991 (918)661-4206		X							
Trinity River Authority P.O. Box 1554 Huntsville, TX 77340 004248 (409)295-5485 (409)295-9116 [fax]	X		N/A	N/A - only the release of water through Lake Livingston dam	N/A	N/A	N/A	N/A	N/A
Chambers-Liberty Cos ND P.O. Box 518 Anahuac, TX 77514 004279	X		Yes	Year round	approx. 66000 acre-ft per year	Irrigation, Municipal	240,000 gpm (the max. pump rate)	Sucker Rods - 6 inches apart	No

TABEL 4.1
- CONTINUED -

COMPANY	*RESPONSE*		*Q1*	*Q2*	*Q3*	*Q4*	*Q5*	*Q6*	*Q7*
	YES	*NO*							
Mr. William S. Edwards P.O. Box 86 Stowell, TX 77661 004305	X		Yes[5]	2 times/year Winter - Jan, Feb Fall - Sept, Oct, Nov	avg. 6-800 acre-ft per year	Fish Culture	14,167 gpm velocity-.4ft/s at full speed	grill; 3/4" iron rods at 2" apart	No
City of League City 300 Walker Street League City, TX 77573 005178	X		N/A	N/A	N/A	N/A	N/A	N/A	N/A
Paktank Corporation Deer Park Terminal 2000 West Loop South Suite 2200 Houston, TX 77027-3597 005191 (713)479-6051 (713)479-2585 [fax]		X							
Southwestern Barge Fleet Service, Inc. 18319 Market Street Channelview, TX 77530 005299 (713)452-5857		X							
Western Towing Company P.O.Box 418 Channelview, TX 77530 005340 (713)452-4555 (713)457-2202 [fax]		X							
Oil Tanking of Texas, Inc. P.O. Box 96290 Houston, TX 77213 003993	X		No						

TABEL 4.1
- CONTINUED -

COMPANY	RESPONSE YES	NO	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Texas Copper Corporation 1201 Logan Texas City, TX 77590 005286 (409)948-0003		X	No	N/A	N/A	heating other liquid		not installed	No
Cooper's Marine Service, Inc. P.O. Box 1643 Channelview, TX 77530 005334 (713)457-1729	X		Yes	3 times maybe per week	0.4 acre-ft per year	to wash grain dust left in barge after unloading	20 gpm	No	Yes[2]
Sterling Chemicals, Inc. P.O.Box 1311 Texas City, TX 77592-1311 005361 (409)945-4431	X		Yes	Daily	approx 75000 acre-ft per year	once through cooling	Rate 48000 gpm; Velocity 0.5-2 ft/sec	rotating screen, mesh size 3/8"[3]	No[4]

1 Questions (Q1 - Q7) appear in Appendix B.

2 Mr. Moulton with the Texas Parks and Wildlife Department has visited the Cooper's Marine Service facility, it has no danger to the fishes of the waters where the facilities are located.

3 Rotating screen rolls objects into a trough. The trough empties into a pipe which returns objects to the cooling water return canal.

4 Sterling Chemicals, Inc. responded: Through conversations with department personnel, we believe that over 90% survive. Often there are large numbers of live bait fish in the screen wash return system.

5 Permit is for maintenance of salt water structure only.

4.2.1.1 P.H. Robinson Generating Station (Landry 1977)

Seasonal occurrence, abundance, and susceptibility to cooling-water operations (i.e., impingement, entrainment, injury rates, and survival in a heated discharge canal) were determined by Landry (1977) for species collected at the P.H. Robinson Generating Station near Bacliff, Texas (Figure 2). The criteria used to classify a fish as injured were:

- puncture wounds resulting from being pinched or bitten by predators;
- hemorrhagic eyes, mouth parts, and fins;
- scale abrasions resulting from contact with the screen during impingement or from being dumped off the screens into the water trough;
- deformation of body parts resulting from impingement between screen mesh;
- rupture of coelomic cavity;
- absence of body parts such as eyes, spines, or fins; and
- decaying fish flesh and body parts.

Actual plant specifications for the Robinson station appear in Table 4.2.

The period of study was from February 1969 through March 1970. Biological data were collected twice weekly from one revolving-screen station (samples collected at 0700, 1500, and 2200 hours), 13 ichthyoplankton-net stations (six in the intake canal and seven in the discharge canal), and four trawl stations (two in the intake canal and two in the discharge canal). More specific details on methods used are available in Landry (1977).

Landry's projections for the number and weight of organisms impinged on intake screens at the Robinson station at Units 1 and 2, and Unit 3 for three sampling periods per day (eight hours each of intermittent rotation) were based on twice weekly collections between February 1969 to February 1970. The actual sampling period was 25 minutes per eight hours. Landry did not give his method for calculating the total number of animals impinged during his study.

Landry (1977) reported that, during his 14-month study, 149,798 fish comprising 89 species were captured. Overall abundance and species totals varied with sampling area, gear type, and life history. Six species, including Gulf menhaden (*Brevoortia patronus*), bay anchovy (*Anchoa mitchilli*), sea catfish (*Arius felis*), sand seatrout (*Cynoscion arenarius*), spot (*Leiostomus xanthurus*), and Atlantic croaker (*Micropogonias undulatus*), comprised 89 percent of all fish taken during this study. Therefore, Landry (1977) concentrated his efforts in describing in detail the effects of cooling-water operations on these species. All other species comprised 1.1 percent [two species - Atlantic cutlassfish (*Trichiurus lepturus*) and bighead searobin (*Prionotus tribulus*)] or less than one percent of the total catch. Recreationally important species such as spotted seatrout (*Cynoscion nebulosus*), black drum (*Pogonias cromis*), red drum (*Sciaenops ocellata*), and southern flounder (*Paralichthys lethostigma*), each composed less than one percent of the total catch (Table 4.3). Revolving screen samples yielded 68,518 organisms and 83 species. Ichthyoplankton net sets in both the intake and discharge canals yielded 46,351 individuals belonging to 39 species.

TABLE 4.2
ROBINSON STATION SPECIFICATIONS

	UNIT 1	*UNIT 2*	*UNIT 3*	*UNIT 4*
Year Operational	1965	1966	1968	1974
Generating Capacity (MW)	450	450	565	750
Pump Capacity (gal/min) (actual)	234,000	230,700	292,500	409,800
Calculated Approach Velocity @ max. low water (ft/sec)	1.51	1.49	1.49	1.48
Calculated Approach Velocity @ mean low water (ft/sec)	1.05	1.04	1.14	1.19
Revolving Screen Mesh Size, Square Clear Opening (in)	3/8	3/8	3/8	3/8
Flow from 12/8/77 to 11/28/78 - 138.6 (BGD)				

TABLE 4.3
SPECIES COMPRISING 1 PERCENT OR MORE OF THE TOTAL IMPINGED DURING STUDY PERIOD FOR HL&P GENERATING STATIONS

SPECIES	P. H. ROBINSON			BERTON	DEEPWATER		WEBSTER	CEDAR BAYOU	
	Landry (1977) Unit 1-3 2/69-2/70	Greene et al. (1980a) Unit 1-4 4/78-3/79	Chase (1978) 6/74-11/74 5/75-9/75	Greene et al. (1979) 1/78-1/79	Greene (1980) 1978	Greene (1980) 1979	Greene et al. (1980b) 12/77-11/78	Jobe et al. (1980) 7/78-5/79	Southwest Research Institute (unpublished) 1973-1980
brown shrimp *(Penaeus aztecus)*		*	*	*			*	*	*
white shrimp *(Penaeus setiferus)*		*	*	*	*	*	*	*	*
blue crab *(Callinectes sapidus)*		*	*	*	*	*	*	*	*
pygmy blue crab *(Callinectes similis)*		*							
shrimp eel *(Ophichthus gomesi)*		*							
Gulf menhaden *(Brevoortia patronus)*	*	*	*	*	*	*	*	*	*
gizzard shad *(Dorosoma cepedianum)*							*		*
threadfin shad *(Dorosoma petenese)*				*					
bay anchovy *(Anchoa mitchilli)*	*	*	*	*	*	*	*	*	*
sheepshead minnow *(Cyprinodon variegatus)*					*				

TABLE 4.3
- CONTINUED -

SPECIES	*P. H. ROBINSON*			*BERTON*	*DEEPWATER*		*WEBSTER*	*CEDAR BAYOU*	
	Landry (1977)	*Greene et al. (1980a)*	*Chase (1978)*	*Greene et al. (1979)*	*Greene (1980)*	*Greene (1980)*	*Greene et al. (1980b)*	*Jobe et al. (1980)*	*Southwest Research Institute (unpublished)*
	Unit 1-3 2/69-2/70	*Unit 1-4 4/78-3/79*	*6/74-11/74 5/75-9/75*	*1/78-1/79*	*1978*	*1979*	*12/77-11/78*	*7/78-5/79*	*1973-1980*
Gulf killifish *(Fundulus grandis)*					*				
sea catfish *(Arius felis)*	*	*	*				*		
Atlantic midshipman *(Porichthys porosissimus)*		*							
sand seatrout *(Cynoscion arenarius)*	*	*	*	*	*	*	*	*	*
spotted seatrout *(Cynoscion nebulosus)*		*					*		
spot *(Leiostomus xanthurus)*	*	*		*	*		*	*	
Atlantic croaker *(Micropogonias undulatus)*	*	*	*	*	*	*	*	*	*
star drum *(Stellifer lanceolatus)*							*		
striped mullet *(Mugil cephalus)*		*		*			*		*

TABLE 4.3
- CONTINUED -

SPECIES	P. H. ROBINSON			BERTON	DEEPWATER		WEBSTER	CEDAR BAYOU	
	Landry (1977)	*Greene et al. (1980a)*	*Chase (1978)*	*Greene et al. (1979)*	*Greene (1980)*	*Greene (1980)*	*Greene et al. (1980b)*	*Jobe et al. (1980)*	*Southwest Research Institute (unpublished)*
	Unit 1-3 2/69-2/70	*Unit 1-4 4/78-3/79*	*6/74-11/74 5/75-9/75*	*1/78-1/79*	*1978*	*1979*	*12/77-11/78*	*7/78-5/79*	*1973-1980*
Atlantic bumper *(Chloroscombrus chrysurus)*			*						
Atlantic cutlassfish *(Trichiurus lepturus)*	*	*	*						*
harvestfish *(Peprilus alepidotus)*		*							
Gulf butterfish *(Peprilus burti)*		*							
bighead searobin *(Prionotus tribulus)*	*	*							
southern flounder *(Paralichthys lethostigma)*		*					*		
lined sole *(Achirus lineatus)*					*				
blackcheek tonguefish *(Symphurus plagiusa)*								*	
least puffer *(Sphoeroides parvus)*		*	*					*	
Atlantic spadefish *(Chaetodipterus faber)*			*						

TABLE 4.3
- CONTINUED -

SPECIES	P. H. ROBINSON			BERTON	DEEPWATER		WEBSTER	CEDAR BAYOU	
	Landry (1977)	*Greene et al. (1980a)*	*Chase (1978)*	*Greene et al. (1979)*	*Greene (1980)*	*Greene (1980)*	*Greene et al. (1980b)*	*Jobe et al. (1980)*	*Southwest Research Institute (unpublished)*
	Unit 1-3 2/69-2/70	*Unit 1-4 4/78-3/79*	*6/74-11/74 5/75-9/75*	*1/78-1/79*	*1978*	*1979*	*12/77-11/78*	*7/78-5/79*	*1973-1980*
Grass shrimp *(Palaemonetes spp.)*									*
Atlantic threadfin *(Polydactylus octonemus)*									*

Gulf Menhaden

The number, size ranges, and peak abundance periods of Gulf menhaden taken by various sampling methods (i.e., intake canal trawl tows, revolving screen, discharge canal icthyoplankton nets, and discharge canal trawl tows) appear in Table 4.4. In addition, the number and percentage of injured organisms by each collection method are included in this table.

The results of the discharge canal sampling (i.e., ichthyoplankton net sets and trawl tows) revealed that 12,671 menhaden were collected in ichthyoplankton nets and 132 organisms were collected in trawl tows. Overall injury rates were 5.1 percent (854 injured individuals) for ichthyoplankton nets and 32.3 percent (63 injured individuals) and 46.1 percent by weight (749.9 g) for trawl tows (Table 4.4).

In summarizing the effects of cooling-water operations in this study, (Landry 1977) stated that Gulf menhaden less than 30 mm standard length (SL) were susceptible to entrainment. Those organisms less than 20 mm were susceptible to entrainment upon entry into the intake canal. Entrainment for those organisms between 20 mm to 30 mm was enhanced by their proximity to the intake structure. Peak periods of entrainment coincided with peak recruitment periods (March and April 1969; January through March 1970).

The 26,741 Gulf menhaden impinged on revolving screens ranged from 14 mm to 200 mm SL (Table 4.4). Overall injury rates were 5.8 percent (1,551 injured individuals) and 6.5 percent by weight (9,867.8 g) (Table 4.4). Gulf menhaden between 35 mm to 85 mm standard length were impinged in the greatest abundance. The highest impingement rates occurred during February through June 1969 when water temperatures were the coolest and the abundance of juveniles was at its peak. Gulf menhaden greater than 90 mm were able to avoid impingement. Peak periods of abundance were characterized by low injury rates (2.3 percent to 6.8 percent for entrained larvae and postlarvae; 0.1 percent to 11.2 percent for impinged organisms). Higher injury rates (25.0 percent to 37.5 percent for entrained individuals and 19.9 percent to 43.1 percent for impinged individuals) occurred during periods of lower abundance, and, therefore, affected fewer individuals.

Landry (1977) projected the total number and weight of organisms impinged during the study. For Units 1 and 2 the projections were 2,186,386 menhaden weighing 12,749 kg. For Unit 3, estimated projections were 1,368,713 menhaden weighing 7,981.1 kg (Table 4.5).

Landry (1977) also addressed the effects of thermal stress on organisms within the discharge canal (Table 4.6). He found that larval and postlarval Gulf menhaden suddenly exposed to effluent temperatures greater than or equal to 30 C exhibited high injury rates and probably did not survive the passage down the discharge canal. Thermal tolerance characterizations for older and larger menhaden were not conducted due to the inability to effectively sample the species with a trawl.

TABLE 4.4
NUMBER, SIZE RANGES, AND INJURY RATES FOR MOST ABUNDANT FISHES TAKEN AT THE HL&P P.H. ROBINSON PLANT ON REVOLVING SCREENS AND IN THE DISCHARGE CANAL BY ICHTHYOPLANKTON NETS AND TRAWLS
(Landry 1977)

SPECIES	REVOLVING SCREEN NUMBER (MM SL)	INJURY RATES		ICHTHYO-PLANKTON NETS	INJURY RATES		TRAWL TOWS NUMBER (MM SL)	INJURY RATES	
		Number (% Injured)	Weights (G) (% Injured)	Number (MM SL)	Number (% Injured)	Weights (G) (% Injured)		Number (% Injured)	Weights (G) (% Injured)
bay anchovy	6,258 (16-78 mm)	2,141 (34.2%)	5,713.2 (31.8%)	15,662 (2.3-42.6)	1,237 (7.9%)	— —	983 (25-40 mm)	147 (15%)	83.4 (16.3%)
sea catfish	1,616 (42-248 mm)	187 (11.6%)	1,556.8 (12.9%)	0	0	0	16	0	0
sand seatrout	3,246 (35-120 mm)	354 (9.6%)	2,357.8 (11.7%)	15 (9.7-76.5)	1 (6.7%)	— —	130 (13-303 mm)	12 (9.2%)	68.7 (6.1%)
spot	2,901 (28-142 mm)	141 (5%)	1,203.5 (6.5%)	64 (4.7-57.0)	— (1.6%)	— —	793 (25-115 mm)	12 (1.5%)	136.4 (3.1%)
Atlantic croaker	21,309 (15-223 mm)	552 (2.6%)	3,784.0 (5.8%)	1,000 (3.4-82.4)	35 (3.6%)	— —	7,497 (12-157 mm)	46 (0.6%)	244 (0.8%)
Gulf menhaden	26,741 (14-200 mm)	1,551 (5.8%)	9,867.8 (6.5%)	12,671 —	854 (5.1%)	— —	132 —	63 —	749.9 (46.1%)

TABLE 4.5
ANNUAL ESTIMATE OF NUMBER AND WEIGHT (Kg) OF MOST ABUNDANT AND COMMERCIALLY/RECREATIONALLY IMPORTANT ORGANISMS IMPINGED AT HL&P GENERATING STATIONS[1]

SPECIES	*P.H. ROBINSON*		*BERTRON*	*DEEPWATER*		*WEBSTER*	*CEDAR BAYOU*	*Total Number and Weight by Species*[2]
	Landry (1977)	*Greene et al. (1980a)*	*Greene et al. (1979)*	*Greene (1980)*	*Greene (1980)*	*Greene et al. (1980b)*	*SRI (unpublished)*	
	Units 1-3 2/69-2/70	*Units 1-4 4/78-3/79*	*1/78-1/79*	*1978*	*1979*	*12/77-11/78*	*1978 Only*	
brown shrimp (*Penaeus aztecus*)		12,619,535 (11,839)	547,135 (2,051)	none impinged	none impinged	1,213,007 (5,714)	20,208,528 (41,379)	34,588,205 (60,983)
white shrimp (*Penaeus setiferus*)		4,910,977 (25,473)	986,469 (4,394)	219 (0.4)	730 (1.2)	1,115,552 (3,226)	8,626,734 (29,036)	15,640,681 (62,130)
blue crab (*Callinectes sapidus*)		1,919,619 (27,093)	256,062 (9,226)	4,453 (5.3)	5,256 (15)	625,891 (23,904)	3,580,320 (74,478)	6,387,148 (134,716)
pygmy blue crab (*Callinectes similis*)		231,606 (428)						
Shrimp eel (*Ophichthus gomesi*)		34,015 (2,607)						
Gulf menhaden (*Brevoortia patronus*)	3,555,099 (20,730)	1,940,691 (9,627)	4,215,385 (27,092)	292 (1.3)	219 (0.9)	1,696,029 (5,852)	14,677,776 (69,188)	22,530,173 (111,760)
gizzard shad (*Dorosoma cepedianum*)						4,071 (538)	15,666 (1,514)	19,737 (2,052)

1 Numbers without parentheses represent the amount of impinged fishes of that species at the particular station. The numbers in parentheses correspond to the total weight of theses fishes in kilograms(kg).

2 Totals calculated by JN by adding projections from Robinson (Greene et al. 1980a), Bertron, Deepwater, Webster, and Cedar Bayou (SRI unpublished).

TABLE 4.5
- CONTINUED -

SPECIES	*P.H. ROBINSON*		*BERTRON*	*DEEPWATER*		*WEBSTER*	*CEDAR BAYOU*	*Total Number and Weight by Species*[2]
	Landry (1977)	*Greene et al. (1980a)*	*Greene et al. (1979)*	*Greene (1980)*	*Greene (1980)*	*Greene et al. (1980b)*	*SRI (unpublished)*	
	Units 1-3 2/69-2/70	*Units 1-4 4/78-3/79*	*1/78-1/79*	*1978*	*1979*	*12/77-11/78*	*1978 Only*	
threadfin shad (*Dorosoma petenense*)			120,324 (599)					
bay anchovy (*Anchoa mitchilli*)	858,925 (2532)	759,972 (1,175)	260,610 (335)	2,044 (2.8)	657 (0.4)	90,731 (201)	928,782 (1,072)	2,042,139 (2,786)
sheepshead minnow (*Cyprinodon variegatus*)				292 (0.6)				
Gulf killifish (*Fundulus grandis*)				438 (1.4)				
sea catfish (*Arius felis*)	168,326 (1,809)	25,059 (1,915)				16,804 (834)		
Atlantic midshipman (*Porichthys porosissimus*)		62,934 (1,790)						
sand seatrout (*Cynoscion arenarius*)	660,452 (3,903)	137,338 (1,351)	244,662 (1,754)	5,913 (68.1)	219 (1.7)	57,754 (647)	633,292 (5,245)	1,078,959 (9,065)
spotted seatrout (*Cynoscion nebulosus*)		32,976 (1,495)	3,790 (132)	none impinged	none impinged	36,851 (658)	47,724 (905)	121,341 (3,190)

[1] Numbers without parentheses represent the amount of impinged fishes of that species at the particular station. The numbers in parentheses correspond to the total weight of theses fishes in kilograms(kg).

[2] Totals calculated by JN by adding projections from Robinson (Greene et al. 1980a), Bertron, Deepwater, Webster, and Cedar Bayou (SRI unpublished).

TABLE 4.5
- CONTINUED -

SPECIES	P.H. ROBINSON		BERTRON	DEEPWATER		WEBSTER	CEDAR BAYOU	Total Number and Weight by Species[2]
	Landry *(1977)*	*Greene et al. (1980a)*	*Greene et al. (1979)*	*Greene* *(1980)*	*Greene* *(1980)*	*Greene et al. (1980b)*	*SRI (unpublished)*	
	Units 1-3 2/69-2/70	*Units 1-4 4/78-3/79*	*1/78-1/79*	*1978*	*1979*	*12/77-11/78*	*1978 Only*	
spot (*Leiostomus xanthurus*)	454,780 (2,843)	254,222 (1,597)	360,971 (2,924)	292 (1.7)	none impinged	33,454 (1,139)		648,939 (5,662)
Atlantic croaker (*Micropogonias undulatus*)	2,606,488 (8,920)	2,305,382 (7,197)	1,134,111 (4912)	1,971 (19.3)	9,636 (76)	1,211,660 (4,970)	5,782,752 (13,751)	10,443,541 (30,906)
black drum (*Pogonias cromis*)		4,240 (232)	6,528 (401)	none impinged	none impinged	1,418 (163)	9,936 (318)	22,122 (1,114)
red drum (*Sciaenops ocellatus*)		31,446 (103)	1,572 (46)	none impinged	none impinged	4,197 (22)	4,422 (16)	41,637 (187)
star drum (*Stellifer lanceolatus*)					511 (0.7)			
striped mullet (*Mugil cephalus*)		60,604 (8,984)	49,963 (3,047)			38,072 (4,072)	48,162 (3,571)	196,801 (19,674)
Atlantic cutlassfish (*Trichiurus lepturus*)		560,514 (5,545)					78,462 (1,594)	
harvestfish (*Peprilus alepidotus*)		103,955 (1,412)						

1 Numbers without parentheses represent the amount of impinged fishes of that species at the particular station. The numbers in parentheses correspond to the total weight of theses fishes in kilograms(kg).

2 Totals calculated by JN by adding projections from Robinson (Greene et al. 1980a), Bertron, Deepwater, Webster, and Cedar Bayou (SRI unpublished).

TABLE 4.5
- CONTINUED -

SPECIES	P.H. ROBINSON		BERTRON	DEEPWATER		WEBSTER	CEDAR BAYOU	Total Number and Weight by Species[2]
	Landry (1977)	Greene et al. (1980a)	Greene et al. (1979)	Greene (1980)	Greene (1980)	Greene et al. (1980b)	SRI (unpublished)	
	Units 1-3 2/69-2/70	Units 1-4 4/78-3/79	1/78-1/79	1978	1979	12/77-11/78	1978 Only	
Gulf butterfish (*Peprilus burti*)		199,992 (682)						
bighead searobin (*Prionotus tribulus*)		182,486 (296)						
southern flounder (*Paralichthys lethostigma*)		16,986 (1,782)	4,731 (130)	none impinged	none impinged	3,678 (549)	22,770 (958)	48,165 (3,419)
lined sole (*Achirus lineatus*)				511 (2.6)				
least puffer (*Sphoeroides parvus*)		184,915 (1,931)						
Atlantic spadefish (*Chaetodipterus faber*)		2,667 (193)	2,050 (19)			42 (2)		

1 Numbers without parentheses represent the amount of impinged fishes of that species at the particular station. The numbers in parentheses correspond to the total weight of theses fishes in kilograms(kg).

2 Totals calculated by JN by adding projections from Robinson (Greene et al. 1980a), Bertron, Deepwater, Webster, and Cedar Bayou (SRI unpublished).

TABLE 4.6
TEMPERATURE (C) AT WHICH FISH BECAME DISTRESSED OR AVOIDED IN HEATED WATERS
(Landry 1977)

	GULF MENHADEN	*BAY ANCHOVY*	*SEA CATFISH*	*SAND SEATROUT*	*SPOT*	*ATLANTIC CROAKER*
Temperature (C)	≥ 30	> 35	> 36	35-36	≥ 35	> 32

Bay Anchovy

The results of the discharge canal sampling (i.e., ichthyoplankton net sets and trawl tows) revealed that 15,662 anchovies (2.3 mm to 42.6 mm SL) were collected in ichthyoplankton net sets and 983 organisms (25 mm to 40 mm SL) were collected in trawl tows. Overall injury rates were 7.9 percent (1,237 injured individuals) for ichthyoplankton net sets and 15.0 percent (147 injured individuals) weighing 83.4 g (46.1 percent by weight) for trawl tows (Table 4.4). Organisms <20 mm SL were entrained upon entering the intake canal, and entrainment was enhanced for organisms between 20 mm to 50 mm with increased proximity to the intake structure (Landry 1977). The peak entrainment period for bay anchovies was from May to September 1969.

The 6,772 anchovies impinged on revolving screens ranged from 20 mm to 65 mm SL (Table 4.4). Overall injury rates were 34.2 percent (2,141 injured individuals) weighing 5,713.2 g (6.5%). Anchovies between 50 mm to 70 mm SL were impinged in the greatest abundance from March through April 1969, and December 1969.

Catch rates for injured individuals collected in the ichthyoplankton samples were seasonal, often varying with abundance. The highest injured catch rates were observed from May to September 1969, which coincided with the warmest effluent temperatures.

Except for February 1970, highest monthly mean injured catch rates were usually observed during months exhibiting highest anchovy abundance (February, March, June, and December 1969). Lowest mean catches occurred during summer and early fall when recruitment was minimal and effluent temperatures were the highest.

Highest injury catch rates (ranging from 54.5% to 75.9%) for impinged anchovies were observed during August through October. These high injury rates coincided with periods of low overall abundance, resulting in a moderate number (197) of injured individuals.

Projections for the number of anchovies impinged at Units 1 and 2 were 528,239 individuals weighing 1,557.5 kg. Projections for the number impinged at Unit 3 were 330,686 individuals weighing 975 kg (Table 4.5).

Summer effluent temperatures in excess of 35 C were very stressful to anchovies transmitting down the discharge canal (Table 4.6). When temperatures reached this high, Landry (1977) found a notable absence of summer residents in the canal, and a virtual absence of viable individuals at the closest station to Galveston Bay in the discharge canal. In addition, some individuals exhibited partially cooked flesh at these temperatures and injury rates were also observed.

Sea Catfish

Landry (1977) reported that 0 and 16 (98 mm to 147 mm SL) individuals were caught in ichthyoplankton net sets and trawl tows, respectively (Table 4.4). No injured individuals were found in trawl tows.

Sea catfish were most vulnerable to intake cooling-water operations during August through October which coincided with the arrival of recently released young into the study area. Due to the practice of oral gestation by male sea catfish, Landry (1977) reported that young-of-the-year of this species were liberated at standard lengths between 35 mm to 40 mm. These organisms were susceptible to entrainment until they reached approximately 50 mm standard length, a period of three to four weeks. The highest period of entrainment was April 1969 and September 1969.

The 1,616 sea catfish impinged on revolving screens ranged from 42 mm to 248 mm SL (Table 4.4). Peak susceptibility to impingement occurred during the late summer and was most critical for individuals ranging in size from 50 to 80 mm standard length (Landry 1977). Overall injury rates were 11.6 percent (187 individuals) weighing 1,556.0 g (12.9 percent of total weight). There appeared to be an inverse relationship between the injury rate and the abundance of impinged sea catfish.

Projections for the number of sea catfish impinged at Units 1 and 2 were 104,136 organisms weighing 1,112.5 kg. For Unit 3, the projection was 64,190 individuals weighing 696.4 kg (Table 4.5).

Discharge trawl samples were practically devoid of sea catfish throughout the study (Table 4.4) which limited the evaluation of the effect of exposure to elevated temperatures. However, the absence of sea catfish in discharge samples (trawl and ichthyoplankton nets) during the summer months, the period of peak influx of liberated young catfish, indicated that temperatures greater than 36 C severely limited the ability of this species to remain viable in the discharge canal.

Sand Seatrout

Within the discharge canal, Landry (1977) reported that 15 sand seatrout ranging from 9.7 mm to 76.5 mm SL were caught in ichthyoplankton nets, and 130 organisms ranging in length from 13 mm SL to 303 mm SL were caught in trawl tows. Overall injury rates were 6.7 percent (one individual) in ichthyoplankton nets and 12 individuals (9.2%) weighing 68.7 g (6.1% of total weight caught) in trawl tows (Table 4.4).

Landry (1977) concluded that the effect of entrainment on sand seatrout was minimal since their abundance in ichthyoplankton samples from both the intake and discharge canals was low. However, sand seatrout caught in ichthyoplankton nets were generally less than 30 mm SL. Greatest abundances were observed in June 1969.

Revolving screen samples contained 3,246 individuals ranging from 35 mm to 200 mm SL. The size of sand seatrout impinged in greatest abundance ranged from 35 mm to 175 mm SL during May to August 1969. Overall injury rates were 9.6 percent (354 of total individuals caught) which comprised 11.7 percent of the total weight caught (Table 4.4). The months characterized by peak numbers of impinged sand seatrout (May through July) exhibited low injury rates ranging from 2.8 percent to 8.7 percent. Peak injury rates of 22.2 percent to 23.6 percent occurred during August and January, when low to moderate numbers of sand seatrout were present.

Landry (1977) projected that, for Units 1 and 2, 406,178 sand seatrout weighing approximately 2,400 kg were impinged. For Unit 3, he projected that 254,274 organisms weighing 1,502 kg were impinged (Table 4.5).

With respect to thermal tolerances, Landry (1977) found that approximately 76 percent of the total sand seatrout catch was taken at temperatures less than or equal to 35 C, with temperatures ranging from 15 C to 40 C. Abundance, injury rates, and laboratory thermal studies indicate that this species exhibits an upper thermal tolerance level between 35 C to 36 C (Table 4.6).

Spot

Within the discharge canal, Landry (1977) reported 64 spot ranging from 4.7 mm to 57.0 mm SL were caught in icthyoplankton nets (Table 4.4). In addition, 793 individuals ranging from 25 mm SL to 115 mm SL were captured in trawl tows. Most spot entrained were less than 30 mm SL and were most abundant in March 1969. Overall injury rates were 1.6 percent in ichthyoplankton nets and 1.5 percent (12 individuals of total caught) weighing 136.4 g (3.1% of total caught).

The 2,901 spot impinged on revolving screens ranged from 28 mm SL to 142 mm SL (Table 4.4). Young spot, approximately 35 mm SL to 70 mm SL, comprised 88 percent of the total catch from revolving screen samples which demonstrates their susceptibility to impingement. Highest periods of impingement occurred from late summer through early winter. Overall injury rates for spot taken in revolving screen samples were five percent (141 individuals) weighing 1,203.5 g (6.5% of total weight captured).

Landry (1977) projected that 279,690 spot weighing 1,748 kg were impinged on revolving screens at Units 1 and 2 during his study. He also projected that 175,090 individuals weighing 1,094 kg were impinged at Unit 3 (Table 4.5).

Landry (1977) found that the sizeable abundance and rapid growth of young-of-the-year residents in the discharge canal during March and April 1969 were indicative that late winter and spring effluent temperatures ranging from 16.5 C to 31 C were favorable to spot. However, he also concluded that the repulsion of overwintering individuals from the discharge canal with the onset of temperatures greater than 35 C in May and the virtual absence of spot thereafter, indicated that summer effluent temperatures greater than or equal to 35 C were stressful to the species (Table 4.6).

Atlantic Croaker

In the discharge canal, 1,000 Atlantic croaker, ranging in size from 3.4 mm SL to 82.4 mm SL were collected in icthyoplankton nets. In addition, 7,497 individuals ranging from 12 mm SL to 157 mm SL were captured in trawls (Table 4.4). Landry (1977) reported that the Atlantic croaker size most susceptible to entrainment was less than 30 mm SL during peak periods of recruitment from March through April 1969 and January through March 1970. Overall injury rates in these samples were 3.6 percent (35 individuals) in ichthyoplankton nets and 0.6 percent (46 individuals) weighing 244 g (0.8 percent of total weight caught) in trawls.

The 21,309 croaker impinged on revolving screens ranged in size from 15 mm SL to 223 SL (Table 4.4). The size of Atlantic croaker impinged in greatest abundance ranged from 30 mm to 65 mm especially during peak impingement periods from February to April 1969. Overall injury rates for impinged croaker were 2.6 percent (552 individuals) weighing 3,784.0 g (5.8 percent of total weight impinged).

Landry (1977) estimated that 1,602,990 Atlantic croaker weighing 5,486 kg were impinged at Units 1 and 2 during the study. In addition, he estimated that 1,003,498 organisms weighing 3,434 were impinged at Unit 3 (Table 4.5).

Effluent temperatures less than 32 C during the winter and early spring were conducive to resident croaker assemblages in the discharge canal. However, temperatures greater than 32 C during late April repelled most resident croaker assemblages from the discharge canal and resulted in their virtual absence from effluent samples through November (Table 4.6).

Other Species

Other species of interest to the Galveston Bay National Estuary Program (GBNEP) that Landry (1977) briefly discussed were spotted seatrout, black drum, red drum, and southern flounder. Landry (1977) reported that 27 spotted seatrout postlarvae (3.8 SL mm to 11.2 mm SL were collected in intake (nine individuals) and discharge canal ichthyoplankton samples (18) during July through September (Table 4.4). None of these post larvae were injured. Trawl samples yielded ten spotted seatrout (57 mm SL to 173 mm SL) in the discharge canal. None of these fish were injured. Spotted seatrout ranging in length from 48 mm SL to 169 mm SL were susceptible to impingement during the fall through winter. The overall injury rate for impinged spotted seatrout was 2.6 percent

Twenty-one black drum were collected during this study, 20 of which were impinged. Impinged black drum ranged in length from 40 mm SL to 283 mm SL with 40 mm SL to 84 mm SL being the range most frequently impinged, especially during June. Overall injury rate for this species was 4.8 percent (Table 4.4).

Seven red drum (6.0 mm SL to 8.5 mm SL) were collected in icthyoplankton net sets during April, May, and July - four in the intake canal and three in the discharge canal. Red drum ranging in size ML from 41 mm SL to 94 mm SL were more susceptible to being impinged on revolving screens. Fifteen red drum were collected in discharge trawl tows. None of these individuals was visibly injured (Table 4.4).

Seventy-seven southern flounder (29 mm SL to 272 mm SL) were collected from revolving screen samples. Overall injury rates were 11.7 percent. Two flounder were collected in discharge canal trawl tows - one was injured. No southern flounder were collected in discharge canal icthyoplankton nets (Table 4.4).

4.2.1.2 P.H. Robinson Station - Chase (1978)

Chase's (1978), Master's thesis addressed the survival rates for organisms impinged during both intermittent and continuous operations of intake screens at the HL&P Robinson plant. Under normal plant operations, screens are rotated intermittently, three times per day. Under continuous operations, screens are rotated on a continual basis. The study period was from June to November 1974, and from May to September 1975. By this time, a fourth unit (750 MW) was in service (Table 4.2) which was not present during Landry's (1971, 1977) studies.

Unlike Landry's (1971, 1977) studies which dealt only with fish, Chase (1978) sampled both fish and macroinvertebrates. In addition, Chase (1978) placed emphasis on sampling during the time when cooling towers were in operation which coincided with the presence of more species in the area. Therefore, he cautioned that the number of organisms caught at the intake screens should not be extrapolated for the purpose of estimating the total number of organisms impinged. His numbers were intended to show the basis for percent survival values.

Overall results indicated that 73,033 organisms were collected in 203 samples. There were 66 species of fish, 17 species of decapod crustaceans, and one cephalopod (squid) species. The 13 most abundant species comprised about 93 percent of the total catch (Table 4.3). These species were white shrimp (*Penaeus setiferus*) - 16,184 (22.1%), brown shrimp (*Penaeus aztecus*) - 15,883 (21.7%), blue crab (*Callinectes sapidus*) - 9,545 (13.1%), Gulf menhaden - 8,942 (12.2%), sand seatrout - 2,892 (4.0%), Atlantic bumper (*Chloroscombrus chrysurus*) - 2,845 (3.9%), Atlantic cutlassfish - 2,772 (3.8%), Atlantic croaker - 1,914 (2.6%), sea catfish - 1,789 (2.4%), bay anchovy - 1,542 (2.1%), Atlantic spadefish (*Chaetodipterus faber*) - 1,488 (2.0%), spot 1,349 (1.8%), and least puffer (*Sphoeroides parvus*) - 846 (1.2%).

Intermittent Screen Rotation

During the intermittent screen rotation part of his study, Chase (1978) collected 37,616 impinged organisms in 99 collections (includes all 10-minute collecting periods), 28,854 (76.7%) from intakes screens at Units 3 and 4. Penaeid shrimp were more numerous (13,468 specimens) than all other crustaceans or fish. Survival rates for most organisms were lower at Units 3 and 4 than at Units 1 and 2, and were much lower for fish than for crustaceans (Table 4.7). The most abundant fish commonly had survival values less than 20 percent, particularly at Units 3 and 4. Survival rates for crab species following impingement were 85.2 percent at Units 1 and 2, and 63.7 percent at Units 3 and 4. For shrimp, survival rates were 72.9 percent at Units 1 and 2, and 30.8 percent at Units 3 and 4.

Continuous Screen Operation

Of the 35,417 specimens collected (i.e., 104 collections during 20-minute collecting periods) in this portion of the study, 74.4 percent were from intake screens at Units 3 and 4. More than half (14,995) of the organisms collected at Units 3 and 4 were shrimp. Shrimp were also abundant (42.0 percent of total) at Units 1 and 2. Blue crab was the most abundant species overall and accounted for 29.5 percent of all individuals. Fish comprised 25.1 percent and 36.5 percent of the catch at Units 1 and 2, and Units 3 and 4, respectively.

TABLE 4.7
SURVIVAL RATES IMMEDIATELY AFTER IMPINGEMENT FOR INTERMITTENT AND CONTINUOUS SCREEN OPERATIONS AT THE ROBINSON STATION (Chase 1978)

SPECIES	*INTERMITTENT OPERATIONS*		*CONTINUOUS OPERATIONS*	
	UNITS 1 & 2	*UNITS 3 & 4*	*UNITS 1 & 2*	*UNITS 3 & 4*
brown shrimp	--------	--------	90.8%	57.0%
white shrimp	71.8%	49.4%	74.2%	56.4%
blue crab	88.8%	81.7%	95.4%	73.7%
Gulf menhaden	-----20.9%-----		34.7%	28.1%
sea catfish	26.2%	20.4%	56.7%	27.7%
sand seatrout	15.1%	16.1%	41.8%	22.6%
spot	31.4%	25.0%	71.4%	47.2%
Atlantic croaker	14.7%	26.4%	30.1%	43.6%
Atlantic spadefish	20.0%	13.8%	51.6%	28.5%
Atlantic cutlassfish	2.1%	3.1%	31.1%	9.1%

Survival rates for the most abundant species were higher for continuous screen operations than for prolonged impingement (intermittent screen rotation). Also, survival rates were higher at Units 1 and 2 than at Units 3 and 4 (Table 4.7). Overall survival rates for shrimp (7 species), crabs (six species), and fish (56 species) at Units 1 and 2, and Units 3 and 4, respectively, were 84.0 percent and 56.7 percent; 95.4 percent and 76.0 percent, and 45.5 percent and 27.0 percent.

Delayed Effects of Impingement

Only organisms collected during continuous operation of the revolving screens were used for the caged study. More live animals were available from these operations than would have been alive from intermittent screen rotation samples. More injury and probably greater delayed mortality occurred as a result of intermittent screen operation than from continuous screen operation (Chase 1978).

For the caged study, 3,568 specimens (48 species) from the intake screens and 1,057 control specimens (27 species) were placed in cages in the intake canal. Survival for control specimens was almost always higher than for test organisms (Table 4.8). Crustaceans (i.e., brown shrimp, white shrimp, and blue crab) generally had high survival rates. Atlantic spadefish had the highest survival rates for fish (78.7%) for specimens from Units 1 and 2, and least puffer had the highest survival rate (58.7%) for fish at Units 3 and 4. The remaining fish species generally had survival rates lower than crustaceans.

Probabilities of Overall Survival

Chase (1978) calculated the probability of survival as:

$$P_{(survival)} = 1.0 - \frac{D + ((A)*(H + E - C)}{I}$$

where: $P_{(survival)}$ = probability of survival following impingement
D = number dead when collected at screens
A = number alive when collected at screens
H = fraction that died during transport from screens to cages
E = fraction that died in the experimental cages
C = fraction that died in the control cages
I = number of live and dead specimens impinged

Calculated probabilities of overall survival appear in Table 4.9. In most cases, probabilities of survival were greater for impinged species taken from Units 1 and 2 as opposed to those collected from Units 3 and 4. Also, probabilities of survival were slightly higher for species collected during continuous operation of the screens versus the normal practice of intermittent operation. Brown shrimp and blue crab had the highest probabilities of survival for crustaceans followed by white shrimp. With the exception of spot (intermittent and continuous) and Atlantic spadefish (continuous) from Units 1 and 2, fish generally had very low (< 0.21) probabilities of survival.

TABLE 4.8
RESULTS OF EXPERIMENTS ADDRESSING THE DELAYED EFFECTS OF IMPINGEMENT
(Chase 1978)

SPECIES	*UNITS 1 AND 2*		*UNITS 3 AND 4*		*CONTROLS*	
	NO.	*SURVIVAL (%)*	*NO.*	*SURVIVAL (%)*	*NO.*	*SURVIVAL (%)*
brown shrimp	260	88.8	623	75.8	118	100
white shrimp	170	68.2	826	79.4	283	95.1
blue crab	210	81.4	181	74.6	139	97.1
Gulf menhaden	17	17.6	116	9.5	126	31.0
sea catfish	30	43.3	85	50.6	55	96.4
sand seatrout	--	39.3	--	13.6	89	96.6
spot	22	77.3	54	16.7	40	97.5
Atlantic croaker	14	35.7	108	22.2	--	--
Atlantic spadefish	47	78.7	57	50.9	--	--
Atlantic cutlassfish	--	0	--	0	18	0
bay anchovy	--	0	--	0	10	20
Atlantic bumper	--	--	--	--	--	--
least puffer	79	63.3	121	58.7	1	100

TABLE 4.9
EMPIRICAL PROBABILITIES OF SURVIVAL
DURING INTERMITTENT AND CONTINUOUS SCREEN OPERATIONS
AT THE ROBINSON STATION
(Chase 1978)

SPECIES	*UNITS 1 AND 2*		*UNITS 3 AND 4*	
	INTERMITTENT	*CONTINUOUS*	*INTERMITTENT*	*CONTINUOUS*
brown shrimp	0.71	0.80	0.39	0.39
white shrimp	0.45	0.47	0.32	0.37
blue crab	0.73	0.79	0.59	0.54
Gulf menhaden	0.06	0.15	0.08	0.10
sea catfish	0.09	0.20	0.05	0.07
sand seatrout	0.06	0.18	0.02	0.03
spot	0.25	0.56	0.04	0.07
Atlantic croaker	0.05	0.10	0.01	0.02
Atlantic spadefish	0.16	0.41	0.07	0.13
Atlantic cutlassfish	0.01	0.21	0.05	0.09

Survival by Species

Brown Shrimp

Chase (1978) reported that for brown shrimp, survival rates at Units 1 and 2 were nearly twice as high as those at Units 3 and 4. Under normal screen operations, fewer specimens were alive at Units 3 and 4 than at Units 1 and 2. Under continuous screen operations, 90.8 percent were alive at Units 1 and 2 and 57.0 percent were alive at Units 3 and 4 (Table 4.7). Most (80.3%) brown shrimp collected were taken from Units 3 and 4. Initial survival rates immediately after impingement were among the highest for all species studied. Results of caged experiments addressing the delayed effects of impingement indicated that 88.8 percent and 75.8 percent of organisms from Units 1 and 2, and Units 3 and 4, respectively, survived (Table 4.8).

For intermittent screen operation, probabilities of overall survival, including the delayed effects of impingement, were 0.71 at Units 1 and 2, and 0.39 at Units 3 and 4 (Table 4.9). For continuous operations, overall probabilities of survival were 0.80 and 0.39 at Units 1 and 2 and Units 3 and 4, respectively. When the probabilities were applied to proportionate catches at respective stations, combined data for normal screen operation (i.e., intermittent screen operation) indicate that 45.4 percent survived the effects of impingement. These results indicate that continuous screen operation did not increase survival rates of this species.

White Shrimp

Overall survival rates for white shrimp collected during normal plant operations were 71.8 percent at Units 1 and 2 and 49.4 percent at Units 3 and 4. Survival rates after impingement for continuous operations were 74.2 percent at Units 1 and 2 and 56.4 percent at Units 3 and 4 (Table 4.7). Survival rates for caged experiments addressing the delayed effects of impingement were 68.2 percent at Units 1 and 2 and 79.4 percent for Units 3 and 4 (Table 4.8).

Probabilities of overall survival for white shrimp during intermittent screen operation were 0.45 at Units 1 and 2, and 0.32 at Units 3 and 4 (Table 4.9). Slightly more than 80 percent of white shrimp were captured at Units 3 and 4. As a result, apportioned catch rates and probability values for both stations combined indicate that only 34.4 percent of impinged white shrimp would survive.

The probability of overall survival for white shrimp during continuous screen operation was 0.47 at Units 1 and 2, and 0.37 at Units 3 and 4 (Table 4.9). Chase (1978) concluded that continuous screen operation did not measurably increase survival rates over those of intermittent operation.

Blue Crab

Initial survival rates under normal operations for blue crab were 88.8 percent at Units 1 and 2 and 81.7 percent at Units 3 and 4. Under continuous screen operations 95.4 percent survived at Units 1 and 2 and 73.7 percent survived at Units 3 and 4 (Table 4.7). Results of experiments addressing the delayed effects of impingement indicate 81.4 percent survival at Units 1 and 2 and 74.6 percent survival at Units 3 and 4 (Table 4.8).

The probability of overall survival during intermittent screen operation was 0.73 at Units 1 and 2, and 0.59 at Units 3 and 4 (Table 4.9). Probabilities of survival and proportionate catch rates for this species indicate that 67.6 percent of crabs impinged survived initial and delayed effects of impingement. Probabilities of overall survival for continuous screen operation demonstrated that survival rates were not measurably improved at Units 1 and 2 (P = 0.79) and Units 3 and 4 (P = 0.54) (Table 4.9).

Gulf Menhaden

Survival rates for menhaden were among the lowest for the most abundant species impinged. Almost 80 percent of menhaden were dead when collected from intake screens during intermittent operation. Survival was improved with continuous operation of the screens with 34.7 percent at Units 1 and 2 and 34.7 percent at Units 3 and 4 (Table 4.7).

Mortality from the delayed effects of impingement was also high: 82.4 percent for Units 1 and 2, and 90.5 percent for Units 3 and 4. Overall survival rates in control cages were also very low indicating that menhaden were sensitive to handling and holding procedures used in testing (Table 4.8). Including the delayed effects of impingement, probabilities of survival for this species during intermittent operations were 0.06 for Units 1 and 2, and 0.08 for specimens from Units 3 and 4 (Table 4.9). Chase (1978) stated that continuous operation of intake screens may have increased survival slightly, but results were not conclusive.

Sea Catfish

Initial survival rates for sea catfish after impingement were also very low. During normal or intermittent screen operations, 30.2 percent were alive at Units 1 and 2 and 20.4 percent were alive at Units 3 and 4. Initial survival was improved with continuous screen operation with 56.7 percent survival at Units 1 and 2 and 27.7 percent survival at Units 3 and 4 (Table 4.7).

The results of cage studies indicated that almost half of those that survived impingement died from injuries suffered on the screens and transport to the cages (Table 4.8). Probabilities of survival for intermittent screen operations were 0.09 and 0.05 at Units 1 and 2, respectively. Probabilities for survival for continuous screen operations at Units 3 and 4 were 0.20 and 0.07, respectively (Table 4.9). Therefore, Chase (1978) concluded that survival doubled with continuous screen operation at Units 1 and 2 and only slightly increased at Units 3 and 4.

Sand Seatrout

The percentage of specimens alive after continuous operation of screens was more than twice the rate for specimens taken during intermittent operation. During normal operations, 15.4 percent were alive at Units 1 and 2 and 16.1 percent were alive at Units 3 and 4. Under continuous operations, 41.8 percent remained alive at Units 1 and 2, while, at Units 3 and 4, 22.6 percent remained alive (Table 4.7).

Considerable mortality occurred in the caged experiments (39.3 percent survival at Units 1 and 2 and 13.6 percent at Units 3 and 4) indicating high mortality due to the delayed effects of impingement. In contrast, nearly all controls (96.6%) were alive at the end of the caged experiments (Table 4.8). With low survival immediately off the screens and in the delayed effects experiments, overall probabilities of survival for this species were 0.06 and 0.02 for intermittent operations at Units 1 and 2, and 0.18 and 0.03 at Units 3 and 4 (Table 4.9). This lead Chase (1978) to conclude that continuous screen operation will not greatly improve survival.

Spot

During intermittent screen rotation under normal plant operations, 31.4 percent of spot collected at Units 1 and 2 survived, while 25.0 percent were alive at Units 3 and 4. During continuous screen operation, 71.4 percent survived at Units 1 and 2 and 47.2 percent survived at Units 3 and 4 immediately after impingement (Table 4.7).

The delayed effects experiments indicated a high survival rate (77.3%) at Units 1 and 2 with a somewhat lower rate (16.7%) at Units 3 and 4 (Table 4.8). These results lead to overall probabilities of survival of 0.25 at Units 1 and 2, and 0.04 at Units 3 and 4 for intermittent or normal screen operation. Overall survival probabilities were 0.56 at Units 1 and 2, and 0.07 at Units 3 and 4 during continuous operation (Table 4.9). While the increase in the overall survival probabilities at Units 1 and 2 with continuous screen operation appeared encouraging, Chase (1978) cautioned that spot was only the ninth most abundant species and did not represent a significant proportion of impinged organisms.

Atlantic Croaker

In contrast to what was normally observed with other species, survival rates were higher at Units 3 and 4 than at Units 1 and 2. Under intermittent operations, 14.7 percent were alive at Units 1 and 2 at the time of collection, while 26.4 percent were alive at Units 3 and 4. Under continuous screen operation, 30.1 percent were alive at Units 1 and 2 and 43.6 percent were alive at Units 3 and 4 (Table 4.7).

Results of experiments addressing the delayed effects of impingement indicated that 35.7 percent of the organisms from Units 1 and 2 survived and 22.2 percent of the organisms from Units 3 and 4 survived (Table 4.8). Overall probabilities of survival for intermittent screen operations were 0.05 at Units 1 and 2, and 0.01 at Units 3 and 4. Overall probabilities of survival for continuous screen operations were 0.10 at Units 1 and 2, and 0.02 at Units 3 and 4 (Table 4.9). Chase (1978) concluded that continuous operation did not appreciably improve probabilities of survival.

Atlantic Spadefish

Under normal (intermittent) plant operations, 20.0 percent of Atlantic spadefish at Units 1 and 2 initially survived impingement while 13.8 percent were alive at Units 3 and 4. For continuous screen rotation, 51.6 percent were alive at Units 1 and 2 when collected, and 28.5 percent were alive at Units 3 and 4 (Table 4.7).

Results of experiments addressing the delayed effects of impingement indicated 78.7 percent of test organisms from Units 1 and 2 survived, while 50.9 percent from Units 3 and 4 survived (Table 4.8). Survival for the caged experiments was among the highest for species tested. Overall probabilities of survival for intermittent screen operations were 0.16 and 0.07 at Units 1 and 2, and Units 3 and 4, respectively. Overall probabilities of survival for continuous operations were 0.41 and 0.13, respectively (Table 4.9).

Atlantic Cutlassfish

For overall survival during intermittent plant operations, the percent alive was slightly higher at Units 3 and 4 (3.1%) than at Units 1 and 2 (2.1%). For continuous operations, 31.1 percent were alive at Units 1 and 2, and 9.1 percent were alive at Units 3 and 4 (Table 4.7).

No specimens survived the delayed effects, caged experiments tests. Even the control specimens died during the delayed effects tests (Table 4.8). Overall probabilities of survival for intermittent operations were 0.01 at Units 1 and 2, and 0.05 at Units 3 and 4. Overall probabilities of survival for continuous operations were 0.21 at Units 1 and 2, and 0.09 at Units 3 and 4 (Table 4.9). These results indicate that continuous screen operation would increase survival of this species. However, Chase (1978) stated that the delayed effects of impingement would be greater than indicated, so the probabilities of survival are probably higher than the actual values.

4.2.1.3 P.H. Robinson - Chase (1977)

Chase (1977) studied the survival of entrained zooplankton and fish eggs and larvae at the Robinson station from June 1974 through September 1975. The primary sampling gear was 153-μm mesh plankton net. A total of 83 taxa were captured and identified during her study. Of that group, only eight zooplankton and six larval fish taxa were captured in sufficient quantities to discuss survival rates.

The calanoid copepod, *Acartia tonsa,* was the most abundant zooplankter collected followed by barnacle nauplii, copepod nauplii, and polychaete larvae. Larval gobies (family Gobiidae) were the most abundant fish taxon collected, particularly larval *Gobiosoma bosci*. Juvenile Gulf menhaden, juvenile bay anchovy, and larval comb-tooth blenny (family Blenniidae) were very abundant at various times of the year. Only those results dealing with fish and commercially important shellfish will be summarized in this report.

Fish egg survival was monitored during 1975. Eggs began to appear from May through September with the largest number captured in August. Almost all fish eggs were alive (93.9 percent to 100 percent survival) in the intake canal during this time while water temperature ranged from 25.6 C to 31.1 C. Survival rates in the discharge canal were much lower (11.3 percent to 54.3%) during June through August when discharge canal water temperatures ranged from 38.4 C to 38.9 C. Survival in the discharge canal was 100 percent in May and September when discharge canal water temperatures were measured at 35.6 C during sample collection.

Juvenile Gulf menhaden (139 individuals) were captured in the discharge canal from December 1974 through March 1975 when water temperatures ranged from 20.0 C to 23.4 C. The percentage of menhaden caught alive ranged from 92.3 percent to 100 percent. Mean standard lengths for Gulf menhaden captured were 22.0 mm with mean lengths per sampling day ranging from 20.6 mm to 23.0 mm.

Juvenile bay anchovies (53 individuals) were collected in the discharge canal in July, August, September, November and December 1974, and January, June and July 1975. The results indicated that 0 percent survived when temperatures ranged from 36.1 C to 40 C. In contrast, survival ranged from 83.2 percent to 100 percent when temperatures 20.0 to 36 C. The mean SL of all bay anchovies collected was 15.3 mm with mean lengths per sampling day ranging from 9.6 mm to 27.8 mm.

Larvae of the family Blenniidae were collected in small numbers (17 individuals) in the intake canal from July through August 1974, and April through June 1975 and August 1975. Temperatures ranged from 23.6 C to 30.0 C while survival was 100 percent during this time. Larvae (14 individuals) were collected in the discharge canal in March 1975 through May 1975, and August 1975. While temperatures ranged from 21.1 C to 32.7 C (March through April 1975), percent survival was 100 percent. Percent survival decreased to 64.3 percent when water temperatures increased to 36.7 C in May 1975. No individuals were found alive after that time with water temperatures ranging as high as 38.4 C.

Larvae of the family Gobidae were the most numerous fish in the intake and discharge samples. Gobiidae were commonly collected from July to October 1974 and from April through September 1975. None were collected from November through March. Survival was almost always 100 percent for 56 individuals collected in the intake canal where temperatures ranged from 22.8 C to 30.6 C. Gobiidae larvae were more numerous in the discharge canal (190 individuals). Percent survival was generally very low during July and August 1974 and May through August 1975 when water temperatures usually exceeded 36 C. The overall mean SL of Gobiidae larvae captured was 3.9 mm.

No live fish eggs were found in the cooling towers from July to September 1975. Water temperatures in the cooling towers ranged from 32.2 C to 34.7 C during this time.

No live bay anchovies were found in the vicinity of the cooling towers (intakes, within, and downstream) from May to July 1975. Water temperatures ranged from 32.2 C to 37.8 C, 30.0 C to 33.9 C, and 32.2 C to 36.7 C, at cooling tower intakes, inside cooling towers, and downstream from cooling towers, respectively. The overall mean SL for anchovies was 17.5 mm.

With few exceptions, most larval bay anchovies were dead when collected at all cooling tower stations. However, fish eggs appeared to be more tolerant to temperature exposure since live eggs were captured at the intakes to cooling towers. With one exception, no fish eggs were found alive in the cooling towers. Chase (1977) suggests that the repeated bouncing on splash fill damaged the delicate eggs.

Chase (1977) accumulated very little data concerning the survival of Penaeid shrimp. Brown shrimp larvae and white shrimp larvae were not collected until April 1975 and July 1975, respectively. However, she observed that passage through the condensers did not cause substantial mortality to brown shrimp at ambient temperatures of 27.8 C to 29.5 C and discharge temperatures of 35.6 C to 38.9 C. *Callinectes* spp. were also found to be highly resistant to stresses encountered during condenser passage.

4.2.1.4 P.H. Robinson - McAden (1977)

McAden (1977) also studied the composition, distribution, and abundance of zooplankton in the cooling water canals at the Robinson station from June 1974 to September 1975. He found similar dominant zooplankton as did Chase (1977), except that bryozoan larvae occurred in greater numbers than in Chase's study. Larval and juvenile fish present in the greatest numbers were larval gobies, *Anchoa* spp. larvae, juvenile *Gobiosoma bosci*, and larval blennies. Other species collected, but in very small numbers, were sand seatrout, spotted seatrout, spot, and Atlantic croaker.

McAden (1977) reported that penaeid shrimp were taken in very small numbers in his study. The 0.5-m net and 12.5 cm Clarke-Bumpus sampler (153-μm mesh size) data revealed that a total of 41 brown shrimp were collected from stations within one location in the intake canal and two within the discharge canal. Most specimens (35) were collected at night. Mean lengths of brown shrimp ranged from 2.2 mm to 3.5 mm.

A total of 119 white shrimp were collected in the 0.5-m nets and Clarke-Bumpus samplers from the three stations. Most specimens (114) were collected at night. Mean lengths ranged from 1.6 mm to 2.8 mm. No differences among stations were determined.

In the 0.5-m net plankton samples, 454 *Callinectes spp.* specimens were collected. Two species of the genus *Callinectes spp.* are reported from the estuarine areas of the upper Texas coast (Felder 1973) with the most abundant species in Galveston Bay being *C. sapidus* (Schmidt 1972, Strawn et al. 1973 and 1974, Chase 1977, Margraf 1977). No positive identification was made to species during this study; however, McAden (1977) assumed that most of the megalops collected were *C. sapidus*. McAden (1977) found that: (1) more megalops were captured during the night; (2) samples collected in the late summer to early fall contained more megalops; and (3) the intake sample station had greater abundance and densities than the two discharge canal stations. *Callinectes* spp. juveniles were not collected in sufficient numbers to be statistically analyzed. Within 12.5-cm Clarke-Bumpus samplers, McAden (1977) collected 17 juvenile crabs ranging from 2.4 mm to 10.0 mm. A total of 84 *Callinectes* spp. juveniles were collected with 0.5-m nets from the intake canal (one location) and the discharge canal (two locations). Mean length sizes ranged from 2.2 mm to 45.4 mm.

Fish collected during this study were not identified due to the lack of suitable larval fish keys. However, McAden (1977) assumed that most eggs taken in the study were spawned by bay anchovy since they were the most abundant fish species taken in trawl and revolving screen samples. Most eggs were collected from June through September.

Twenty-six species of fish were collected in Clarke-Bumpus and 0.5-m plankton net collections. Thirty-eight juvenile bay anchovies were captured with the Clarke-Bumpus net ranging in mean length from 10.4 mm to 38 mm. In the intake canal, they were caught from March through June, and August through September. In the discharge canal, they collected from May through July and from September through October.

Using the 0.5-m plankton net, more juvenile bay anchovies were collected from the intake canal (529 individuals with mean lengths ranging from 13.8 mm to 31.3 mm) than from the discharge canal (174 individuals from Stations 2 and 3 with mean lengths ranging from 11.3 mm to 45.1 mm). Juvenile bay anchovies were collected from May through September and November through January.

McAden (1977) reported that three species of larval blennies were collected during his study but they were grouped together for reporting purposes. Larval blennies were present in the study area from June through September 1974 and from March through September 1975.

McAden (1977) also reported that larval gobies were collected during his study with the greatest majority being the naked goby *Gobiosoma bosci*. Few naked goby were collected during the study but they were most abundant during the summer months and absent from midfall through the spring.

McAden (1977) and Chase (1977) reported similar dominant fish species (i.e., Gobiidae larvae (mostly *G. bosci*), juvenile Gulf menhaden, juvenile bay anchovy, and larval Blenniidae). However, McAden (1977) found cyphonaute barnacle larvae to be dominant where as Chase (1977) did not report collecting them.

McAden (1977) hypothesized that mechanical stresses encountered by all zooplankters during passage through the power plant condenser system probably decreased their ability to survive temperatures approaching their normal thermal limits. He also concluded from results of day-night sampling that net avoidance and vertical migration had a great effect on abundance of most zooplankters.

4.2.1.5 P.H. Robinson - (Greene et al. 1980a)

In Greene et al.'s (1980a) impingement study at the Robinson station, from April 1978 to March 1979, biweekly samples (26 collections) were collected from each of two intakes (i.e., A and B), three times over at eight-hour intervals over a 24-hour period. The actual sampling period was ten minutes per eight hours or 30 minutes per sampling day. Intake A included Units 1 and 2, and intake B included Units 3 and 4. Daily total numbers and weights were computed by adding the three sample values, multiplying by 24 hours and dividing by 1.5 hours (i.e., three, 30 minute samples). Appropriate adjustments were made for subsampling and when the sample period exceded 30 minutes on a few occassions. Subsampling procedures used are explained in Greene et al. (1980a). The projected annual impingement was calculated by dividing the sum of the 26 collections by 26 and multiplying this number by 365. Plant specifications for the Robinson station appear in Table 4.2.

There were 81 species of fish, 23 species of crustaceans, and one mollusc species collected during this study. A total of 33,622 fish weighing 246 kg and 45,715 invertebrates weighing 297 kg were collected during this study. Thirteen of 20 species comprising one percent or more of animals collected from intake screens during this study appear in Table 4.10 along with other species of commercial or recreational importance.

A total of 17,556,118 organisms weighing 121,724 kg were projected impinged during the study period (Greene et al. 1980a). Estimates of total animals impinged for Greene et al. (1980a) and Landry (1977) had six species in common. For Units 1 and 2, Landry's (1977) projections were an order of magnitude higher for Gulf menhaden, sea catfish, sand seatrout, and spot. Estimates for bay anchovy and Atlantic croaker were 2.2 times and 1.1 times greater, respectively.

Greene et al. (1980a) compared their projections to Landry's (1971) by increasing Landry's predictions by 35 percent to account for the additional pumping capacity of Unit 4 which was added after Landry's study. They then compared only total projections for finfish since Landry's study did not include shellfish. Greene (et al. 1980) concluded that the estimates of total annual impingement weight for all finfish between the two studies were of the same order of magnitude, and differences would be due to normal year-to-year variations. He did acknowledge disparate results for total number of fish impinged.

4.2.2 Webster Generating Station (Green et al. 1980b)

The Webster station is located in southern Harris County on the north side of Clear Creek, 3.5 miles upstream from its mouth on Clear Lake (Figure 2). A summary of plant specifications appear in Table 4.11.

Both entrainment and impingement data were collected during this study. The intake structure consisted of seven intake bays, two each for Units 1 and 2 and three for Unit 3. Organisms impinged were sampled on a bi-weekly basis from December 8, 1977 to November 28, 1978 (i.e. 26 collections at the intake structure). Each bi-weekly collection consisted of three samples collected at eight-hour intervals over a 24-hour period. At the beginning of the 24-hour sampling period, the intake screens were rotated to clean off all impinged organisms and debris. All animals impinged since the previous screen cleaning were collected while the screens were rotated for 10 minutes to sample organisms (i.e., 30 minutes of collection time during each sampling day). Daily total numbers and weights were computed by adding the three eight-hour sample values. Appropriate adjustments were made for subsampling. Subsampling procedures used are explained in Greene et al. (1980b). The projected annual impingement was calculated by dividing the sum of the 26 collections by 26 and multiplying this number by 365.

Sixty-two fish species, one species of amphibian, 13 crustacean species, and one species of mollusc were collected during impingement sampling. Only 13 species were abundant enough to comprise as much as one percent of the total number or weight (Table 4.3). Brown shrimp, white shrimp, and blue crab comprised 47.3 percent by number and 61.6 percent by weight of all organisms impinged. The major forage fish were Gulf menhaden, threadfin shad, and bay anchovy. These species accounted for 28.7 percent by number and 11.5 percent by weight of the organisms impinged. Nine species of commercial or recreationally importance were also impinged. These species included sand seatrout, spotted seatrout, Atlantic croaker, black drum, red drum, and southern flounder. Only the Alantic croaker made up a significant portion of the organisms impinged (9.3 percent by weight and 19.4 percent by number). Striped mullet (*Mugil cephalus*) made up 7.6 percent by weight of animals impinged but only 0.6 percent by number. The number, length-frequency and seasonal abundance information for the most abundant, commercially important, and recreationally important species collected from intake screens during this study appear in Table 4.12. A total of 6,252,239 organisms weighing 53,304 kg were projected impinged during the study period (Greene et al. 1980b). Brown shrimp most abundant in late May and early June, and again in November. Rest of the year they were rare to absent. White shrimp had a minor peak in late August and early September, and a major one from the end of November to early January. The winter peak had smaller shrimp.

TABLE 4.10
NUMBER, WEIGHTS, SIZE RANGES, AND PEAK IMPINGEMENT PERIODS FOR SPECIES COMPRISING 1% OR MORE AND COMMERCIALLY/RECREATIONALLY IMPORTANT SPECIES COLLECTED FROM INTAKE SCREENS AT THE ROBINSON STATION FROM APRIL 1978 TO MARCH 1979
(Greene et al. 1980a)

SPECIES	UNITS 1 AND 2		UNITS 3 AND 4		PERIODS OF GREATEST ABUNDANCE	SIZE RANGE (mm SL)	MEAN SIZE RANGE (mm SL)
	NUMBER	WEIGHT (kg)	NUMBER	WEIGHT (kg)			
brown shrimp (*Penaeus aztecus*)	2,221	7,743	10,219	45,346	Sept.-Nov. May-June	10-170	43.5-108.8
white shrimp (*Penaeus setiferus*)	5,948	28,144	15,982	85,632	July-Sept. Nov.-Dec.	30-170	49.2-158.1
blue crab (*Callinectes sapidus*)	4,546	43,377	4,236	77,061	All year round	5-200	23.8-88.1
pygmy blue crab (*Callinectes similis*)	554	1,138	481	783			
shrimp eel (*Ophichthus gomesi*)	116	8,123	36	3,508			
Gulf menhaden (*Brevoortia patronus*)	2,541	14,175	6,104	28,710	September, Dec.-March	15-185	45-75
bay anchovy (*Anchoa mitchilli*)	1,075	1,998	2,327	3,256			
sea catfish (*Arius felis*)	54	3,417	58	5,186			
Atlantic midshipman (*Porichthys porosissimus*)	161	4,405	121	3,622			
sand seatrout (*Cynoscion arenarius*)	179	1,376	434	4,646	No Apparent Seasonal Pattern	20-225	60.8-91.4

TABLE 4.10
- CONTINUED -

SPECIES	*UNITS 1 AND 2*		*UNITS 3 AND 4*		*PERIODS OF GREATEST ABUNDANCE*	*SIZE RANGE (mm SL)*	*MEAN SIZE RANGE (mm SL)*
	NUMBER	*WEIGHT (kg)*	*NUMBER*	*WEIGHT (kg)*			
spotted seatrout (*Cynoscion nebulosus*)	88	5,407	59	1,250	Dec.-March	50-470	91.1-105.7
spot (*Leiostomus xanthurus*)	286	2,861	850	4,267			
Atlantic croaker (*Micropogonias undulatus*)	6,440	18,800	3,831	13,311	Jan.-April	5-315	26.7-124.5
black drum (*Pogonias cromis*)	13	658	6	377			
red drum (*Sciaenops ocellatus*)	112	383	28	75	Mid Dec. 1978 to Mid March 1979	35-95	49.6-62.5
striped mullet (*Mugil cephalus*)	172	25,185	98	15,030			
Atlantic cutlassfish (*Trichiurus lepturus*)	1,548	12,415	954	12,455			
harvestfish (*Peprilus alepidotus*)	73	951	403	5,487			
Gulf butterfish (*Peprilus burti*)	323	849	570	2,193			
bighead searobin (*Prionotus tribulus*)	583	844	230	476			
southern flounder (*Paralichthys lethostigma*)	35	4,336	41	3,687	All year round except July	10-375	
least puffer (*Sphoeroides parvus*)	664	7,005	161	1,604			

TABLE 4.11
WEBSTER STATION SPECIFICATIONS

	UNIT 1	*UNIT 2*	*UNIT 3*
Year Operational	1954	1955	1964
Generating Capacity (MW)	118	118	390
Pump Capacity (gal/min) (actual)	80,000	80,000	231,000
Max. Design Velocity (ft/sec)	1.97	1.97	3.4
Max. Actual Velocity Corrected for Subsidence (ft/sec)	1.48	1.48	2.56
Revolving Screen Mesh Size, (in)	3/8	3/8	3/8
Flow During Study Period 138.6 (BGD)			

TABLE 4.12
- CONTINUED -

SPECIES	*TOTAL COLLECTED*		*PEAK IMPINGEMENT PERIOD*	*SIZE RANGE (mm SL)*	*MEAN SIZE RANGE (mm SL)*
	NUMBER	*WEIGHT (g)*			
Atlantic croaker (*Micropogonias undulatus*)	86,310	353,996	March 16 thru April 27, 1978 Present year round	10-220	42.8-147.5
black drum (*Pogonias cromis*)	101	11,592	January 1978	25-260	42.5-58.0
red drum (*Sciaenops ocellatus*)	299	1,566			
striped mullet (*Mugil cephalus*)	2,712	290,032			
southern flounder (*Paralichthys lethostigma*)	262	39,107	no pattern	70-375	93.6-247.5

Blue crab generally had a high weight through the warm part of the year and a low weight in the cold part of the year (December through early March). Numbers followed the weight trends except that the period of low numbers extended only from late January through February.

Gulf menhaden were abundant in December and January and again in late November 1978. There was a peak of small menhaden in early April. Atlantic croaker had an inconsistent pattern of abundance and weight. However, they appeared most abundant in the spring and early summer and least abundant in late summer and fall.

Entrainment - Ichthyoplankton

Entrainment samples were collected on a bi-weekly basis from December 22, 1977 to November 28, 1978. Each bi-weekly collection consisted of three samples collected at eight-hour intervals over a 24-hour period. Plankton samples were collected by pumping water from the intake canal and filtering it through #10 mesh (153 um) plankton nets. Only the results of ichthyoplankton collections will be presented in this report.

Ten fish taxa were taken in entrainment samples, but four species (bay anchovy, naked goby (*Gobiosoma bosci*), Gulf menhaden, and Atlantic croaker) accounted for 98.9 percent of total number of fish. Bay anchovy and naked goby larvae and juveniles were present from April through November 1978. Young Gulf menhaden and Atlantic croaker were present only from February through mid-April 1978.

4.2.3 Sam Bertron Station (Greene et al. 1979)

The Sam Bertron Generating Station is located on the Houston Ship Channel near the Baytown Tunnel in eastern Harris County (Figure 2). A summary of plant specifications appears in Table 4.13.

There were two intake structures (i.e., A and B) at the facility which consisted of four intake bays per intake structure. Intake screens were sampled on a biweekly basis from January 12, 1978, to January 2, 1979 (i.e., 26 collections). Each biweekly collection consisted of three samples collected at eight-hour intervals over a 24-hour period. At the beginning of the 24-hour cycle, intake screens were rotated to clean off impinged organisms and trash. When each of three samples was taken thereafter, all animals impinged since the previous sample or screen cleaning were collected. At each collection, the screens were rotated for 10 minutes and all organisms were washed off, collected, and counted (i.e, 30 minutes of sampling during each collection day). Large sample collections were subsampled as needed and all reported values were adjusted for subsampling as necessary. Samples from both intake structures were usually combined to determine impingement for the entire facility. Daily total numbers and weights were calculated by adding the sums of the three 8-hour sample values. Projected annual impingement was calculated by dividing the total of 26 collections by 26, and multiplying the result by 365.

In 26 collections, 479,448 fish weighing 3,099 kg and 132,450 invertebrates weighing 1,125 kg were collected. Sixty-eight species of fish, 17 species of crustaceans, and one species of mollusc were captured during this study.

Only 10 species comprised as much as one percent of the total by number or weight (Table 4.3). The number impinged, length-frequency and seasonal abundance information for the most abundant, commercially important, and recreationally important species collected from intake screens during the sampling period appear in Table 4.14.

A total of 6,252,239 organisms weighing 53,304 kg were projected impinged during the study period (Greene et al. 1979). Brown shrimp, white shrimp, and blue crab accounted for 96.2 percent by number and 99.2 percent by weight of the projected annual impingement of all invertebrates. Major forage species included Gulf menhaden, threadfin shad, and bay anchovy which accounted for 68.3 percent by number and 64.4 percent by weight of the projected annual impingement figures for finfish. Other commercially or recreationally important finfish impinged included sand seatrout, spotted seatrout, Atlantic croaker, red drum, and southern flounder which made up 20.7 percent of all fish by number and 16.9 percent by weight. Two other species taken in large numbers were spot and striped mullet which comprised 6.1 percent of all fish by number and 10.1 percent by weight. The 14 species previously mentioned account for 95.4 percent by number and 96.2 percent by weight of all organisms impinged.

4.2.4 Deepwater Generating Station (Greene 1980)

The Deepwater Station is located on the Houston Ship Channel just east of the mouth of Vince Bayou (Figure 2). Greene et al. (1980) reported the results from TDWR which sampled the revolving screens once per month in 1978 and 1979 (i.e, one collection month per each year at one intake structure with three intake bays). The screens were not rotated after midnight, and then were rotated at about 1000 to collect impinged animals. Each sample period theoretically represented animals impinged during the previous ten-hour period. However, because the screens were normally rotated when necessary, the sampling time usually represented a longer period, up to and possibly exceeding 24 hours (Greene 1980). Annual impingement was calculated by multiplying the total numbers of animals collected per year by the number of hours of collection per day (i.e., 24 hr per day/10 minimum collection time per day) by the remaining number of additional sampling days in a year (i.e., 365/12). Station specifications appear in Table 4.15.

In general, the maximum flow during the sampling period occurred during the heat of the summer when all or most of the units were on line for peak power production. Cooling water flow is much less in the winter when Units 1-6 are used to a lesser extent. However, no animals were impinged June through October in both 1978 and 1979, and May 1979 when the maximum flows were observed. During the two-year sampling period, 17 species of fish and two species of invertebrates were captured. A total of 146 invertebrates weighing 301 g were impinged over both years. A total of 327 finfish weighing 2,478 g were captured during the same period. The most abundant species were blue crab, sand seatrout, Atlantic croaker, bay anchovy, and white shrimp (Tables 4.16 and 4.17). Several freshwater species were also captured at this location. Length-frequency data for the five most abundant species collected from intake screens are also reported in Tables 4.16 and 4.17. A total of 16,717 organisms weighing 104 kg were projected impinged in 1978 and 17,812 organisms weighing 98,185 kg were projected impinged in 1979 (Greene 1980).

TABLE 4.13
BERTRON STATION SPECIFICATIONS

	UNIT 1	*UNIT 2*	*UNIT 3*	*UNIT 4*
Year Operational	1958	1956	1959	1960
Generating Capacity (MW)	156	156	219	219
Pump Capacity (gal/min) (actual)	116,000	116,000	141,000	141,000
Calculated Approach Velocity @ max. low water (ft/sec)	1.38	1.38	2.33	2.33
Calculated Approach Velocity @ mean low water (ft/sec)	1.05	1.04	1.14	1.19
Revolving Screen Mesh Size, Square Clear Opening (in)	3/8	3/8	3/8	3/8
Flow During Study Period 241.1 (BGD)				

TABLE 4.14
NUMBER, WEIGHT, SIZE RANGE AND PEAK IMPINGEMENT PERIODS FOR SPECIES COMPRISING 1% OR MORE AND COMMERCIALLY/RECREATIONALLY SPECIES COLLECTED FROM INTAKE SCREENS AT THE BERTRON STATION JANUARY 1978 TO JANUARY 1979 (Greene et al. 1979)

SPECIES	*TOTAL COLLECTED*		*PERIODS OF GREATEST ABUNDANCE*	*SIZE RANGE*	*MEAN SIZE RANGE*
	NUMBER	*WEIGHT (g)*			
brown shrimp (*Penaeus aztecus*)	38,974	146,107	Mid May to End of June		
white shrimp (*Penaeus setiferus*)	70,269	312,990	End of June to End of Sept.; First of Nov. to Jan.		
blue crab (*Callinectes sapidus*)	18,240	657,186	No consistent pattern	5-210	35.7-95.0
Gulf menhaden (*Brevoortia patronus*)	300,274	1,929,816	First of Nov. to Mid- Dec.	20-230	54.6-104.5
threadfin shad (*Dorosoma petenense*)	8,571	42,675			
bay anchovy (*Anchoa mitchilli*)	18,564	23,831			
sand seatrout (*Cynoscion arenarius*)	17,428	124,936	First of Nov. to First of Jan. 1979	5-325	53.0-280.0
spotted seatrout (*Cynoscion nebulosus*)	270	9,374	First of Nov. - End of March	65-280	77.5-197.5
spot (*Leiostomus xanthurus*)	25,713	208,273			
Atlantic croaker (*Micropogonias undulatus*)	80,786	349,865	End of March to mid-May	5-245	50.6-109.4

TABLE 4.14
- CONTINUED -

SPECIES	*TOTAL COLLECTED*		*PERIODS OF GREATEST ABUNDANCE*	*SIZE RANGE*	*MEAN SIZE RANGE*
	NUMBER	*WEIGHT (g)*			
black drum (*Pogonius cromis*)	465	28,559			
red drum (*Sciaenops ocellatus*)	112	3,267	End of Jan. - End of Feb.	40-380	65.8-74.8
striped mullet (*Mugil cephalus*)	3,559	217,065			
southern flounder (*Paralichthys lethostigma*)	337	9,273	Mid April - First of June	40-290	48.8-192.5

TABLE 4.15
DEEPWATER STATION SPECIFICATIONS

	UNIT 1	*UNIT 2*	*UNIT 3*	*UNIT 4*	*UNIT 6*	*UNIT 7*
Year Operational	1922	1923	1926	1928	1930	1945
Generating Capacity (MW)	15	15	25	30	30	183
Pump Capacity (gal/min)	37,500	37,500	60,000	42,500	42,500	85,000
Max. Design Screen Approach Velocity (ft/sec) with all units in operation	0.98					
Max. Present Screen Approach Velocity (ft/sec) with all units in operation	0.76					
Revolving Screen Mesh Size	3/8	3/8	3/8	3/8	3/8	3/8
Flow For 1978 - 45.3 (BGD) Flow For 1979 - 39.9 (BGD)						

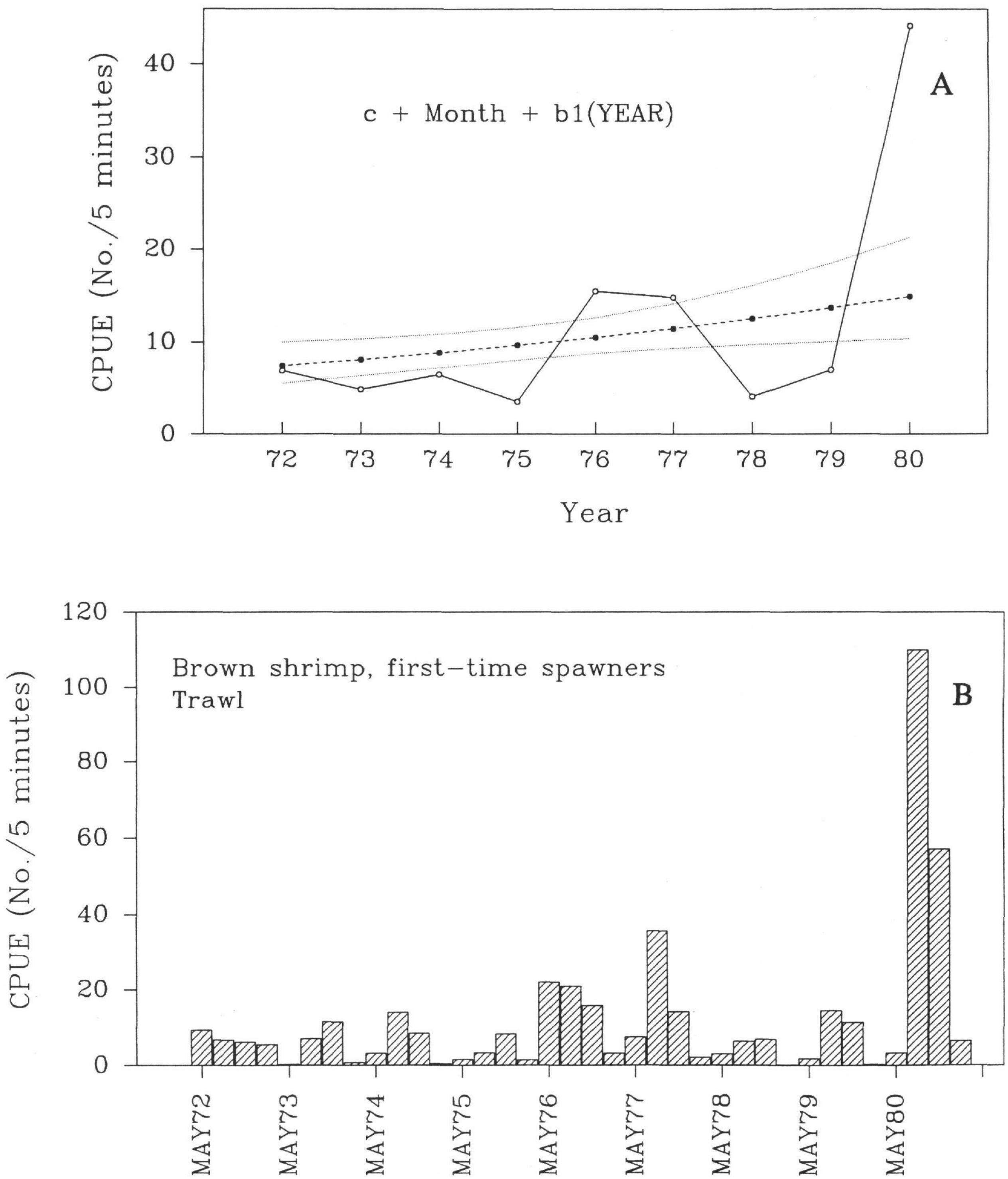


Figure III.19. A. Mean seasonal (May-August) CPUE and predicted CPUE with confidence intervals for first-time spawning brown shrimp (85-110 mm) caught by trawl, 1972-1980 (TPWD/NMFS data). B. Mean CPUE by month, May-August only.

TABLE 4.16
- CONTINUED -

SPECIES	TOTAL COLLECTED		PERIODS OF GREATEST ABUNDANCE	SIZE RANGE (mm SL)
	NUMBER	WEIGHT (g)		
Atlantic croaker (*Micropogonias undulatus*)	27	263.7	Jan., April, and Dec.	50-120
fat sleeper (*Dormitator maculatus*)	1	7.9		
lined sole (*Achirus lineatus*)	7	35.3		

TABLE 4.17
NUMBER, WEIGHT, AND SIZE RANGE, AND PEAK IMPINGEMENT PERIODS FOR ALL SPECIES COLLECTED FROM INTAKE SCREENS DURING 1979 AT THE DEEPWATER STATION
(Greene 1980)

SPECIES	*TOTAL COLLECTED*		*PEAK ABUNDANCE PERIOD*	*SIZE RANGE (mmSL)*
	NUMBER	*WEIGHT (g)*		
white shrimp (*Penaeus setiferus*)	10	17.0	Dec.	30-60
blue crab (*Callinectes sapidus*)	72	206.6	Jan.-March Nov.-Dec.	10-60
Gulf menhaden (*Brevoortia patronus*)	3	12.1		
threadfin shad (*Dorosoma petenense*)	1	4.7		
bay anchovy (*Anchoa mitchilli*)	9	5.3	Nov. thru Dec.	20-30
sheepshead minnow (*Cyprinodon variegatus*)	1	2.6		
Gulf killifish (*Fundulus grandis*)	2	7.2		
sailfin molly (*Poecilia latipinna*)	1	2.1		
black bullhead (*Ictalurus melas*)	1	3.2		
sea catfish (*Arius felis*)	1	6.0		
Atlantic midshipman (*Porichthys porosissimus*)	1	3.1		

TABLE 4.17
- CONTINUED -

SPECIES	*TOTAL COLLECTED*		*PEAK ABUNDANCE PERIOD*	*SIZE RANGE (mmSL)*
	NUMBER	*WEIGHT (g)*		
sand seatrout (*Cynoscion arenarius*)	3	22.7	Nov.	70
Atlantic croaker (*Micropogonias undulatus*)	132	1,042.8	Nov.	20-60
star drum (*Stellifer lanceolatus*)	7	9.6		

4.2.5 Cedar Bayou Generating Station

4.2.5.1 Cedar Bayou Generating Station - Jobe et al. (1980)

From June 1978 through May 1979, Jobe et al. (1980) calculated the survival rates of nekton impinged on revolving screens and routed through a fish pump system at the HL&P Cedar Bayou Generating Station. The purpose of the fish pump system was to route impinged nekton around the plant through a 1,550-ft discharge line into the condenser cooling water discharge canals. The purpose of the study was to determine (1) the survival rates of impinged species after passage through the fish pump system, and (2) the survival rates of impinged and pumped organisms subjected to elevated temperatures found in the discharge canal. Test species included sand seatrout, spot, Atlantic croaker, white shrimp, brown shrimp, and blue crab. Test organisms were collected on a monthly basis near the end of the fish pump system in an experimental laboratory building. Control organisms were collected after impingement on the revolving intake screens. Two experimental groups were maintained in a tank at ambient temperatures inside the laboratory. A third group was placed in cages in the discharge canal for thermal shock studies. Organisms in the cages were examined for mortality at 2, 4, 8, 12, 24, 48, 72, and 96 hours.

A total of 9,355 fish weighing 34.7 kg and 2,201 crustaceans weighing 24.0 kg were collected at the intake screens. Ninety one per cent (91%) of the fish and 95 percent of the crustaceans caught on the intake screens were alive when collected. The following organisms were impinged in the largest numbers during the study: Gulf menhaden (6,602), Atlantic croaker (1,801), white shrimp (1,463), blue crab (322), brown shrimp (274), bay anchovy (252), sand seatrout (195), and spot (150) were the most abundant species impinged on the intake screens (Table 4.3). The recreationally or commercially important species spotted seatrout, southern flounder, black drum, and red drum comprised 0.3 percent of the total number of organisms impinged on the intake screens (Table 4.18).

A total of 13,087 fish weighing 65.1 kg and 7,262 crustaceans weighing 57.9 kg were collected after being impinged and passing through the fish pump. The most abundant organisms which were impinged and passed through the fish pump were: Gulf menhaden (7,053), white shrimp (5,344), Atlantic croaker (3,707), brown shrimp (903), blue crab (807), blackcheek tonguefish (*Symphurus plagiusa*) (477), sand seatrout (439), bay anchovy (420), least puffer (201), and spot (201). The recreationally or commercially important species spotted seatrout, southern flounder, black drum, and red drum comprised less than 0.4 percent of the total number of organisms impinged on intake screens and passed through the fish pump (Table 4.18).

Only limited information regarding lengths for the most abundant species was provided in this report. The following mean lengths (mm SL) and size ranges (mm SL), respectively, were provided for some of the most abundant species: sand seatrout - 75 mm, and 32 mm to 171 mm; spot - 56 mm, and 32 mm to 127 mm; Atlantic croaker - 43 mm, and 20 mm to 120 mm; blue crab - 87 mm, and 15 mm to 196 mm; brown shrimp - 80 mm, and 45 mm to 122 mm; and white shrimp - 85 mm, and 41 mm to 147 mm (Table 4.18).

TABLE 4.18
NUMBER, WEIGHT, AND SIZE RANGE OF THE MOST ABUNDANT (>1%) AND COMMERCIALLY/RECREATIONALLY IMPORTANT SPECIES COLLECTED AFTER IMPINGEMENT AND PASSAGE THROUGH THE FISH PUMP AT THE CEDAR BAYOU STATION FROM JULY 1978 TO MAY 1979
(Jobe et al.1980)

SPECIES	ORGANISMS COLLECTED AT INTAKE SCREENS		ORGANISMS COLLECTED AFTER IMPINGEMENT AND PASSAGE THROUGH FISH PUMP		MEAN LENGTH (mm SL)	SIZE RANGE (mm SL)
	NUMBER	WEIGHT (g)	NUMBER	WEIGHT (g)		
bay anchovy (*Anchoa mitchilli*)	252	172	420	342		
Gulf menhaden (*Brevoortia patronus*)	6,602	17,094	7,053	36,904		
sand seatrout (*Cynoscion arenarius*)	195	1,769	439	3,242	75	32-171
spotted seatrout (*Cynoscion nebulosus*)	19	299	15	372		
spot (*Leiostomus xanthurus*)	150	1,040	201	1,319	56	32-127
Atlantic croaker (*Micropogonias undulatus*)	1,801	3,308	3,707	6,373	43	20-120
southern flounder (*Paralichthys lethostigma*)	11	626	50	2,295		
black drum (*Pogonias cromis*)	1	80	4	52		
red drum (*Sciaenops ocellatus*)	1	4	3	12		
least puffer (*Sphoeroides parvus*)	44	145	201	684		

TABLE 4.18
- CONTINUED -

SPECIES	*ORGANISMS COLLECTED AT INTAKE SCREENS*		*ORGANISMS COLLECTED AFTER IMPINGEMENT AND PASSAGE THROUGH FISH PUMP*		*MEAN LENGTH (mm SL)*	*SIZE RANGE (mm SL)*
	NUMBER	*WEIGHT (g)*	*NUMBER*	*WEIGHT (g)*		
blackcheek tonguefish (*Symphurus plagiusa*)	55	265	477	2,992		
blue crab (*Callinectes sapidus*)	322	17,178	807	30,652	87	15-196
brown shrimp (*Penaeus aztecus*)	274	1,577	903	5,013	80	45-122
white shrimp (*Penaeus setiferus*)	1,463	5,130	5,344	22,145	85	41-147

Survival

Jobe et al. (1980) reported that 91 percent of the fish and 95 percent of the crustaceans caught on intake screens were alive when collected. Survival rates for species most frequently impinged ranged from 44 percent to 97 percent with the majority in the range from 76 percent to 97 percent. The two most frequently impinged species, Gulf menhaden and Atlantic croaker, which comprised 87 percent of the fish impinged, had survival rates immediately after impingement of 96 percent and 78 percent, respectively (Table 4.19). Survival rates decreased by 21 percent to 72 percent for fish (sand seatrout, spot, and Atlantic croaker) held 96 hours after impingement. Survival rates for crustaceans (white shrimp, brown shrimp, and blue crab) decreased very little (3% to 7%) and, in fact, increased by one percent for brown shrimp after being held 96 hours after impingement (Table 4.19).

Survival rates decreased from 9 percent to 26 percent for fish after impingement and passage through the fish pump. The most sensitive fish were Atlantic croaker (52 percent survival), southern flounder (70 percent survival), blackcheek tonguefish (60 percent survival), and spotted seatrout (67 percent survival) (Table 4.19).

TABLE 4.19
PERCENT SURVIVAL FOR SHORT TERM, LONG TERM, AND HEAT SHOCK TESTS AT THE CEDAR BAYOU STATION FROM JULY 1978 TO MAY 1979
(Jobe et al.1980)

SPECIES	*IMMEDIATELY AFTER IMPINGEMENT*	*CONTROL IMPINGED ORGANISMS HELD FOR 96 HOURS*	*IMMEDIATELY AFTER IMPINGEMENT AND PASSAGE THRU FISH PUMP SYSTEM*	*IMPINGED AND PASSAGE THROUGH FISH PUMP, HELD FOR 96 HOURS*	*HEAT SHOCK STUDY - HELD FOR 96 HOURS*
bay anchovy (*Anchoa mitchilli*)	82 (252)[1]		70 (420)		
Gulf menhaden (*Brevoortia patronus*)	96 (6,602)		85 (7,053)		
sand seatrout (*Cynoscion arenarius*)	88 (195)	16 (88)	74 (439)	13 (118)	0 (77)
spotted seatrout (*Cynoscion nebulosus*)	84 (19)		67 (15)		
spot (*Leiostomus xanthurus*)	97 (150)	55 (42)	88 (201)	68 (19)	22 (18)
Atlantic croaker (*Micropogonias undulatus*)	78 (1,801)	57 (618)	52 (3,707)	50 (359)	40 (361)
southern flounder (*Paralichthys lethostigma*)	91 (11)		70 (50)		
black drum (*Pogonias cromis*)	100 (1)		50 (4)		
red drum (*Sciaenops ocellatus*)	100 (1)		0 (3)		

[1] Number in parentheses represents the total number of organisms observed or tested.

TABLE 4.19
- CONTINUED -

SPECIES	*IMMEDIATELY AFTER IMPINGEMENT*	*CONTROL IMPINGED ORGANISMS HELD FOR 96 HOURS*	*IMMEDIATELY AFTER IMPINGEMENT AND PASSAGE THRU FISH PUMP SYSTEM*	*IMPINGED AND PASSAGE THROUGH FISH PUMP, HELD FOR 96 HOURS*	*HEAT SHOCK STUDY - HELD FOR 96 HOURS*
least puffer (*Sphoeroides parvus*)	44 (98)		98 (201)		
blackcheek tonguefish (*Symphurus plagiusa*)	76 (55)		60 (477)		
blue crab (*Callinectes sapidus*)	97 (322)	94 (204)	87 (807)	86 (198)	66 (165)
white shrimp (*Penaeus setiferus*	96 (274)	89 (157)	93 (903)	70 (166)	19 (221)
brown shrimp (*Penaeus aztecus*)	95 (1,463)	96 (134)	84 (5344)	84 (171)	27 (178)

[1] Number in parentheses represents the total number of organisms observed or tested.

Crustaceans were much more resistant to the effects of impingement and travel through the fish pump. For blue crab, white shrimp, and brown shrimp, survival percentages immediately after impingement were 97 percent, 96 percent, and 95 percent, respectively. Immediately after impingement and passage through the fish pump, survival rates ranged from to 84 percent to 93 percent (Table 4.19).

Tests were conducted with only six species to determine the long-term effects (i.e., 96 hours) of impingement and passage through the fish pump. Again, fish were more sensitive over the 96-hour period. Only 16 percent of sand seatrout tested survived 96 hours after being impinged. This number decreased to 13 percent after impingement and passage through the fish pump. No sand seatrout survived 96 hours after impingement, passage through the fish pump, and being placed in the heated discharge canal. Atlantic croaker were somewhat hardier with 57 percent survival 96 hours after impingement, 50 percent survival 96 hours after impingement and passage through the fish pump, and 40 percent after the first two treatments and placement in the discharge canal for 96 hours. Spot had a survival rate of 55 percent 96 hours after impingement, 68 percent after impingement and passage through the fish pump, and 22 percent after 96 hours in the discharge canal after the first two treatments (Table 4.19).

The blue crab was the hardiest species with respect to the long-term tests. Survival rates were 94 percent, 96 hours after impingement; 86 percent 96 hours after impingement and passage through the fish pump, and 66 percent in the discharge canal. Both white shrimp and brown shrimp had similar survival rates 96 hours after impingement (i.e., 89 percent and 96 percent, respectively) survival rates after impingement and passage through the fish pump were (70 percent for white shrimp and 84 percent for brown shrimp). However, survival rates drastically decreased (19 percent for white shrimp and 27 percent for brown shrimp) for the two species 96 hours after placement in the discharge canal (Table 4.19).

4.2.5.2 Cedar Bayou Generating Station - Southwest Research Institute (unpublished)

GBNEP requested that JN review the data collected by Southwest Research Institute (SRI) for HL&P during an impingement study conducted at the Cedar Bayou station from April 1973 to December 1980. The data were obtained by Mr Mike Hightower, Sea Grant College Program, TAMU, and provided to JN in an ASCII file. A Lotus (Version 3.1) spreadsheet was developed by JN to manipulate the Cedar Bayou data. No other information regarding the study design or purpose of the study was given to JN except as provided by personal communication with Mr. Hightower. Plant specifications provided by Mr. Bill Baker, HL&P, and Mr. Frank G. Schlicht, Ph.D., former head of the Ecology Division of the HL&P Environmental Protection Department and now retired from HL&P.

According to information provided by Mr. Baker, there were two intake structures (A and B) at the Cedar Bayou station (Table 4.20). Intake A, which consisted of six screens, was associated with two generating units (Unit 1 - 740 MW and Unit 2 - 770 MW) with a pumping capacity of 354,000 gpm each. The calculated approach velocity at maximum low water was 0.920 fps for each unit, and the calculated approach velocity at average low water was 0.830 fps for each unit. Intake B, which also consisted of six screens, was associated with a single, 770 MW generating unit with a pumping capacity of 334,000 gpm. The calculated approach velocity at maximum low water was 0.868 fps, and the calculated approach velocity at average low water was 0.783 fps (Table 4.20).

TABLE 4.20
CEDAR BAYOU STATION SPECIFICATIONS

	UNIT 1	*UNIT 2*	*UNIT 3*
Generating Capacity (MW)	740 750*	770 750*	770 750*
Pump Capacity (GPM)	354,000	354,000	334,000
Calculated Approach Velocity at Average Low Water (Ft./Sec.)	0.920	0.920	0.868
Calculated Approach Velocity at Average Low Water (Ft./Sec.)	0.830	0.830	0.783
Design and Confirmed Approach Velocities at Mean Sea Level (Ft./sec)	1.0*	1.0*	O.5*
Revolving Screen Mesh Size, Square Clear Opening	1/2" (FOR ALL SCREENS) 3/8" (FOR ALL SCREENS)*		

* Specifications represent conditions at time of study according to Dr. Frank G. Schlicht, former head of HL&P Ecology Division, Environmental Protection Division

However, according to information provided by Dr. Schlicht, the capacity ratings for all three units at the time of the study were 750 MW (Table 4.20). In addition, the design and confirmed approach velocities at the time of the study were 1.0 ft/sec at mean sea level (msl) for intake A (i.e., Units 1 and 2) and 0.5 ft/sec at msl for intake B (i.e., Unit 3). According to Mr. Baker, the screen mesh size is currently 1/2 inches. However, according to Dr. Schlicht, the screen mesh size at the time of the study was 3/8 inches.

According to a JN review of hard copies of Cedar Bayou data, it appeared that the sampling schedule varied a great deal during the duration of this study (Table 4.21). From April 1973 to December 1974, only intake A was sampled because intake B was under construction during 1973 and 1974. Beginning January 1975, both intakes A and B were sampled on a regular basis. Quarterly (January, April, July, and October) and bimonthly samples were collected at intake A from April 1973 through November 1977 and at intake B from April 1975 through November 1977. Monthly sampling only was conducted at intake A from December 1977 through December 1980 and at intake B from December 1977 through September 1980.

Quarterly sampling included 12 separate 20-minute collections at each intake structure preceded by a screen wash to remove impinged matter. Bimonthly monitoring included four 20-minute sampling periods preceded by a screen wash. Impinged organisms were identified by taxon (usually species), the length range (mm) for fish only in each sample, and the total weight (g) by species for each sample.

After reviewing the data, JN determined that SRI collected 1,274 samples from intakes A and B during the eight-year study period. Overall, 786 samples were collected from intake A and 488 samples from intake B. During the period when both intakes were sampled simultaneously, 545 samples were collected from intake A and 488 from intake B (Table 4.21).

A total of 5,225,116 organisms were collected during the 8-year study (Table 4.22). A total of 168 taxonomic groups were identified including fish, crustaceans, amphibians, and reptiles. Twelve species of fish or crustaceans each comprised over 1% of the total number of organisms collected, which included Gulf menhaden, Atlantic cutlassfish, striped mullet, Atlantic croaker, white shrimp, grass shrimp (*Palaemonetes spp.*), brown shrimp, blue crab, bay anchovy, gizzard shad (*Dorosoma cepedianum*), Atlantic threadfin (*Polydactylus octonemus*), and sand seatrout (Tables 4.3 and 4.22). These twelve species comprised approximately 93% of the total number of organisms collected (Tables 4.3 and 4.22). For the most frequently impinged species, more individuals were collected at intake A than at intake B (Table 4.22).

TABLE 4.21
NUMBER OF SAMPLES COLLECTED BY MONTH FOR INTAKES A AND B AT THE HL&P CEDAR BAYOU STATION (SRI UNPUBLISHED)

INTAKE A

Year	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1973				17	8	8	20	8	8	17	8	8	102
1974	21	8	8	16	8	8	21	8	8	17	8	8	139
1975	21	0	8	17	7	8	13	8	8	17	8	8	123
1976	21	8	8	17	8	12	17	8	16	9	12	4	140
1977	21	8	16	9	11	5	21	8	8	20	7	4	138
1978	4	4	4	4	4	4	4	4	4	4	4	4	48
1979	4	4	4	4	4	4	4	4	4	4	4	4	48
1980	4	4	4	4	4	4	4	4	4	4	4	4	48
	96	36	52	88	54	53	104	52	60	92	55	44	786

INTAKE B

Year	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1975	3	8	8	17	8	7	17	8	8	17	8	8	117
1976	21	0	0	4	8	12	17	8	16	9	12	4	111
1977	17	4	16	9	11	6	21	8	8	20	9	4	133
1978	4	3	4	4	4	4	4	4	4	4	4	4	47
1979	4	4	4	4	4	4	4	4	4	4	0	4	44
1980	4	4	4	4	4	4	4	4	4				36
	53	23	36	42	39	37	67	36	44	54	33	24	488

TABLE 4.22
TOTAL NUMBER, SIZE RANGES AND PEAK IMPINGEMENT PERIODS FOR SPECIES COMPRISING 1% OR MORE AND COMMERCIALLY/RECREATIONALLY IMPORTANT SPECIES IMPINGED AT THE CEDAR BAYOU STATION FROM APRIL 1973 TO DECEMBER 1980 (SRI UNPUBLISHED)

Species	Number of Organisms Impinged			Peak Period of Impingement	Size Range (mm)
	Intake A	Intake B	Total		
bay anchovy *Anchoa mitchilli*	61,753	13,971	75,724	Mar – May	15 – 90
Gulf menhaden *Brevoortia patronus*	2,492,237	297,342	2,789,579	Nov – Apr	5 – 105
blue crab *Callinectes sapidus*	77,762	60,164	137,926	May – Sep	NA
sand seatrout *Cynoscion arenarius*	42,654	9,949	52,603	May – Jul	20 – 285
spotted seatrout Cynoscion nebulosus	301	124	425	Nov – Apr	30 – 285
gizzard shad *Dorosoma cepedianum*	65,419	169	65,588	Apr – Jul	30 – 310
Atlantic croaker *Micropogonias undulatus*	221,504	123,765	345,269	Feb – Jun	10 – 300
striped mullet *Mugil cephalus*	356,975	292	357,267	Mar – Apr	20 – 390
grass shrimp *Palaemonetes sp.*	231089	4965	236054	Apr – Jul	NA
southern flounder *Paralichthys lethostigma*	89	69	158	May – Jun	20 – 340
brown shrimp *Penaeus aztecus*	144,056	49,188	193,244	May – Jul	NA
white shrimp *Penaeus setiferus*	219,895	60,109	280,004	Sep – Dec	NA
black drum *Pogonias cromis*	174	12	186	Mar – Nov	40 – 280
Atlantic threadfin *Polydactylus octonemus*	55,607	15	55,622	Apr – Aug	45 – 150
red drum *Sciaenops ocellata*	33	39	72	Jan – Mar	40 – 325
Atlantic cutlassfish *Trichiurus lepturus*	365,465	0	365,465	Mar – Jul	40 – 705

A discussion of the number, size range, peak impingement periods (Table 4.22), and the annual estimates of weights (kg) and numbers (Table 4.23) for the most abundant (>1%) and commercially or recreationally important species (i.e., spotted seatrout, black drum, red drum, and southern flounder) follows. The annual estimates of the number and weights of organisms impinged at each intake during the 8-year study were calculated according to the following equations:

Estimated Monthly Impingement =

$$\left(\frac{\textit{No. of organisms collected per month}}{\textit{No. of collections per month}}\right)\left(\frac{1440\ \text{min}/\textit{day}}{20\ \text{min}\ \textit{collection per sample}}\right)\left(\frac{\textit{No of Days}}{\textit{Month}}\right)$$

Estimated Yearly Impingement =

$$\left(\frac{\textit{No. organisms collected per year}}{\textit{No. of collections per year}}\right)\left(\frac{1,440\ \text{min}/\textit{day}}{20\text{mincollectionpersample}}\right)\left(\frac{365\textit{Days}}{\textit{Year}}\right)$$

Annual estimates were calculated only for the 12 species which comprised one percent of more of the total number of organisms impinged and four additional commercially/recreationally important species (Tables 4.5 and 4.23). For these 16 taxa, a total of 1,087,960,254 organisms weighing 3,435,623 kg were projected impinged during the study period (Table 4.23).

Gulf Menhaden

Gulf menhaden was the most frequently impinged species during this study. A total of 2,789,579 menhaden weighing 8,562 kg was collected representing approximately 53% of the total number of organisms impinged. Individuals collected ranged in length between 5 mm and 105 mm (Table 4.22). While menhaden were impinged throughout the year, they were most frequently impinged between November and April (Table 4.22). By far, the vast majority were collected in March.

A total of 602.8 million Gulf menhaden weighing 1.9 million kg was estimated impinged during the 8-year study period (Table 4.23). There appeared to be an overall decreasing trend in the estimated number of menhaden impinged during the study period (Appendix L). The most menhaden (223,859,027) were impinged during 1974, a year when intake B was not being sampled. In 1980, an estimated 12,507,174 menhaden were impinged representing a 99% decrease since the peak in 1974. The estimated total weight of organisms impinged from 1973 to 1980 also showed a decreasing trend with a peak of 804,996 kg in 1974 followed by a decline to a low of 19,285 kg in 1980 (Appendix L).

TABLE 4.23
ANNUAL ESTIMATES OF NUMBER AND WEIGHTS (KG)* OF MOST ABUNDANT AND COMMERCIALLY/RECREATIONALLY IMPORTANT SPECIES IMPINGED AT THE CEDAR BAYOU STATION FROM APRIL 1973 TO DECEMBER 1980 (SRI UNPUBLISHED)

Species	1973 No. and Wt. Impinged	1974 No. and Wt. Impinged	1975 No. and Wt. Impinged	1976 No. and Wt. Impinged	1977 No. and Wt. Impinged	1978 No. and Wt. Impinged	1979 No. and Wt. Impinged	1980 No. and Wt. Impinged	Total No. and Wt. by Species
Atlantic croaker	13,924,102	2,247,347	9,083,621	15,020,502	17,103,613	5,782,752	18,236,610	12,593,538	93,992,085
(Micropogonias undulatus)	(38,355)	(10,251)	(27,436)	(59,732)	(30,903)	(13,751)	(26,228)	(18,397)	(225,053)
Atlantic cutlassfish	16,798,094	49,083,587	43,001	139,097	132,675	78,462	2,160	47,934	66,325,010
(Trichiurus lepturus)	(425)	(33,188)	(804)	(3,534)	(1,163)	(1,594)	(21)	(993.4)	41,722
Atlantic threadfin	9,106,183	1,491,730	6,930	310,509	27,423	0	0	0	10,942,775
(Polydactylus octonemus)	(2,387)	(235)	(27)	(3,012)	(206)	(0)	(0)	(0)	(5,867)
bay anchovy	588,469	5,160,747	2,660,607	1,519,776	879,583	928,782	2,560,536	1,696,428	15,994,928
(Anchoa mitchilli)	(324)	(1,602)	(1,118)	(874)	(642)	(1,072)	(1,749)	(949)	(8,330)
black drum	0	9,729	4,043	13,299	693	9,936	5,364	1,098	44,162
(Pogonias cromis)	(0)	(313)	(258)	(976)	(80)	(318)	(401)	(118)	(2,464)
blue crab	3,788,593	3,648,664	6,893,940	4,480,992	4,318,287	3,580,320	6,464,088	3,622,732	36,797,616
(Callinectes sapidus)	(75,813)	(68,898)	(130,105)	(141,839)	(100,879)	(74,478)	(95,783)	(53,319)	(741,114)
brown shrimp	1,700,534	7,335,343	6,032,915	7,232,084	7,396,419	20,208,528	1,817,314	8,539,414	60,262,551
(Penaeus aztecus)	(4,633)	(18,995)	(16,077)	(27,111)	(28,282)	(41,379)	(4,329)	(19,967)	(160,773)
gizzard shad	6,085,343	4,616,962	45,904	50,433	20,897	15,666	162,702	17,748	11,015,655
(Dorosoma cepedianum)	(2,293)	(1,307)	(2,415)	(2,016)	(1,300)	(1,514)	(4,719)	(632)	(16,196)
grass shrimp	26,484,191	15,583,824	353	0	0	0	0	0	42,068,368
(Palaemonetes spp.)	(751)	(208)	(2)	(0)	(0)	(0)	(0)	(0)	(961)

*Numbers without parentheses represent the total number of organisms impinged by while the numbers in parentheses correspond to the total weight (Kg) of organisms impinged by species.

TABLE 4.23

ANNUAL ESTIMATES OF NUMBER AND WEIGHTS (KG)* OF MOST ABUNDANT AND COMMERCIALLY/RECREATIONALLY IMPORTANT SPECIES IMPINGED AT THE CEDAR BAYOU STATION FROM APRIL 1973 TO DECEMBER 1980 (SRI UNPUBLISHED) (cont.)

Species	1973 No. and Wt. Impinged	1974 No. and Wt. Impinged	1975 No. and Wt. Impinged	1976 No. and Wt. Impinged	1977 No. and Wt. Impinged	1978 No. and Wt. Impinged	1979 No. and Wt. Impinged	1980 No. and Wt. Impinged	Total No. Impinged By Species
Gulf menhaden	131,978,504	223,859,027	73,713,219	73,547,731	48,669,656	14,677,776	23,825,214	12,507,174	602,778,301
(Brevoortia patronus)	(281,686)	(804,996)	(154,234)	(309,170)	(161,071)	(69,188)	(95,928)	(19,285)	(1,895,558)
red drum	0	0	1,619	348	558	4,422	27,270	558	34,775
(Sciaenops ocellatus)	(0)	(0)	(63)	(69)	(1)	(16)	(105)	(6)	(260)
spotted seatrout	4,445	8,952	5,482	6,257	8,411	47,724	83,502	10,332	175,105
(Cynoscion nebulosus)	(106)	(331)	(154)	(96)	(135)	(905)	(1,522)	(172)	(3,421)
striped mullet	25,561,162	40,321,395	23,056	78,299	24,747	48,162	339,984	22,356	66,419,161
(Mugil cephalus)	(991)	(12,571)	(1,293)	(5,375)	(2,745)	(3,571)	(19,202)	(1,306)	(47,054)
white shrimp	3,395,666	4,794,667	18,709,141	12,983,240	6,378,972	8,626,734	4,372,506	6,651,918	65,912,844
(Penaeus setiferus)	(10,408)	(19,498)	(52,014)	(43,015)	(26,627)	(29,036)	(14,177)	(16,070)	(210,845)
Total No. and Wt.	241,225,208	360,227,729	119,633,556	116,308,629	86,143,392	54,665,326	62,409,164	47,347,250	1,087,960,254
by Year	(426,745)	(983,622)	398,108	604,585	(359,761)	(243,025)	(283,495)	(136,282.4)	(3,435,623)

*Numbers without parentheses represent the total number of organisms impinged by while the numbers in parentheses correspond to the total weight (Kg) of organisms impinged by species.

Atlantic Cutlassfish

The Atlantic cutlassfish was the second most frequently impinged species. A total of 365,465 Atlantic cutlassfish weighing 189 kg was collected representing 7% of the total number of organisms collected. Individuals collected ranged in length between 40 mm and 705 mm. Peak impingement months were from February through October with the majority collected between March and July. Most Atlantic cutlassfish were impinged in April. Only a very small number of this species were collected from November through January (Table 4.22).

An estimated total of 66.3 million Atlantic cutlassfish weighing 41,722 kg was estimated impinged during the 8-year study period (Table 4.23). There appeared to be an overall decreasing trend in the estimated number of Atlantic cutlassfish impinged during the study period (Appendix L). The number then increased from almost 17 million in 1973 to over 49 million in 1974. The estimated number impinged decreased sharply after 1974 with a range of 2,160 in 1979 to slightly more than 139,000 in 1976. The total estimated weight impinged also showed a peak in 1974 (33,188 kg) followed by a declining trend to a minimum of 21 kg in 1979 (Table 4.23 and Appendix L).

Striped Mullet

A total of 357,267 striped mullet weighing 201 kg was collected during the study representing 6.8% of all impinged organisms. Individual sizes ranged from 20 mm to 390 mm. Striped mullet were impinged throughout the year but most frequently during March and April (Table 4.22). The fewest were impinged during February.

An estimated total of 66.4 million striped mullet weighing 47,054 kg was estimated impinged during the study period (Table 4.23). The maximum number of mullet estimated impinged occurred in 1974 (40,321,395) followed by a decreasing trend to a low of 22,000 in 1980 (Table 4.23 and Appendix L). No clear trend was reflected in the data for the estimated annual impinged weight (Appendix L). The total annual weight of striped mullet estimated impinged during the study period was highest in 1974 (12,571 kg) and 1979 (19,202 kg) (Table 4.23). During 1973 and 1975 through 1978, no more than 5,375 kg of striped mullet were estimated impinged (Table 4.23).

Atlantic Croaker

A total of 345,269 Atlantic croaker weighing 937 kg was impinged during the study representing 6.6% of all impinged organisms. Individuals collected ranged from 10 mm to 300 mm in length. The peak months of impingement for Atlantic croaker were February through June with a maximum occurring in March (Table 4.22).

A total of 93,992,085 croakers weighing 225,053 kg was estimated impinged during the study period (Table 4.23). No obvious trend was detected in the number of croakers impinged between 1973 and 1980 (Appendix L). The fewest number were estimated impinged in 1974 and 1978 when the totals were 2,247,347 and 5,782,752, respectively. The greatest number estimated impinged (18,236,610) occurred in 1979 (Appendix L, Table 4.23). The total weight of Atlantic croaker estimated impinged during the eight-year study period followed a similar trend to that of the number impinged. The highest total weight was impinged in 1976 (59,732 kg) followed by a decrease to 18,397 kg in 1980.

White Shrimp

White shrimp comprised 5.4% of the total number of impinged organisms with 280,004 counted weighing a total of 898 kg. Length data were not recorded for this species. The highest rate of impingement occurred during September through December. The peak impingement period was October (Table 4.22).

A estimated total of 65,912,844 white shrimp weighing a total of 210,845 kg was impinged during the study period. There was an increasing trend in estimated numbers impinged from an overall low of 3,395,666 in 1973 to an overall high of 18,709,141 in 1975 (Appendix L and Table 4.23). The peak in 1975 was followed by a steady decline through the study period to a low of 4,372,506 in 1979. The estimated total weight of white shrimp impinged followed a similar pattern to that of total numbers, gradually increasing from 1973 to 1975 followed by a steady decline to the end of the study period. The largest annual weight impinged weight was 52,014 kg in 1975 with a low of 10,408 kg in 1973 (Table 4.23).

Grass Shrimp

A total of 236,054 grass shrimp weighing 10 kg comprised approximately 4.4% of all impinged organisms. Ninety five percent (95%) of these were not identified beyond the genus *Palaemonetes*. *P. intermedius, P. pugio,* and *P. vulgaris* comprised the remainder. Only those identified as *Palaemonetes spp.* in the data are discussed. The peak impingement period occurred during April through July, with a peak in June. Length ranges were not recorded for this genus (Table 4.22).

An estimated total of 42,068,368 grass shrimp weighing 961 kg was estimated impinged during the eight-year study (Table 4.23). A decreasing trend was observed in the annual number impinged from a maximum of 26,484,191 in 1973 to 15,583,824 in 1974 (Table 4.23 and Appendix L). After 1973, less than 353 were collected during any year from 1975 through 1980. The annual total weight of grass shrimp estimated impinged during the study period followed a similar trend to that of the number impinged (Appendix L).

Brown Shrimp

A total of 193,244 brown shrimp weighing 572 kg was collected during the study period comprising 3.7% of all taxonomic groups. The peak months of impingement for brown shrimp were May through July with a maximum in May. No length information was recorded during the study for this species (Table 4.22).

A total of 60,262,551 brown shrimp weighing 160,773 kg was estimated impinged during the eight-year study (Table 4.23). During this period, an increasing trend was observed from 1973 when 1,700,534 were impinged to 1978 when 20,208,528 were impinged (Table 4.23 and Appendix L). The 1978 peak was followed by a 91% decrease to 1,817,314 in 1979 with an increase in 1980 to 8,539,414. The trend in total weight of impinged brown shrimp was similar to the estimated number impinged except the increase from 1973 (4,633 kg) to 1978 (41,379 kg) was more gradual (Appendix L and Table 4.23). The peak in 1978 was followed by a decline to 4,329 kg in 1979 and a rise to 19,967 kg in 1980.

Blue Crab

A total of 137,926 blue crabs weighing 2,965 kg was collected representing 2.6% of all organisms impinged. Blue crabs were impinged throughout the year, but predominantly from May through September. The peak month for impingement was July. No length data were recorded for this species (Table 4.22).

A total of 36,797,616 blue crabs weighing 741,114 kg was estimated impinged during the eight-year study period. No definite trend was observed in the number estimated impinged. However, there was an increase from 1973 (3,788,593) to an overall maximum in 1975 (6,893,940). The estimated number then declined from 1975 to 1978 (3,580,320), increased to 6,464,088 in 1979, and then decreased to 3,622,732 in 1980 (Table 4.23 and Appendix L). The trend in total estimated annual weight impinged followed a similar pattern as the number estimated impinged, except that weight continued to rise for one year to 1976 after the number decreased in 1975 (Appendix L). The estimated weights impinged ranged from a low of 53,319 kg in 1980 to a maximum of 141,839 kg in 1976.

Bay Anchovy

A total of 75,724 bay anchovies weighing 33 kg was collected during the study period representing 1.5% of all organisms impinged. Lengths ranged from 15 mm to 90 mm. Bay anchovies were impinged throughout the year. However, most were impinged from March through May with a peak in April (Table 4.22).

A total of 15,994,928 bay anchovies weighing 8,330 kg was estimated impinged during the study period. No distinct trend for annual numbers impinged was observed (Appendix L). However, the estimated number impinged increased from 588,469 in 1973 to a peak of 5,160,747 in 1974. This was followed by a decrease to an overall low of 879,583 in 1977. The number impinged then increased to 2,560,536 in 1979 followed by a slight decrease to 1,696,428 in 1980 (Table 4.23 and Appendix L). The estimated total weight of bay anchovies annually impinged followed a similar pattern as the number estimated impinged. Highs of 1,602 kg and 1,749 kg were estimated for 1974 and 1979, respectively. These highs were preceded by lows of 324 kg in 1973 and 642 kg in 1977 (Table 4.23 and Appendix L).

Gizzard Shad

A total of 65,588 gizzard shad with a combined weight of 60 kg was collected representing 1.3% of the total number of organisms impinged. Individual lengths ranged from 30 mm to 310 mm. No seasonal pattern for numbers of gizzard shad impinged was reflected in the data as wide fluctuations were found throughout the study period. The overall peak month of impingement for this species was July with a minimum in February (Table 4.22).

An estimated total of 11,015,655 gizzard shad weighing 16,196 kg was estimated impinged during the eight-year study. There was a declining trend in the number impinged annually, with the maximum occurring in 1973 (6,085,343) decreasing to 45,904 in 1975. Between 1976 through 1980, the estimated numbers impinged ranged from 15,666 in 1978 to 162,702 in 1979 (Table 4.23 and Appendix L). The estimated annual weight of gizzard shad impinged fluctuated from 2,293 kg in 1973 to 1,514 kg in 1978. After 1978, there was a rapid increase in 1979 to an overall maximum of 4,719 kg, followed by a rapid decrease in 1980 to an overall minimum of 632 kg (Table 4.23 and Appendix L).

Atlantic Threadfin

A total of 55,622 Atlantic threadfin weighing 27 kg was collected during the study. These represented 1.1% of all taxonomic groups. Lengths ranged from 45 mm to 150 mm. Most Atlantic threadfin were impinged between April through August, with the peak occurring in May (Table 4.22).

An estimated total of 10,942,775 Atlantic threadfin weighing 5,867 kg was estimated impinged. There appeared to be an overall decreasing trend in the total number of Atlantic threadfin estimated impinged during the study period with a maximum of 9,106,183 estimated impinged in 1973, followed by 1,491,730 in 1974 and 6,930 in 1975. After 1975, there was a small increase to 310,509 in 1976 followed by a decrease to 27,423 in 1977. The total estimated weight of Atlantic threadfin estimated impinged followed a similar pattern from 1973 to 1975 as the estimated number impinged (Appendix L). A peak of 2,387 kg in 1973 was followed by a low of 27 kg in 1975. The low in 1975 was followed by an overall maximum of 3,012 kg in 1976 which corresponded to a much smaller rise in the number impinged that same year. This was followed by a rapid decrease to 206 kg in 1977. No Atlantic threadfin were collected after 1977 (Table 4.23 and Appendix L).

Sand Seatrout

A total of 52,603 sand seatrout weighing 269 kg representing approximately 1% of the total number of organisms impinged was collected during the study. Lengths ranged from 20 mm to 285 mm. Most sand seatrout were impinged from May through July with a peak in July (Table 4.22).

A total of 15,137,142 sand seatrout weighing a total of 73,270 kg was estimated impinged during the study. The number generally decreased from 1,808,983 in 1973 to an overall minimum of 633,292 in 1978. This trend was followed by an overall maximum of 4,500,738 in 1979. A decline to 1,633,788 in 1980 followed the peak year of 1979. The total annual weight estimated impinged during the study period followed a pattern similar to that of the numbers estimated impinged for this species. A peak of 18,756 kg was estimated impinged for 1979, and a minimum of 4,820 kg for 1980 (Table 4.23 and Appendix L).

Spotted Seatrout

A total of 425 spotted seatrout weighing nine (9) kg was collected representing approximately 0.008% of all taxonomic groups collected during the study. Lengths ranged from 30 mm to 285 mm. The most spotted seatrout were impinged from November through April with a peak recorded in January (Table 4.22).

A estimated total of 175,105 spotted seatrout weighing 3,421 kg was impinged during the eight-year study period. The estimated number impinged varied slightly from 1973 (4,445) through 1977 (8,411). This period was followed by a rapid increase in 1978 (47,724) and 1979 (83,502). After 1979, the number decreased drastically to 10,332 in 1980. The total weight of seatrout estimated impinged annually followed a similar trend to that reflected in the number impinged. A peak of 1,522 kg occurred in 1979, while annual totals ranged between 96 kg (1976) to 331 kg (1974) prior to 1977. The maximum weight estimated impinged, 1,522 kg in 1979, coincided with the maximum number impinged in 1979 (Appendix L and Table 4.23).

Black Drum

A total of 186 black drum weighing 11 kg was collected representing approximately 0.003% of all impinged organisms. Individuals collected ranged from 40 mm to 280 mm in length. Though black drum were impinged throughout the year, the largest number were impinged from March through November with a peak in September (Table 4.22).

An estimated total of 44,162 black drum weighing 2,464 kg was impinged during the study period. Generally, annual numbers of impinged black drum tended to alternate from relatively high values to relatively low values from year to year. The peak years were 1974 (9,729), 1976 (13,299), and 1979 (5,364). The lowest numbers were recorded in the years 1973, 1977 and 1980 ranging from 0 to 1,098 fish. A similar pattern was observed for estimated weights impinged. The maximum estimated weight occurred in 1976 (976 kg) with the minimum estimated in 1973 (0 kg) (Appendix L and Table 4.23).

Southern Flounder

A total of 158 southern flounder weighing 7 kg was collected from intake screens. This number represented 0.003% of all impinged organisms. The highest impingement rates were recorded during May and June with the maximum occurring in June. Individual lengths ranged from 20 mm to 340 mm (Table 4.22).

An estimated total of 59,776 southern flounder weighing 2,735 kg was estimated impinged during the study period. The annual trend in the numbers of this species impinged generally increased during the study period. From a low of 939 in 1973, numbers increased to a peak value of 22,770 in 1978 before declining to 2,232 in 1980. The total annual weight of impinged flounder generally increased throughout the study period. An increasing trend was observed from 1973 (72 kg) to a maximum of 958 kg in 1978. After 1978, weights decreased dramatically to 248 kg in 1980 (Table 4.23 and Appendix L).

Red Drum

A total of 72 red drum weighing 1.0 kg was collected during the study which represented less than 0.001% of all impinged organisms. The largest number were impinged from January through March with a peak in February. Individual lengths ranged from 40 mm to 325 mm (Table 4.22).

A estimated total of 34,775 red drum weighing 260 kg was impinged during the eight-year study period. The estimated number of red drum impinged was fairly steady from 1973 to 1977 when the number impinged ranged from 0 to 1,619, respectively. After 1977, there was a dramatic increase to an overall maximum of 27,270 in 1979. Following the peak year of 1979, the number of impinged red drum decreased to 558 in 1980. The estimated annual weight of red drum impinged did not follow as definable a pattern. Peak years occurred in 1975 (63 kg), 1976 (69 kg), and 1979 (105 kg), while the lowest weights were recorded during 1973 to 1974 (0 kg), 1977 (1 kg) and 1980 (6 kg) (Table 4.23 and Appendix L).

4.2.6 <u>Texas Water Commission Studies</u>

4.2.6.1 Houston Ship Channel (Seiler et al. 1991)

Seiler et al. (1991) sampled two segments of the Houston Ship Channel (Segment 1007 - Greens Bayou to the turning basin and Segment 1006 - the San Jacinto River to Greens Bayou) from March 1988 through July 1989 for fish, macroinvertebrates, and water quality. Collections were made using seines, gill nets, and revolving screens at the HL&P Deepwater station and the Occidental Chemical Deer Park Plant.

A total of 19,707 organisms from 65 taxa was collected from the revolving screens. The results indicated that at the Deepwater location, revolving screen catches were mostly dominated by blue crab (August 1988 - November 1988 and May 1989 - July 1989), bay anchovy (November 1988 - April 1989), and Atlantic croaker (December 1988 -April 1988). The authors also found that mean catch per unit effort (CPUE), mean number of taxa and cumulative number of taxa were highest at this location from November 1988 through March 1989 when temperatures were lowest and bottom dissolved oxygen concentrations were at their highest. Conversely, these numbers were lowest during the summer of 1989 when dissolved oxygen and salinity were at their lowest.

The dominant species collected from the Oxychem location were bay anchovy (August 1988 - April 1989), Gulf menhaden (December 1988 - March 1989), Atlantic croaker (February 1989 - April 1989), blue crab (December 1988 - July 1989), and Sergestid shrimp (*Acetes americanus*) (September 1988 - January 1989). At Oxychem, mean catch per unit effort (CPUE) and mean number of taxa were highest in the summer and early fall when mean bottom temperatures and mean dissolved oxygen concentrations were at their highest and lowest, respectively. Cumulative number of taxa were highest in this segment during the winter months.

4.2.6.2 Houston Ship Channel Monitoring Program 1973-1978

The Houston Ship Channel Monitoring program (Texas Department of Water Resources 1980) was begun in January 1972 because of concern for the quality of water entering Galveston Bay. Five monitoring stations were established for collection of a variety of water quality parameters on a monthly basis. Biological monitoring consisted of monthly plankton, zooplankton, benthics, and nekton. Nekton samples were collected from intake screens at Armco Steel (channel mile 17.2), HL&P - Deepwater Station (channel mile 19.7), and Diamond Shamrock - Deer Park (channel mile 11.5).

Twenty six (26) collections were made at the Armco facility between 1976 to 1978. Of the 18 species collected, the species most frequently caught on intake screens at this location were blue crab (264), Atlantic croaker (162), star drum (*Stellifer lanceolatus*) (66), Gulf killifish (*Fundulus grandis*) (17), sheepshead minnow (*Cyprinodon variegatus*) (49), sailfin molly (*Poecilia latipinna*) (23), and white shrimp (29).

Between 1972 to 1978, the most frequently caught of 38 species collected at the HL&P-Deepwater in 67 collections at the intake screens were bay anchovy (49), blue crab (330), Atlantic croaker (320), star drum (155), Gulf menhaden (194), sheepshead minnow (87), sand seatrout (299), and white shrimp (162).

Seventy four (74) collections were made at the Diamond Shamrock intake screens from 1972 to 1978. Of the 60 species represented, the most frequently caught species at the Diamond Shamrock-Deer Park Plant were bay anchovy (11,159), blue crab (16,077), Atlantic croaker (216,438), star drum (3,985), southern hake (*Urophycis floridanus*) (3,245), Gulf menhaden (13,710), sand seatrout (3,628), brown shrimp (17,559), white shrimp (63,354), and spot (6,500).

4.3 Fish Kill Records

Fish mortality information collected from the various State and local agencies totaled 321 separate fish kill reports occurring in estuarine and tidal portions of the Galveston Bay system between 1970 and 1990. Data were obtained from the TWC and its predecessor agency, the TDWR, TPWD, and the Harris County Pollution Control Department (HCPCD). TWC data for the study area included 143 records spanning an 18-year period from May 1970 through August 1988. Data obtained from the TPWD included a 13-year period of record extending from October 1978 to June 1991, which involved a total of 76 incidents. No fish kill events were recorded in the Galveston Bay area by the TWC between September 1983 and February 1986, and only ten incidents were reported by the TPWD during the same period. The TWC and TPWD currently share in the responsibilities for gathering and reporting information concerning fish mortality in waters of the State. The HCPCD Department provided information spanning a 13-year period from June 1978 to September 1990. Only three of the HCPCD reports were applicable to this study. Many of the early records collected by HCPCD were lost in a 1981 fire.

The fish kill reports used in this study were limited to those which contained data concerning numbers of fish killed. As stated earlier, 101 of the 321 available reports were determined to be uninfluenced by human activity, outside the study area, and did not include numbers killed data. Of the remaining 220, 56 were attributed to point source pollution, 43 to nonpoint sources and 121 were due to unknown sources. In the available 220 records pertaining to the Galveston Bay system, a total of 175,195,598 fish was reported killed: point sources caused 1.4 percent of the total, nonpoint sources caused 9.3 percent, and 89.3 percent were killed by unknown sources. These data are summarized in Table 4.24.

4.3.1 Sources of Fish Mortality

As described earlier, sources of fish kills were grouped under a three-tiered system. These are primary sources (point sources, nonpoint sources, and unknown sources), secondary sources (subcategories within primary sources that describe the types of industry or activity which caused the fish kill), and tertiary sources (mechanisms by which the pollutant was allowed to enter the environment). Of the three-primary sources, 56 point source incidents, 43 non-point source, and 121 unknown source incidents were identified from the available data. Fish kills included in the unknown sources category were those that agency records indicated were probably attributable to human activities but the exact cause was unknown.

Point source pollution sources identified during the development of this study include in permitted domestic and industrial discharges, spills due to mishandling accidents or equipment failure, and illegal waste disposal activities. Point source pollution results in fish kills primarily through toxic poisoning, physical impacts (such as sudden detonation of explosives), and dissolved oxygen reduction due to algal respiration increased by nutrient input. Other causes of point source fish kills were activities associated with electric power generation facilities. In addition, the illegal dumping and accidental spilling of oil and other wastes may have a significant effect on a waterbody whose aquatic population has not developed a resistance to specific pollutants through chronic exposure to these substances.

Due to its close proximity to major metropolitan areas, Galveston Bay is subject to a wide variety of human activities which are potentially damaging to fish populations. Large quantities of toxic and hazardous wastes are generated by sprawling industrial districts located along the coast. Tidal portions of the Galveston Bay system receive treated wastewater generated by several million people located within a 30-mile radius of the bay. In 1990, there were 441 municipal and 463 industrial wastewater outfalls with a combined permitted discharge rate of 1520.2 million gallons per day (MGD) discharging to 27 of the 42 segments within the Galveston Bay study area for which fish kills were reported. Permitted dischargers are listed according to waterbody segment in Table 4.25.

Nonpoint source pollution (NPS) generated by stormwater runoff from agricultural, urban, and industrial lands contribute large quantities of pollutants to aquatic environments. Nonpoint source pollutants are those which enter surface waters in a diffuse form and at intermittent intervals as dictated by rainfall events. These impact fish populations primarily by inducing low dissolved oxygen levels through increased algal respiration due to nutrient input. Nonpoint sources of pollution potentially affecting fish populations are more difficult to control than point sources due to their regional nature and because many different sources may contribute to the total loading.

TABLE 4.24
TOTAL MORTALITY BY SPECIES

Species	Common Name	Point Sources	Nonpoint Sources	Unknown Sources	Total Killed	Percent of Total
Micropogonias undulatus	Atlantic Croaker	9673	132	206	10011	0.006
Strongylura marina	Atlantic Needlefish	0	0	2	2	<0.001
Anchoa mitchilli	Bay Anchovy	73337	28	0	73365	0.042
Pogonias cromis	Black drum	12872	0	0	12872	0.007
Makaira nigricans	Blue Marlin	0	2	0	2	<0.001
Brevoortia gunteri	Finescale menhaden	0	0	50000	50000	0.029
Unclassified Gamefish	Game Fish	13666	83370	2165466	2262502	1.291
Lepisosteidae (family)	Gar	0	1	0	1	<0.001
Dorosoma cepedianum	Gizzard Shad	9478	0	82	9560	0.005
Paralicthys albigutta	Gulf Flounder	0	200	0	200	<0.001
Brevoortia patronus	Gulf Menhaden	587870	4670774	3627511	8886155	5.072
Opsanus beta	Gulf Toadfish	40	0	0	40	<0.001
Arius felis	Hardhead Catfish	268	260	102	630	<0.001
Clupeidae (family)	Herring	0	0	1500000	1500000	0.856
Menidia beryllina	Inland Silverside	0	180	0	180	<0.001
Cyprinodontidae (family)	Killifish	300	0	0	300	<0.001
Menticirrhus sp.	Kingfish	0	0	50	50	<0.001
Bothidae (family)	Lefteye Flounders	0	0	14	14	<0.001
Gambusia affinis	Mosquitofish	42	0	0	42	<0.001
Lagodon rhomboides	Pinfish	82953	0	0	82953	0.047
Sciaenops ocellatus	Red Drum	156	310	58	524	<0.001
Lutjanus campechanus	Red Snapper	2	0	0	2	<0.001
Unclassified Rough Fish	Rough Fish	1419257	11563763	148386673	161369693	92.108
Poecilia latipinna	Sailfin Molly	1	0	0	1	<0.001
Cynoscion arenarius	Sand Seatrout	96	0	100	196	<0.001
Dorosoma sp.	Shad	0	0	3000	3000	0.002
Archosargus probatocephalus	Sheepshead	898	0	70	968	0.001
Cyprinodon variegatus	Sheepshead Minnow	2000	750	0	2750	0.002
Bairdiella chrysoura	Silver Perch	94	0	200	294	<0.001
Paralichthys lethostigma	Southern Flounder	22	75	459	556	<0.001
Myrophis punctatus	Speckled Worm Eel	0	0	500	500	<0.001
Leiostomus xanthurus	Spot	55226	90	200	55516	0.032
Lepisosteus oculatus	Spotted Gar	1	0	0	1	<0.001
Cynoscion nebulosus	Spotted Seatrout	174	14	101	289	<0.001
Morone saxatilis	Striped Bass	0	2000	0	2000	0.001
Mugil cephalus	Striped Mullet	32926	277	4739	37942	0.022
Dorosoma petenense	Threadfin Shad	0	0	32	32	<0.001
Unidentified Fish	Unidentified Fish	75951	0	756504	832455	0.475
	Total	2377303	16322226	156496069	175195598	99.998

TABLE 4.25
PERMITTED OUTFALLS WITHIN THE STUDY AREA *

Classified Segment	Number of Permitted Outfalls		Permitted Flows	
	Domestic Facilities	Industrial Facilities	Domestic Facilities (mgd)	Industrial Facilities (mgd)
0702	4	23	9.3	78.85
0801	10	3	5.82	0
0901	11	23	3.94	11.04
1001	15	11	7.54	8.34
1005	1	21	0.01	37.21
1006	214	106	175.43	186.13
1007	62	124	547.92	82.79
1013	58	12	72.82	0.08
1101	9	0	18.23	0
1103	3	4	3.75	0.08
1107	4	6	0.16	13.81
1109	1	1	0.02	0
1113	5	5	13.14	0
2421	5	3	11.84	0.2
2422	6	0	0.9	0
2423	0	0	0	0
2424	9	3	9.92	0.02
2425	3	11	0.89	0.05
2426	3	5	6.92	0.14
2427	0	29	0	19.84
2428	0	0	0	0
2429	0	3	0	0.5
2431	1	6	8.3	0.38
2432	5	1	5.24	0
2437	0	41	0	20.97
2438	0	5	0	15.81
2439	12	17	15.08	126.81
	441	463	917.17	603.05

* From: The State of Texas Water Quality Inventory, 10th Edition, 1990, LP-90-06, Texas Water Commission.

Eighteen secondary sources were identified from the 220 fish kill reports including 14 point source and four nonpoint source categories. Secondary sources grouped under the point source category include undefined industries, construction activities, chemical manufacturing and storage, food processing, pipelines, trucking and barge operations, illegal waste disposal activities, sewage treatment plants, power generation facilities, commercial fishing, seismic testing, and ocean dumping. Secondary sources within the NPS category include runoff from undefined sources, urban and agricultural runoff, and runoff from industrial landfills. As would be expected, a larger number of categories were defined for point sources than non-point sources since more detailed information can be gathered for a localized event associated with a specific activity. Information pertaining to nonpoint sources is more difficult to obtain due to the regionality of its origin.

Twenty five tertiary sources were identified from the available fish kill reports which describe the mechanisms by which pollutants were released into the environment resulting in fish mortalities. Eighteen of these are subcategories of point sources and six are associated with nonpoint source pollution. A separate tertiary code (16) was used to define unknown mechanisms. Secondary and tertiary source codes are defined in Tables 3.3 and 3.4.

4.3.2 Point Sources

Point source (PS) pollution was identified as the cause of 2,377,303 reported fish deaths. This represents only 1.4 percent of the total number of fish killed from all sources (including unknown sources) identified in this study but comprised 25 percent of the incidents reported (Figure 3). Power generation facilities accounted for 34 percent of the total number killed by point sources, ocean dumping killed 21 percent, sewage treatment facilities killed 17 percent, chemical spills from chemical manufacturers accounted for 12 percent, seismic testing killed 10 percent, detonations of explosives (other than seismic testing) killed three percent, and the remainder (less than 1%) were killed by of construction activities, food industry wastewater discharges, oil pipeline spills, trucking accidents, illegal waste disposal, barge operation spills, cull from commercial fishing operations, and miscellaneous industries.

Of the number of PS incidents which resulted in fish kills, 28 percent originated from power generation facilities, 16 percent from miscellaneous industries, 16 percent from sewage treatment facilities, 12 percent from chemical manufacturing or storage facilities, 7 percent from barge operations, five percent from commercial fishing, four percent from oil pipeline leaks, and less than two percent each from construction activities, food processing, trucking, illegal waste disposal, seismic testing, detonation of explosives, and ocean disposal operations. Species mortality caused by point sources are presented in Table 4.26.

Power Generating Plants (V)

Four primary mechanisms were identified for point source mortality caused by electrical power generation facilities. These are mishandling spills (source code V21), discharges of heated cooling water (V24), impingement on intake screens (V61), and spills from undefined activities (V16). A reported 820,929 fish were killed by pollution associated with power plants. Approximately two percent of the fish reported killed by these sources combined were commercial or sport fish varieties and the remainder were rough fish. By contrast, 77 percent of the fish killed from thermal discharges alone were commercial or sport fish.

TABLE 26
SPECIES MORTALITY BY POINT SOURCES

Secondary Source	Tertiary Source	Common Name	No. Killed	Percent of Total Killed by PS	No. Incidents Species Occurred
Undefined Activity	Explosives	Unidentified Fish	75235	3.165	1
Other Industries	Unknown Activity	Rough Fish	18982	0.798	5
		Game Fish	2018	0.085	3
		Unidentified Fish	1	<0.001	1
			21001	0.883	
Other Industries	Mishandling Spill	Hardhead Catfish	50	0.002	1
Other Industries	Unsecured Pipe	Sheepshead Minnow	2000	0.084	1
Other Industries	Leakage from Pits	Gulf Menhaden	1000	0.042	1
		Striped Mullet	50	0.002	1
			1050	0.044	
Construction	Explosives	Striped Mullet	18	0.001	1
		Gulf Menhaden	8	<0.001	1
			26	0.001	
Chemical Mfg. and Storing	Pipe Leak	Gulf Menhaden	200000	8.413	1
		Striped Mullet	800	0.034	2
		Killifish (family)	300	0.013	1
			201100	8.459	
Chemical Mfg. and Storing	Unknown Activity	Rough Fish	88415	3.719	3
		Game Fish	85	0.004	2
			88500	3.723	
Chemical Mfg. and Storing	Mishandling Spill	Unidentified Fish	6	<0.001	1
Chemical Mfg. and Storing		Rough Fish	4950	0.208	1
		Game Fish	50	0.002	1
			5000	0.21	1
Food Industry	Fish Processing	Gulf Menhaden	2677	0.113	1
Oil Pipelines	Pipeline Leak	Rough Fish	140	0.006	1
		Game Fish	60	0.003	1
		Mosquitofish	42	0.002	1
		Gizzard Shad	11	<0.001	1
		Spotted Gar	1	<0.001	1
			254	0.011	
Trucking Industry	Truck Collision	Gulf Menhaden	12	0.001	1

TABLE 26
SPECIES MORTALITY BY POINT SOURCES
(cont.)

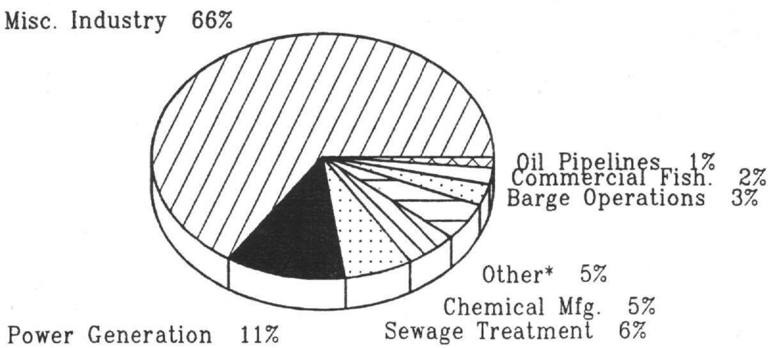
Secondary Source	Tertiary Source	Common Name	No. Killed	Percent of Total Killed by PS	No. Incidents Species Occurred
Illegal Waste Disposal	Unknown Activity	Game Fish	123	0.005	1
		Rough Fish	50	0.002	1
			173	0.007	
Barge Operations	Unknown Activity	Rough Fish	1600	0.067	1
Barge Operations	Mishandling Spill	Unidentified Fish	100	0.004	1
Barge Operations	LIquid Transfer Spill	Unidentified Fish	115	0.005	2
Sewage Treatment	Lift Station Bypass	Striped Mullet	18796	0.791	1
		Gulf Menhaden	211	0.009	1
			19007	0.8	
Sewage Treatment	Sewer Line Leak	Unidentified Fish	1	<0.001	1
Sewage Treatment	STP Plant Bypass	Gulf Menhaden	379200	15.951	3
		Sailfin Molly	1	<0.001	1
			379201	15.951	
Sewage Treatment	Storage Tank Leak	Unidentified Fish	106	0.004	1
		Gulf Menhaden	100	0.004	1
			206	0.009	
		Gulf Menhaden	4100	0.172	1
			4100	0.172	
Power Generation	Unknown Activity	Rough Fish	792100	33.319	2
		Game Fish	8000	0.337	1
			800100	33.656	
Power Generation	Mishandling Spill	Black drum	50	0.002	1
		Gulf Menhaden	50	0.002	1
		Striped Mullet	50	0.002	1
			150	0.006	

TABLE 26
SPECIES MORTALITY BY POINT SOURCES
(cont.)

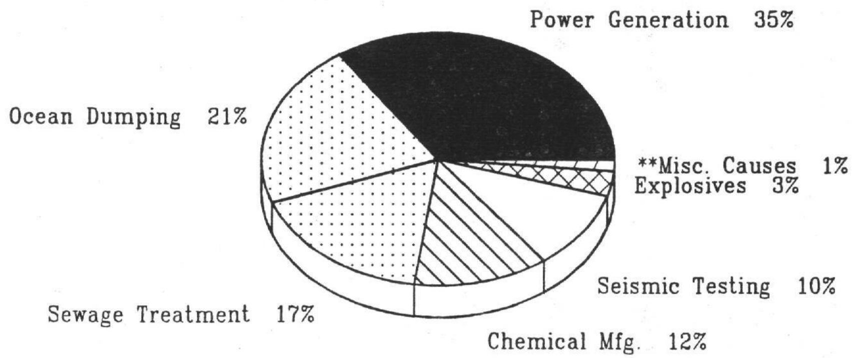
Secondary Source	Tertiary Source	Common Name	No. Killed	Percent of Total Killed by PS	No. Incidents Species Occurred
Power Generation	Cooling Water	Game Fish	3330	0.14	5
		Atlantic Croaker	2676	0.113	5
		Rough Fish	2020	0.085	3
		Gulf Menhaden	512	0.022	2
		Unidentified Fish	493	0.021	2
		Gizzard Shad	407	0.017	3
		Spot	220	0.009	1
		Hardhead Catfish	212	0.009	6
		Pinfish	206	0.009	1
		Spotted Seatrout	174	0.007	3
		Red Drum	156	0.007	3
		Sand Seatrout	96	0.004	2
		Striped Mullet	58	0.002	3
		Sheepshead	50	0.002	1
		Gulf Toadfish	40	0.002	1
		Southern Flounder	22	0.001	2
		Black drum	5	<0.001	1
		Red Snapper	2	<0.001	1
			10679	0.449	
Power Generation	Impingement	Rough Fish	10000	0.421	1
Commercial Fishing	Fishing Boat Cull	Striped Mullet	2112	0.089	1
		Atlantic Croaker	1056	0.044	1
		Rough Fish	1000	0.042	1
		Hardhead Catfish	6	<0.001	1
		Sheepshead	6	<0.001	1
			4180	0.176	
Seismic Testing	Explosives	Pinfish	82747	3.481	1
		Bay Anchovy	73337	3.085	1
		Spot	55006	2.314	1
		Black drum	12817	0.539	1
		Striped Mullet	11042	0.464	1
		Atlantic Croaker	5941	0.25	1
		Sheepshead	842	0.035	1
		Silver Perch	94	0.004	1
			241826	10.172	
Ocean Dumping	Barge Leak	Rough Fish	500000	21.032	1
		Grand Total	**2377303**		

FIGURE 3
POINT SOURCES CAUSING FISH MORTALITY

Point Sources Causing Fish Kills (%)



Fish Killed By Point Sources (%)



*Includes 7 sources of 1 incident each.

**Includes 8 sources 1% or less of total

Ninety six percent (96%) of the fish mortality caused by power plants resulted from a single incident (V16) in which a toxic cleansing solution was spilled on May 14, 1970 in the HL&P Webster Station discharge canal on Clear Lake. This resulted in the second largest number of fish killed per incident among all point sources. Essentially all of the fish killed from this incident were rough fish species.

Discharges of heated cooling water (V24) caused 75 percent of the incidents associated with power plants but only 1.3 percent of the number of fish killed. The impact (number of fish killed per incident) from heated water discharges were only two percent of the average from all point sources. More taxonomic groups (18) were reported affected by cooling water discharge than any other point source, probably due to the quality of the investigation by HL&P staff. The number of incidents reported by power generation facilities may be disproportionately high compared to other sources due to more diligent reporting by facility personnel. Commercial and sport fish species comprised 73 percent of the total identified as killed by thermal discharges. Impingement on rotating screens killed a reported 10,000 classified rough fish species in a single incident at an HL&P facility located on the Houston Ship Channel in January 1972. This was the only incident involving impingement recorded in fish kill investigation reports by any of the three agencies from which reports were obtained. This represents only a small number of the fish killed by impingement at power generation facilities and is included here only because it was included in the available fish kill incident reports.

A single mishandling spill (V21) involving turbine oil accounted for less than 0.02 percent of the total number of fish killed below power generation facilities. Equal numbers of black drum, Gulf menhaden, and striped bass were reported killed during this event.

Ocean Dumping (ZZ)

A single incident involving a leak in a deep sea ocean dumping barge (ZZ62) resulted in 21 percent of all fish killed by point sources. During this event, an unknown quantity of an undescribed substance was spilled in San Jacinto Bay in October of 1973 killing approximately 500,000 rough fish species. The incident represents the greatest point source impact recorded in the Galveston Bay area in terms of fish killed per incident during the previous 20-year period.

Sewage Treatment (T)

Sewage treatment plants (STPs) caused 17.4 percent of all fish mortality by point sources and represented 14 percent of the total number of point source incidents involving fish kills. Discharges of raw or partially treated sewage accounted for 97 percent of the total number of fish killed by STPs. Five sources were identified for incidents associated with STPs. These are lift station by-passes (T30), sewer line leaks (T32), STP by-passes (T33), storage tank leaks (T35), and accidental explosions (T48).

Incidents involving the release of raw or partially treated sewage were the most damaging from this category. Four reported incidents involving STP or lift station by-passes accounted for 97 percent of fish deaths originating from domestic waste treatment facilities. By-passes caused relatively high impacts to fish populations accounting for twice the average of all point source incidents. Ninety five percent (95%) of all of the fish reported affected by sewage input were

Gulf menhaden. This species was affected in all five reported by-pass incidents. A single incident involving a sewer line leak had negligible effect.

Storage tank leaks and explosions resulted in three percent of the number of fish killed in association with STP operations. Gulf menhaden and gizzard shad were the two species that were most affected by STP incidents not associated with sewage discharge.

Chemical Manufacturing/Storing (I)

Four categories of chemical manufacturing and storage facility sources were identified causing 12 percent of the fish killed due to point sources. These include pipe leaks (I4), elevated pollutant levels in permitted discharges (I44), mishandling spills (I21), and unknown spills (I16). Sixty eight percent (68%) of all fish affected by spills from chemical manufacturing facilities were either commercial or sport fish species. The effects of specific pollutants that were identified as causing fish kills from chemical spills are discussed in more detail in Section 4.5.

Pipe leaks (I4) involving toxic chemicals resulted in 68 percent of the number of fish killed due to chemical manufacturing sources and were involved in two of the seven reported incidents. These events resulted in 8.5 percent of the number of fish killed due to all point sources. Ninety nine percent (99%) of the fish affected by pipe leaks at chemical facilities were Gulf menhaden and were killed due to a single incident.

There were three incidents of unknown causes resulting in chemical spills (I16). Thirty percent (30%) of the total number of fish killed by chemical manufacturers were killed in these three incidents. Impacts due to these sources were less than 66 percent of the average for all point sources. Over 99 percent of the affected fish were rough fish species.

A single incident (I44) involving discharge of high BOD wastewater from a permitted outfall at the Union Carbide plant on the Texas City Harbor caused the deaths of less than two percent of the fish killed by discharges from chemical plants. Ninety nine percent (99%) of these were rough fish species.

Seismic Testing (Y)

Blasting associated with seismic testing operations (Y50) in West Galveston Bay resulted in 10.2 percent of the total number of fish reported killed due to point sources. Approximately 70 percent of these were either commercial or sport fish species and the remainder were rough fish. This operation was conducted during October 1990, to explore deep natural gas deposits using dynamite blasts at 100-foot depths. At that time the TPWD requested that a survey be conducted during testing operations to evaluate the effects the blasting would have on fish in the bay. The relatively high number of fish reported killed during this operation can be attributed to the extensive efforts used to recover fish stunned by the blasts. During blasting operations, an otter trawl was employed for subsurface recovery of fish carcasses. Floating fish were collected from the surface concurrently in order to develop a correlation between surface and subsurface mortalities. Because of these extensive efforts more information was gathered during these events than would be collected during most fish kill investigations.

Miscellaneous Sources (BB)

Less than six percent of fish killed by point sources resulted from miscellaneous sources not previously described. These include explosions from undefined sources (B50) which killed 3.2 percent of the total, 'other' industries (BB16, BB21, BB40, and BB52) caused 1.2 percent of fish mortality, cull from commercial fishing operations (X25) killed 0.2 percent, fish processing waste discharges (J17) killed 0.1 percent, and less than 0.1 percent each were affected by construction activities (G50), crude oil spills from pipe leaks (P4), spills caused by truck accidents (Q19), barge operations (S16, S21, and S22), and illegal waste disposal (QQ16).

4.3.3 Nonpoint Sources

Non-point sources (NPS) caused 43 percent of the total number of incidents and 87 percent of the total number of fish reported killed from identified point and non-point sources combined. Of all reported fish kills (point source, non-point source and unknown source), NPS accounted for nine percent of the total killed. Over 16.3 million fish were reportedly killed by nonpoint sources (Table 4.24). Of all NPS-related incidents, 93.7 percent of the fish killed were affected by undefined NPS runoff (DD7), 6.1 percent resulted from agricultural runoff (CF15 & CF58), and the remaining 0.2 percent died from the effects of runoff originating in both urban areas (EE51) and industrial landfills (U38 & U45) combined. Figure 4 presents the nonpoint sources causing fish mortality. Species mortality associated with nonpoint sources is quantitatively shown in Table 4.27.

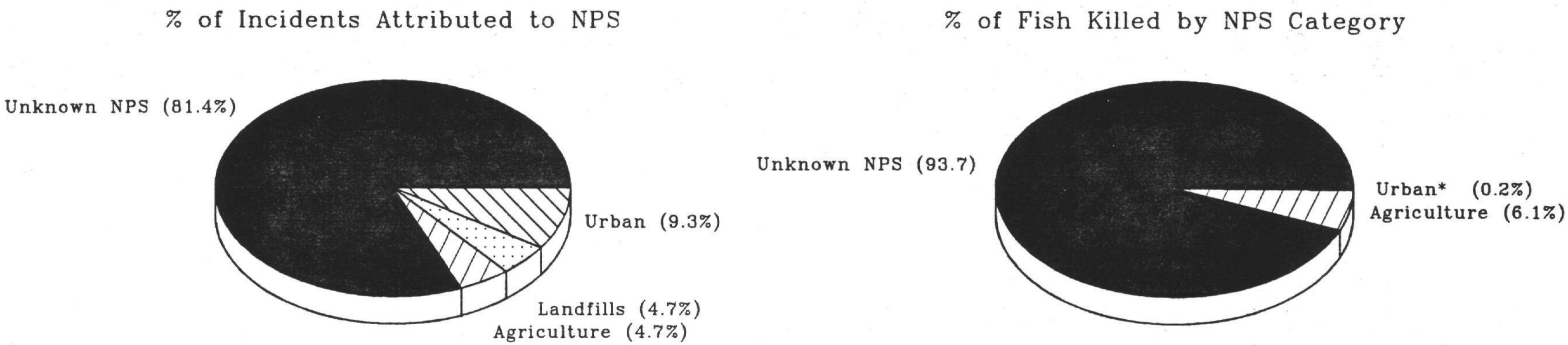
Agricultural Runoff (CF)

Fish kills resulting from agricultural runoff involved two separate incidents. Irrigation tailwater contaminated with pesticides (CF58) was discharged into Trinity Bay near McCullum Park on April of 1971 resulting in a reported 1,000,000 fish deaths representing six percent of the NPS-caused mortality. This single incident resulted in the highest number killed per incident of all identified nonpoint sources representing 270 percent of the average. Rough fish species accounted for 98 percent of the total killed during this incident. A second event involved anoxic water released into Robinson Lake from a nearby rice field (CF15). That incident resulted in 200 each of Gulf flounder and hardhead catfish killed representing less than 0.01 percent of the total due to NPS runoff.

Urban Runoff (EE)

Four fish kill incidents were reported involving urban runoff. These together accounted for only 0.1 percent of all fish killed due to nonpoint sources (EE51). The most damaging of these events occurred in Dickinson Bayou resulting in over 20,000 fish killed of which over 99 percent were Gulf menhaden. This incident had an impact on fish populations that was five percent of the average due to nonpoint sources. A second incident occurring in Highland Bayou resulted in 1,000 Gulf menhaden deaths. A third incident occurred in Nassau Bay in which 270 fish were killed, including striped mullet and inland silversides. A fourth incident occurred in a private canal in Crystal Beach killing seven striped bass.

FIGURE 4
NONPOINT SOURCES CAUSING FISH MORTALITY



*Urban runoff & runoff from industrial landfills

TABLE 4.27
SPECIES MORTALITY BY NONPOINT SOURCES

Secondary Source	Tertiary Source	Common Name	No. Killed	Percent Total Killed by NPS	No. Incidents Species Occurred
Agricultural Industry	Rice Field Drainage	Gulf Flounder	200	0.001	1
		Hardhead Catfish	200	0.001	1
			400	0.002	
Agricultural Industry	Irrigation Tailwater	Rough Fish	980000	6.004	1
			980000	6.004	1
Nutrient Buildup	Unknown Runoff	Rough Fish	10583763	64.843	24
		Gulf Menhaden	4647774	28.475	8
		Game Fish	63370	0.388	8
		Red Drum	310	0.002	1
		Striped Mullet	180	0.001	2
		Atlantic Croaker	130	0.001	1
		Spot	90	0.001	1
		Southern Flounder	75	<0.001	2
		Hardhead Catfish	60	<0.001	1
		Bay Anchovy	28	<0.001	1
		Spotted Seatrout	14	<0.001	1
		Blue Marlin	2	<0.001	1
			15295796	93.711	
Urban Nutrient Buildup	Urban Runoff	Gulf Menhaden	21000	0.129	2
		Inland Silverside	180	0.001	1
		Striped Mullet	97	0.001	2
		Atlantic Croaker	2	<0.001	1
		Gar (family)	1	<0.001	1
			280	0.002	
Industrial Landfills	On-Site Landfarm Runoff	Gulf Menhaden	1000	0.006	1
Industrial Landfills	Greater than Design Storm Runoff	Striped Bass	2000	0.012	1
		Gulf Menhaden	1000	0.006	1
		Sheepshead Minnow	750	0.005	1
			3750	0.023	
		Grand Total	**16322226**		

Runoff from Industrial Landfills (U)

Industrial landfill runoff resulted in two separate incidents which accounted for less than 0.1 percent of the fish mortality due to nonpoint sources. One involved the inactive Monsanto dump site adjacent to Dollar Bay from which an oily water discharge (U38) resulted in the deaths of 1,000 menhaden and shad. The second reported incident involved a breach of containment walls due to high tides (U45) resulting from hurricane Alicia at the Amoco Oil Company landfarm located in Texas City. This event caused oily water to be released into adjacent marsh areas killing 3,750 fish, of which 80 percent were commercial or sport fish species. The total impacts due to runoff from industrial landfarms was less than two percent of the average for all nonpoint sources.

Undefined Nonpoint Sources (DD)

The largest number of fish killed by nonpoint sources was attributed to nutrient input from unidentified areas (DD7). These accounted for 94 percent of all fish killed and 81 percent of the incidents due to NPS. Rough fish accounted for 69 percent of the total number killed due to these sources.

4.4 Unknown Sources

The third primary source category (unknown sources) accounted for 121 reported incidents and 156,496, 069 fish killed. This represents approximately 89 percent of all fish reported killed and 55 percent of the incidents from point sources, nonpoint sources, and unknown sources combined. Of the total number of fish killed by undefined sources, 96 percent were rough fish and approximately four percent were commercial or sport fish species. For these events, no information was contained in the reports which indicated the source of the fish kills.

4.5 Identified Pollutants

Fish mortality data were organized according to spilled materials identified within each of the ten pollutant categories. These include PS and NPS designations. Identified PS pollutant categories include chemical spills (code C), food industry waste (F), heated water (H), industrial wastes (I), oil (O), sewage (S), and shockwaves created by explosives detonation (X). NPS pollution categories include agricultural runoff (AR), undefined NPS runoff (UNPS), and urban runoff (UR). NPS pollutants are not identified in the fish kill reports other than as nutrient sources. For these, broad generalizations were used in the fish kill reports to describe the causes of fish mortality. Generally, these causes were described as low dissolved oxygen levels due to algal blooms produced by nutrient input. Oil pollution was found to be associated with both PS and NPS in historical records. Results are summarized in Figure 5.

Five of the pollutant categories resulted in the death of 98 percent of the total number of fish killed by identified sources. These include undefined nonpoint sources (81.8%), agricultural runoff (5.4%), chemical spill materials (4.9%), industrial wastewater (3.8%), and untreated sewage (2.1%). The remaining categories caused less than three percent of the total fish mortality. Species mortality due to pollutants associated with both PS and NPS are summarized in Tables 4.28a and b. The number of fish killed by pollutant category is summarized in Table 4.29.

FIGURE 5

NUMBER OF FISH KILLED ACCORDING TO POLLUTANT CATEGORY

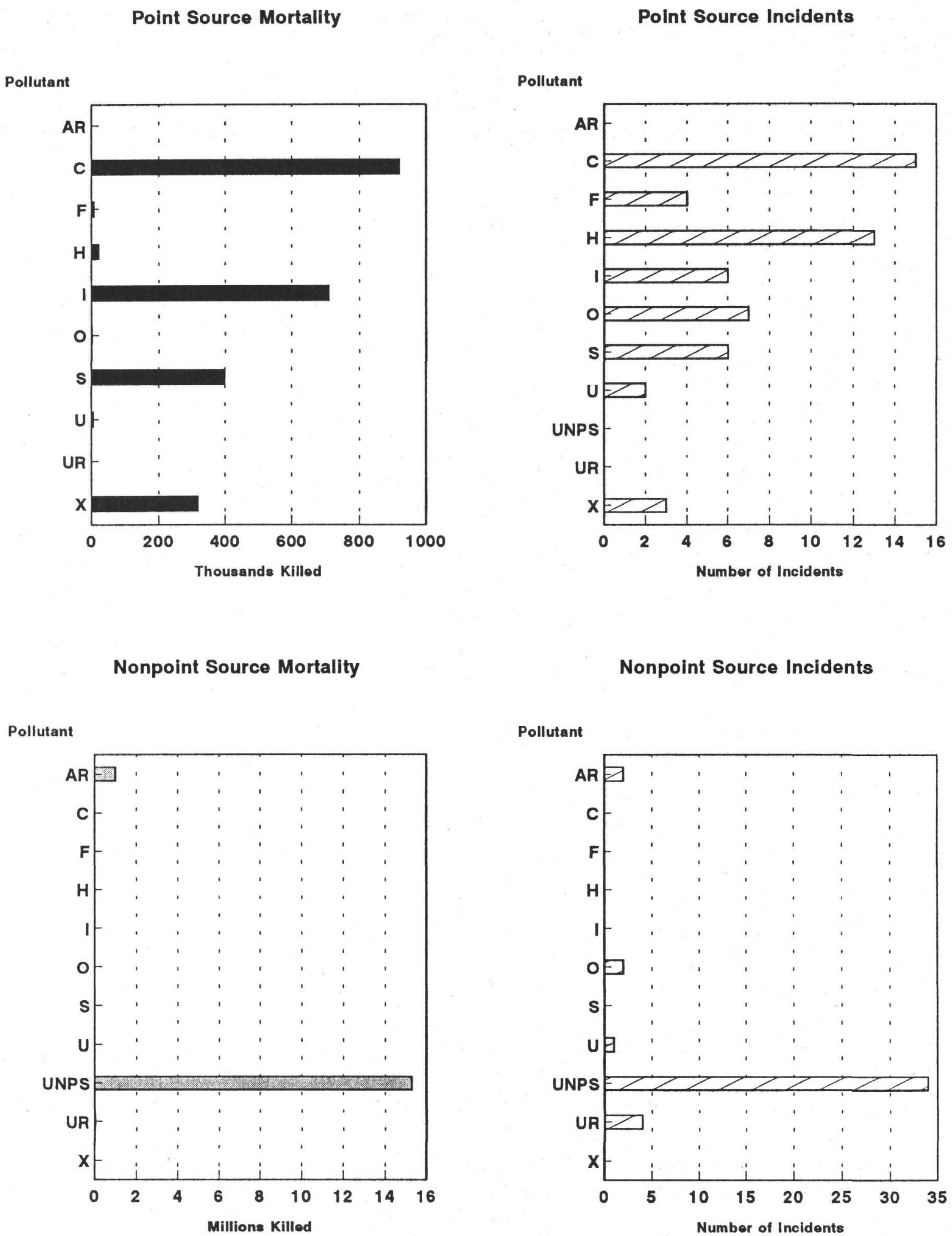


TABLE 4.28A
SPECIES MORTALITY ASSOCIATED WITH POINT SOURCE POLLUTANT CATEGORY

Pollutant Type	Common Name	No. Killed	Percent of Total Killed by PS Category	No. Incidents Species Occurred
Chemical Spill	Rough Fish	892877	37.558	6
	Game Fish	10023	0.422	3
	Gizzard Shad	9060	0.381	1
	Gulf Menhaden	5212	0.219	4
	Sheepshead Minnow	2000	0.084	1
	Unidentified Fish	121	0.005	3
	Hardhead Catfish	50	0.002	1
	Stripped Mullet	50	0.002	1
		919393	38.674	
Food Industry Waste	Gulf Menhaden	2677	0.113	1
	Striped Mullet	2112	0.089	1
	Atlantic Croaker	1056	0.044	1
	Rough Fish	1000	0.042	1
	Hardhead Catfish	6	<0.001	1
	Sheepshead	6	<0.001	1
		6857	0.288	
Heated Water Discharge	Rough Fish	12020	0.506	4
	Game Fish	3330	0.14	5
	Atlantic Croaker	2676	0.113	5
	Gulf Menhaden	512	0.022	2
	Unidentified Fish	493	0.021	2
	Gizzard Shad	407	0.017	3
	Spot	220	0.009	1
	Hardhead Catfish	212	0.009	6
	Pinfish	206	0.009	1
	Spotted Seatrout	174	0.007	2
	Red Drum	156	0.007	3
	Sand Seatrout	96	0.004	2
	Striped Mullet	58	0.002	3
	Sheepshead	50	0.002	1
	Gulf Toadfish	40	0.002	1
	Southern Flounder	22	0.001	2
	Black drum	5	<0.001	1
	Red Snapper	2	<0.001	1
		20679	0.87	

TABLE 4.28A
SPECIES MORTALITY ASSOCIATED WITH POINT SOURCE POLLUTANT CATEGORY
(cont.)

Pollutant Type	Common Name	No. Killed	Percent of Total Killed by PS Category	No. Incidents Species Occurred
Industrial Wastewater	Rough Fish	507920	21.365	4
	Gulf Menhaden	200000	8.413	1
	Striped Mullet	800	0.034	2
	Killifish (family)	300	0.013	1
	Game Fish	80	0.003	3
		709100	29.828	
Oil Spills	Rough Fish	290	0.012	3
	Game Fish	183	0.008	2
	Unidentified Fish	101	0.004	2
	Striped Mullet	50	0.002	1
	Gulf Menhaden	50	0.002	1
	Black drum	50	0.002	1
	Mosquitofish	42	0.002	1
	Gizzard Shad	11	<0.001	1
	Spotted Gar	1	<0.001	1
		778	0.033	
Sewage Spills	Gulf Menhaden	379411	15.96	4
	Striped Mullet	18796	0.791	1
	Sailfin Molly	1	<0.001	1
	Unidentified Fish	1	<0.001	1
		398209	16.75	
Unknown Sources	Rough Fish	5150	0.217	2
	Game Fish	50	0.002	1
		5200	0.219	
Shock Waves	Pinfish	82747	3.481	1
	Unidentified Fish	75235	3.165	1
	Bay Anchovy	73337	3.085	1
	Spot	55006	2.314	1
	Black drum	12817	0.539	1
	Striped Mullet	11060	0.465	2
	Atlantic Croaker	5941	0.25	1
	Sheepshead	842	0.035	1
	Silver Perch	94	0.004	1
	Gulf Menhaden	8	<0.001	1
		317087	13.338	
	Grand Total	**2377303**		

TABLE 4.28B
SPECIES MORTALITY ASSOCIATED WITH NONPOINT SOURCE POLLUTANT CATEGORY

Pollutant Type	Common Name	Number Killed	Percent of Total Killed Nonpoint Sources	No. Incidents Species Occurred
Agricultural Runoff	Rough Fish	980000	6.004	1
	Game Fish	20000	0.123	1
	Gulf Flounder	200	0.001	1
	Hardhead Catfish	200	0.001	1
		1000400	6.129	
Nonpoint Source Oil Spills (e.g. waste dumps and lanfills)	Gulf Menhaden	2000	0.012	2
	Stripped Bass	2000	0.012	1
	Sheepshead Minnow	750	0.005	1
		4750	0.029	
Unknown Source	Southern Flounder	5	<0.001	1
Unknown Nonpoint Source	Rough Fish	10583763	64.843	24
	Gulf Menhaden	4647774	28.475	8
	Game Fish	63370	0.388	8
	Red Drum	310	0.002	1
	Stripped Mullet	180	0.001	2
	Atlantic Croaker	130	0.001	1
	Spot	90	0.001	1
	Southern Flounder	70	<0.001	1
	Hardhead Catfish	60	<0.001	1
	Bay Anchovy	28	<0.001	1
	Spotted Seatrout	14	<0.001	1
	Blue Marlin	2	<0.001	1
		15295791	93.711	
Urban Runoff	Gulf Menhaden	21000	0.129	2
	Inland Silverside	180	0.001	1
	Stripped Mullet	97	0.001	2
	Atlantic Croaker	2	<0.001	1
	Gar (family)	1	<0.001	1
		21280	0.131	
	Grand Total	16322226		

TABLE 4.29
NUMBER OF FISH KILLED BY POLLUTANT CATEGORY

Pollutant	No. of Fish Killed	No. of Incidents	Percent Total Killed	No. of Fish Killed per Incident
Undefined Nonpoint Source	15295796	34	81.798	449876
Agricultural Runoff	1000400	2	5.35	500200
Chemical Spills	919393	15	4.917	61293
Industrial Wastewater	709100	6	3.792	118183
Sewage Spills	398209	6	2.13	66368
Shockwaves	317087	3	1.696	105696
Urban Runoff	21280	4	0.114	5320
Heated Water Discharge	20679	12	0.111	1723
Food Industry Waste	6857	4	0.037	1714
Oil Spills	5528	10	0.03	553
Unknown Pollutants	5200	2	0.028	2600
Total	**18699529**	**96**	**100**	**194787**

SOURCES WITHIN CHEMICAL SPILL CATEGORY

Pollutant	No. of Fish Killed	No. of Incidents	Percent Total Killed	Percent of Kills Caused by Chemical Spills
Cleansing solutions	800000	1	4.278	87.014
Unspecified chemical	80000	1	0.428	8.701
Titanium chloride	15000	1	0.08	1.632
Styrene	13160	1	0.07	1.431
Benzene	3500	1	0.019	0.381
Toxic waste	2800	1	0.015	0.305
p–Xylene	2000	1	0.011	0.218
Fertilizer	1600	1	0.009	0.174
Hydrochloric acid	1050	1	0.006	0.114
Vinyl acetate	105	1	<0.001	0.011
Ferric chloride	100	1	<0.001	0.011
Malathion	50	1	<0.001	0.005
Sugar	12	1	<0.001	0.001
Butyl acrylate	10	1	<0.001	0.001
Phenol	6	1	<0.001	0.001
Total	**919393**	**15**	**4.916**	**100**

Undefined Nonpoint Source Pollutants (UNPS)

Nonpoint source pollutants originating from undefined areas (UNPS) accounted for 86 percent of the fish killed by identified causes and 35 percent of the reported incidents due to point and nonpoint sources combined. UNPS also resulted in the highest number killed per incident (impact) at approximately 2.5 times the average rate. The high mortalities attributed to this pollutant category are probably due to the large amount of incidents for which specific causes could not be identified. As a result, data from many incidents were generalized into this category. Unclassified rough fish and Gulf menhaden were the species most affected by undefined NPS. Unclassified rough fish comprised approximately 69 percent of the total number killed and Gulf menhaden comprised 30 percent.

Agricultural Runoff (AR)

Runoff from agricultural areas was the second most damaging pollutant identified in this study. A total of 1,000,000 fish (of which 98 percent were unclassified rough fish) were killed in a single incident in Trinity Bay in which runoff contaminated with pesticides entered Trinity Bay. A second incident occurring in East Galveston Bay killed several hundred Gulf flounder and hardhead catfish from the anoxic water discharged from a rice field.

Chemical Spills (C)

Point source chemical spills were identified as the cause of five percent of the fish mortality and 16 percent of the number of incidents reported. Ninety seven percent (97%) of the affected fish were unclassified rough fish found in six of the 15 reported incidents. Seven other fish categories were included in the remaining three percent. Gulf menhaden and/or unclassified game fish were killed in four incidents while the remaining species were each killed due to single events. The most damaging material reported spilled from chemical manufacturing facilities was industrial wastewater which resulted in 68 percent of the fish killed by these sources.

Fifteen separate materials were identified as associated with chemical spill events (Table 4.29). Each were associated with single incidents. The most destructive material was unspecified cleansing solutions spilled into the HL&P discharge canal above Clear Lake. This resulted in 792,000 rough fish killed or 89 percent of the number of fish killed by chemical spills affecting primarily unclassified rough fish. Unspecified chemicals spilled in Double Bayou near the Brown and Root shipyard resulted in 9 percent of the total chemical spill fish mortality of which all were rough fish species. An estimated 80,000 unclassified rough fish were killed in this event. A titanium tetrachloride spill occurring in Ditch A of the Bayport Industrial Complex killed 15,000 rough fish or approximately two percent of the total from all chemical spills. A styrene spill resulting from an explosion at the Arco Refinery in Channelview wastewater treatment facility caused the deaths of 9,060 gizzard shad and 4,100 Gulf menhaden which comprised 1.4 percent of the total chemical spill related fish kills. The remaining 11 compounds reported spilled resulted in less than two percent of the fish mortality due to chemical spills.

Industrial Wastewater (I)

Spills of industrial wastewater caused approximately four percent of the fish mortality from identified pollutants. These included a total of six incidents of which two accounted for 99 percent of fish kills related to industrial wastewater release. One of these resulted from a leak in a deep sea dumping barge resulting in the deaths of 500,000 unclassified rough fish. The second incident involved a pipeline break at the Goodyear Tire Company plant releasing in excess of 100 barrels of unspecified wastewater into Ditch A of the Bayport Industrial Complex. The most affected fish type was unclassified rough fish representing 72 percent of the total. Gulf menhaden comprised essentially all of the remainder.

Sewage (S)

Six fish kill incidents involving sewage spills in the Galveston Bay system were included in the historical records. These resulted in 389,209 fish killed representing 2.3 percent of the total from all identified pollutants. Approximately 95 percent of fish killed by sewage spills were Gulf menhaden and five percent were striped mullet.

Four of the six incidents associated with sewage input caused 95 percent of the mortalities due to these sources. Of these, 50 percent were killed by sewage spills from the League City STP on Clear Creek resulting from high tides caused by Hurricane Allen in 1980. During this incident, 200,000 Gulf menhaden were reported killed. A second incident occurred in the Bayou Vista subdivision canal above Jones Bay. In this event, a release of raw sewage caused by an STP upset killed approximately 100,000 Gulf menhaden. The third high impact incident occurred due to an upset at the Alta Loma WCID #8 STP releasing partially treated sewage into a diversionary canal entering Highland Bayou. A reported 79,200 Gulf menhaden were killed during this event. The fourth incident occurred in Dollar Bay due to a raw sewage by-pass at the Texas City Lift Station #4 which killed a reported 19,429 striped mullet.

Two less impacting incidents included a private sewer line leak in Taylor Bayou and a by-pass at the Royalwood Wastewater Treatment Plant discharging to the Houston Ship Channel. Both events killed small numbers of fish.

Shockwaves (X)

Shockwaves caused by explosives detonation resulted in 317,087 fish deaths from three separate incidents. The data concerning affected fish types were more evenly distributed for this causal mechanism and included a larger percentage of commercial and sport fish varieties than was shown for other pollutants. Three affected species represented over 66 percent of the mortality, pinfish (26%), bay anchovy (23%), and spot (17%). Unidentified fish comprised 24 percent of the total.

Mortality data for this category is more comprehensive than for other fish kill events because a large portion of the number killed (76%) were collected during an extensive survey that was conducted concurrently with seismic testing operations in West Bay. This was done to correlate fish mortality quantitatively with seismic testing operations in order to develop a formula for predicting explosives effects on area fish. Boats utilizing subsurface trawls and surface were employed during these tests to gather detailed information as the blasting occurred.

For normal fish kill incidents, less thorough methods are used and investigators are usually not present immediately after a fish kill occurred resulting in less reliable data. In the absence of these pre-planned collection measures it is unlikely that comprehensive data would have been gathered. Affected species included Atlantic croaker, bay anchovy, black drum, sheepshead, striped mullet, spot, silver perch, and pinfish.

An additional 24 percent of the fish killed by shock waves were associated with the detonation of explosives from an undefined activity on Clear Lake. During this incident, over 75,000 unidentified fish were killed.

Urban Runoff (UR)

Runoff from urban areas was the seventh most damaging pollutant in terms of numbers of fish killed though it represented only 0.1 percent of the total from identified pollutants. Two UR incidents resulted in 21,289 fish killed of which 99 percent were Gulf menhaden. Of these reported 20,000 Gulf menhaden were killed in Dickinson Bayou near the I-45 bridge. The second incident occurred in Highland Bayou killing a reported 1,000 Gulf menhaden.

Heated Water Discharges (H)

Thermal input from cooling water discharges at power generating facilities resulted in approximately 0.1 percent of the total number of fish killed by point or nonpoint sources. A large number of these incidents (21 percent of the total) were reported which included a large variety of species but low numbers of fish killed. More taxonomic groups (18) were reported killed by these events than for all other pollutant categories combined. Unclassified rough fish comprised 58 percent, unclassified game fish made up 16 percent, and Atlantic croaker represented 13 percent of the total. The remaining 13 percent of affected fish included predominantly commercial and sport fish varieties. Five of the 12 incidents occurred at the HL&P Robinson power generation facility in upper Galveston Bay between June 1976 and June 1988. A reported 9,581 fish were killed here representing 92 percent of the total. The HL&P power plant on Cedar Bayou reported four incidents occurring in 1983 in which a total of 836 fish were killed.

Food Industry Wastes (F)

A small number of fish (0.04 percent of the total) were killed in four incidents associated with discharges from fish processing plants. Gulf menhaden, striped mullet, and Atlantic croaker represented 85 percent of the total number killed. The remainder were identified as unclassified rough fish, hardhead catfish, and sheepshead. Three incidents were caused by cull from fishing vessels, accounting for 85 percent of the total killed and included mainly striped mullet, Atlantic croaker, and unclassified rough fish. A third incident resulted from discharge from a fish processing plant in Jarbo Bayou killing 2,677 Gulf menhaden.

Oil (O)

Oil pollution was the least damaging of the identified pollutants and resulted in approximately 0.03 percent of the total number killed, however it was associated with 11 percent of the reported incidents. A relatively large number of taxonomic groups (12) were affected by oil pollution including six commercial or sport fish species and five rough fish species. Oil contamination was associated with both point, nonpoint source, and unknown sources in the Galveston Bay area.

Six incidents were associated with point sources and caused a total of 555 fish deaths. Point source events involved more incidents and affected more species, but killed fewer numbers of fish than nonpoint source events. Two involved turbine oil spills into the Houston Ship Channel from the HL&P Bertron plant. Two hundred fifty (250) fish were killed by these two incidents including striped mullet, black drum, Gulf menhaden and unclassified rough fish. A third incident was caused by a Shell Oil Company pipeline leak into Buffalo Bayou which killed 54 rough fish. The fourth incident involved an oil pipeline leak into a drainage ditch above Moses Lake. This event killed approximately 200 fish, primarily unclassified rough fish. A fifth incident was caused by an illegal discharge in an unnamed tributary to West Galveston Bay killing a reported 50 rough fish. The sixth incident occurred due to the release of cutting oil at the Onyx Corporation. This entered a tributary of Basford Bayou with negligible effects on fish.

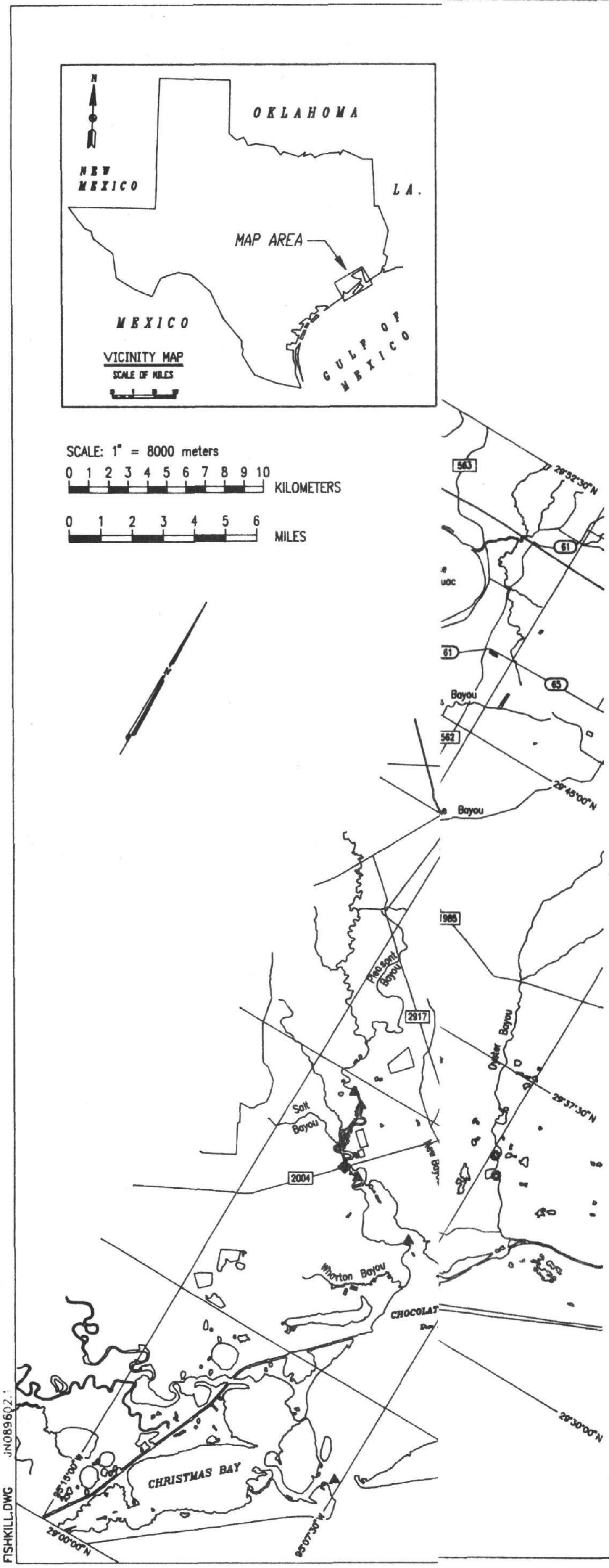
Two NPS incidents were recorded involving a total of 4,750 fish. One event involved oil contaminated runoff from the Monsanto Company dump. A reported 1,000 Gulf menhaden were killed during this event in Dollar Bay adjacent to Lower Galveston Bay. A second incident involving oil contaminated runoff from the Amoco Oil Company landfarm near Texas City resulting from loss of containment killed 2,000 striped bass, 100 Gulf menhaden, and 750 sheepshead minnows.

4.6 Affected Waterbody Segments

Fish mortality data were evaluated for specific waterbodies using three basic criteria; total numbers of fish killed, numbers of reported incidents, and pollution sources affecting individual segments. The following discussion describes waterbody segments that either experienced large numbers of fish killed or a high number of incidents. Figure 6 shows the locations of fish kill incidents reported in the study area.

4.6.1 Point Sources

Fish kills caused by point sources (PS) included 13 classified and 12 unclassified segments. Fifty six (56) PS incidents were reported resulting in approximately 2.4 million fish deaths. This amount represents only 1.4 percent of the total number killed by point sources, nonpoint sources, and unknown sources combined. Low numbers of taxonomic groups were found in the available information due to the large amount of data that were composed of unclassified rough fish and game fish for which further delineations were unavailable. Table 4.30 and Figure 7 summarize the number of fish killed by point sources in each of the waterbodies.



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Galveston Bay National Estuary Program

- ◆ POINT SOURCE INCIDENTS
- ● NONPOINT SOURCE INCIDENTS
- ▲ UNDEFINED SOURCE INCIDENTS

FIGURE 6

FISH KILL LOCATION MAP

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TABLE 4.30
LOCATION OF SPECIES MORTALITY CAUSED BY POINT SOURCES

Water Body (TWC Segment No.)	Common Name	Number Killed	Percent of Total Fish Killed	No. Incidents Species Occurred
Tributaries to Cedar Bayou (x0901)	Game Fish	200	0.008	1
Cedar Bayou (0901)	Game Fish	75	0.003	1
	Rough Fish	75	0.003	1
		150	0.006	
Tributaries to the Houston Ship Channel–San Jacinto River (x1005)	Rough Fish	100	0.004	1
Houston Ship Channel–San Jacinto River (1005)	Gizzard Shad	9060	0.381	1
	Gulf Menhaden	4100	0.172	1
		13160	0.554	
Tributaries to Houston Ship Channel (x1006)	Rough Fish	1600	0.067	1
Houston Ship Channel (1006)	Rough Fish	10000	0.421	1
	Black drum	50	0.002	1
	Gulf Menhaden	50	0.002	1
	Striped Mullet	50	0.002	1
		10150	0.427	
Houston Ship Channel/Buffalo Bayou (1007)	Sailfin Molly	1	<0.001	1
Buffalo Bayou (1013)	Mosquitofish	42	0.002	1
	Gizzard Shad	11	<0.001	1
	Spotted Gar	1	<0.001	1
		54	0.002	
Clear Creek (Tidal) (1101)	Gulf Menhaden	200100	8.417	2
Tributaries to Chocolate Bayou (Tidal) (x1107)	Rough Fish	3465	0.146	1
	Game Fish	35	0.001	1
		3500	0.147	
Tributaries to Upper Galveston Bay (x2421)	Rough Fish	2920	0.123	2
	Atlantic Croaker	2543	0.107	3
	Game Fish	580	0.024	2
	Gulf Menhaden	512	0.022	2
	Unidentified Fish	493	0.021	2
	Spot	220	0.009	1
	Pinfish	206	0.009	1
	Hardhead Catfish	190	0.008	3
	Spotted Seatrout	172	0.007	2
	Sand Seatrout	96	0.004	2
	Gizzard Shad	52	0.002	2
	Sheepshead	50	0.002	1
	Striped Mullet	27	0.001	2
	Red Drum	12	0.001	1
	Southern Flounder	10	<0.001	1
	Red Snapper	2	<0.001	1
		8085	0.34	

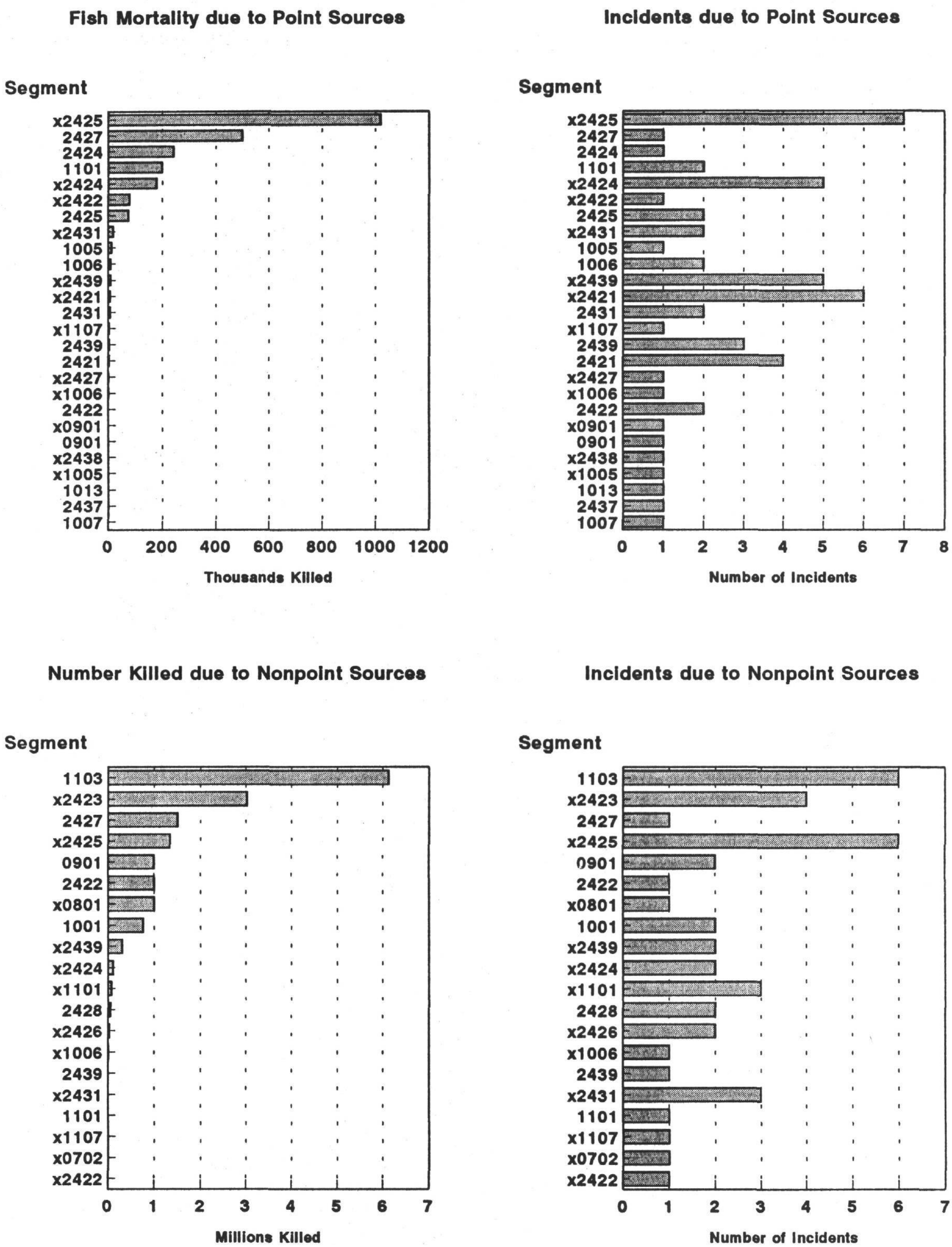
TABLE 4.30
LOCATION OF SPECIES MORTALITY CAUSED BY POINT SOURCES
(cont.)

Water Body (TWC Segment No.)	Common Name	Number Killed	Percent of Total Fish Killed	No. Incidents Species Occurred
Upper Galveston Bay (2421)	Game Fish	2475	0.104	1
	Atlantic Croaker	131	0.006	1
	Gulf Toadfish	40	0.002	1
	Red Drum	32	0.001	1
	Striped Mullet	31	0.001	1
	Rough Fish	25	0.001	1
	Hardhead Catfish	16	0.001	1
	Southern Flounder	12	0.001	1
	Sheepshead	6	<0.001	1
	Spotted Seatrout	2	<0.001	1
		2770	0.117	
Tributaries to Trinity Bay (x2422)	Rough Fish	80000	3.365	1
Trinity Bay (2422)	Gizzard Shad	355	0.015	1
	Red Drum	112	0.005	1
	Hardhead Catfish	12	0.001	2
	Black drum	5	<0.001	1
	Atlantic Croaker	2	<0.001	1
		486	0.02	
Tributaries to West Galveston Bay (x2424)	Gulf Menhaden	179212	7.538	2
	Game Fish	123	0.005	1
	Rough Fish	50	0.002	3
	Unidentified Fish	1	<0.001	1
		179386	7.545	
West Galveston Bay (2424)	Pinfish	82747	3.481	1
	Bay Anchovy	73337	3.085	1
	Spot	55006	2.314	1
	Black drum	12817	0.539	1
	Striped Mullet	11042	0.464	1
	Atlantic Croaker	5941	0.25	1
	Sheepshead	842	0.035	1
	Silver Perch	94	0.004	1
		241826	10.172	
Tributaries to Clear Lake (x2425)	Rough Fish	807200	33.953	3
	Gulf Menhaden	203677	8.567	3
	Game Fish	8000	0.337	1
	Striped Mullet	350	0.015	2
	Unidentified Fish	1	<0.001	1
		1019227	42.871	
Clear Lake (2425)	Unidentified Fish	75235	3.165	1
	Striped Mullet	18	0.001	1
	Gulf Menhaden	8	<0.001	1
		75261	3.166	

TABLE 4.30
LOCATION OF SPECIES MORTALITY CAUSED BY POINT SOURCES
(cont.)

Water Body (TWC Segment No.)	Common Name	Number Killed	Percent of Total Fish Killed	No. Incidents Species Occurred
Tributaries to San Jacinto Bay (x2427)	Sheepshead Minnow	2000	0.084	1
San Jacinto Bay (2427)	Rough Fish	500000	21.031	1
Tributaries to Moses Lake (x2431)	Striped Mullet	18796	0.791	1
	Gulf Menhaden	211	0.009	1
	Rough Fish	140	0.006	1
	Game Fish	60	0.003	1
		19207	0.808	
Moses Lake (2431)	Rough Fish	6930	0.291	2
	Game Fish	70	0.003	2
		7000	0.294	
Texas City Ship Channel (2437)	Unidentified Fish	10	<0.001	1
Tributaries to Bayport Channel (x2438)	Unidentified Fish	105	0.004	1
Tributaries to Lower Galveston Bay (x2439)	Rough Fish	6752	0.284	3
	Game Fish	2048	0.086	3
	Striped Mullet	500	0.021	1
	Killifish (family)	300	0.013	1
	Unidentified Fish	100	0.004	1
		9700	0.408	
Lower Galveston Bay (2439)	Striped Mullet	2112	0.089	1
	Atlantic Croaker	1056	0.044	1
	Gulf Toadfish	50	0.002	1
	Unidentified Fish	6	<0.001	1
		3224	0.136	
	Grand Total	**2377409**		

FIGURE 7
FISH MORTALITY BY WATERBODY



The occurrences of point source incidents were concentrated in three areas. These include the Taylor Lake drainage southwest of the community of Shoreacres, the industrial area to the south of Texas City, and the discharge canal for the HL&P Robinson generation facility located in Bacliff. Other point source incidents occurring in the study area were reported over a more diffuse area with nearly twice as many reported in Galveston County than in Harris County. Chambers and Brazoria counties together experienced only 11 percent of the total number in the Galveston Bay study area.

Ninety percent (90%) of the total number of fish killed due to point sources were found in only five waterbody segments. These include tributaries to Clear Lake (42.9%), San Jacinto Bay (21%), West Bay (10.2%), Clear Creek (8.4%), and tributaries to West Bay (7.5%). Unclassified rough fish and Gulf menhaden were the most affected taxonomic groups.

Clear Creek (Segment 1101)

Two point source incidents resulted from discharges originating from the League City Sewage Treatment Plant (STP) on Clear Creek. Approximately 200,000 Gulf menhaden were killed by a single incident involving a raw sewage by-pass resulting from higher than normal tides caused by Hurricane Allen in 1980. This event accounted for over 99 percent of the total number killed by point sources in Clear Creek. In a second incident, a small number of Gulf menhaden were killed by a ferric chloride spill from a leaking storage tank at this facility.

Upper Galveston Bay (Segment 2421)

A large number of incidents associated with a small number of fish killed were reported for the HL&P Robinson Power Generation facility near Bacliff. Five incidents were reported for which heated water discharges killed approximately 7,100 fish. Twenty eight percent (28%) of these were unclassified rough fish and the remainder included 12 taxonomic categories of commercial or sport fish species. The incidents occurred during the summer months when high temperatures in the discharge exceeded the temperature tolerance limits of the affected species. The large number of reported incidents was probably due to diligent reporting by facility personnel and is not necessarily an indication that this area is a "hotspot" for fish kill incidents.

West Bay (Segment 2424)

All of the fish reported killed in West Bay due to point sources resulted from seismic testing operations during exploration for natural gas deposits. As described in Section 4.4.1, collection methods used to determine the number of fish killed by the detonation of explosives were more extensive than are normally employed during fish kill investigations. A total of 241,826 fish carcasses was collected during this effort. The data included eight species of which seven were sport or commercial varieties. Seventy percent (70%) of the total number killed were sport or commercial fish and the remainder were rough fish varieties.

Tributaries to West Bay (Segment x2424)

Five incidents were identified as causing a reported 13.8 million fish to be killed in tributaries to West Bay. Incidents included STP by-passes, illegal waste disposal activities, a trucking accident, and an unidentified industrial spill. Two incidents involving sewage treatment plant by-passes caused over 99 percent of the total number killed. Both facilities, one of which was identified as the Alta Loma WCID #8 unit, have outfalls located along canals. In both events, Gulf menhaden were the only species affected. Illegal waste disposal activities in which oil was apparently disposed of in a nearby waterway resulted in less than 0.1 percent of the total number of mortalities and included roughly equal numbers of unclassified rough fish and game fish species. Negligible numbers of fish were affected by a truck accident spill involving sugar, and a spill of an undetermined amount of cutting oil from an unidentified industrial facility.

Tributaries to Clear Lake (Segment x2425)

Tributaries to Clear Lake (excluding Clear Creek) were affected by seven identified incidents resulting in a total of 1,019,228 fish mortalities. This represents 43 percent of the total reported for all point sources. Seventy nine percent (79%) of the fish killed in this segment were unclassified rough fish while Gulf menhaden comprised 20 percent of the total. The drainage area experienced both a large number of reported incidents and a large number of fish killed.

The most impacting event occurring here was a single incident in which cleansing solution was spilled into the HL&P Webster Station discharge canal entering Clear Creek causing 78 percent of the fish mortalities recorded for this segment. Ninety nine percent (99%) of the fish killed during this event were unclassified rough fish and the remainder were unclassified game fish.

The drainage area upstream of Taylor Lake in the vicinity of the Shoreacres community experienced four reported point source incidents occurring in Ditch A of the Bayport Industrial Complex which ultimately drains into Taylor Lake from the northeast. A combined 216,350 fish were killed in Ditch A by chemical spill incidents involving titanium chloride, hydrochloric acid, and a pipe leak of industrial wastewater. Two hundred (200) unclassified rough fish were killed due to an unidentified material spilled into Ditch A. For these incidents Gulf menhaden accounted for approximately 93 percent of the total and unclassified rough fish comprised 7 percent. Nonpoint source and unknown source incidents also occurred frequently in this area and are discussed in Sections 4.6.2 and 4.6.3. Fish processing waste discharges, and a single incident involving leakage from a private sewer line together killed less than one percent of the total in this drainage area due to point sources.

San Jacinto Bay (Segment 2427)

A single incident was recorded for San Jacinto Bay caused by a leak of an unspecified material from a deep sea dumping barge. This event killed 500,000 rough fish species in September of 1973 and was the single largest fish kill event recorded for the Galveston Bay area due to point sources. No other point source related incidents involving fish mortality were recorded for San Jacinto Bay.

Industrial Area South of Texas City (Segments 2437, x2439 and 2439)

Five point source incidents occurred in the industrial area to the south of Texas City north of Lower Galveston Bay (x2439) killing a reported 9,700 fish. Seventy percent (70%) of these were unclassified rough fish, 21 percent were game fish, and the remainder were striped mullet, and killifish. Affected segments included the Texas City Harbor, the Union Carbide Corporation canal, and the Texas City Barge Canal. Two incidents were recorded for the Texas City Harbor which together killed 6,000 fish. One incident, involving the discharge of industrial wastewater from an unidentified source, killed 990 rough fish and ten game fish species. The second incident involved an unidentified material released near the Union Carbide outfall killing 4,950 rough fish and 50 game fish. A single incident involving a toxic waste spill was recorded in the Union Carbide Canal which killed 1,988 game fish and 812 rough fish. The Texas City Barge Canal experienced a single reported incident in which 6,000 gallons of 2-ethyl hexanol was spilled from a tank barge killing approximately 100 unidentified fish. A concentrated wastewater discharge into a flood canal in Texas City near the Union Carbide plant killed in 500 striped mullet and 300 killifish.

A total of three incidents was reported for Lower Galveston Bay (2439) killing 3,224 game fish species. One of these occurred near Texas City killing 3,168 fish including striped mullet and Atlantic croaker. In two separate incidents phenol and malathion were spilled into the bay killing a small number of fish.

A single incident was recorded in the Texas City Ship Channel (Segment 2437) in which butyl acrylate was spilled killing ten unidentified fish.

4.6.2 Nonpoint Sources

Nonpoint source related fish kills occurred in eight classified and 12 unclassified segments. Fish killed due to nonpoint sources represented only 9.3 percent of the total number killed by point sources, nonpoint sources, and unknown sources combined. NPS related fish kills resulted in nearly seven times the number killed due to point sources alone (Table 4.24). Table 4.31 summarizes fish mortality caused by NPS within each waterbody segment.

A relatively large number of incidents caused by nonpoint sources were recorded for three localized areas as shown in Figures 6 and 7. These include the area near the confluence of Goose Creek with the San Jacinto River in the vicinity of Baytown (Segments x2426, 2427, 2428), the drainage area entering Taylor Lake from the northeast in the vicinity of Shoreacres in Galveston County (x2425), and tidal portions of Dickinson Bayou (1103). Other notable occurrences of nonpoint source incidents were located in Moses Lake, the Nassau Bay area upstream of Clear Lake (x2425), and the industrial area to the south of Texas City.

Almost 92 percent of all fish killed by nonpoint sources were found in seven of the 18 segments affected by NPS events including Dickinson Bayou (37.5%), tributaries to East Galveston Bay (18.5%), San Jacinto Bay (9.2%), tributaries to Clear Lake (8.2%). Six percent (6%) each were recorded for Cedar Bayou, Trinity Bay, and unnamed tributaries of the Trinity River.

Tributaries to the Trinity River (Segment x0801)

A single incident involving undefined nonpoint source runoff killed approximately one-million Gulf menhaden in Old River in Chambers County. The cause was attributed to oxygen depletion due to an algae bloom.

TABLE 4.31
LOCATION OF SPECIES MORTALITY CAUSED BY NONPOINT SOURCES

Water Body (TWC Segment No.)	Common Name	No. Killed	Percent of Total Killed NPS	No. Incidents Species Occurred
Tributaries to Intracoastal Waterway (x0702)	Striped Mullet	7	<0.001	1
Tributaries to Trinity River (x0801)	Gulf Menhaden	1000000	6.127	1
Cedar Bayou (0901)	Gulf Menhaden	500000	3.063	1
	Rough Fish	495000	3.033	1
	Game Fish	5000	0.031	1
		995000	6.096	
San Jacinto River (Tidal) (1001)	Rough Fish	752500	4.61	2
		760000	4.656	2
Tributaries to Houston Ship Channel (x1006)	Rough Fish	5000	0.031	1
Tributaries to Clear Creek (x1101)	Gulf Menhaden	72464	0.444	1
	Rough Fish	3500	0.021	1
	Striped Mullet	50	<0.001	1
	Bay Anchovy	28	<0.001	1
	Spotted Seatrout	14	<0.001	1
		76056	0.466	
Clear Creek (Tidal) (1101)	Gulf Menhaden	310	0.002	1
	Red Drum	310	0.002	1
	Atlantic Croaker	130	0.001	1
	Striped Mullet	130	0.001	1
	Spot	90	0.001	1
	Southern Flounder	70	<0.001	1
	Hardhead Catfish	60	<0.001	1
		1100	0.007	
Dickinson Bayou (Tidal) (1103)	Rough Fish	5000006	30.633	3
	Gulf Menhaden	1120000	6.862	3
	Game Fish	6	<0.001	1
	Atlantic Croaker	2	<0.001	1
	Gar (family)	1	<0.001	1
		6120015	37.495	
Tributaries to Chocolate Bayou (x1107)	Rough Fish	300	0.002	1
Inlets to Trinity Bay (x2422)	Southern Flounder	5	<0.001	1
Trinity Bay (2422)	Rough Fish	980000	6.004	1
	Game Fish	20000	0.123	1
		1000000	6.127	

TABLE 4.31
LOCATION OF SPECIES MORTALITY CAUSED BY NONPOINT SOURCES
(cont.)

Water Body (TWC Segment No.)	Common Name	No. Killed	Percent of Total Killed NPS	No. Incidents Species Occurred
Tributaries to East Bay (x2423)	Rough Fish	3020000	18.502	3
	Gulf Flounder	200	0.001	1
	Hardhead Catfish	200	0.001	1
		3020200	18.504	
Tributaries to West Bay (x2424)	Rough Fish	109048	0.668	1
	Game Fish	1101	0.007	1
	Gulf Menhaden	1000	0.006	1
		111149	0.681	
Tributaries to Clear Lake (x2425)	Rough Fish	862000		4
	Gulf Menhaden	475000	2.91	1
	Inland Silverside	180	0.001	1
	Striped Mullet	90	0.001	1
		1337270	8.193	
Tributaries to Tabbs Bay (x2426)	Rough Fish	30564	0.187	1
	Game Fish	308	0.002	1
	Blue Marlin	2	<0.001	1
		30874	0.189	
San Jacinto Bay (2427)	Gulf Menhaden	1500000	9.19	1
Black Duck Bay (2428)	Game Fish	48500	0.297	1
	Rough Fish	3500	0.021	2
		52000	0.319	
Tributaries to Moses Lake (x2431)	Rough Fish	2195	0.013	2
	Gulf Menhaden	1000	0.006	1
	Game Fish	105	0.001	1
		3300	0.02	
Tributaries to Lower Galveston Bay (x2439)	Rough Fish	300150	1.839	2
	Game Fish	850	0.005	1
		301000	1.844	
Lower Galveston Bay (2439)	Striped Bass	2000	0.012	1
	Gulf Menhaden	1000	0.006	1
	Sheepshead Minnow	750	0.005	1
		3750	0.023	
	Grand Total	**16322226**		

Cedar Bayou (Segment 0901)

Two separate incidents involving nonpoint source runoff from undefined sources together killed approximately 0.5 million each of Gulf menhaden and unclassified rough fish in Cedar Bayou in the vicinity of the State Highway 146 bridge. Both incidents were attributed to algae blooms.

Dickinson Bayou (Segment 1103)

Six nonpoint source related incidents were reported in Dickinson Bayou. Approximately 6.1 million fish were killed of which 82 percent were unclassified rough fish and 18 percent were Gulf menhaden. Five of these events were due to runoff from undefined areas and one resulted from urban runoff in the vicinity of Interstate 45. NPS runoff from undefined areas caused over 99 percent of the total number killed and was attributed to low dissolved oxygen levels resulting from algal blooms. Urban runoff caused less than one percent of the total number of fish killed in Dickinson Bayou, essentially all Gulf menhaden.

Trinity Bay (Segment 2422)

Runoff of irrigation water contaminated with pesticides resulted in the deaths of approximately one million unclassified rough fish and 20,000 game fish near McCallum Park due to a single incident.

Tributaries to East Galveston Bay (Segments x2423 and x0702)

In the nonpoint source category, the majority of dead fish in tributaries to East Bay were killed by undefined NPS. Five separate incidents resulted in the deaths of three million unclassified rough fish and 400 commercial and sport fish. Sixty seven percent (67%) of the total (all rough fish) were killed near the confluence of Oyster Bayou and Onion Bayou due to runoff from unidentified areas in two separate incidents. A reported one million unclassified rough fish were killed near the Sun Oil Company boat dock due to undefined area runoff. Approximately 200 each of Gulf flounder and hardhead catfish were killed due to rice field drainage involving the release of anoxic water into Robinson Lake located north of East Galveston Bay. The fifth incident was attributed to urban runoff and occurred in a private canal in Crystal Beach in which seven striped mullet were reported killed.

Tributaries to West Galveston Bay (Segment x2424)

Two incidents were recorded in tributaries to West Galveston Bay resulting in a total of 111,149 fish killed. Ninety eight percent (98%) of these were unclassified rough fish. One incident involved runoff from undefined areas killing 110,149 fish in a drainage ditch entering Highland Bayou in southern LaMarque. A second incident occurred in Highland Bayou near Hitchcock killing 1,000 Gulf menhaden due to urban runoff.

Inlets to Clear Lake (Segment x2425)

Six nonpoint source incidents were reported for drainages to Clear Lake (this segment does not include Clear Creek). A reported 1.3 million fish were killed in this segment. Rough fish species comprised 43 percent of the total and Gulf menhaden accounted for most of the remainder. Affected waterbodies included Taylor Lake (one incident), Taylor Bayou (three incidents), Ditch A of the Bayport Industrial Complex (one incident), and Nassau Bay (one incident). The Nassau Bay event was attributed to urban runoff while the other five were caused by NPS runoff originating from undefined sources. The dominant cause of fish mortality was identified as low dissolved oxygen levels due to algal blooms. Of the two sources, undefined NPS accounted for over 99 percent of the total number killed. For one of these incidents, high levels of zinc, barium, cadmium, and manganese were detected through water analysis, though this was not concluded to be a contributory cause. Urban runoff affecting Nassau Bay was reported to have killed 180 inland silversides and 90 striped mullet.

Goose Creek/San Jacinto River Confluence (Segments 2427, 2428, & x2426)

The area near the confluence of Goose Creek with the San Jacinto River included four NPS incidents occurring in San Jacinto Bay, Black Duck Bay, and Goose Creek. Of 1.6 million fish killed, 94 percent were Gulf menhaden and the remainder were unclassified rough fish and game fish. All reported NPS incidents in this area were caused by dissolved oxygen depletion due to algae blooms. The most impacting incident occurred in San Jacinto Bay south of Highway 146 and was attributed to cloudy conditions in conjunction with an algal bloom event. Resulting low dissolved oxygen conditions killed approximately 1.5 million Gulf menhaden. Two incidents in Black Duck Bay in the vicinity of the Baytown tunnel killed 52,000 fish of which 93 percent were unclassified game fish and the remainder were rough fish. Goose Creek experienced two incidents near Baytown which caused 30,874 fish deaths of which 99 percent were rough fish.

Moses Lake/Dollar Bay and Tributaries (Segment x2431)

Three incidents were reported affecting tributaries to Moses Lake and Dollar Bay. Two incidents occurring in tributaries to Moses Lake were caused by algae blooms due to undefined nutrient input and one incident in Dollar Bay was caused by runoff from an industrial landfill. A reported 3,300 fish were killed in this area of which 67 percent were rough fish, 30 percent Gulf menhaden and 3 percent unclassified game fish. A single incident occurring in the 34th Street drainage ditch located in Texas City killed 1,995 rough fish and 105 game fish due to low dissolved oxygen levels caused by an algae bloom. Another incident occurring in a Texas City canal killed 200 unclassified rough fish due to runoff from undefined areas. A single incident involving oil contaminated runoff from the Monsanto Corporation waste dump resulted in approximately 1,000 Gulf menhaden and shad killed in waters adjacent to Dollar Bay.

Tributaries to Lower Galveston Bay (Segment x2439)

The industrial district to the south of Texas City included two incidents which killed a total of 301,000 fish. Both incidents were caused by undefined NPS runoff killing predominantly unclassified rough fish. One incident occurred in Swan Lake affecting 850 game fish and 250 rough fish. The second occurred in a boat slip east of Moses Lake killing 300,000 unclassified rough fish.

Lower Galveston Bay (Segment 2439)

A single incident recorded in Lower Galveston Bay resulted in 3,750 fish killed due to nonpoint source runoff from undefined sources. Fifty three percent (53%) of these were striped bass, 27 percent were Gulf menhaden, and 20 percent were sheepshead minnows. High tides caused by Hurricane Alicia in 1983 resulted in loss of containment at the Amoco Oil Company land farm allowing oil contaminated runoff to enter surrounding marshlands.

4.6.3 Unknown Sources

Fish kills due to unknown sources were reported for a total of 13 unclassified segments and 15 unclassified waterbodies. Unknown source pollution killed a reported 164 million fish of which 96 percent were unclassified rough fish and the remainder commercial and sport fish. Five of the 28 affected waterbodies recorded 75 percent of the total number of fish killed by unknown sources. These include the Houston Ship Channel (37.6%), Upper Galveston Bay (10.9%), the Bayport Channel (10.6%), tributaries to West Galveston Bay (8.8%), and unnamed tributaries to Cedar Bayou (7%).

Relatively high concentrations of fish kill incidents due to unknown sources occurred in seven zones within the study area. These include the drainage above Taylor Lake near the community of Shoreacres (x2425), Clear Lake (2425), Dickinson Bayou (1103), Moses Lake (2431), Bayou Vista subdivision above West Galveston Bay (x2424), Galveston Bay in the vicinity of Texas City (x2439), and Offats Bayou on Galveston Island (x2439).

Tributaries to Cedar Bayou (Segment x0901)

All fish kills reported due to unknown sources adjacent to Cedar Bayou occurred in the HL&P Cedar Bayou station discharge canal. Here, three incidents resulted in the deaths of ten million rough fish, one million Gulf menhaden and 1,000 game fish species. These incidents were not attributed to discharge of heated water, but were listed as due to unknown causes.

Houston Ship Channel (Segment 1006)

An estimated 61.7 million fish were killed due to unknown sources in the Houston Ship Channel involving five incidents. Over 99 percent of the fish killed in this segment were attributed to a single dissolved oxygen depletion event which killed a reported 61.5 million unclassified rough fish between Green's Bayou and the Baytown Tunnel. Of the other events occurring here, 67 percent of the affected fish were unclassified game fish and the remainder were unclassified rough fish.

Tributaries to the Houston Ship Channel (Segment x1006)

An estimated 2,072,869 fish were killed during eight incidents caused by unknown sources in inlets to the Houston Ship Channel. Affected waterbodies included Lower Hunting Bayou, Green's Bayou, Patrick's Bayou, Old River, and an unnamed brackish pond. The most damaging incident occurred in Old River where 1.5 million unclassified herring were reported killed. Three incidents occurring in Green's Bayou killed a total of 6,533 fish comprised of approximately 50 percent striped mullet and 50 percent shad. A single incident was reported in each of the remaining three waterbodies where rough fish were the most affected fish type.

Upper Galveston Bay (Segment 2421)

Five incidents reported in Upper Galveston Bay killed an estimated 17 million fish. Ninety one percent (91%) of these were unclassified rough fish and the remainder were unclassified game fish. Eighty eight percent (97%) of the total were killed during a single incident for which extreme dissolved oxygen fluctuation was reported as the cause.

Tributaries to West Galveston Bay (Segment x2424)

An estimated 13.8 million fish were killed in the drainage area entering West Galveston Bay. These include sixteen total incidents occurring in Offats and English Bayous, Lake Madeline, Highland Bayou, Jones Bay, the Lampasas Street canal, and several unnamed canals. Three separate incidents in Offats and English Bayous resulted in 12 million fish killed. Essentially all of these were rough fish. Lake Madeline included three incidents killing approximately 9,000 fish of which 89 percent were Gulf menhaden and the remainder unclassified rough fish. A single event occurring in the Lampasas Street Canal resulted in 112,500 Gulf menhaden killed. Incidents occurring in unnamed canals at the Bayou Vista Subdivision killed a total of 1.6 million fish of which 94 percent were rough fish and the remainder were Gulf menhaden. Highland Bayou and Jones Bay both recorded small numbers of fish killed in three separate incidents.

Clear Lake Drainages (Segment x2425)

Fourteen incidents which killed 6.5 million fish were identified for the drainage entering Clear Lake from the northeast. This includes Taylor Lake and the developed area west of the Shoreacres community. Ninety four percent (94%) of the affected fish were unclassified rough fish and the remainder were game fish. Six incidents occurred in Ditches A and B of the Bayport Industrial Complex. Ninety eight percent (98%) of 42,285 fish killed in Ditch A were unclassified rough fish and an additional 200 rough fish were reported killed in Ditch B. The causes for the incidents in Ditches A and B were generally described as dissolved oxygen depletion due to unknown sources. One of the incidents occurring in Ditch B, in which 100 unclassified rough fish were killed was attributed to organic wastes. Three separate incidents occurred in Taylor Lake killing a total of 5.8 million fish. The cause was attributed to low dissolved oxygen levels. No pollutant was identified as contributing to these events. Ninety three percent (93%) of the reported fish mortality in Taylor Lake included unclassified rough fish. Approximately 647,800 fish were reported killed in three incidents arising in Taylor Bayou above Taylor Lake due to undetermined oxygen depletion. Approximately 99 percent of the fish affected here were rough fish varieties.

Clear Creek (Segment 1101)

Five incidents were reported in Clear Creek which together killed 3,571 fish. Over 97 percent of these were unclassified rough fish. An unidentified chemical was involved in one of the incidents reported in this segment which killed 300 fish of which 95 percent were unclassified rough fish. No other causal mechanisms or pollutants were identified in this segment.

Dickinson Bayou (Segment 1103)

Nine incidents due to unknown sources killing a total of 11,079,697 fish occurred in tidal portions of Dickinson Bayou. Seven of these events, affecting over 99 percent of the total, were found in the vicinity of Dickinson, of which the majority were unclassified rough fish. No causes for the incidents were identified.

Moses Lake (Segment 2431)

A single event occurred in Moses Lake in which an estimated 1,000,000 Gulf menhaden were killed. The deaths were attributed to low dissolved oxygen levels of unknown origin.

Tributaries to Moses Lake (Segment x2431)

Tributaries of Moses Lake were impacted by seven incidents from unknown sources resulting in 4.1 million fish deaths. Approximately 3.1 million of these were killed at the 34th Street drainage ditch in Texas City in five reported incidents. Essentially all of the fish killed here were unclassified rough fish. A 34th Avenue boat slip experienced an incident in which 1,000,000 unclassified rough fish were killed. A single event occurred in Moses Bayou killing 3,000 unclassified rough fish. Low dissolved oxygen levels of unknown origin were reported as the cause of each of these events.

Lower Galveston Bay (Segment 2439)

Approximately 21,850 fish were killed in Lower Galveston Bay in four unidentified source incidents. Affected fish included ten taxonomic groups as well as unclassified rough fish and game fish. Unclassified rough fish comprised 78 percent of the total, and unclassified game fish included 10 percent and commercial or sport fish species comprised the remainder.

Tributaries to Lower Galveston Bay (Segment x2439)

Galveston Bay in the vicinity of Texas City experienced six incidents due to unknown sources. Ninety eight percent (98%) of 210,700 fish reported killed here were unclassified rough fish. Two of the incidents occurred in the Texas City Harbor, two occurred in industrial barge canals and two events occurred in a pump station discharge canal. Texas City Harbor experienced 2,700 fish deaths of which 96 percent were rough fish varieties. Of these, 700 rough fish were killed by a high BOD load occurring at the Monsanto Boat Dock. An unidentified toxicity source in combination with low dissolved oxygen levels caused the deaths of 200,000 rough fish and 6,000 unclassified game fish in two separate incidents occurring in the pump station discharge canal located on Loop 197. An estimated 1,000 fish were killed in the Union Carbide Barge canal attributed only to dissolved oxygen depletion. The spill of an unidentified chemical from an unknown source killed 1,000 rough fish in an industrial barge canal connected to the Texas City Turning Basin.

4.7 Size Distribution

Fish length data were available for 1.3 percent of the total number of fish reported killed and 12 incidents due to point and nonpoint sources combined. This included 249,878 fish in 21 taxonomic groups. Point source data included the majority of fish length information accounting for 98 percent of the total and 82 percent of the PS and NPS incidents combined for which length data were available. Less than 0.001 percent of the data were associated with unknown sources.

More fish length data were available for commercial and sport fish species than for rough fish varieties. Commercial and sport fish comprised 70 percent of the total amount of data for which fish lengths were recorded although, overall, rough fish comprised 93 percent of the total number of fish reported killed with or without length information. Fourteen (14) taxonomic groups of commercial and sport species and five (5) rough fish categories were included in the fish length data. This is due, to a large extent on the importance of management activities for commercial and recreational important species by the state. For this reason, more extensive efforts go into the collection of those biological data that can be used to collect monetary damages from responsible parties.

There is limited applicability of these data to trend analyses since most of the data concerning numbers of species killed within a size range were based on a single incident. Size data that are based on a small number of incidents are less likely be representative of all fish kills in Galveston Bay.

Point Sources

Peak size ranges could be seen in the data for certain species affected by point sources. These include the Atlantic croaker, Gulf menhaden, and striped mullet. Data concerning species that have a limited size range such as the bay anchovy predictably do not show a peak affected size range. Atlantic croaker and Gulf menhaden were most affected in the four to six-inches size range. Striped mullet data showed a less defined peak ranging from 12 to 16 inches. Available data concerning numbers of each species killed in each size range due to point sources are presented in Appendix G.

The majority of fish length data obtained from point source incidents were collected during seismic testing operations (source code Y50) in West Galveston Bay. Length information was available for 241,826 fish comprising 99 percent of the total amount of data collected. A disproportionately large amount of information was gathered during these operations because an intensive collection effort was conducted in conjunction with the blasting to determine the effects on fish species in the area. These data were treated separately since the effort expended in collecting information was not comparable to that during normal fish kill investigations. Fish length data gathered during seismic testing operations are summarized in Table 4.32.

Seismic blasting primarily affected bay anchovy, pinfish, and spot. These species comprised 87 percent of the total number killed by this source. Pinfish lengths ranged from four to six inches of which 73 percent were in the five-inch range. Numbers of spot killed were evenly distributed between five and six inches. Bay anchovy, with their limited size range, was found in one to two-inches in lengths. Other affected species were the Atlantic croaker (6 to 7 inches), black drum (8 inches), sheepshead (11 to 15 inches), silver perch (5 inches), and striped mullet (6, 12 and 14 inches). The low numbers of commercial fish affected by seismic testing is probably due, in part, to the timing of the operations. Blasting occurred in the fall when adult flounder, croaker and red drum move out of the bays to spawn in the Gulf.

Length-frequency data for fish killed due to point sources other than seismic testing were available for 2,292 fish. Eighty eight percent (88%) of these were associated with cooling water discharges from power generation facilities (V24). Liquid transfer spills from barge operations (S22) caused 4.6 percent, storage tank leaks from STPs (T35) caused 4.4 percent, and the remaining three percent were killed due to mishandling spills from undefined industries (BB21), explosives detonation at construction sites (G50), oil pipeline leaks (P4), sewer line leaks (T32), and STP plant by-passes (T33).

Ninety percent (90%) of the fish length data obtained from heated water discharges involved Atlantic croaker, Gulf menhaden, gizzard shad, hardhead catfish, and red drum. All croaker deaths from this source occurred from three separate incidents during the month of May. Lengths ranged from two to 14 inches. Seventy percent of the croakers killed were in the six-inch size range and 26 percent were four inches in length. Gulf menhaden data included fish lengths of two to six inches. Eighty percent (80%) of these were in the four-inch range. Fish length data for gizzard shad included two separate incidents, one of which caused 97 percent of the total killed, all approximately 17 inches in length. The second incident affected gizzard shad in the 13 to 15 inches range. Size data for hardhead catfish ranged from two to 16 inches. Between 20 and 30 percent each of the total amount of data for this species were in either the two-, six-, or 12-inch lengths. Red drum data varied widely from 13 to 38 inches. Fifty five percent (55%) of these were between 28 and 32 inches long. The reduction in numbers beyond the 30-inch size range is probably attributable to the life cycle of the red drum. Red drum tend to stay in the bays and surf zones in tidal passes until their fourth year when a 30-inch length is normally attained. At this size, red drum reach sexual maturity and move to the Gulf permanently, except for infrequent returns to the bays. Table 4.33 summarizes fish length data associated with thermal discharges.

The remaining fish length data included 635 individuals affected by seven miscellaneous source categories (Table 4.34). These were sewer line leaks which killed 58 percent of the total, a barge liquid transfer spill involving vinyl acetate killing 16.5 percent, and a sewage leak from a storage tank accounting for 15.7 percent of the total. The remaining 10 percent were caused by several less impacting events including explosives detonation at a construction site, pipe leaks involving crude oil, a sewage treatment plant by-pass, and a mishandling spill from an unidentified industry.

TABLE 4.32
LENGTH–FREQUENCY DATA FOR FISH KILLED BY SEISMIC OPERATIONS

Fish Length (in.)	Species	Common Name	No. Killed	Percent of Total Fish Killed
1	Anchoa mitchilli	Bay Anchovy	40340	16.681
2	Anchoa mitchilli	Bay Anchovy	32997	13.645
4	Lagodon rhomboides	Pinfish	5474	2.264
5	Lagodon rhomboides	Pinfish	60690	25.097
	Leiostomus xanthurus	Spot	27503	11.373
	Bairdiella chrysoura	Silver Perch	94	0.039
			88287	36.508
6	Leiostomus xanthurus	Spot	27503	11.373
	Lagodon rhomboides	Pinfish	16583	6.857
	Micropogonias undulatus	Atlantic Croaker	5474	2.264
	Mugil cephalus	Striped Mullet	5474	2.264
			55034	22.758
7	Micropogonias undulatus	Atlantic Croaker	467	0.193
8	Pogonias cromis	Black drum	12817	5.3
11	Archosargus probatocephalus	Sheepshead	94	0.039
12	Archosargus probatocephalus	Sheepshead	187	0.077
	Mugil cephalus	Striped Mullet	5474	2.264
			5661	2.341
13	Archosargus probatocephalus	Sheepshead	187	0.077
14	Archosargus probatocephalus	Sheepshead	280	0.116
	Mugil cephalus	Striped Mullet	94	0.039
			374	0.155
15	Archosargus probatocephalus	Sheepshead	94	0.039
		Grand Total	**241826**	**100**

* Includes only those data for which fish length information were available

TABLE 4.33
LENGTH–FREQUENCY DATA FOR FISH KILLED BY THERMAL DISCHARGES

Fish Length (in.)	Lowest Practical Taxon	Common Name	No. Killed	Percent of Total Fish Killed	No. of Incidents	Fish Killed per Incident
2	Brevoortia patronus	Gulf Menhaden	80	3.949	1	80
	Arius felis	Hardhead Catfish	50	2.468	1	50
	Micropogonias undulatus	Atlantic Croaker	20	0.987	1	20
	Archosargus probatocephalus	Sheepshead	20	0.987	1	20
	Opsanus beta	Gulf Toadfish	15	0.74	1	15
	Mugil cephalus	Striped Mullet	1	0.049	1	1
			186	9.181	2	93
3	Brevoortia patronus	Gulf Menhaden	12	0.592	1	12
	Arius felis	Hardhead Catfish	2	0.099	1	2
			14	0.691	1	14
4	Brevoortia patronus	Gulf Menhaden	410	20.237	1	410
	Micropogonias undulatus	Atlantic Croaker	160	7.897	1	160
	Opsanus beta	Gulf Toadfish	25	1.234	1	25
	Archosargus probatocephalus	Sheepshead	20	0.987	1	20
			615	30.355	2	308
5	Micropogonias undulatus	Atlantic Croaker	10	0.494	1	10
	Mugil cephalus	Striped Mullet	2	0.099	1	2
			12	0.592	2	6
6	Micropogonias undulatus	Atlantic Croaker	370	18.263	1	370
	Arius felis	Hardhead Catfish	42	2.073	2	21
	Brevoortia patronus	Gulf Menhaden	10	0.494	1	10
	Paralichthys lethostigma	Southern Flounder	10	0.494	1	10
	Mugil cephalus	Striped Mullet	1	0.049	1	1
			433	21.372	3	144

* Includes only those data for which fish length information were available.

TABLE 4.33
LENGTH–FREQUENCY DATA FOR FISH KILLED BY THERMAL DISCHARGES (cont.)

Fish Length (in.)	Lowest Practical Taxon	Common Name	No. Killed	Percent of Total Fish Killed	No. of Incidents	Fish Killed per Incident (Impact)
7	Arius felis	Hardhead Catfish	12	0.592	2	6
	Micropogonias undulatus	Atlantic Croaker	1	0.049	1	1
			13	0.642	2	7
8	Micropogonias undulatus	Atlantic Croaker	40	1.974	1	40
	Cynoscion arenarius	Sand Seatrout	10	0.494	1	10
	Mugil cephalus	Striped Mullet	10	0.494	1	10
	Arius felis	Hardhead Catfish	1	0.049	1	1
			61	3.011	2	31
10	Arius felis	Hardhead Catfish	11	0.543	2	6
	Micropogonias undulatus	Atlantic Croaker	10	0.494	1	10
			21	1.037	2	11
12	Arius felis	Hardhead Catfish	60	2.962	1	60
	Mugil cephalus	Striped Mullet	15	0.74	2	8
	Micropogonias undulatus	Atlantic Croaker	10	0.494	1	10
	Cynoscion arenarius	Sand Seatrout	10	0.494	1	10
	Cynoscion nebulosus	Spotted Seatrout	6	0.296	1	6
			101	4.985	3	34
13	Cynoscion nebulosus	Spotted Seatrout	5	0.247	1	5
	Dorosoma cepedianum	Gizzard Shad	4	0.197	1	4
	Micropogonias undulatus	Atlantic Croaker	1	0.049	1	1
	Sciaenops ocellatus	Red Drum	1	0.049	1	1
			11	0.543	2	6
14	Dorosoma cepedianum	Gizzard Shad	5	0.247	1	5
	Sciaenops ocellatus	Red Drum	4	0.197	1	4
	Cynoscion nebulosus	Spotted Seatrout	3	0.148	1	3
	Micropogonias undulatus	Atlantic Croaker	1	0.049	1	1
	Pogonias cromis	Black drum	1	0.049	1	1
			14	0.691	2	7

* Includes only those data for which fish length information were available.

TABLE 4.33
LENGTH–FREQUENCY DATA FOR FISH KILLED BY THERMAL DISCHARGES
(cont.)

Fish Length (in.)	Lowest Practical Taxon	Common Name	No. Killed	Percent of Total Fish Killed	No. of Incidents	Fish Killed per Incident (Impact)
15	Mugil cephalus	Striped Mullet	18	0.888	1	18
	Cynoscion arenarius	Sand Seatrout	10	0.494	1	10
	Archosargus probatocephalus	Sheepshead	10	0.494	1	10
	Dorosoma cepedianum	Gizzard Shad	2	0.099	1	2
	Sciaenops ocellatus	Red Drum	2	0.099	1	2
			42	2.073	3	14
16	Sciaenops ocellatus	Red Drum	3	0.148	1	3
	Pogonias cromis	Black drum	1	0.049	1	1
	Arius felis	Hardhead Catfish	1	0.049	1	1
			5	0.247	2	3
17	Dorosoma cepedianum	Gizzard Shad	355	17.522	1	355
	Cynoscion nebulosus	Spotted Seatrout	3	0.148	1	3
	Sciaenops ocellatus	Red Drum	1	0.049	1	1
			359	17.72	2	180
18	Mugil cephalus	Striped Mullet	2	0.099	1	2
	Sciaenops ocellatus	Red Drum	1	0.049	1	1
			3	0.148	2	2
20	Pogonias cromis	Black drum	1	0.049	1	1
	Mugil cephalus	Striped Mullet	1	0.049	1	1
			2	0.099	2	1
GT 20	Sciaenops ocellatus	Red Drum	112	5.528	1	112
	Pogonias cromis	Black drum	2	0.099	1	2
			114	5.627	1	114
		Grand Total	2026		3	675

* Includes only those data for which fish length information were available.

TABLE 4.34
LENGTH–FREQUENCY DATA FOR FISH KILLED BY MISCELLANEOUS POINT SOURCES

Source Category	Fish Length (in.)	Species	No. Killed	Percent of Total Fish Killed	No. of Incidents
Mishandling Spill from Undefined Industry	6	Hardhead Catfish Arius felis	50	7.874	1
Detonation of Explosives at Construction Site	4	Gulf Menhaden Brevoortia patronus	8	1.26	1
Pipe Leaks from Distribution System	17	Spotted Gar Lepisosteous oculatus	1	0.157	1
Liquid Transfer Spill from Barge Operations	3	Unidentified fish	100	15.748	1
	12	Unidentified fish	5	0.787	1
			105	16.535	1
Sewer Line Leaks	36	Unidentified fish	370	58.268	1
Sewage Treatment Plant By–Pass	2	Sailfin Molly Poecilia latipinna	1	0.157	1
Sewage Leak from Storage Tank	3	Gulf Menhaden Brevoortia patronus	100	15.748	1
		Grand Total	635		7

* Includes only those data for which fish length information were available.

Nonpoint Sources

Data for 5,760 individual fish representing 2.3 percent of the total amount of fish length information were included for only three nonpoint source incidents. Species included for this source were the Atlantic croaker, Gulf menhaden, hardhead catfish, red drum, sheepshead minnow, southern flounder, striped bass, and striped mullet. A peak size range of nine to 11 inches was identified for the red drum. Little data were available to determine size ranges for other species affected by nonpoint sources. Nonpoint source pollution from undefined areas (DD7) caused 17.6 percent of the total number of fish deaths by all NPS for which fish length data were available. These were all caused by a single incident occurring in Clear Creek. Affected species include Atlantic croaker, Gulf menhaden, red drum, hardhead catfish, southern flounder, and striped mullet. Within this source category (DD7), Gulf menhaden killed were all in the three-inch range, red drum and hardhead catfish ranged from seven to 15 inches, striped mullet ranged from nine to 13 inches and southern flounder ranged from nine to 11 inches in length. A peak size range of nine to 11 inches was identified for the red drum. Little data were available to determine size ranges for other species affected by nonpoint sources. Presentation of data on species size distribution affected by nonpoint sources appears in Appendix H.

Nonpoint source pollution from undefined areas (DD7) caused 17.6 percent of the total number of fish deaths by all NPS for which fish length data were available. These were all caused by a single incident occurring in Clear Creek. Affected species include Atlantic croaker, Gulf menhaden, red drum, hardhead catfish, southern flounder, and striped mullet. Within this source category (DD7), Gulf menhaden in the three-inch size range were the most affected species. This was the only size of either Gulf menhaden or Atlantic croaker affected. Red drum and hardhead catfish killed by this source ranged from seven to 15 inches. For both species, the size range most affected was 11 inches. Striped mullet comprised 13 percent of the fish length data associated with source DD7. Seventy seven percent (77%) of striped mullet killed by source DD7 were in the 13-inch range. These data are summarized in Table 4.35.

Urban runoff (EE51) accounted for 17.4 percent of all fish killed by NPS for which length information were available. This resulted from a single incident occurring in a tributary to West Galveston Bay. All affected fish were Gulf menhaden in the three-inch size range.

Runoff from an industrial landfarm due to a large storm event (U45) affected Gulf menhaden, striped bass, and sheepshead minnows during a single event in Lower Galveston Bay. This source generated 65 percent of the total NPS mortality data that included fish lengths. All Gulf menhaden were in the three-inch range, sheepshead minnows were all one-inch in length, and striped bass ranged from six to eight-inches in length.

4.8 Temporal Patterns

Fish mortality data were grouped according to the months and years of occurrence, numbers killed, and numbers of reported incidents for each taxonomic group. These were further separated into point source, nonpoint source and unknown source causes. As described earlier, 89.3 percent of the fish reported killed were associated with unknown sources, 9.3 percent were killed by nonpoint sources and 1.4 percent were killed due to point source events.

TABLE 4.35
LENGTH–FREQUENCY DATA FOR FISH KILLED BY NONPOINT SOURCES *

Source Code	Fish Length (in.)	Species	Common Name	No. Killed	Percent of Total Fish Killed	No. of Incidents	Fish Killed per Incident (Impact)
U45	1	Cyprinodon variegatus	Sheepshead Minnow	750	13.02	1	750
**	3	Brevoortia patronus	Gulf Menhaden	2310	40.1	3	770
DD7		Micropogonias undulatus	Atlantic Croaker	130	2.257	1	130
				2440	42.36	3	813
U45	6	Morone saxatilis	Striped Bass	1000	17.36	1	1000
DD7	7	Sciaenops ocellatus	Red Drum	40	0.694	1	40
DD7		Arius felis	Hardhead Catfish	10	0.174	1	10
				50	0.868	1	50
U45	8	Morone saxatilis	Striped Bass	1000	17.36	1	1000
DD7	9	Sciaenops ocellatus	Red Drum	70	1.215	1	70
DD7		Paralichthys lethostigma	Southern Flounder	50	0.868	1	50
DD7		Mugil cephalus	Striped Mullet	20	0.347	1	20
DD7		Arius felis	Hardhead Catfish	10	0.174	1	10
				150	2.604	1	150
DD7	11	Sciaenops ocellatus	Red Drum	170	2.951	1	170
DD7		Arius felis	Hardhead Catfish	20	0.347	1	20
DD7		Paralichthys lethostigma	Southern Flounder	20	0.347	1	20
DD7		Mugil cephalus	Striped Mullet	10	0.174	1	10
				220	3.819	1	220
DD7	13	Mugil cephalus	Striped Mullet	100	1.736	1	100
DD7		Sciaenops ocellatus	Red Drum	20	0.347	1	20
DD7		Arius felis	Hardhead Catfish	10	0.174	1	10
				130	2.257	1	130
DD7	15	Arius felis	Hardhead Catfish	10	0.174	1	10
DD7		Sciaenops ocellatus	Red Drum	10	0.174	1	10
				20	0.347	1	20
			Grand Total	5760		3	1920

* Includes only those data for which fish length information were available
** Gulf menhaden : 43% U45, 43% EE51 and 13% DD7

Approximately 87 percent of the total fish mortalities caused by all sources occurred from July through October with the peak occurring in October. The largest number of incidents caused by combined sources (42 incidents or 19%) were reported in August. Peak mortality months for PS and NPS events were May and August, respectively. Monthly mortality distribution patterns are resummarized in Figure 8. Effects on individual species are provided in Appendix I for point sources and Appendix J for nonpoint sources.

The number of human-induced fish kills reported to agencies from 1970 through 1991 exhibited a general decreasing trend (Appendix K). However, the largest number of fish kills were reported in 1971 (29 fish kills) and 1982 (34 fish kills). The fewest numbers were reported in 1987 (0 fish kills), and one fish kill in 1984, 1989, and 1991 (Appendix K). During the same period, the number of fish killed also exhibited a general decreasing trend (Appendix K). The most number of fish were killed in 1972 (38,782,159) and 1977 (61,568,867). The fewest number of fish were killed in 1984 (7 dead fish) and 1987 (0 dead fish).

Point Sources

Fish mortality due to point sources was found to be less tied to seasonal patterns than were nonpoint source induced incidents. This would be expected since rainfall induced runoff has less effect on point sources such as industrial outfalls, accidental spills and explosives detonation. An exception is sewage treatment plant by-passes resulting from rain induced inflow and infiltration which cause treatment facilities to become hydraulically overloaded. Over 99 percent of fish mortalities associated with raw sewage by-passes occurred in August and September which are the peak rainfall months for the study area.

Ninety nine percent (99%) of the PS mortality occurred from May through October with peaks in May and September. Sixty percent (60%) of the fish killed during May through October were unclassified rough fish and 25 percent were Gulf menhaden. Twenty one percent (21%) of the incidents and 37 percent of the deaths were reported during the month of May (Table 4.36). September included 25.5 percent of the total number killed. Incidents occurring during May were dominated by a single event involving a leak in an ocean dumping barge. This resulted in the deaths of 500,000 unclassified rough fish. In September, a single incident during which cleaning solution was spilled into the HL&P Webster station discharge canal to Clear Lake. Here, approximately 792,000 unclassified rough fish and 8,000 game fish were killed.

Nonpoint Sources

Fish mortalities and incidents reported to be caused by nonpoint sources coincided with meteorological conditions favorable for algal induced oxygen depletion. This supports the contention that nonpoint sources were correctly identified as the cause of these fish kills in the available reports. Ninety four percent (94%) of the total number of fish killed by NPS were found between June and September (Table 4.37). This coincides with the time of year when temperatures and light intensities favor conditions for algal growth. These are also the four months when Harris, Galveston, Chambers, and Brazoria counties experience the highest average rainfalls. Nutrient input through stormwater discharge together with favorable conditions for algal growth allow the development of high concentrations of phytoplankton which, in the absence of light stop producing oxygen and cause a net reduction in dissolved oxygen levels during nighttime respiration.

FIGURE 8
MONTHLY FISH MORTALITY DISTRIBUTION PATTERNS

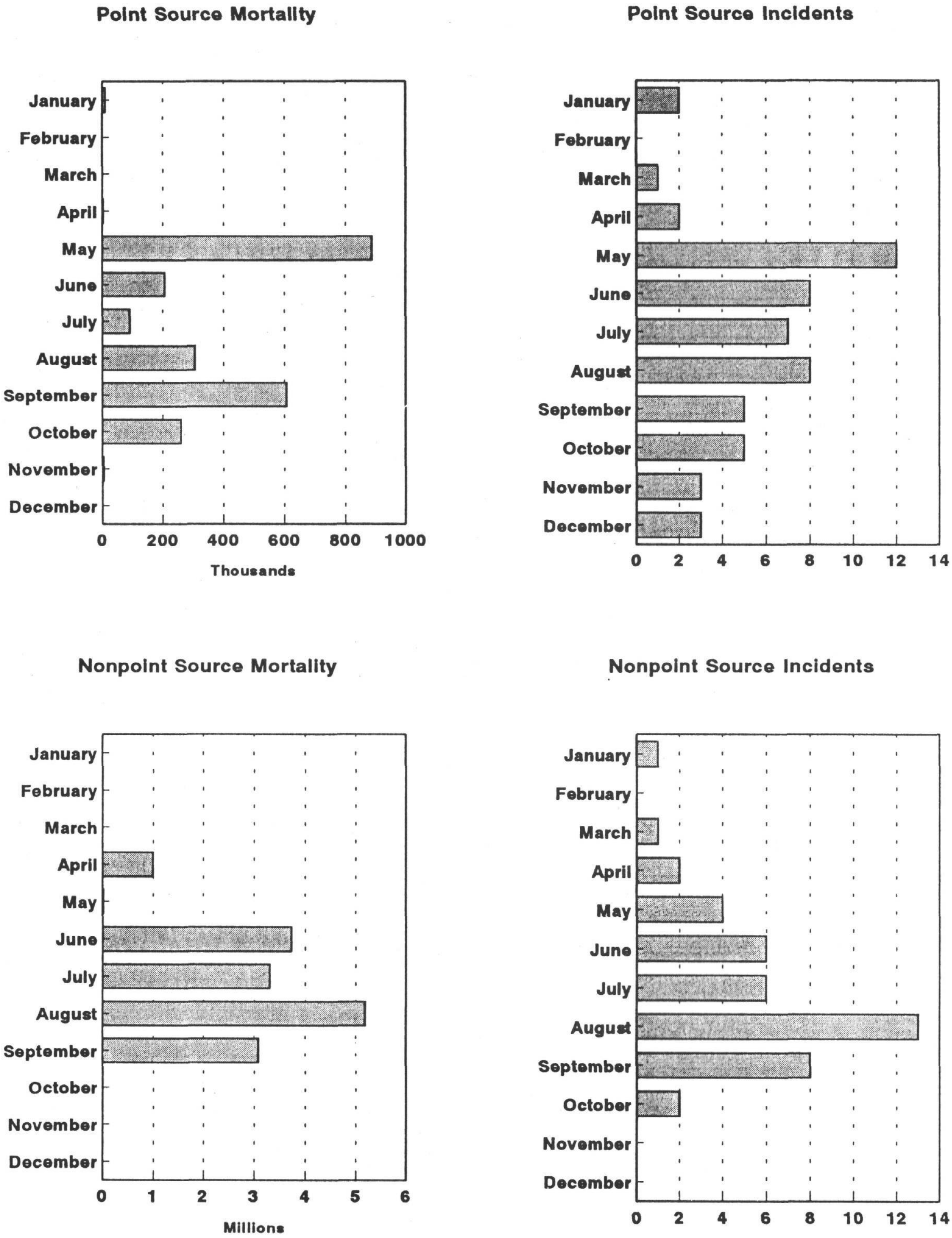


TABLE 4.36
MONTHLY SPECIES MORTALITY CAUSED BY POINT SOURCES

Month	Species	No. Killed	Percent of Total Killed by Point Sources	No. of Reported Incidents	No. Fish Killed per Incident
January	Unclassified Rough Fish	10000	0.421	1	10000
	Gambusia affinis	42	0.002	1	42
	Dorosoma cepedianum	11	<0.001	1	11
	Lepisosteus oculatus	1	<0.001	1	1
		10054	0.423	2	5027
March	Unidentified Fish	1	<0.001	1	1
April	Unclassified Rough Fish	2970	0.125	2	1485
	Unclassified Gamefish	30	0.001	2	15
		3000	0.126	2	1500
May	Unclassified Rough Fish	874145	36.77	6	145691
	Unclassified Gamefish	8478	0.357	5	1696
	Mugil cephalus	2182	0.092	3	727
	Micropogonias undulatus	1678	0.071	3	559
	Brevoortia patronus	550	0.023	2	275
	Dorosoma cepedianum	355	0.015	1	355
	Arius felis	187	0.008	3	62
	Sciaenops ocellatus	112	0.005	1	112
	Archosargus probatocephalus	56	0.002	2	28
	Pogonias cromis	55	0.002	2	28
	Cynoscion arenarius	30	0.001	1	30
	Paralichthys lethostigma	10	<0.001	1	10
		887838	37.346	12	73987

TABLE 4.36
MONTHLY SPECIES MORTALITY CAUSED BY POINT SOURCES (cont.)

Month	Species	No. Killed	Percent of Total Killed by Point-Sources	No. of Reported Incidents	Number of Fish Killed per Incident
June	Brevoortia patronus	200012	8.413	2	100006
	Unclassified Gamefish	2975	0.125	2	1488
	Micropogonias undulatus	2054	0.086	3	685
	Unidentified Fish	598	0.025	3	199
	Mugil cephalus	308	0.013	2	154
	Leiostomus xanthurus	220	0.009	1	220
	Lagodon rhomboides	206	0.009	1	206
	Cynoscion nebulosis	174	0.007	3	58
	Cynoscion arenarius	66	0.003	1	66
	Dorosoma cepedianum	52	0.002	2	26
	Sciaenops ocellatus	44	0.002	2	22
	Unclassified Rough Fish	25	0.001	1	25
	Arius felis	21	0.001	3	7
	Paralichthys lethostigma	12	0.001	1	12
	Lutjanus campechanus	2	<0.001	1	2
		206769	8.698	7	29538
July	Unidentified Fish	75441	3.173	3	25147
	Dorosoma cepedianum	9060	0.381	1	9060
	Brevoortia patronus	4212	0.177	3	1404
	Unclassified Rough Fish	1600	0.067	1	1600
	Arius felis	50	0.002	1	50
		90363	3.801	8	11295
August	Brevoortia patronus	300000	12.619	2	150000
	Unclassified Rough Fish	6150	0.259	3	2050
	Unclassified Gamefish	50	0.002	1	50
	Opsanus beta	40	0.002	1	40
	Mugil cephalus	30	0.001	1	30
	Arius felis	10	<0.001	1	10
	Unidentified Fish	7	<0.001	2	4
		306287	12.883	11	152184

TABLE 4.36
MONTHLY SPECIES MORTALITY CAUSED BY POINT SOURCES
(cont.)

Month	Species	No. Killed	Percent of Total Killed by Point-Sources	No. of Reported Incidents	No. Fish Killed per Incident
September	Unclassified Rough Fish	508415	21.386	3	169472
	Brevoortia patronus	79411	3.34	2	39706
	Mugil cephalus	18796	0.791	1	18796
	Unclassified Gamefish	85	0.004	2	43
		606707	25.521	5	121341
October	Lagodon rhomboides	82747	3.481	1	82747
	Anchoa mitchilli	73337	3.085	1	73337
	Leiostomus xanthurus	55006	2.314	1	55006
	Unclassified Rough Fish	15000	0.631	1	15000
	Pogonias cromis	12817	0.539	1	12817
	Mugil cephalus	11092	0.467	2	5546
	Micropogonias undulatus	5941	0.25	1	5941
	Brevoortia patronus	3677	0.155	2	1839
	Archosargus probatocephalus	842	0.035	1	842
	Bairdiella chrysoura	94	0.004	1	94
	Unidentified Fish	10	<0.001	1	10
		260563	10.96	5	52113
November	Cyprinodon variegatus	2000	0.084	1	2000
	Unclassified Gamefish	1988	0.084	1	1988
	Unclassified Rough Fish	812	0.034	1	812
	Mugil cephalus	500	0.021	1	500
	Cyprinodontidae (family)	300	0.013	1	300
		5600	0.236	3	1867
December	Unclassified Rough Fish	140	0.006	1	140
	Unclassified Gamefish	60	0.003	1	60
	Mugil cephalus	18	0.001	1	18
	Brevoortia patronus	8	<0.001	1	8
	Poecilia latipinna	1	<0.001	1	1
		227	0.01	3	76
	Grand Total	**2377303**		**56**	

TABLE 4.37
MONTHLY SPECIES MORTALITY CAUSED BY NONPOINT SOURCES

Month	Lowest Practical Taxon	Common Name	No. Killed	Percent Killed by NPS	No. Incidents Species Occurred
Jan	Mugil cephalus	Striped Mullet	7	<0.001	1
Mar	Unclassified Rough Fish	Rough Fish	300	0.002	1
April	Unclassified Rough Fish	Rough Fish	980006	6.004	2
	Unclassified Gamefish	Game Fish	20006	0.123	2
			1000012	6.127	
May	Unclassified Rough Fish	Rough Fish	13995	0.086	2
	Brevoortia patronus	Gulf Menhaden	1000	0.006	1
	Unclassified Gamefish	Game Fish	105	0.001	1
	Makaira nigricans	Blue Marlin	2	<0.001	1
			15102	0.093	
Jun	Unclassified Rough Fish	Rough Fish	3729048	22.846	6
	Unclassified Gamefish	Game Fish	1101	0.007	1
			3730149	22.853	
Jul	Unclassified Rough Fish	Rough Fish	3294500	20.184	6
	Unclassified Gamefish	Game Fish	12500	0.077	2
			3307000	20.261	

TABLE 4.37
MONTHLY SPECIES MORTALITY CAUSED BY NONPOINT SOURCES
(cont.)

Month	Lowest Practical Taxon	Common Name	No. Killed	Percent Killed by NPS	No. Incidents Species Occurred
Aug	Unclassified Rough Fish	Rough Fish	3035714	18.599	5
	Brevoortia patronus	Gulf Menhaden	2093774	12.828	6
	Unclassified Gamefish	Game Fish	49658	0.304	3
	Morone saxatilis	Striped Bass	2000	0.012	1
	Cyprinodon variegatus	Sheepshead Minnow	750	0.005	1
	Sciaenops ocellatus	Red Drum	310	0.002	1
	Arius felis	Hardhead Catfish	260	0.002	2
	Paralicthys albigutta	Gulf Flounder	200	0.001	1
	Mugil cephalus	Striped Mullet	180	0.001	2
	Micropogonias undulatus	Atlantic Croaker	132	0.001	2
	Leiostomus xanthurus	Spot	90	0.001	1
	Paralichthys lethostigma	Southern Flounder	70	<0.001	1
	Anchoa mitchilli	Bay Anchovy	28	<0.001	1
	Cynoscion nebulosus	Spotted Seatrout	14	<0.001	1
	Lepisosteidae (family)	Gar	1	<0.001	1
			5183181	31.755	
Sep	Brevoortia patronus	Gulf Menhaden	2575000	15.776	4
	Unclassified Rough Fish	Rough Fish (unclassifi	510200	3.126	3
	Menidia beryllina	Inland Silverside	180	0.001	1
	Mugil cephalus	Striped Mullet	90	0.001	1
			3085470	18.903	
Oct	Brevoortia patronus	Gulf Menhaden	1000	0.006	1
	Paralichthys lethostigma	Southern Flounder	5	<0.001	1
			1005	0.006	
		Grand Total	**16322226**	**100**	

4.9 Fish and Shellfish Trends in Galveston Bay - (Loeffler and Walton 1992)

In an effort to determine what impact any non-fishing human induced mortalities would have on fisheries population dynamics in Galveston Bay, it was necessary to understand the status of fisheries populations in the bay. Loeffler and Walton (1992) conducted fish and shellfish trend analyses using National Marine Fisheries Service (NMFS) historical data (1963 to 1968) and TPWD data collected by gill nets (1975 through 1980), bag seines (1977 through 1990), and otter trawls (1982 through 1990). In summarizing results, Loeffler and Walton (1992) concluded that, of the 14 species analyzed (i.e., blue crab, white shrimp, red drum, spotted seatrout, brown shrimp, grass shrimp (*Palaemonetes spp.*), Atlantic croaker, bay anchovy, black drum, Gulf menhaden, pinfish (*Lagodon rhomboides*), sand seatrout, southern flounder, and striped mullet) catch per unit effort (CPUE) showed a chronic decline only for blue crab and white shrimp. If there was no change in the population parameters of these two species, then their populations may continue to decline (Loeffler and Walton 1992). Their results also demonstrated that most species investigated showed different life stages for a single species to be a mixture of trends, including no trends. They noted that it was natural for the abundances of age classes within a species to vary and to have differing trends occurring simultaneously. However, declines in young of the year and first-time spawners (the life stage most valuable for reproduction) were of concern, particularly if they occurred simultaneously. The following results were reported for the species analyzed. However, pinfish results will not be discussed in this JN report because it was not one of the most frequently impinged species at any of the HL&P facilities or affected to any great extent in fish kills.

Blue Crab

Blue crab young of the year (25 mm to 45 mm) increased, but there was a strong decreasing trend for juveniles (50 mm to 70 mm), first-time spawners (120 mm to 140 mm), and other adult crabs (>140 mm). Loeffler and Walton (1992) suggested that the decrease in large crabs might be a response to the dramatic increase in crab harvest since 1981 and the loss of wetland habitat.

White Shrimp

Young of the year white shrimp (35 mm to 55 mm) showed no trend while all larger white shrimp (e.g., juveniles - 80 mm to 100 mm and first-time spawners - 110 mm to 130 mm) showed a marked decline in abundance. Overharvesting and/or the increase in shrimping effort in recent years were cited as probable causes for the decline.

Brown Shrimp

The trend analyses of NMFS and TPWD data for total catch and first-time spawners (85 mm to 110 mm) revealed no clear trend. However, a slight upward trend was detected from 1972 through 1980. Using TPWD data, both young of the year (30 mm to 55 mm) caught by bag seine and first-time spawners (85 mm to 110 mm) caught by trawl showed great year to year variation without a significant annual trend. Overfishing and loss of vegetated habitat (salt marsh and seagrass beds) were discussed as two factors that may affect the abundance of brown shrimp.

Grass Shrimp

Grass shrimp (25 mm to 35 mm) in bag seine catches decreased from 1983 to 1987 followed by an increase through 1990. Loeffler and Walton (1992) reported that the documented quadratic trends may reflect normal population fluctuations or may be the result of local environmental changes.

Atlantic Croaker

Young of the year croaker (30 mm to 50 mm) increased from 1977 to 1983, then decreased through 1989. Croakers approaching their first spawn (115 mm to 135 mm) caught by trawl increased from 1983 through 1990. Also, juvenile croaker (no lengths given) caught by bag seines decreased slightly while mature croaker (230 mm to 275 mm) increased in trawl and gill net catches. The inference was made that populations of mature croaker were influenced by other factors than juveniles because of the increasing trend in trawl and gill net data contrasted with the quadratic trend and net decrease in the bag seine data. They stated that the differences could be related to differing food supplies, loss of nursery habitat, or higher survival from juvenile to adult life stages.

Bay Anchovy

Juvenile (15 mm to 34 mm), first-time spawner (35 mm to 54 mm), and remaining adult (>55 mm) bay anchovies caught by bag seine decreased in abundance from 1978 to 1990. In contrast, similar size classes caught by trawl showed an increasing trend from 1983 to 1990. Loeffler and Walton (1992) stated that the differences may be related to gear type used since both showed slight increases between 1984 through 1990.

Black Drum

Young of the year (55 mm to 85 mm) black drum decreased in abundance from 1978 through 1990 while first-time spawners (300 mm to 400 mm) and remaining adults (>400 mm) increased. The drop in abundance of young of the year in 1984 might be related to the freeze in 1983 to 1984 and a toxic dinoflagellate bloom off Galveston in June 1984. They also suggested that increases in abundance of first-time spawners and remaining adult black drum since 1984 might be related to regulation of the commercial and sport fisheries.

Gulf Menhaden

Young of the year (20 mm to 30 mm) menhaden CPUE decreased while there was little change in first-time spawners (100 mm to 120 mm), and remaining adults showed no apparent trend. The factors affecting catch rates for the different size classes vary. The authors inferred that factors affecting young fish (e.g., loss of estuarine marsh) had a more profound effect on menhaden populations than those factors affecting older menhaden.

Red Drum

Young of the year (25 mm to 65 mm) red drum CPUE gradually increased from 1978 until 1982, then decreased from 1983 to 1986, followed by a rapid increase in 1987. Both juvenile (375 mm to 500 mm) and first-time spawners (501 mm to 700 mm) showed a general increase in CPUE from 1977 through 1986 followed by a decline in 1987. Year-to-year variation in CPUE was large for young of the year and juveniles in comparison with that observed in first-time spawners. The causes of the observed trends were not fully understood. However, Loeffler and Walton (1992) cited the following factors as possibly having an effect: loss of habitat, fluctuations in prey populations (e.g., shrimp), and regulations and stocking efforts.

Sand Seatrout

Bag seine results were inconclusive. However, trawl and gill net results showed: an increase in juveniles (65 mm to 85 mm); no trend for first-time spawners (140 mm to 160 mm); and a decrease in remaining adults. Fishing pressure was cited as one possible reason for differing trends among size groups. In addition, loss of the preferred food supply of adults and shrimp bycatch were mentioned as needing further investigation.

Southern Flounder

No significant trends in CPUE for young of the year (20 mm to 45 mm) or adult (>250 mm) southern flounder were reported, suggesting a balance of factors increasing and decreasing the abundance of this species.

Spotted Seatrout

Young of the year (35 mm to 75 mm) spotted seatrout showed a linear decrease in abundance from 1978 to 1990. First-time spawners' (350 mm to 450 mm) CPUE increased from 1977 to 1987, followed by a decrease in 1990. Remaining adults (>450 mm) also increased nonlinearly in abundance. The authors stated that the decrease of young of the year fish may be related to the loss of nursery habitat. The recent slight decrease in adult populations may be random variation, a cyclic pattern, a true decrease related to the decrease in juveniles, or increased fishing pressure.

Striped Mullet

Young of the year striped mullet (20 mm to 40 mm) had peak CPUEs in 1981 and 1987 with five years of poor recruitment between peaks. First-time spawners (230 mm to 275 mm) increased from 1983 to 1990, with peaks in the winters of 1985-86 and 1989-90. CPUEs for remaining adults had a decreasing trend from 1975 to 1979 (e.g., 275 mm to 314 mm) then maintained a constant level through 1990. Adults >314 mm had no quantifiable trend during the same period. The authors concluded that further research was necessary to determine factors affecting changes in the abundance of various striped mullet size classes.