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BIOLOGICAL AND ECONOMICAL ASSESSMENT OF AN OYSTER RESOURCE DEVELOPMENT PROJECT IN APALACHICOLA BAY, FLORIDA

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ABSTRACT During 1986 and 1987, the Florida Department of Natural Resources restored 155.8 hectares (385 acres) of oyster reefs in Apalachicola Bay, Franklin County, Florida. Oyster reefs, including substrate and standing stocks were severely depleted during passage of Hurricane Elena in September 1985. Special management practices were applied and recovery processes were monitored on restored reefs. Field surveys were conducted on Bulkhead Bar, a 20.2 hectare (50 acre) restored reef. Standing stocks increased to 160 oysters/m^2 one year after setting and reached 578 oysters/m^2 after 18 months. Controlled harvesting was applied when standing stocks reached densities of 22.7 marketable oysters/m^2; estimated yields ranged from 15,648 to 18,373 bags. Controlled harvesting accounted for 6,083 bags valued at $135,020 in seven days; added yields during the summer harvesting season were estimated at 11,734 bags. Combined yields were predicted to provide $395,515 in dockside revenues. Actual and estimated revenues from Bulkhead Bar demonstrated that restoration costs were recovered after the first harvesting season. Cost:benefit ratios ranged from 1:2.3 after two years to 1:20.7 after ten years. Economic analyses indicated that restoration efforts ultimately benefit levels of the industry from harvest to retail sales; added value benefits from Bulkhead Bar were predicted to reach $1,575,000 after two years.

KEY WORDS: oysters, Apalachicola Bay, resource management, population dynamics, economics

INTRODUCTION

Extreme environmental and meteorological conditions associated with the passage of Hurricane Elena from 29 August through 2 September 1985 resulted in severe devastation of oyster reefs in Apalachicola Bay, Franklin County, Florida (Berrigan 1988). Apalachicola Bay contains Florida's most commercially productive reefs and was the source of 92% of the oysters, *Crassostrea virginica* (Gmelin 1791), landed in the State in 1984. Reported landings for Franklin County in 1984 were 6.2 million pounds (2,820,000 kg) of oyster meats valued in excess of $6.8 million. From January through August 1985, 3.8 million pounds (1,720,000 kg) were landed and less than 0.5 million pounds (230,000 kg) were landed in 1986. Declining landings were a direct result of resource losses associated with Hurricane Elena (Berrigan 1989).

Following Hurricane Elena, assessments of oyster resources throughout the Apalachicola Bay system identified oyster reefs located in western St. George Sound and eastern Apalachicola Bay as the most severely damaged (Berrigan 1988). Reefs classified as severely impacted were historically productive reefs which sustained extensive losses of live oysters and cultch or were subjected to extensive sedimentation. Progressive recovery of severely impacted reefs was expected to be slow and largely dependent upon reconstructive efforts.

In response to debilitating losses of oyster resources, the Florida Department of Natural Resources and the Florida Marine Fisheries Commission implemented comprehensive management programs and regulatory restrictions to foster resource recovery and facilitate restoration. An important component of the recovery plan was the large scale restoration of severely damaged reefs. Oyster resource restoration, based on the concept of providing accessible and suitable substrate for oyster larvae to attach, has long been an accepted practice of fisheries managers and shellfish leaseholders along the Gulf Coast (May 1971, Whitfield 1973, Dugas 1977, MacKenzie 1977, and Hoffstetter 1981). Although, the Florida Department of Natural Resources has managed a program to construct and rehabilitate oyster reefs for 40 years (Whitfield and Beaumariage 1977, Futch 1983), the extent of damage resulting from Hurricane Elena necessitated expanding the scope of restoration efforts (Berrigan 1988).

Expanded resource restoration efforts were implemented using emergency assistance funding through the Commercial Fisheries Research and Development Act, Public Law 88-309(4B). In 1985, $1,570,000 were released from congressional appropriations to restore damaged reefs in Apalachicola Bay. In 1986, $918,000 were used to restore severely damaged reefs and $553,960 were released to complete the project in 1987. Approximately 385 acres (155.8 ha) were restored using 96,230 yd^3 (73,578 m^3) of clam shell.

Reefs restored during this project were protected as Special Resource Recovery Areas and special management was applied while recovery progressed. Restored reefs were monitored throughout the recovery process, and emergency measures to regulate oyster harvesting provided a unique opportunity to focus on the value of fisheries information. Stock assessments, yield estimates, harvesting pressure, and landing statistics were used to determine the success of resource rehabilitation programs. Damaged reefs were expected to produce marketable oysters as early as two years after restoration, demonstrating the cost effectiveness of oyster resource development programs.

A special harvesting season on Bulkhead Bar was implemented in May 1989 based on the availability of stocks sufficient to support limited harvesting. Controlled harvesting during the special season was designed to provide a mechanism to evaluate fisheries management practices and reduce harvesting pressure on reefs in the winter harvesting area, while providing timely economic benefits to the depressed oyster industry.

MATERIALS AND METHODS

Bulkhead Bar, a restored reef presented the most advantageous experimental protocol to evaluate reef restoration and shellfish management practices. Successful spatfall during September 1987 was verified in May 1988, subsequent sampling indicated growth among juvenile oysters, and in April 1989 field surveys demonstrated that marketable oyster stocks were sufficient to support commercial harvesting activity. Additionally, the reef's location within the summer harvesting area provided protection from harvesting throughout the recovery process. Initial harvesting was conducted by commercial harvesters under controlled conditions to maintain the "natural laboratory" experimental protocol. Controlled harvesting efforts applied to a special harvesting season provided the mechanism to 1) evaluate stock assessment techniques, 2) validate population estimates as a predictive index for potential landings, 3) monitor oyster population dynamics in response to harvesting pressure, and 4) accurately project cost:benefit ratios for resource development projects.

Description of Study Area

Bulkhead Bar is an oyster reef located in eastern Apalachicola Bay, approximately 10 km southeast of the mouth of the Apalachicola River. Historically, Bulkhead Bar was part of a large consolidated shoal orientated perpendicular to the mainland and St. George Island forming a geographic demarcation between Apalachicola Bay to the west and St. George Sound to the east. More recently, construction of the Bryant Patton Bridge and Causeway along the long axis of the shoal and dredging the Gulf Intracoastal Waterway across the shoal, have obscured the geographical distinction of the reef (Fig. 1).

Extreme hydrologic activity associated with Hurricane Elena reduced the southwestern portion of Bulkhead Bar to a relatively barren and compacted shoal. The surface of the shoal was covered by sand and shell rubble; live oysters and shell suitable for supporting oysters were conspicuously absent. Affected areas exhibited moderate elevation surrounded by areas of soft sediments; water depths ranged from 1 to 2 meters (MLW).

Shellfish growing waters in the Apalachicola Bay system are classified as Conditionally Approved based on bacteriological water quality and seasonality. Oyster harvesting in Conditionally Approved shellfish growing waters is regulated on a seasonal basis, including summer and winter harvesting seasons. Harvesting during the summer season is permitted from July 1 through September 30; the winter harvesting season extends from October 1 through June 30. Bulkhead Bar is located in the summer harvesting area in Apalachicola Bay near the boundary between the winter harvesting area in St. George Sound. Bacteriological water quality at Bulkhead Bar satisfies criteria for Conditionally Approved shellfish growing waters during the summer months, but does not satisfy criteria necessary for Conditionally Approved shellfish growing waters during all the winter months. However, under favorable meteorological and hydrographic conditions, water quality satisfies criteria for harvesting during the warmer and drier months of the winter harvesting season.

Resource Restoration

Methods for applying cultch to improve substrate characteristics have become common practice for increasing oyster productivity by promoting larval attachment and survival. Cultch planted in areas where natural reproduction occurs stimulates larval setting and establishment of new oyster populations. Reef restoration activities were initiated in May to take advantage of potential summer through fall spatfall peaks. Earlier research had shown that spawning in Apalachicola Bay is seasonally regular and of long duration, but that setting intensity is variable (Ingle and Dawson 1953). More recent investigations indicated that successful spatfall occurred in eastern portions of the bay during late summer and in the fall (Berrigan 1989).

Oyster reef restoration was divided into two phases; Phase I was completed in May 1986 and Phase II was completed in June 1987 (Table 1). During Phase I, 225 acres (91.1 hectares) of oyster reefs were restored using 56,470 yd^3 (43,177 m^3) of clam shell; including acreage on Hotel Bar in Apalachicola Bay and Peanut Ridge Bar in St. in St. George Sound. During Phase II, 160 acres (64.7 hectares) were restored using 39,760 yd^3 (30,401 m^3) of clam shell; including acreage on Cat Point and Bulkhead Bar in Apalachicola Bay and Peanut Patch Bar in St. George Sound (Figure 1). Restoration of Bulkhead Bar was completed on 3 June 1987 and required 12,500 yd^3 (9,558 m^3) of shell at a cost of $174,265. The amount of reef area restored was based on application rates of approximately 250 yd^3 of cultch/acre (472 m^3/ha).

Clam shells, *Rangia* spp., dredged from Lake Pontchartrain, Louisiana, were transported by barge to planting sites where they were transferred to shallow draft barges. Cultch was washed overboard using high pressure water cannons and pumps aboard a second barge. Both units were positioned and moved across reefs by a tug boat. Perimeter boundaries were marked before restoration efforts were initiated. Initially, boundary markers were positioned and reef areas calculated using LORAN C. Bulkhead Bar was resurveyed after construction and the delineated area was calculated using coordinate geometry to 49.9 acres (20.2 ha).

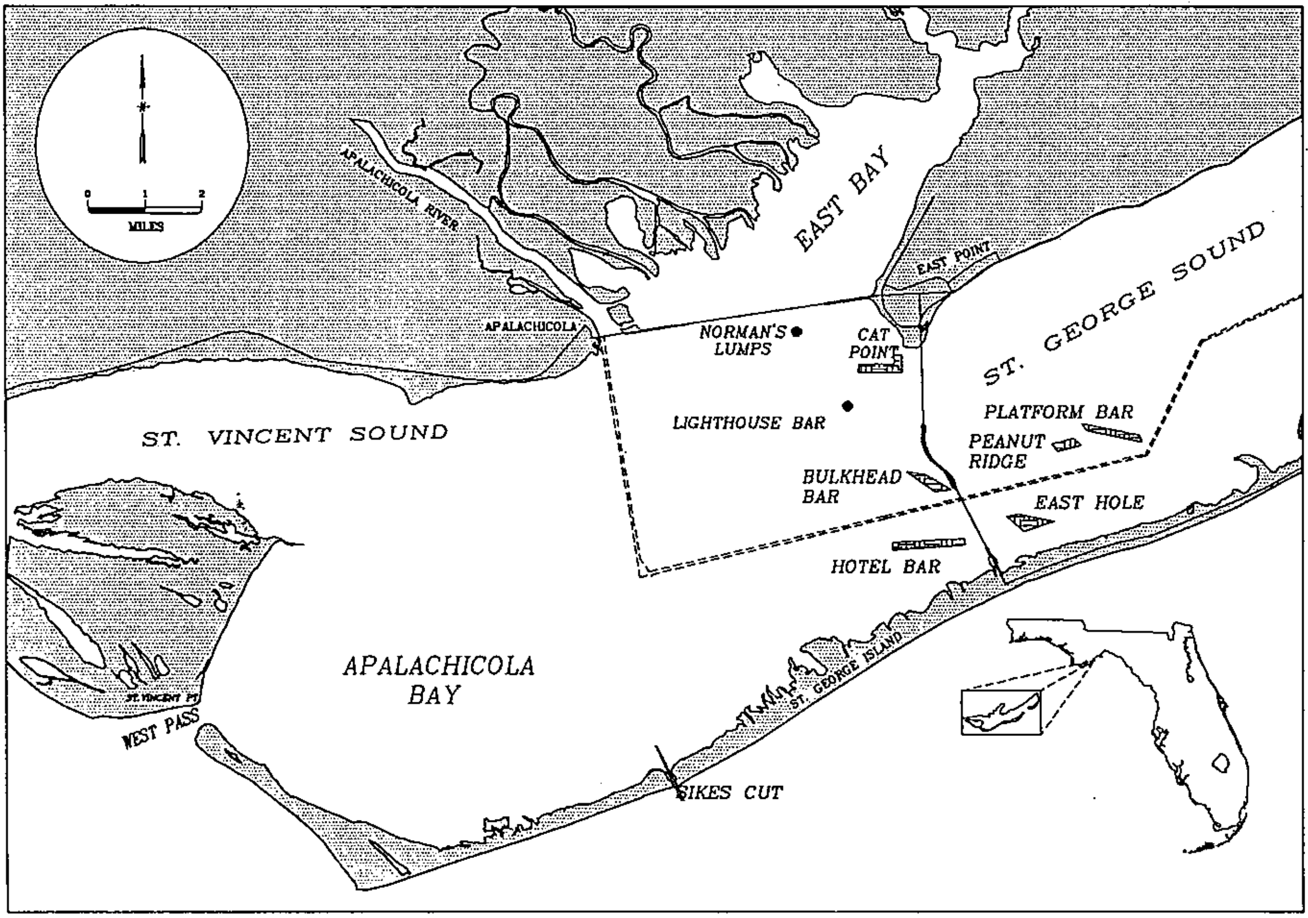

Figure 1. Location of resource restoration sites in Apalachicola Bay, Florida from 1986 through 1987.

Approximately 45 acres (18.2 ha) of the delineated 50 acres (20.2 ha) of Bulkhead Bar were improved during the cultch planting project. Maneuvering barges under various hydrographic and meteorological conditions made uniform application difficult, especially along peripheral areas. Estimates of restored area based on effective cultch dispersal alone, may represent overestimates of improved substrate. Field surveys conducted on transects across Bulkhead Bar on 21 April 1989 demonstrated density differences across the delineated reef area. Differences between quadrats and transects reflected levels of substrate improvement resulting from varying cultch application rates and indicated that restoration was not uniform over the entire reef. The abundance of cultch and oysters was used to define reef areas as fully restored, improved, and unimproved. Estimates of fully restored substrate included 25 acres (10.1

TABLE 1.

Oyster reefs in Apalachicola Bay and St. George Sound restored in May 1986 and June 1987

			Cultch		Area		
Reef	Phase	Date	(m^3)	(yd^3)	(ha)	(ac)	Cost ($)
Platform Bar	I	5/86	12,593	16,470	26.3	65	267,638
East Hole Bar	I	5/86	12,425	16,250	24.3	60	264,262
Hotel Bar	I	5/68	18,159	23,750	40.5	100	386,097
Phase I Totals			43,177	56,470	91.1	225	917,997
Cat Point	II	6/87	13,197	17,260	28.3	70	240,301
Bulkhead Bar	II	6/87	9,558	12,500	20.2	50	174,265
Peanut Ridge	II	6/87	7,646	10,000	16.2	40	139,380
Phase II Totals			30,401	39,760	64.7	160	553,946
Project Totals			73,578	96,230	155.8	385	1,471,943

hectares) in the center of the reef, improved areas included 20 acres (8.1 hectares) in marginal areas, and about 5 acres (2.0 hectares) in peripheral areas were not improved (Table 2). Subsequent field surveys were confined to transects in areas where substrate had been improved and restored.

Resource Assessment

Field surveys were conducted on Bulkhead Bar using sampling protocol and statistical analyses designed to validate sampling and analytical techniques used in a comprehensive oyster resource assessment program in Apalachicola Bay which began in 1982 (Berrigan 1989). Oyster populations were compared using the Kruskal-Wallis test to determine significant differences between length-frequency distributions among replicate samples and between successive sampling intervals (Statistical Analysis System 1985). Sampling on Bulkhead Bar was conducted on 29 September 1988, 21 April 1989, 23 May 1989, and 1 November 1989. These dates were approximately 16 and 23 months after restoration, following controlled harvesting, and following the summer harvesting season, respectively. Transects were established across the restored reef and quadrats were selected along transects by tossing a PVC grid from the survey vessel. The number of samples ranged from 5 to 20 quadrats per sampling period (Table 2). Transects and quadrats were considered unbiased, since the reef was subtidal and oyster distributions and densities could not be determined from surface observations.

A weighted 0.25 m^2 PVC grid was used to delineate sample quadrats. Samples were collected by divers; live oysters, shell, and associated fauna were removed to a depth of 15 cm, placed in mesh collecting bags, and delivered to the survey vessel. Live oysters were measured to the nearest lower 0.5 cm length (longest dimension). All live oysters were measured from samples collected on 29 September 1988, 23 May 1989, and 1 November 1989. During the 21 April 1989 sampling period, only oysters greater than 75 mm (3 in) were measured from all 20 quadrats; all live oysters were measured from 10 quadrats. Substrate characteristics, competitors, and freshly dead oysters (boxes) were noted.

Standing stocks were estimated from oysters collected from 0.25 m^2 quadrats. Length-frequency distributions were developed for each sampling period (Figure 2). Oysters equal to or greater than 25 mm (1 in) in length were used in population estimates. Oysters between 50 mm to 70 mm in length were used to predict growth rates, mortality rates, and recruitment into marketable size classes (greater than or equal to 75 mm). Legal-sized oysters equal to or greater than 75 mm in length provided estimates of marketable oysters/m^2 and densities were extrapolated to calculate potential production levels. Estimated yield was defined as bags/acre, where the capacity of a 60 lb bag (27.2 kg) was 225 oysters (Berrigan 1989). Production estimates used in data analyses were extrapolated for 45 (18.2 ha) and 50 (20.2 ha) acres. Estimated standing stocks and yields were

TABLE 2.
Population parameters for oysters sampled during field surveys of Bulkhead Bar.

Transect No.	No. Oysters (0.25 m^2)	Mean (mm)	Stand. Dev.	Range Min. (mm)	Range Max. (mm)
		September 1988			
1	31	41.9	11.4	25	65
1	66	47.7	8.6	30	80
1	31	47.4	9.7	30	70
1	27	46.1	9.8	30	70
1	46	45.9	9.6	30	65
1 (Total)	201	46.1	9.7	25	80
		April 1989			
1	278	36.6	13.6	25	135
1	74	40.8	19.3	25	95
1	132	35.6	14.6	25	90
1	120	46.1	19.1	25	90
1	161	32.5	10.5	25	75
2	71	33.2	13.2	25	80
2	83	33.8	14.7	25	80
2	295	32.2	11.8	25	110
2	86	35.3	15.9	25	90
2	142	40.9	21.8	25	110
2 (Total)	1,142	36.2	15.6	25	135
		May 1989			
1	63	30.5	11.0	25	70
1	42	30.2	11.2	25	85
1	96	33.0	14.2	25	70
1	99	32.8	13.8	25	90
1	150	30.9	9.5	25	80
2	127	36.9	15.5	25	95
2	90	37.3	15.6	25	95
2	74	36.6	17.5	25	90
2	129	33.6	12.9	25	70
2	146	35.3	15.6	25	110
3	223	33.3	15.6	25	100
3	255	34.1	12.8	25	80
3	116	34.3	16.1	25	95
3	84	30.7	14.2	25	95
3	43	34.3	13.4	25	70
4	21	45.0	13.3	25	80
4	42	34.4	10.7	25	60
4	21	30.2	11.1	25	65
4	109	35.0	14.8	25	95
4	89	35.6	14.1	25	90
4 (Total)	2,019	34.0	14.2	25	110
		November 1989			
1	70	40.4	16.0	25	85
1	58	32.8	10.0	25	70
1	33	33.5	8.4	25	60
1	31	39.8	14.7	25	75
1	120	39.0	11.6	25	80
2	44	34.3	13.8	25	80
2	47	33.3	12.3	25	80
2	40	37.8	9.5	25	65
2	55	36.6	12.7	25	75
2	51	35.3	11.6	25	70
3	18	32.2	8.4	25	60
3	88	34.0	9.9	25	70
3	74	39.3	11.8	25	70
3	25	32.4	9.7	25	60
3	40	39.9	11.7	25	75
3 (Total)	794	36.6	12.1	25	85

expressed as oysters per acre and bags per acre, conforming to common terminology.

Natural Mortality

Estimates of population losses were important in predicting yields based on standing stock assessments. Mortality rates for the populations surveyed were expressed as:

$$r_1 = \frac{Y_2 - Y_1}{t_2 - t_1}$$

where Y_2 and Y_1 are densities in oysters/m^2 and t_2 and t_1 are the corresponding times (weeks) at which the densities were observed (Tyler and Gallucci 1980). Thus, if Y_1, the time period, and r_1 are known, densities (Y_2) can be predicted. Estimated mortality rates were calculated using direct correlations between predicted densities over selected time intervals. These calculations do not account for numerous factors affecting natural mortality, but provide an estimate of mortality among similar populations.

Harvesting

Field surveys on 21 April 1989 indicated that standing oyster stocks on Bulkhead Bar were sufficient to support commercial harvesting. Concurrently, water quality data and bacteriological analyses demonstrated that water quality parameters satisfied Conditionally Approved shellfish growing water criteria and did not threaten public health. In accordance with the management plan to foster resource and economic recovery of Apalachicola Bay's oyster industry, the Department of Natural Resources recommended a special harvesting season.

Oyster harvesting was permitted on Bulkhead Bar from 8 May through 18 May 1989. Oystermen were asked to participate in controlled harvesting under current management provisions for commercial harvesting in Apalachicola Bay. Harvesting from the specified reef was permitted from sunrise until 4 p.m. on Monday through Thursday, and all oysters harvested were reported and tagged at the on-site check station before they were delivered to certified shellfish dealers. Check stations, established as part of the recovery management plan following Hurricane Elena, monitored daily harvests, number of vessels engaged in harvesting, catch per vessel, and number of oysters per bag. Provisions for commercial harvesting also included size limits of 3 inches (75 mm), daily bag limits of fifteen 60-lb bags (408 kg), and gear was restricted to hand tongs only.

Before oysters were tagged at the check station, selected bags were routinely sampled to determine whether they met legal size requirements. Additionally, oysters from selected bags were counted to determine the number of oysters/bag. Counts during routine inspections ranged from 255 to 423 oysters/bag and averaged 360 oysters/bag. Since yield estimates were based on bags containing 225 oysters, the actual number of "tagged bags" was converted to "adjusted bags" also containing 225 oysters.

Controlled harvesting was terminated at 4:00 pm on 18 May 1989 due to declining landings and reduced harvesting effort. Harvesting from Bulkhead Bar was prohibited until 3 July 1989, when harvesting was permitted under conditions of the summer harvesting season. During the summer harvesting season, harvesting was permitted Monday through Thursday from July 1 through September 30. Exclusive monitoring of Bulkhead Bar, including harvesting effort and landings was not part of the monitoring program during the summer harvesting season.

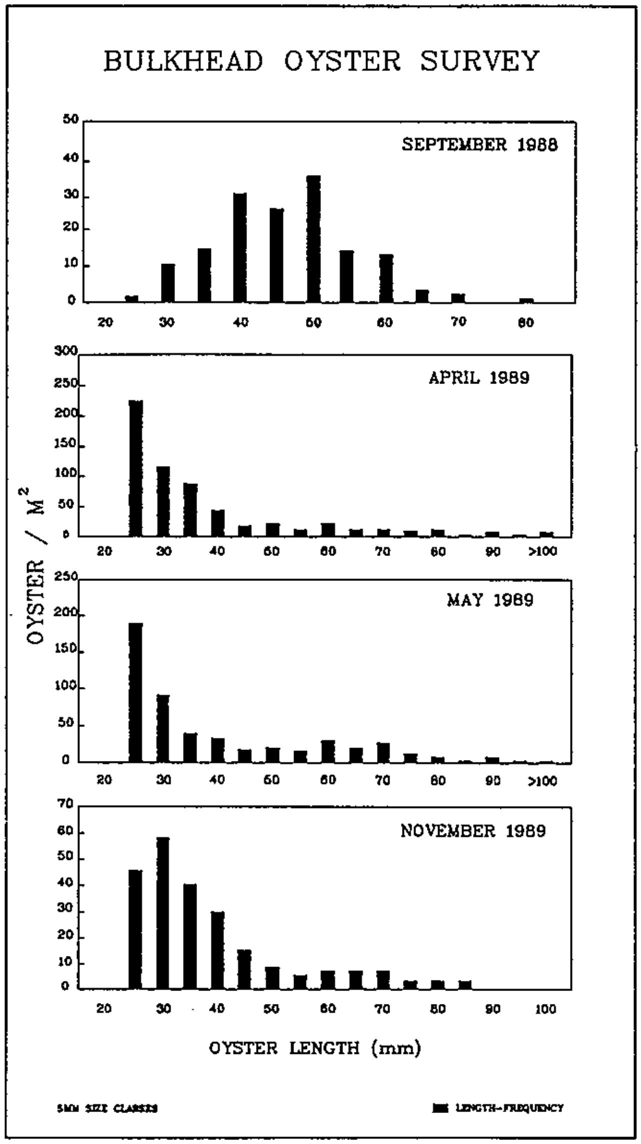

Figure 2. Length-frequency histograms for oyster populations on Bulkhead Bar between September 1988 and November 1989.

RESULTS

Successful spatfall occurred on Bulkhead Bar four times during the survey period (June 1987 through October 1989). Initially, spatfall occurred in fall 1987, followed by intensive spatfall in fall 1988 and moderate spatfall events in spring and fall 1989. Field surveys indicated standing stocks increased from essentially zero to 160 oysters/m^2 in one year. Standing stocks increased to 578 oysters/m^2 in April 1989 and declined to 212 oysters/m^2 in November 1989 (Figure 2).

Field surveys of Bulkhead Bar on 21 April 1989 indicated that standing stocks of marketable size oysters (3 inches) exceeded 17.4 oysters/m^2; standing stocks of marketable size oysters from more productive reef areas ranged from 22.7 to 25.6 oysters/m^2. Standing stocks, defined as marketable oysters/m^2, were converted to estimated yields, defined as bags/acre. Estimated yields ranged from 313 bags/acre over the entire reef to 460 bags/acre over the most productive reef areas (Table 3).

Standing stocks of marketable oysters were calculated by extrapolating the number of oysters equal to or greater than 75 mm/0.25 m^2. Estimated yields and economic benefits were calculated using the following assumptions; a) delineated area of Bulkhead Bar was 50 acres (20.25 hectares), b) improved reef area was estimated at 45 acres (18.23 hectares), c) a 60-lb bag contains 225 oysters, and d) shellstock was valued at $0.37/lb ($22.20/bag). Differences in standing stocks and estimated yields reflected areas where substrate differences were demonstrated. Accordingly, densities of 17.4 oysters/m^2 were extrapolated to 3,520,900 marketable oysters or 15,648 bags for 50 acres. Similarly, densities of 22.7 oysters, representing only the improved substrate, were extrapolated to 4,134,015 marketable oysters or 18,373 bags for 45 acres. Standing stocks represented potential dockside revenues ranging from $347,385 to $407,880, if marketable stocks could be completely harvested.

TABLE 3.

Population estimates for oysters on a restored reef, Bulkhead Bar, and two undamaged natural reefs, Lighthouse Bar and Norman's Lumps, before and after the 1989 summer harvesting season.

Date	No. Quad.	Field Surveys Oysters /m^2	>50mm/m^2	>75mm/m^2	>75mm/ac	Bags /acre
			Bulkhead Bar			
9/29/88	5[a]	161	73	0.8	3,561	16
4/21/89	10[a]	577	104	25.6	103,603	460
	15[b]	NS	NS	22.7	91,867	408
	20[c]	NS	NS	17.4	70,418	313
5/23/89	20[b]	404	61	10.6	42,898	191
11/1/89[d]	15[b]	212	29	3.5	14,165	63
			Lighthouse Bar			
6/13/89	5	300	127	16.8	67,990	302
10/31/89[d]	5	163	83	6.4	25,901	115
			Norman's Lumps			
6/13/89	10	157	82	18.4	74,465	331
10/31/89[d]	10	146	42	5.2	21,044	94

[a] includes quadrats from restored areas (25 acres);
[b] includes quadrats from improved areas (20 acres);
[c] includes quadrats from unimproved areas (5 acres);
[d] samples collected after 1989 summer harvesting season;
NS indicates that only oysters >75 mm were measured.

The special harvesting season in May 1989 marked the first time that the Bulkhead Bar Resource Recovery Area had been commercially harvested since it was restored. Fisheries statistics collected at the on-site check station indicated that 3,802 bags of oysters were harvested by 561 vessel-trips during seven harvesting days. Actual bags counts (3,802 tagged bags) were recalculated to provide an adjusted value (adjusted count) which more accurately represented total landings. Bags measured at check stations contained an average of 360 oysters; adjusted landings were converted to 1,368,720 oysters, or 6,082 bags when adjusted to 225 oysters/bag (Table 4). Dockside value of oysters landed during the controlled harvesting period was estimated at $135,020 (6,082 bags @ $22.20/60-lb bag).

Daily landings ranged from 1,944 bags (tagged) on the first day to 33 bags (tagged) on the final day. Similarly, the number of vessels engaged in harvesting declined from 208 to 10 vessels during the same period. Concomitant efficiency declined from 9.3 to 3.3 bags/vessel/day. Initial plans were to continue controlled harvesting throughout May, discontinue harvesting during June, and continue harvesting during the summer harvesting season (July through September). However, concentrated harvesting pressure rapidly depleted standing stocks and substantially shortened the planned harvesting period. Harvesting during the first two days accounted for 77.5% of the total landings. The marked decrease in harvesting effort after the second day indicated that stocks were rapidly exploited to a level where harvesting efficiency was no longer more advantageous on Bulkhead Bar than on reefs in the winter harvesting area. Continued declines in harvesting effort and landings prompted the termination of the special season after seven harvesting days. Field surveys following controlled harvesting indicated that yield estimates had been reduced to a level where harvesting effort was predicted to slow.

Field surveys of Bulkhead Bar on 23 May 1989 following the controlled harvesting period indicated that standing stocks of marketable size oysters had been reduced to densities of 10.6 oysters/m^2; estimated yield was reduced to 191 bags/acre (Table 3). Potential production from the remaining population extrapolated over 45 acres was 1,930,410 marketable oysters, indicating a reduction of 2,203,605 oysters between sampling periods. Landings during controlled harvesting accounted for 1,368,720 oysters, or 62% of the estimated reduction in standing stocks, assuming that standing stocks and harvesting effort were concentrated on improved areas only.

Following the summer harvesting season, field surveys on 1 November 1989 indicated that densities were reduced to 3.5 marketable oysters/m^2, or 63 bags/acre on Bulkhead Bar. Potential yields from 45 acres, based on projected

TABLE 4.

Tagged and adjusted oyster landings from Bulkhead Bar reported to monitoring stations between 8 May and 18 May 1989.

Date	Tagged Bags	Adjusted Bags	Vessels	Tagged Bags/ Vessel	Adjusted Bags/ Vessel
May 8	1,944	3,110	208	9.3	15.0
May 9	1,001	1,602	188	5.3	8.8
May 11	338	540	58	5.8	9.3
May 15	293	469	56	5.2	8.4
May 16	104	166	21	5.0	7.9
May 17	89	142	20	4.5	7.1
May 18	33	53	10	3.3	5.2
Total	3,802	6,082	561	6.8	10.8

growth and mortality rates, ranged from 11,734 bags to 21,447 bags with estimated values of $260,495 and $476,123, respectively. However, because landings from individual reefs were not recorded at check stations during the summer harvesting season, yields and values for Bulkhead Bar were not determined. Check stations reported 16,001 bags landed in July, 9,947 bags landed in August, and 3,871 bags landed in September, totaling 29,819 (tagged) bags for the summer harvesting season from all reefs in the summer harvesting area. The number of bags tagged was converted to 47,710 bags landed.

Field surveys of oyster reefs in the summer harvesting area, including Lighthouse Bar and Norman's Lumps, indicated that standing stocks were reduced to levels of approximately 100 bags/acre after the summer harvesting season (Table 3). Standing stock estimates suggested that harvesting pressure may have been concentrated on Bulkhead Bar at the end of the summer harvesting season when other reefs were also depleted. Estimated yields were reduced to 63 bags/acre on Bulkhead Bar compared to 115 bags/acre on Lighthouse Bar and 94 bags/acre on Norman's Lumps.

DISCUSSION

Production

Ingle and Whitfield (1968) and Whitfield (1973) estimated that about 400 bu/acre could be harvested from productive artificially constructed reefs within two years of planting cultch. During field surveys of natural and constructed oyster reefs in Apalachicola Bay, Berrigan (1989) developed a scale using defined sampling protocol to determine the relative condition of oyster resources based on production estimates. Estimated production exceeding 400 bags/acre was applied as an indicator of healthy oyster reefs capable of sustaining commercial harvesting. Accordingly, oyster populations were 1) capable of supporting limited commercial harvesting when stocks exceeded 200 bags/acre, 2) below levels necessary to support commercial harvesting when stocks fell below 200 bags/acre, and 3) considered depleted when marketable stocks were below 100 bags/acre. Estimated yields for Bulkhead Bar ranged from 313 bags/acre for the delineated 50 acres to 408 bags/acre for the improved acreage (45 acres) by 21 April 1989. Estimated yields reached 460 bags/acre in 18.5 months (80 weeks) on highly productive reef areas (25 acres). Estimated production from Bulkhead Bar ranged from 15,648 to 18,373 bags.

Two critical factors influencing estimated yields and landings were identified during data analyses. First, estimated yield (bags available for harvest) was a function of the area where substrate was improved and level of improvement. Over estimates of the productive area may have contributed to disparity between estimated stock reductions and stock reductions accounted for in landings. Secondly, harvesting success (bags landed) was a function of the number of oysters contained in each bag landed. To compensate for areal dependent production estimates (acres) and numerical dependent landings (bags), both yield estimates and landings were recalculated using adjusted values (45 acres and 225 oysters/bag) to evaluate resource assessment techniques.

Adjusted values provided a standard unit to compare yield estimates with harvesting success and landings. Population estimates used in data analyses were extrapolated for 45 acres to represent productive acreage and the area where harvesting effort was concentrated. Standing stocks and estimated yields were adjusted to represent fully restored, improved, and unimproved reef areas (Table 3). Yield estimates ranged from 313 to 460 bags/ac; lowest levels reflected standing stocks over the entire 50 acres while highest levels were confined to the most productive 25 acres. Sampling was subsequently confined to improved areas to reduce variations in population estimates.

The number of oysters in each bag harvested was also adjusted to compensate for oystermen overfilling their bags. It is common practice among oystermen to overfill bags since neither volumetric measure (ten gallons) nor weight (60-lb/bag) are strictly monitored when there is no obvious intent to circumvent daily bag limits. However, adjusted landings suggested that some harvesters exceeded 15 bag limits (900 lbs) on the first day of controlled harvesting (Table 4).

To evaluate yield estimates made from standing stock assessments on Bulkhead Bar, declines in predicted yields were compared to adjusted landings. Predicted yield was 18,373 bags for 45 acres before harvesting was initiated. Following controlled harvesting, remaining yields of marketable oysters were estimated at 8,580 bags indicating a decrease of 9,793 bags. Landings accounted for 6,082 bags (adjusted) or 62% of the estimated yield. Declines in estimated yields from 408 bags/acre to 191 bags/acre indicated reductions of 217 bags/acre; landings accounted for 135 bags/acre. Natural mortality was calculated to account for approximately 15% of population losses between sampling intervals. When losses to natural mortality prior to harvesting were calculated, landings accounted for 86% of population reductions.

Population Structure

Analyses of oyster populations on Bulkhead Bar were aided by the fact that the date when the population under surveillance was established could be determined. Intensive spatfall occurred during a single event of relatively short duration making population analyses relatively straightforward compared to analyzing populations in which recruitment occurs over an extended period. When intense spatfall occurs in the spring, continuous low intensity spatfall throughout the summer followed by peaks in the fall tend to obfuscate population trends. In this instance, a single event occurred following restoration of the substrate. Rapid growth during the fall and winter further distinguished this cohort from oysters recruited during the following spring. Intensive spatfall did not occur until the fall of 1988 and again during the spring of 1989 (Figure 2).

Population parameters at Bulkhead Bar, including recruitment, standing stocks, growth rates, mortality rates, and harvesting pressure, were developed from field surveys for the population established in September 1987. Analyses of these parameters provided data for developing assumptions to provide population dynamics for subsequently recruited stocks. Estimated growth rates and mortality rates were particularly important to predicting potential yields based on standing stock assessments. Estimates of recruitment to marketable stocks were critical to developing long term cost:benefit ratios when landings from Bulkhead Bar were not exclusively monitored.

Juvenile oysters observed on Bulkhead Bar in May 1988 indicated that successful spatfall had occurred during the fall of 1987. Length-frequency distributions developed from field surveys in September 1988 confirmed that juvenile stocks were the result of setting in September or October 1987. Median lengths (44 mm) of oysters sampled 29 September 1988 indicated growth rates of 0.85 mm/wk, assuming that spatfall occurred during the same week in September 1987 (0.85 mm $\times$ 52 weeks = 44.2 mm). Approximately 25% of the sample population was greater than 50 mm in length, suggesting that growth rates among rapidly growing oysters may have exceeded 0.96 mm/wk. Growth rates were expressed as the mean length (mm) increase over time (52 weeks), and did not account for variability among individuals, size dependent growth, density dependence, and environmental factors. Growth rates of 0.9 mm/wk (Ingle and Dawson 1952) and 0.85 mm/wk (Berrigan 1988) have been reported for Apalachicola Bay.

Assuming growth rates of 0.96 mm/wk, fastest growing oysters in the population established in September 1987 on Bulkhead Bar should have reached marketable size by the end of April 1989 (80 weeks post set). On 29 September 1988 (52 weeks post set), oysters greater than or equal to 50 mm numbered 72 oysters/m^2. Assuming growth rates of 0.90 mm/wk and no losses to mortality, standing stocks should have reached 73 marketable oysters/m^2 after an additional 28 weeks. However, surveys in April 1989 from the same transects indicated standing stocks of 25.6 marketable oysters/m^2 (Table 3). Declines in standing stocks from densities of 73 to 25.6 marketable oysters/m^2 suggested that losses to natural mortality had been substantial or growth rates were lower than predicted. Significantly slower growth rates between the sampling periods were discounted since growth rates were expected to be highest during periods when water temperatures are cooler (Berrigan 1989, Ingle and Dawson 1952). Therefore, natural mortality was considered the most probable causative factor reducing standing stocks of adult and subadult oysters within the sample population.

Differences in standing stocks between sample intervals were compared to determine the effects of natural mortality on predicted yields. A weekly mortality rate, expressed as the average number of oysters/m^2 lost each week during the 28 week sampling interval, was used to represent reductions in extant populations. For example, during the first week of the sampling interval (week 52), 1.7 oysters/m^2 were lost from the initial population of 73 oysters/m^2; by the last week of the sampling interval (week 80) 1.7 oysters/m^2 were lost from the surviving population of 27.3 oysters/m^2. Natural mortality, expressed as percent reduction, ranged from 2.3% to 6.2% per week, respectively. Population losses attributed to natural mortality accounted for a 65% reduction during 28 weeks, or a mean reduction of 3.34% per week. Extending intervals to 30 weeks, accounting for additional losses during the two weeks between the previous sampling period and when harvesting was initiated, increased cumulative population losses to 70%.

Similarly, growth and mortality rates were included in calculations based on length-frequency distributions of oysters between 60 and 75 mm to predict yields during the next summer harvesting season. Standing stocks of marketable oysters during the summer harvesting season were estimated from 1) marketable stocks remaining after the special harvesting season (9 oysters/m^2), 2) recruitment of sublegal-sized oysters to marketable stocks (21 oysters/m^2), and 3) population losses due to natural mortality. Combined standing stocks, including recruitment and mortality, were expected to produce approximately 18 marketable oysters/m^2 at the beginning of the summer harvesting season. Throughout the three month harvesting season, more than 30 marketable oysters/m^2 were expected to be available for harvest. Cumulative production from standing stocks during the summer harvesting season was estimated at 121,410 oysters/acre (5,463,450 oysters/45 ac), or 24,282 bags. Estimated value of standing stocks, assuming \$22.20/bag, was \$539,060.

However, during the warm summer months, mortality may be expected to increase over levels projected during the cooler months. Increased mortalities may be associated with the pathogenic protozoan, *Perkinsus marinus* and increased stress (Berrigan 1989, Quick and Mackin 1971). Furthermore, slower growth may also be expected during spawning peaks when oysters expend greater metabolic energy on reproduction than on growth. The combined effect of these factors may reduce actual standing stocks when compared to predicted standing stocks. Theoretically, growth rates and mortality rates can be adjusted to account for variability between populations and to predict a range for potential yields. As an example, reducing growth rates by 25% and increasing mortality rates by 25% in the standing stocks previously discussed would reduce predicted densities from 30 to 18 marketable oysters/m^2 available during the summer harvesting season. This more conservative estimate, representing the lower range of potential yields expected during the summer months, would produce 72,846 marketable oysters/acre (3,278,070 oysters/45 ac) or 14,569 bags during the summer season. Estimated value of these stocks would be $323,432, assuming $22.20/bag. Based on projected recruitment and field surveys following the summer harvesting season, potential landings from 45 acres ranged from 11,734 bags to 21,447 bags with estimated values of $260,495 and $476,123, respectively.

Reported landings from all reefs in the summer harvesting area suggested that conservative yield estimates for Bulkhead Bar may more closely reflect standing stocks and landings during the summer season than estimates based on more optimal conditions. Additionally, projections based on recruitment, growth, and mortality during optimal periods (October through April) may not accurately estimate population levels during the warmer months (May through September).

Economic Benefits

Success of resource restoration programs is difficult to evaluate within an environmental and economical context. The environmental value of oysters resources, although clearly identifiable as a critical element in the Apalachicola Bay ecosystem, can not easily be expressed in economical terms. Within an economical framework, the most practical alternative is to identify economic contributions of restored resources to commercial fisheries and dependent industries. Economic value to harvesting and marketing sectors consists of revenues from landings and revenues generated by added value through wholesale and retail sales. In this context, the present evaluation of an oyster resource restoration project provides an analytical framework based on revenues from commercial landings, predictions of revenues based on stock assessments, and predictions of added value revenues.

Restoration of Bulkhead Bar was completed at a cost of $174,265. The project was accomplished by contract and included all costs except costs of contract administration. Economic benefits were determined by monitoring commercial landings during controlled harvesting and by predicting yields during the regular summer harvesting season. During controlled harvesting, 6,082 bags (adjusted) of oysters were landed and valued at $135,020. Dockside value accounted for 77% of restoration costs during initial harvesting efforts. Furthermore, estimated yields during the summer harvesting season resulted in additional values ranging from $260,495 to $476,123. Combining the more conservative value for estimated yields during the summer harvesting season, accounting for approximately 25% of dockside value of landings during the summer harvesting season, and dockside value of landings during the controlled harvesting period, would produce revenues of $395,515 after two years.

Actual and estimated revenues from restored resources on Bulkhead Bar indicated that restoration costs were recovered after the first harvesting season or within two years of restoration. Cost:benefit ratios based on predicted dockside values ranged from 1:2.3 to 1:3.5 after two years. Experience has shown that restored reefs remain productive for ten or more years (Whitfield 1973). With no further costs to maintain reefs over this period, conservative cost:benefit ratios may reach 1:9.2 after five years and 1:20.7 after ten years, assuming continued productivity. Cost:benefit ratios of 1:20 have been reported for successful shell plants in Louisiana (Dugas 1988). Considering restoration costs of $3,873/acre, benefits would exceed $8,790/acre annually and range from $2.30 after the second year to $20.70 over ten years for each $1.00 expended.

Apalachicola Bay oysters are sold throughout the United States. Much of the nationwide distribution is concentrated in sales for the half-shell market. Prochaska and Keithly (1984) reported that 78% of sales were generated through sales of unshucked oysters. This trend has continued since 1985, and sales of shellstock remain the primary marketing channel. Because of this marketing strategy, added value to the product is primarily in distribution rather than processing. Currently, added value from processing may consist simply of washing, grading, and packaging.

In this marketing strategy, the majority of added value is received by distributors and retailers who may be outside the local industry. Colberg and Windam (1965) indicated that oyster tongers share about 14%, packers about 7%, and truckers and retailers about 79% of retail value of half-shell oysters. In a review of the U.S. oyster industry, Dressel et al. (1983) reported that, oyster harvesters receive 33.3% of retail dollar sales, while the remaining 66.7% goes to processors, distributors, wholesalers, and retailers. Estimated values for Texas's oyster industry were recently generated using an economic multiplier of $3.12 dollars for each $1.00 of direct input (Quast et al. 1988). Roberts (1988) used an economic multiplier of 6.9 to determine retail values from dockside values for domestic oyster sales nationwide. In the absence of better indicators, a multiplier of $4.00 for each $1.00 in dockside value may be appropriate to express the economic impact of Apalachicola Bay oysters at the retail level (Whitfield 1973).

Thus, economic contributions from resource restoration efforts ultimately benefit levels from harvest to retail sales. Added value revenues exceeding $35,000 per acre annually represent returns ranging from $9.20 after the second year to $82.80 after ten years for each $1.00 expended. Cost:benefit ratios increase to 1:36.8 after five years and to 1:82.8 after ten years. Estimated economic benefits from Bulkhead Bar after two years would reach $1,575,000, exceeding costs for the entire program and restoration of 385 acres in Apalachicola Bay.

The economic estimates developed for Bulkhead Bar are expected to be representative for reef restoration efforts. However, accurate fisheries information is lacking for all other reefs restored during the program, hence there is no assurance that oyster populations on Bulkhead Bar are representative of oyster populations on other reefs. The vagaries of environmental conditions throughout Apalachicola Bay strongly influenced population dynamics on individual reefs throughout the recovery phase. While production may be variable between reefs, the magnitude of returns from restored productive acreage probably more than compensates for periods of low productivity.

At a time when oyster resources are increasingly stressed by a barrage of factors and resource managers face tightening fiscal constraints to rehabilitating depleted resources, proven resource restoration and development practices remain viable and economical alternatives for oyster fisheries management. Restoring suitable habitat provides shellfish resource managers the almost singular opportunity to mitigate resource losses, enhance productivity, and contribute direct economic benefit to the fishery industry and its dependent economy.

REFERENCES CITED

Berrigan, M. E. 1988. Management of oyster resources in Apalachicola Bay following Hurricane Elena. *J. Shellfish Res.* 7(2):281–288.

Berrigan, M. E. 1989. Oyster resources in Apalachicola Bay. (Unpublished Manuscript) Fla. Dept. Nat. Res. Tallahassee, Florida. 93 p.

Colberg, M. R. & D. M. Windam. 1965. The oyster-based economy of Franklin County, Florida. *U.S. Pub. Health Serv.*, Washington D.C. 23 p.

Dressel, D. M., D. Whitaker & T. Hu. 1983. The U.S. oyster industry: an economic profile for policy and regulatory analysts. *Natl. Mar. Fish. Serv.*, Washington, D.C. 44 p.

Dugas, R. J. 1977. Oyster distribution and density on the production portion of state seed grounds in southeastern Louisiana. *La. Dept. Wildl. Fish. Tech. Bull.* No. 1. 27 p.

Dugas, R. J. 1988. Administering the Louisiana oyster industry. *J. Shellfish Res.* 7(3):493–499.

Futch, C. R. 1983. Oyster reef construction and relaying programs. Andree, S. ed. Apalachicola oyster industry: conference proceedings. Florida Sea Grant College Rept. No. 57:34–38.

Hofstetter, R. P. 1981. Rehabilitation of public oyster reefs damaged or destroyed by a natural disaster. Management Data Series No. 21. Texas Pks. & Wildl. Dept. Austin, Texas. 9 p.

Ingle, B. M. & C. E. Dawson. 1952. Growth of the American oyster, *Crassostrea virginica* (Gmelin), in Florida waters. *Bull. Mar. Sci. Gulf Carib.* 2(2):393–404.

Ingle, B. M. & W. K. Whitfield, Jr. 1968. Oyster culture in Florida. Fla. Board. Conser. *Mar. Res. Lab., Ed. Ser.* No. 5. 25 p.

Mackenzie, C. L., Jr. 1977. Development of an aquacultural program for rehabilitation of damaged oyster reefs in Mississippi. *Mar. Fish. Rev.* 39(8):1–13.

May, E. B. 1971. A survey of the oyster and oyster shell resources in Alabama. *Ala. Mar. Res. Bull.* 4:1–53.

Prochaska, F. J. & W. R. Keithly. 1985. Market structure and channels for Florida processed and marketed oysters. Ward, D. R. & G. Treece. eds. Proceedings Tenth Annual Tropical and Subtropical Fisheries Conference of the Americas. Texas A&M Univ. Sea Grant. No. 86-102. p 23–31.

Quast, W. D., M. A. Johns, D. E. Pitts, Jr., G. C. Matlock, & J. E. Clark. 1988. Texas Oyster Fishery Management Plan. Fishery Management Plan Series No. 1. Texas Pks. & Wildl. Dept. Austin, Texas. 178 p.

Quick, J. A., Jr., & J. G. Mackin. 1971. Oyster parasitism by *Labyrinthomyxa marina* in Florida. *Fla. Dept. Nat. Resour. Mar. Res. Lab., Prof. Pap. Ser.* No. 13. 55 p.

Roberts, K. 1988. Economic Profile of the U.S. Oyster Industry. Burrage, D. ed. The Mississippi Oyster Industry: Past Present and Future. Mississippi/Alabama Sea Grant Consortium, MASGP 88-048. p 4–7.

SAS Institute, Inc. 1985. SAS User's Guide: Statistics. Cary, North Carolina. 956 p.

Tyler, A. V. & V. F. Gallucci. 1980. Dynamics of fished stocks. Lackey R. T. & L. A. Nielsen. eds. Fisheries Management. Oxford, England: Blackwell Scientific Publications. p 111–147.

Whitfield, W. K., Jr. 1973. Construction and rehabilitation of commercial oyster reefs in Florida from 1949 through 1971 with emphasis on economic impact in Franklin County. *Fla. Dept. Nat. Resour. Mar. Res. Lab., Spec. Sci. Rept.* No. 38. 42 p.

Whitfield, W. K., Jr. & D. S. Beaumariage. 1977. Shellfish management in Apalachicola Bay. Past-present-future. Livingston, R. J., & E. A. Joyce, Jr. eds. Proceedings of the Conference on the Apalachicola Drainage System. *Fla. Mar. Res. Lab. Publ.* No. 26:130–140.