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A CASE STUDY OF THE EFFECTS OF GAS AND OIL PRODUCTION ON ARTIFICIAL REEF AND DEMERSAL FISH AND MACROCRUSTACEAN COMMUNITIES IN THE NORTHWESTERN GULF OF MEXICO. Expochem Proceedings: In press

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INTRODUCTION

Increased development of petroleum reserves in offshore habitats is inevitable if the United States is to realistically reduce its dependency on foreign energy supplies. Thus, over the past few years, the Federal Government has intensified offshore marine research efforts in order to obtain information concerning the environmental consequences of increased oil and gas development on the outer continental shelf (OCS). Among the recent research efforts in this regard has been the Environmental Assessment of Buccaneer Gas and Oil Field in the Northwestern Gulf of Mexico, a project funded by the Environmental Protection Agency (EPA) through interagency agreement with the National Oceanic and Atmospheric Administration (NOAA) and managed by the National Marine Fisheries Service (NMFS), Southeast Fisheries Center (SEFC), Galveston Laboratory in Galveston, Texas. The major goals of this program have been:

(1) To identify the types and extent of environmental and ecosystem alterations associated with development of and release of contaminants from an active gas and oil field.

(2) To determine the specific contaminants, their quantity, and effects on the various components of the marine ecosystem.

(3) To develop capabilities to describe and predict sources, fate and effects of gas and oil field contaminants in major components of the marine ecosystem.

Studies designed to provide information enabling an assessment of the effects of offshore oil and gas development activities on marine ecosystems in the northwestern Gulf of Mexico have historically consisted of broad multidisciplinary ecological surveys performed over large geographical areas. Two previous studies have been performed. The initial effort was a multidisciplinary study performed in 1973-1974 offshore Louisiana in the intensively-developed "oil patch" (Gulf Universities Research Consortium [GURC] 1974). This investigation was predicated upon synoptic comparisons of impacted (platform sites) with control sites which had not experienced petroleum activity (no platforms). As might have been expected, one of the major findings of the GURC study was the "reef effect" of the platforms. However, seasonal variation in most response variables were found to have been substantially greater than treatment variation, such that few significant differences could be delineated. The program yielded a wealth of descriptive data (about 1.5 million data points), but most of the data were inadequate to provide a meaningful assessment of impacts because of (1) the inadequacy of the controls (comparison of reef to non-reef habitats) and (2) the lack of depth of the investigations (study was multi- as opposed to interdisciplinary). More recently (1978-1979), the GURC study was essentially repeated by the Bureau of Land Management's (BLM) study, Ecological Investigations of Petroleum Production Platforms in the Central Gulf of Mexico. Again, the "reef effect" of platforms was documented and measurable environmental and ecological change was found restricted to the immediate vicinity of the platforms.

The second historical approach to obtain data for evaluating effects of offshore oil and gas development has been based upon the baseline concept. Undeveloped areas subject to lease to industry for development have served as study areas for large multidisciplinary surveys intended to provide an "environmental benchmark" against which comparisons could be made following development (e.g. the BLM's Environmental Studies of the South Texas Outer Continental Shelf). Again, a wealth of descriptive data have been provided by these studies. However, due to annual and other sources of natural variability as well as to the general lack of depth in most of the disciplinary efforts attributable to the breadth of the surveys, the resulting data hold little immediate promise in terms of making realistic impact projections.

The approach of the Buccaneer Gas and Oil Field (BGOF) studies has been to sacrifice breadth of spatial and disciplinary coverage for depth in selected studies specifically designed to measure impacts. Following a brief pilot study in 1975 (Harper et al. 1976), the first year's investigation (1976-1977) consisted of a multidisciplinary ecological survey comparing the relatively isolated BGOF to control, or undeveloped areas. Following the initial descriptive effort of 1976-1977, a series of iterative project reviews held on an annual basis served to not only reduce the disciplinary scope as appropriate, but also to transform the multidisciplinary effort to an interdisciplinary one. In this manner, the finite project resources were committed to in-depth investigations of key processes deemed suitable for study in terms of their promise for yielding data enabling a quantitative assessment of impacts. In 1977-1978, investigations were intensified within the BGOF, comparing conditions around production platforms (source of contaminant discharge) to those around satellite structures (structures with no contaminant discharges). In 1978-1979, studies focused more on production platforms, particularly in terms of the amounts, fate, and effects of contaminants being discharged and the processes accounting for the observed dispersal and distribution of contaminants in the environment (circulation, hydrography, trophic linkages). During the final year, field studies were reduced to fill data gaps in areas of remaining uncertainty, and the major effort was devoted to preparing integrated milestone reports evaluating the effects of the BGOF on ecological and environmental systems. This report provides a synthesis of the observed effects of the BGOF on biological systems and fisheries of the study area. Demersal fishes and macrocrustaceans, the biofouling community, reef and pelagic fishes were used as indicators of impacts. Other biological components (bacteria, plankton and in-faunal benthos) were considered as part of the "environment" and were addressed only to the extent that they directly impacted or limited the primary indicator groups.

STUDY AREA

The BGOF is located approximately 52 km south by east from Galveston, Texas (Fig. 1). The field was delineated in the late 1950's and early 1960's. Five types of structures were represented in the field during the study, including 2 production platforms, 2 flare stacks, 2 quarters platforms, 13 satellite jackets, and a pipeline network connecting platforms in the field and the field to mainland facilities. Collectively, the platforms provided some 16,000 m^2 of hard substrate.

Both production platforms were active at the time of project initiation, but Production Platform 288-A was active only intermittently after November of 1978. During the early stages of the project, production of gas was about 600 MMCF/day and production of oil and condensate was about 400 bbl/day. Production declined markedly through the course of the study. In early 1980, production of gas was only about 12.5 MMCF/day and oil and condensate was being produced at a rate of 450 bbl/day.

The separation of oil and gas began on the lower deck of each production platform. The product (condensate) flowed into high-pressure or first stage vessels which essentially separated the gas from oil and water. All of the gas produced from the field was compressed at Platform 296-B using air-cooled turbine compressors located on the upper deck. Once compressed, the gas was piped to Production Platform 288-A and thence to the Freeport facility.

The remaining oil and water flowed to interstage, pressure-step-down vessels which were located on the upper decks of the platforms. Here the pressure was further reduced to that of the atmosphere as the product flowed into the next vessel or "gun barrel." The "gun barrels" served as gravity separators, segregating the oil from the water. All of the oil produced and separated was piped to the large storage tanks located on the upper deck of Platform 288-A.

Following the separation of oil and gas, the remaining "produced water" flowed to "skim tank" vessels, also at atmospheric pressure, located on the lower decks. All drains on the production platform, including those from "drip pans," "skid pans," and gutters, also flowed into the "skim tanks". All petroleum products entering this vessel were separated and put back onto the oil-stream flow. The remaining water was then discharged overboard through pipes extending along a leg on the west side of the platform from the skim tank down to a point about 2 m above the water. Produced water discharge ranged from about 1,000 bbl/day early in the study to an average of about 1,400 bbl/day in 1978-1979.

The levels of microbial organisms which cause corrosion in the BGOF production system necessitated the use of biocides. For the period 1975 through April of 1978, two Champion Chemical Company biocides (BACTRON K-31 and K-14) were used and alternated to prevent the bacteria from developing resistant strains. This treatment was only partly successful and Shell switched to the use of the Magna Corporation acrolein biocide, Magnacide B. The biocides were injected in the system and flowed to the skim tank where they were scavenged prior to discharge.

Quarters platforms contained in addition to kitchen, living and recreational quarters, a gas-fired electrical generator, a desalinization plant, and a sewage treatment plant. Small amounts of treated sewage and heated cooling water from the electrical generating plant were discharged from quarters platforms. Flare stacks were not characterized by discharges except in emergency situations. In these instances, condensate was shunted from the production platforms and discharged out the flare stacks. These discharges, although infrequent were spectacular.

INVESTIGATIVE PROGRAM

Project Development and Approach

As indicated earlier, the first year of the study (1976-1977) was expended in characterizing the regional environment and biota. While most of the work was, by necessity, descriptive (the area had been little, if any, studied), the experimental design was (1) to compare the BGOF to control areas located 9.3 km from the field in each of the northeast and southwest directions and (2) to document and describe the "reef effect" of BGOF platforms. Work performed during the initial research year consisted of 13 work units devoted to (1) development of a data base and data management system (Work Units 2.1 and 2.2), (2) biological surveys (benthos, 2.3.3; demersal fishes and macrocrustaceans, 2.3.4; recreational and predatory pelagic fishes, 2.3.5; ichthyoplankton, 2.3.6; structure communities, 2.3.8 [two separate work units]), and (3) environmental characterizations (sedimentology and geochemistry, 2.3.2; hydrography, 2.3.9; hydrocarbon concentrations, 2.4.2; trace metal concentrations, 2.4.2; and levels of sediment organic carbon and composition, 2.4.3). Results of the 1976-1977 investigations are presented in Jackson (1977).

As the first year's survey was in progress, an initial conceptual model of the ecosystem surrounding the BGOF was developed (Gallaway et al. 1976) as a means to facilitate program integration, future research planning and impact assessment. Important ecosystem components and key processes were identified, and a detailed description of the BGOF in terms of historical and current activities was developed. Indicators of impacts from the BGOF on biological systems were selected based largely upon their perceived importance to man (direct, or indirect), and the likelihood of their being subject to impact either from direct exposure to contaminants or indirect exposure through the food chain. Information from other disciplines which was believed necessary in order to be able to make the biological assessment was identified and incorporated as additional objectives for the non-biological disciplines. Additionally, sample needs for other disciplines from the biological work group were identified. The program was thus integrated by means of a matrix of interdisciplinary data needs which identified the kinds of information each discipline needed from other disciplines. Care was taken to insure that data which was not readily appropriate for impact assessment purposes was not included in the study design.

The indicators selected for study of biological impact were (1) standing crop biomass, community structure and composition, production and health or condition of the biofouling community; (2) relative abundance of demersal fishes and macrocrustaceans; (3) pelagic fishes; and (4) reef fishes. Ichthyoplankton studies were continued to document spawning activities of important species aggregated at the platforms, but infaunal benthic studies were discontinued. Results from the benthic investigations of 1976-1977 appeared adequate to delineate the direct impacts of historical operations and to characterize infaunal benthic faunas in terms of their seasonal abundance relative to the different bottom types represented in the study area. Further, the infauna was sparse and did not appear of much direct trophic importance to most of the indicators being investigated.

The 1977-1978 research was organized into eleven work units--one (2.2.3) for data management, five biological investigations, 4 physical/chemical investigations and one ecological modeling effort (2.5.1). Biological studies consisted of bioassay work (2.3.4), investigations of pelagic, reef and demersal fishes and macrocrustaceans (2.3.5), bacterial processes (2.3.7) and studies of the biofouling community, including what was erroneously believed at that time, the top predator, Atlantic spadefish. The physical/chemical program consisted of sedimentology and geochemistry (2.3.2), oceanographic processes (2.3.9), and investigations of the levels of hydrocarbons (2.4.1) and trace metals (2.4.2) in important ecosystem components. Results and detail of these investigations were compiled in a three-volume report (Jackson 1979a, 1979b, 1979c).

The basic thrust of 1977-1978 investigations emphasized comparisons of conditions at and around production platforms to those at similar depths and distances around satellite jackets which served as controls. This approach enabled an assessment of direct effects. Additional emphasis was placed upon trophic linkages and systems ecology in order to assess (1) the integrity of the system, (2) contaminant pathways and (3) indirect effects within the system.

Research efforts for 1978-1979 utilized the same general approach undertaken in 1977-1978 (Fig. 2); but, emphasis was placed upon "near-field" effects. In other words, emphasis was placed upon delineating the spatial extent of observed effects which had been indicated by the comparisons of sites and locations on discharging and non-discharging structures in the proximity of the produced water discharge. Further, major information gaps concerning suspended sediments, plankton biomass and contaminant dispersal and diffusion (given the observed hydrological regimes) were identified and addressed. Ichthyoplankton data which had been obtained over the first two years were considered adequate, and sampling was discontinued. Thus, work unit distribution remained the same as for 1977-1978 except for the deletion of the ichthyoplankton work unit (2.3.6) and the addition of work unit 2.5.2, Hydrodynamic Modeling. Plankton studies were incorporated as part of work unit 2.4.2. Results of the 1978-1979 program are reported in Jackson (in press).

During 1979-1980, field sampling in the biological program was reduced to only that necessary to fill data gaps addressing the remaining uncertainties considered to be of importance (red snapper population levels, trophic linkages, condition of barnacles). The primary goal of the last year of the program was to produce a milestone report, an integrated synthesis of the major findings of the project.

Sampling Methods

A precis of the methods that were employed in the study of the selected indicator groups is presented below. Detail as to exact methods can be found in referenced reports of the Principal Investigators. For convenience, the descriptions provided below are grouped under (1) demersal fishes and macrocrustaceans, (2) biofouling, and (3) structure-associated fishes.

Demersal fishes and macrocrustaceans. Field studies of this group were conducted throughout the program by means of otter trawling (Emiliani et al. 1977, Workman and Jones 1979, Gallaway and Martin 1980). A 12-m semiballon otter trawl was used in 1976-1977, a 6.1-m trawl in 1977-1978, and a 12-m trawl was again utilized in 1978-1979. Time of trawl hauls and number of replicates differed among investigators. Studies performed in 1978-1979 consisted of triplicated trawl hauls, each of which was of 10-min duration. These samples were believed to provide the best estimates of seasonal and spatial abundance and are heavily relied upon herein.

Biofouling community. Initial biofouling studies in the BGOF were conducted by Fotheringham (1977) and utilized scraping and photogrammetric techniques to characterize fouling community composition and structure, particularly in terms of relative abundance and coverage of platform substrate. During the remainder of the program, biofouling efforts were conducted by Gallaway et al. (1979a), Howard et al. (1980) and this study. These studies relied largely upon scraping techniques utilizing templates to obtain replicated quadrat samples (Fig. 3). Standing crop biomass and rates of recolonization by the biofouling community of cleaned areas were emphasized and supplemented by experimental studies of production and condition of community dominants. *In-situ* respirometry investigations (Gallaway et al. 1979a, Howard et al. 1980) were used to further define effects of produced water on the biofouling community.

Structure-associated fishes. Pelagic, reef and other structure-associated fishes were investigated using a variety of field sampling techniques including (1) diver observation (Fotheringham 1977, Workman and Jones 1979, Gallaway et al. 1979a, Gallaway and Martin 1980, this study); photography (Workman and Jones 1979, this study);

trolling, gillnetting and long-lining (Trent 1977); hook-and-line (Fotheringham 1977, Emiliani et al. 1977, Trent 1977, Workman and Jones 1979, Gallaway et al. 1979a, Gallaway and Martin 1980, this study); air lift and other diver-operated devices (Fotheringham 1977, Workman and Jones 1979, Gallaway et al. 1979a, Gallaway and Martin 1980, this study); quantitative diver census of sedentary reef fish (Workman and Jones 1979, Gallaway and Martin 1980) and mark-recapture experiments (Workman and Jones 1979, Gallaway et al. 1979a, Gallaway and Martin 1980, this study). Field sampling was designed to yield (1) qualitative and quantitative estimates of population levels and structure, (2) descriptions of trophic ecology, (3) an assessment of the health and condition of species being investigated and (4) characterizations of the BGOF recreational fisheries.

Sample and Data Analysis

Samples returned to the laboratory for analysis were analyzed following published protocols for the respective disciplines with all data provided to project data management (Work Unit 2.2.3). In general, collection data were summarized using information theory species diversity indices and cluster analysis (see Gallaway et al. 1979a). Where data were adequate, statistical analyses were made using factorial analysis of variance supplemented by either orthogonal contrasts or Duncan's Multiple Range Tests (see Howard et al. 1980) to compare significance of differences among means.

Seasonal population estimates were made using both single- and multiple-census techniques (Gallaway and Martin 1980), and, for small cryptic species, by replicated quadrat counts (Workman and Jones 1979, Gallaway and Martin 1980). Food habitat investigations were based upon both qualitative (Workman and Jones 1979) and quantitative gravimetric methods (Gallaway et al. 1979a, Gallaway and Martin 1980, this study) with feeding periodicity evaluated using index of fullness values (Gallaway et al. 1979a).

Health and condition evaluations for fishes were based upon (1) analysis of covariance of length-weight regressions (Workman and Jones 1979, Gallaway et al. 1979a, Gallaway and Martin 1980) and by direct histopathological (Gallaway and Martin 1980) and microbial examination (Gallaway and Martin 1980, Sizemore 1980). For barnacles, health and condition indices were determined using regressions of cavity volume on meat weight (Boland 1980).

ENVIRONMENTAL SETTING AND ALTERATIONS

Setting

Water depths in the BGOF range from 17 to 22 m and overlay a rather diverse bottom (Anderson and Schwarzer 1979; Fig. 4). The majority of the BGOF structures are sited over silty/clayey sand, but two (including one of the controls, Satellite 288-5) were located on silty sand. The consensus reached from examination of all available information (Anderson and Schwarzer 1977, 1979; Behrens 1977; Middleditch 1977, 1979, 1980; Brooks and Estes 1980; Martin 1977; Armstrong 1979, 1980) was that bottom sediments of the area were scoured; i.e. sedimentation rates were characteristically low due to resuspension and transport out of the area by bottom currents.

Currents in the BGOF were found to be aligned principally in long-shore directions, reversing seasonally from upcoast toward the northeast in summer (May-August) to downcoast toward southwest for October-April (Armstrong 1979, 1980). Transitional conditions appeared to rule in September and April. Current meter records showed layering of contrasting flows during some seasons. Local winds were apparently the main driving force for the circulation. Flow was typically with the wind but was deflected by the coastline such that there was compensating offshore transport with onshore winds, or to the right of the winds due to Ekman transport. Distinct departures from local wind-driven circulation develop during spring, when it seems high river discharge may establish a downcoast, geostrophic current which, from current meter records, may account for the layered currents of summer. Also, during early fall, currents of the area do not appear to relate to local winds, but may be responding to larger-scale atmospheric alterations. Spectral analyses of current meter records indicate that tidal currents and wind shifts account for most of the variability in flow dynamics, with dominant periods perhaps associated with passage of continental air masses in winter and fall, and longer-period maritime air mass development during summer.

<u>Water column structure</u>. As might be deduced from the above, the general structure of the BGOF water column underwent marked seasonal changes which are characterized below using 1979-1980 observations (Figs. 5-8). In general, during periods of vertical stratification, salinity stratification was more pronounced than temperature, and the distribution of turbid, or nepheloid, layers corresponded with pycnoclines. In summer 1979, two nepheloid layers were present under the conditions depicted by Fig. 5. The level of total suspended particulate material (TSM) in surface waters (288 μg/ℓ) was lower than that of bottom waters (538 μg/ℓ) and also differed in composition. On a relative basis, zooplankton

("cellular") particulates dominated in the upper part of the water column whereas clays were the dominant particulate in near-bottom water (Brooks and Estes 1980).

During fall 1979, the water column was characterized by a single, but deep, nepheloid layer over the bottom (Fig. 6). Particulate concentrations in surface and bottom waters were similar to summer levels, but relative abundance patterns of the components differed greatly--clay was the dominant particulate in each water mass (Fig. 6). During winter 1979-1980, the entire water column was highly turbid (TSM = ≥ 100 μg/ℓ) and temperature-salinity stratification was weak or absent (Fig. 7). Clay and phytoplankton were the co-dominant particulate types on a relative basis, and zooplankton was scarcely represented in the samples. Surface waters contained measurable levels of non-cellular organic material during winter--probably representing winter-blooming mat organisms sloughed from the biofouling community.

The water column during spring 1980 was characterized by the presence of three turbid layers and marked salinity stratification. During this period of transition, the water column was changing from a vertically mixed system to the characteristic stratified condition as exemplified by the summer data described above. Surface waters were represented by a highly turbid lens (TSM = 800 μg/ℓ) of low salinity (≈30‰), isolated from the waters below by a pycnocline at about 5 m in depth (Fig. 8). The mid-depth nepheloid layer was at about 12 m and, again, was associated with a pycnocline which probably accounted for the selective congregation of sinking particulates at the observed mid-depth density interface. The dramatic bottom nepheloid layer (TSM = 1550 μg/ℓ) was attributable to turbulent mixing associated with bottom currents.

Although clay was the dominant suspended material in both surface and bottom waters during spring, phyto- and zooplankton were well represented, particularly in surface waters. Non-cellular biomass (probably of biofouling origin) was relatively abundant in surface waters (Fig. 8). As will be described in later sections, this material (suspended particles of biofouling mat; e.g. hydroids) is particularly important to the BGOF trophic system during the spring season.

In summary, the water column in the BGOF was stratified during all seasons except winter, with the seasonal density interfaces providing points of accumulation for suspended particulates of appropriate density (dense particles would "fall through" the pycnoclinal barriers whereas those less dense than the waters below would set at the interface). The presence of a near-bottom nepheloid layer during all seasons indicated that fine-grained surficial sediments within the field were in a continued state of resuspension, reworking, and transport.

Clay was the dominant particulate material in the water column during all seasons. The organic fraction consisted almost exclusively of cellular material (phytoplankton, zooplankton, and/or bacteria) during most seasons. However, particulate non-cellular carbon, probably of biofouling origin, comprised 4 to 8% of the particulate load in surface waters during late winter and spring, respectively. The winter season was characterized by the highest levels of organic nutrients and an associated phytoplankton bloom.

Bacteria. Bacterial populations of the BGOF were of marine origin (94% of those enumerated required salt for growth) with biomass estimated to range between 5.2 and 44.0 x 10^{-6} g C/ℓ (Sizemore 1980). The dominant genera represented included *Vibrio*, *Pseudomonas*, *Aeromonas*, *Acinetobacter* and *Moraxella*. Bacterial diversity changed with season and was lowest in spring. Ninety percent of the bacteria in the water column were found to have been attached to particles greater than 3 μ in diameter.

A number of potential fish pathogens were well represented as part of the typical bacterial assemblage found in the water and on suspended sediments, surficial sediments and fish (Sizemore 1980, Gallaway and Martin 1980). These included several hemolytic species of *Vibrio* as well as species of *Aeromonas*. These opportunistic pathogens were implicated as potential agents for the spadefish disease epidemics observed during the winter seasons.

Benthos. The benthic macroinfauna of the BGOF was diverse (estimated between 400 and 420 species) and abundant (Harper et al. 1976, Harper 1977). During summer 1976, mean density of benthic organisms in the field was approximately 8,000 individuals/m^2, but declined from this level to approximately 4,500/m^2 in January 1977. By spring 1977, populations had increased to an average of about 6,000 individuals/m^2. Although the seasonal trends observed in the BGOF were similar to those observed for a nearby, more inshore area off Freeport, Texas, the densities of macroinfauna in the BGOF was an order of magnitude larger than the densities observed offshore Freeport. Polychaetes (65 to 70%) and amphipods (10 to 20%) dominated the fauna. Biomass levels of benthos were not measured in the study, but were considered low. Attempts to obtain a large enough (≃5 to 10 g wet weight) sample of infauna for chemical analyses were seldom successful due to the small size of the average infaunal organism.

Alterations

Types and amounts of contaminants. The most obvious environmental alteration in the BGOF was the addition of an estimated 16,000 m^2 of hard substrate habitat extending from the bottom to some 21 m above the water's surface. The only discharges from these structures of any consequence were produced water from the production platforms and treated sewage effluent from the quarters platform. Produced water discharge, although variable, was estimated to have averaged about 2.5 ℓ/sec. Discharge of sewage effluent was intermittent, but was estimated to have been approximately 30 ℓ/h (0.008 ℓ/sec).

Produced waters were characterized in terms of alkanes, aromatics, volatiles, sulfur, and biocides by Middleditch (1980). He estimated the daily discharge of alkanes to have been, on the average, 382 g which represented 19% of the estimated 2 kg/day total of oil discharged from BGOF production platforms in produced waters. The light aromatic fraction of hydrocarbons in produced water was represented by some 68 different compounds having an average total concentration of 104.2 ppb. Twelve normal, branched and cyclic alkanes were characterized in the analysis of produced water volatiles. Three aromatics, comprising 64% of the volatile components measured, were identified as bezene, toluene and ethybenzene.

In contrast to the low levels of hydrocarbons being discharged in produced water, some 207 kg of sulfur was believed to have been discharged daily from BGOF production platforms. As sulfur has a specific gravity of about two and is insoluable in water, it may serve as the major transporter for oil through the water column and into sediments--if hydrocarbons can be absorbed on sulfur particles. The acrolein biocide used to control microbial aggrevated corrosion of pipes and vessels was not detected in produced water discharge samples. This biocide, while highly toxic, is quite labile.

Tillery (1980) found produced waters to have been enriched in Ba and Sr, but characterized the levels of other trace metals in the discharge as being extremely low. These findings confirmed the previous work of Anderson and Schwarzer (1979), also performed in the BGOF.

Produced water was found to have been toxic to marine organisms with crustaceans more sensitive than fish (Zein Eldin 1979, ERCO 1980):

Table 1. Toxicity of produced waters to BGOF organisms.

Organism	Concentration (ppm) $\bar{x}$ 96-h LC50	$\bar{x}$ 48-h LC50	Concentration (%)
Larval brown shrimp		9500	0.95
Subadult white shrimp	68,000	-	6.8
Adult white shrimp	70,000	-	7.0
Barnacle	83,000	-	8.3
Subadult brown shrimp	100,000	-	10.0
Adult brown shrimp	116,000	-	11.0
Crested blenny	269,000	-	26.9

The most sensitive organism among those tested was the larval brown shrimp which had a mean 96-h LC50 of about 9,500 ppm (1% produced water in seawater).

Water column. We used two methods to project the concentrations of produced water in the receiving seawater. The first method was utilized by ERT (1980) to establish an initial concentration for use in hydrodynamic model. Based upon dye studies performed by Workman and Jones (1979), the produced water (due to turbulent mixing beneath the platform) was assumed to completely mix in a volume of water approximately 1/8 of the volumn occupied by the platform (Fig. 9). (The effects of pycnoclines on dye dispersion can be seen by comparing Figs. 5 and 9). The relative concentration of 0.088% of produced water in this volume beneath the platform was determined by letting

Q = rate of discharge (m^3/sec)
U = ambient current (m/sec)
L = length of the platform (m)
Z = water depth (m)

and then estimating the time (t) for the pollutant to be swept past the platform using:

$$t = L/U$$

The volume (V) of pollutant discharged during this time was calculated using:

$$V = Qt = \frac{QL}{U}$$

This volume of pollutant was considered to have been initially mixed into a volume (Vo) of ambient water approximately equal to:

$$Vo = 1/2\ L^2 Z$$

leading to the relative concentration (Xo) of 0.088% calculated:

$$Xo = \frac{V}{Vo} = \frac{8Q}{(ULZ)}$$

for the conditions where

$U = 0.05$/msec
$L = 50$ m
$Z = 20$ m
$Q = 0.055\ m^3$/sec

The relative contaminant concentration projected by this method agrees well with the pollutant concentrations observed in waters beneath the platform (see Middleditch 1980, Tillery 1980) given the initial levels of contaminants in the produced water being discharged.

The second method employed was to use an analytic steady state approximation for diffusion from a continuous point source discharge having a mean advective component (ambient current) perpendicular to the dispersion (Fig. 10). The mean concentration ($\bar{C}$) at any point was determined using:

$$\bar{C} = \frac{Q}{4 \pi r (K_y K_z)^{1/2}} \exp - \frac{U}{4x} \frac{y^2}{Ky} + \frac{Z^2}{Ky}$$

Explanation of symbols is provided in Fig. 10. Although this model can be rightfully criticized (mixing beneath the platform is far more complex and effective than simple eddy diffusion), we believed it could be used to estimate maximum zones of toxicity around the point source under "worst case" conditions.

Eddy diffusion coefficients ($K_y = 0.1$ m^2/sec; $K_z = 0.01$) were selected based upon Nichoul (1975) and, although considered typical for the mixed layer, represent the greatest uncertainty associated with the above model. Typical current velocities in the BGOF range between 0.05 and 0.25 m/sec (Hazelton Environmental Sciences 1980) and were used in the above model in conjunction with the average loading value at the point source ($\simeq 2.5$ ℓ produced water/sec) to calculate the results shown by Fig. 11. Under the conditions depicted, the maximum zone of toxicity (assuming a 1% concentration of produced water in seawater to be toxic) was about ≤ 1 m^3. Decreasing the diffusion rates each by an order of magnitude resulted in the "potentially toxic" volume increasing to up to 5 m^3, mostly in the direction of current flow (Fig. 12). Increasing the diffusion rates resulted in a decrease in the potentially toxic volume, and in the limiting case, approximated results from method one described above.

Sedimentary regimes. Particulate and sedimentary regimes of the BGOF were highly dynamic. The combination of wave and current energy served to resuspend and transport particulates out of the area following only intermittent and brief periods of static conditions. BGOF operations appeared to alter sedimentary regimes in several ways. The structures themselves not only contributed to turbulent mixing, but yielded a "rain" of metal ranging in size from microscopic flakes (Anderson and Schwarzer 1977) to large pieces of grating and batteries. We believe that the source of the small metal flakes which were very abundant in the water and sediment samples taken beneath the platforms was corrosion of the metal gratings which comprised the decks of the platforms. In any case, the observed metal flakes probably were a major source of the trace metal contamination of sediments reported for samples taken adjacent to the platforms.

As mentioned above, particulate sulfur was a major component in the produced water and, along with the metal flakes, may have served as a transporter of hydrocarbons to the bottom. Hydrocarbon levels in sediments beneath the production platforms, although highly variable, were typically higher than levels in sediments in control areas. Another possible transporter of hydrocarbons to the bottom was oily sand which was sometimes present in the skim tank and discharged overboard.

The presence of the structures allows development of a reef community which contributes particulates of biogenic origin ranging from parts of colonial organisms to fish scales to fecal pellets to whole barnacles. The latter break-off the platforms during storms and have, in effect, formed a shell-rubble pad beneath the structures in the field. The observed decreasing gradient in organic and inorganic carbon away from the platforms in the BGOF was probably attributable to the contribution from the reef communities which develop on and around the structures.

With the exception of the large pieces of metal and the barnacle shells, the residence time of particulates beneath the platform was presumably very short due to resuspension (waves) and transport out of the area (currents). The direction of sediment transport appeared controlled by seasonal current patterns. Dilution and/or biodegradation appears to reduce levels of contaminants to that of background conditions within very short distances (≤ 50 m) from the platforms.

Bacteria. The bacteria data provide evidence that the degree of hydrocarbon contamination emanating from the BGOF was, indeed, minimal. Bacterial diversity and density levels in the BGOF were markedly similar to those in control areas. Although numerical densities and taxa represented in collections from the two areas were the same, the relative abundance of taxa was different between the BGOF and control areas. BGOF samples contained relatively more oil-degrading, sulfur-oxidizing and sulfate-reducing bacteria than did samples from control areas outside the field. These data indicate chronic, low-level pollution was occurring, but not to the extent that population levels were significantly increased.

Produced water inhibited or retarded the growth of laboratory cultures of bacteria, but appeared to have either no effect, or a stimulatory effect, on isolates obtained from the BGOF. Both pure and mixed cultures of bacteria from the BGOF exhibited the ability to degrade significant portions of the n-alkanes in BGOF crude oil.

Presumptive coliform microorganisms were more commonly encountered in samples taken near quarters platforms than in samples obtained from control areas, but no fecal coliforms were observed in any samples. Based upon the evidence provided by bacteria data,

data, the BGOF was an environmentally clean operation during the period of study.

Benthos. Numerical (cluster) analysis of the benthic data based upon 67 abundant species yielded four distinct site groups. Site group I consisted of the majority of the stations in the study area, all of which exhibited a high degree of ecological similarity. Site group II was a group of five stations, mostly associated with clay substrates, characterized by reduced populations. Site group III was comprised of stations in the vicinity of Production Platforms 288-A and 296-B and was also considered to have had reduced populations. The last site group delineated was one consisting of only two stations. Both were markedly dissimilar from all the other groups as well as from each other. The reduced populations near production platforms are believed by us to have been attributable more to sediment differences than to contaminant levels.

The benthic collections around platforms were sometimes characterized by high densities of intact shells of a planktonic pteropod. We believe, based upon results of our Atlantic spadefish trophic investigations described below, that these accumulations were attributable to predation by Atlantic spadefish. On occasions during summer months, the guts of spadefish would be literally packed to maximum capacity with pteropods, many of which were probably passed with little or no digestive deterioration.

MAJOR ECOSYSTEM COMPONENTS AND EFFECTS

Demersal Fishes and Macrocrustaceans

Characterization. Demersal nekton communities in the vicinity of the BGOF were diverse and abundant. During 1976-1977, Emiliani et al. (1977) trawled 97 species of finfish and macrocrustaceans represented among 47,530 specimens. A much reduced trawl program conducted in 1977-1978 yielded 61 species (Workman and Jones 1979), and 104 species and 49,481 specimens were taken in 1978-1979 by Gallaway and Martin (1980). One undescribed species of jawfish was taken in the 1978-1979 program and the BGOF records will be included in a forthcoming revision of the jawfishes by William F. Smith-Vaniz of the Academy of Natural Sciences of Philidelphia. Specimens were deposited with the Academy.

As exemplified by Fig. 13, demersal nekton were basically represented by two seasonal assemblages (summer and winter), separated by periods of transition in the spring and fall. The summer assemblage was characterized by low abundances, few species and strong dominance by one species, the longspine porgy. In contrast, the winter assemblage was characterized by high abundance, many species and dominance by a macrocrustacean--namely sugar shrimp. Commercially important shrimps (*Penaeus*) were never a collection dominant although brown shrimp were relatively abundant in collections taken during the fall periods of migration. The commercial shrimping fleet was seldom observed fishing within the BGOF but was active during summer and fall in the silty-sand area east of the BGOF (see Fig. 4).

Most species of the demersal nektonic community were benthic feeders, and they, in turn, were found to serve as an important source of food for some benthic reef species such as red snapper. The demersal nekton community was a major contributor to the ichthyoplankton--engraulids, sciaenids and bothids were the three most abundant taxa of fish larvae represented in the BGOF (Finucane et al. 1979). Surprisingly, based upon egg abundance the BGOF is a spawning ground for anguilliforms, callionymids, clupeids, sciaenids, scombrids and soleids, but eggs of ichthyoplankton of reef fish were not abundant. Finucane et al. (1979) did not detect any effects of contaminant discharges on ichthyoplankton.

Effects. The results reported by Emiliani et al. (1977), suggest that demersal nekton communities within the BGOF were more diverse and abundant than those associated with the control areas. These differences may have been partly attributable to the greater habitat diversity associated with the field, particularly the presence of structures and exposed pipelines.

Comparisons of levels of species diversity and the abundances of dominant species within the BGOF were made by Gallaway and Martin (1980). Collections taken at a structure over a silty-sand substrate had significantly lower diversity than collections taken at structures over silty-clayey-sand substrates (Fig. 14). Within the latter substrate type, species diversity was significantly higher at the control satellite structure (no discharge) than at the production platforms (with contaminant discharge). This difference in species diversity was not associated with marked differences in the number of taxa represented in collections taken at two types of habitats, but appeared to result from the greater abundance of a few of the seasonally dominant species at production platforms than at satellite jackets (e.g. sugar shrimp, Fig. 15; chevron shrimp, Fig. 16). Most of the abundant species represented in the BGOF collections exhibited neither an attraction to, nor an avoidance of, discharging structures as compared to non-discharging structures. We believe that most of the observed differences in diversity and abundance were more attributable to substrate than to any other factor.

Brown shrimp were used as indicators of the health of the demersal nekton community. No histopathological anomalies were found and no evidence of any disease was observed. Bacterial flora on brown shrimp collected at production platforms was highly similar to the flora of specimens collected at control structures.

Biofouling Community

Characterization. The biofouling community colonizing BGOF structures was diverse and abundant. Fotheringham (1977) identified 16 algae and 101 species of invertebrates. The community consisted of two main components--shelled organisms which comprise and shape the overall habitat, and an encrusting "mat community" which provides additional habitat. Each of the above is characterized by a closely associated cryptic fauna.

The large Meditteranean barnacle, *Balanus tintinnabulum*, was the perennial dominant of the biofouling community and was estimated to occupy some 77% of the original platform substrate. Individuals of this banracle were observed to attain basal diameters of 3-4 cm and 6-8 cm in height. They characteristically grew in clusters forming a three-dimensional habitat some 10-15 cm thick.

The dominance of biofouling communities on BGOF structures by the Meditteranean barnacle represents a major zoogeographic finding of the program. It has been reported as an incidental species in the Gulf for some 20 years, and remains so on most platforms we have examined in the Western Gulf of Mexico offshore Louisiana. Our observations indicate that this species may be the dominant barnacle on platforms from the BGOF to areas offshore West Cameron, but it is seldom abundant on structures further east.

The Mediterranean barnacle is a filter feeder on particulates and plankton which feeds mostly during the night (Fig. 17). It spawns during late spring or early summer and in fall, usually somewhat later than the competing acorn barnacles which are seasonally abundant in the BGOF. The combination of the rapid growth and large size of the Mediterranean barnacle enable it to settle on and overgrow the smaller acorn barnacles.

The principal predators of BGOF barnacles were sheepshead and triggerfish and, to a much lesser degree, stone crabs. Another major source of natural mortality was large clusters breaking-off and sinking to the bottom during periods of high waves and/or currents. Barnacle shells were the major component of the rubble pads observed on the bottom beneath BGOF structures.

The barnacle community provided critical habitat for cryptic species such as pistol shrimp, stone crab and blennies, as well as clean surface for colonization by the mat community. Clean surface was provided not only by shell growth but also by scars left where clusters had broken-off and fallen to the bottom.

The mat portion of the biofouling community was characterized by a virtually inseparable interspersion of macroalgae, sponges, bryozoans and hydroids. The macroalgae (mostly green and red algae) represented a relatively small percentage of the total standing crop biomass, and were more abundant in summer than in winter. The faunal component of the mat, however, bloomed during winter seasons (particularly the stalked bryozoan *Bugula neritina*, and the hydroid, *Tubularia crocea*), but declined markedly over short periods during spring (Fig. 18) resulting in the characteristic low levels of mat observed for summer and fall.

The faunal components of the mat community are also filter feeders on particulates and plankton, and were utilized for food by sheepshead, triggerfish and small reef fishes. During periods of the spring decay, hydroid stalks suspended in the water column provided an important food for Atlantic spadefish. The "bushy" hydroids and bryozoans were used as habitat by small microcrustacean species (amphipods and copepods) as well as by brittle stars.

Although the numerical dominants of the cryptic assemblage associated with the biofouling community were represented by microcrustaceans; blennies, stone crab, pistol shrimp, polychaetes and brittle stars dominated from a biomass standpoint.

Cryptic species which were dependent upon bushy hydroids and bryozoans as cover and/or food (microcrustaceans and brittle stars) bloomed in winter and declined during warm seasons. In contrast, cryptic species dependent upon barnacles for habitat, and which did not outgrow the cover provided (e.g. pistol shrimp, polychaetes, and blennies), were characterized by rather stable seasonal population levels. Other cryptic species were apparently recruited to the structures from the plankton, flourished and grew until they exceeded a size allowing use of the habitat as cover. They were then either harvested by predators or left the area prior to reaching a reproducing size (e.g. stone crabs).

Principal predators on microcryptic species were sheepshead, triggerfish, blennies and small reef fishes; sheepshead and triggerfish were principal predators on larger cryptic species. Almaco jacks showed a marked preference for blennies.

A species of blenny new to the Gulf of Mexico was discovered during the last year of the BGOF investigation. The species represented is currently being described by Dr. Smith-Vaniz; and, prior to our discovery, was previously known only from St. Bartheleny Island (Lesser Antilles), Venezuela (precise locality unknown) and the Gulf of Uraba, Columbia.

The biomass dynamics of the biofouling community by depth and biological season with respect to characteristic water column conditions are summarized by Fig. 19. During all seasons, biomass levels near the bottom were markedly lower than biomass levels in the upper water column. The depth of this biomass discontinuity appears to coincide with the distribution of the year-round bottom nepheloid layer, and was mainly attributable to the absence of barnacles. As shown, biomass levels in winter were significantly higher than summer levels. Most of the observed seasonal change was attributable to the blooms of the mat community. High dissolved nutrient levels and phytoplankton blooms were also characteristic of the early winter season, and may have contributed to the increased biofouling levels.

Effects. The discharge of produced water had detrimental effects on the biomass levels and production rates of the biofouling community; but, using the 5% level to determine differences, significant alterations of the community were restricted to a vertical distance of about 1 m and a horizontal distance of less than 10 m (Fig. 20 and 21). These results, which were obtained *in-situ*, agree well with the projected zones of toxicity described for worst-case conditions above. The near-surface zones in the immediate vicinity of the outfall were characterized by the virtual absence of any living large barnacles but small (usually dead) barnacles were sometimes obtained in the collections taken there. Organisms colonizing this area may do quite well until worst-case hydrographic conditions occur. In addition, organisms colonizing this zone were probably periodically subjected to nearly 100% concentrations of produced water when they are exposed in the troughs of waves. Based upon recolonization information (Fig. 21), worst-case conditions were apparently encountered more frequently in spring through fall periods than during other seasons. The surface effect of produced water on recolonization rates for spring to summer and summer to fall periods is readily apparent in Fig. 21. However, production rates beneath the outfall at depths greater than 1 m were typically equal to, or greater than, production rates on control structures at the same depths during the same periods. Production rates at the surface beneath the outfall were even greater than rates at the surface station on the control structure during the fall to winter period. The fall to winter period was one of high energy and turbulent mixing prevailed. The winter to spring season was characterized by low production rates at all stations throughout the field and no significant differences were apparent.

Results of respirometry experiments indicated low rates of biofouling primary production and that a stress response (increased oxygen uptake) had been illicited from the communities subjected to treatment. In retrospect, the stress response was attributable to the fact that the concentrations of produced water to seawaters (10 to 25%) exceeded the 96-h LC50 value of most of the organisms being tested. For example, a common amphipod of the biofouling community (*Jassa falcata*) suffered 100% mortality when placed in a 10% produced-seawater mixture for 48 h.

The effects of produced water on the condition of the Mediterranean barnacle was reported by Boland (1980). Barnacles taken from locations as close as 1 m to the surface at the outfall were not significantly different in condition from those taken at control stations. He did find, however, that barnacles taken immediately below the sewage outfall were characterized by significantly higher condition than barnacles taken in control areas. He also found that Mediterrranean barnacles from the BGOF were characterized by significantly higher condition than the same species collected from a structure offshore West Cameron, Louisiana.

Barnacles were not found to contain measurable amounts of petroleum alkanes but the fouling mat in the immediate vicinity of the outfall was observed to have been oiled by direct exposure. The cryptic blennies which were relatively insensitive to produced water (96-h LC50 = 27%) and which were apparently attracted to the area of outfall (Gallaway and Martin 1980), also showed evidence of marked petroleum contamination. The mean alkane concentration in this fish in 1978-1979 was 6.79 ppm, considerably higher than levels found in any other fish. No evidence of any significant trace metal contamination of the biofouling community attributable to production activities was found during the BGOF investigations.

Structure Associated Fishes

Natural and artificial structures, including petroleum platforms, in the marine environment serve as aggregation points for large numbers of fishes representing many species. The mechanism of attraction (increased food, thigmotropism, etc.) and degree of permanency varies depending upon the ecological role of the species in question, as well as on the time of year and related hydrographic conditions encountered.

In the most general sense, the structure-associated fish fauna of the BGOF can be classified as either seasonal transients or residents. The most important, from at least a fisheries standpoint, of the seasonal transients are the warm-season pelagic predators and their plankton-particulate feeding prey. The predatory species representing this group in the BGOF included king mackeral, cobia, bluefish, little tuny, dolphin, sharks, blue runner, sharksuckers and jack crevalle. Prey species included spanish sardine, scaled sardine, and rough scad. The attraction of the seasonal-transient assemblage of fishes appears to be the structures *per se*, but residence times at the structures for most of the species were believed to have been short.

Klima and Wickham (1971) and Wickham et al. (1973) documented the effectiveness of artificial structures and floating objects in attracting pelagic predators and their prey. Although large variations in daily numbers of fish were observed, as many as 10,000 pelagic fish were estimated around floating structures one day after they had been positioned. The congregations of fishes were observed highly transient in nature, with different schools constantly moving into and away from structures.

The predator and prey species maintained different spatial relationships with the structures. Prey species were normally in the upper half of the water column either around the structure or upcurrent from it. Predators stayed either at the level of the structure or below it, seldom swimming above. Feeding was observed among the prey species but never among predators. Although large predators were infrequently observed directly, considerable evidence of their presence and feeding was noted in the form of mutilated fish. The authors interpreted their data as evidence that the initial attraction of fishes to structures is probably the result of a visual stimulus provided by a structure in the optical void of the pelagic environment.

Wickham et al. (1973) reported that the attraction of the gamefish species involved species-specific behavioral mechanisms. King mackeral and little tuny were seldom observed unless baitfish were present, but dolphin, cobia, and great barracuda were attracted to the structures *per se*. They presented evidence that baitfish were able to use artificial structures for predator avoidance in that the competing visual stimuli of structures disrupted the predator's visual fix on the prey which was required for a successful attack.

Studies of the seasonal transient fishes in the BGOF were directed towards bluefish; which, because of their tendency towards remaining in the vicinity of platforms for longer times and being more visible than other species, seemed most susceptible to investigative effort. In contrast to most pelagic predators, bluefish were typically abundant during cool seasons (fall, winter, and spring) and rare during summer (except during 1978-1979 when they were abundant during all seasons). Although no tagged fish were observed in census efforts, visual estimates made by divers indicated as many as 3,000 to 5,000 bluefish might be associated with a structure at a given time during the periods of seasonal abundance. Most specimens of BGOF bluefish were about 45 to 50 cm in fork length. We received no tag returns from bluefish by sportsfishermen.

Bluefish fed mainly on fish during fall and winter, but relied heavily upon demersal macrocrustaceans during spring (Fig. 22). Although some pelagic prey species were represented in the unidentified fish category, most of the food contained in the stomachs of specimens collected were representative of the demersal fish community. Bluefish, when present in the BGOF, were characterized by healthy populations and no evidence of any impacts from petroleum operations were observed for this species.

The resident species in the BGOF were found to include (1) fishes which were indicated directly dependent upon the biofouling community for both food and cover, and (2) those which appeared attracted to the structures mainly for cover alone (they exhibited little or no trophic dependency on the biofouling community). In the former category, we have included sheepshead (biomass dominant), blennies (numerical dominant), triggerfish, and amberjacks; as well as small pelagic (damselfishes, butterfly fishes, angelfishes, small sea basses, etc.) and demersal (cubbyu, wrasses) "reef" fish. In the latter category, we have included pelagic reef forms such as spadefish (usually the numerical and biomass dominant of the entire fish community) and tomtate; as well as benthic reef species such as red snapper and groupers. Sheepshead and blennies were studied as representatives of the reef-trophically-dependent segment of the population, and spadefish and red snapper were studied as representatives of the non-reef-trophically-dependent segment of the population.

<u>Sheepshead</u>. The sheepshead is a common inshore sportsfish of the Atlantic and Gulf coasts. Along the coast, the sheepshead frequents pilings, jetties and oyster reefs and sometimes moves up rivers into fresh waters (Pew 1971). In coastal habitats, the sheepshead feeds on barnacles and small fish. Young sheepshead are collected in spring and early summer along the beach and in the marsh (Dahlberg 1975), and we have observed young sheepshead particularly abundant in high-salinity grassbeds in Texas during spring and summer.

Very little work has been done with respect to the biology of offshore sheepshead populations. Gallaway et al. (1979b) reported sheepshead as one of the dominant species around petroleum platforms offshore Louisiana seaward to about the 37-m-depth contour. At this point, however, the relative abundance of sheepshead began to decline with distance offshore, or depth; and they were not observed at platforms investigated which were located seaward of the 64-m depth contour. Sheepshead investigations were conducted during the 1978-1979 research year by Gallaway and Martin (1980) and the results are summarized below.

Characterization--With the exception of early April 1979, populations of sheepshead at BGOF structures were relatively stable during research year 1979-1979 (Fig. 23). The observed population levels in April represented 17- to 19-fold increases over the population sizes estimated for each structure the previous quarter. We believe the observed concentrations represented a spawning congregation as the fish were mostly running ripe, and many were exhibiting what we interpreted as courtship behavior. Similar congregations were observed at all the structures examined in the BGOF during early April 1979. We do not know exactly how long the congregations persisted; populations had returned to the normally observed ranges by mid-May. We believe these observations represent the first evidence of spawning migration and aggregations for this species.

Recruitment of sheepshead to BGOF structures appears to be an annual event related to spring spawning aggregations at this habitat (Fig. 23). During August 1978, we were able to harvest all but about 10 of the sheepshead observed at Satellite 288-2. The observable population remained at about 10 fish until April 1979; after which the observable population was estimated at about 36 individuals (69% of the pre-harvest level, insert B, Fig. 23). Density of sheepshead at the two censused habitats (Production-Quarters 296-B, S288-5) were remarkably stable during each season with the obvious exceptions of April at both structures and summer at the Production-Quarters 296-B Habitat (Fig. 23). With the exception of movement between the adjacent production-quarters structures, sheepshead appeared habitat-faithful. No marked fish were seen at a structure other than where they had been marked. As indicated by Fig. 23, density of sheepshead was typically slightly higher at the satellites than at production-quarters structures.

Sheepshead in the BGOF during 1978-1979 ranged from about 22- to 50-cm fork length (Fig. 24). Fish between 22 and 35 cm usually dominated the collections, particularly during summer. In the latter case, nearly all the specimens at Satellite 288-2 were harvested and comprised a rather complete sample of the resident population.

The seasonal length-weight relationships for sheepshead were characterized by equal slopes and significant differences (5% level) were indicated among the seasonal levels of condition (F = 2.99 at 3 and 90 d.f.). Sheepshead collected in winter and summer were significantly heavier at an adjusted mean length than fish at the same length in fall and spring. Fall fish were not significantly different from summer and spring fish. The greatest difference in condition was observed between April and May sheepshead; the former group were in spawning condition, and, at a given length, averaged 6.3% heavier than fish collected after the spawning activity.

The food habits of sheepshead varied with season (Fig. 25). During summer 1978, portunid crabs comprised 67% (by weight) of the diet and were supplemented by biofouling organisms. During each of the fall, winter and spring seasons, the biofouling community comprised the majority of the diet. Most of the material in the "unidentified" category was believed to have been of biofouling origin. The presence of sargassum in stomachs of spring specimens supports visual observations of sheepshead grazing on rafts of this material as well as on the organisms utilizing the sargassum as habitat.

Sheepshead were characterized by higher Index of fullness values in winter (26.0) and spring (24.0) than in summer (19.0) and fall (14.0), but the data showed on almost uniform feeding periodicity over the 24-h cycle during each of the four seasons. Index of fullness values for the periods 2401-0600, 0601-1200, 1201-1800, and 1801-2400 h were 19.0, 19.3, 19.0, and 12.6, respectively. This species was heavily dependent upon the biofouling community for food; but, as described below, also obtained food from other sources (including food scraps from the platforms).

Effects--The bacterial flora of sheepshead was similar to that observed for other fish species collected from the BGOF. Species of *Vibrio* were represented each season and were usually the dominant form. Of interest, hemolytic *Vibrio* sp., typically abundant, were not isolated from sheepshead collected during fall 1979. *Aeromonas* sp. was one of the dominant taxa on sheepshead collected at each of the two sampled habitats in summer, and was also represented on fish taken at each structure in fall. This potential fish pathogen was not isolated from winter specimens and was represented only on Production Platform 296-B specimens in spring. The two categories of structure types (discharging and non-discharging) did not show marked differences in terms of sheepshead bacterial flora.

The most notable histopathological finding with respect to sheepshead was the vertical absence of any anomalous condition in tissue samples taken from specimens collected during the brief period of the spawning aggregation observed in the BGOF in April. Typically, sheepshead collected during other seasons exhibited five to seven different tissue anomalies, with each condition represented in 20 to 100% of the specimens collected. With the exception of gill hyperplasia which was characteristic of all specimens collected during the summer and four of five specimens collected at Production Platform 296-B in fall, most of the anomalies in the tissues examined were lesions in association with the presence of, or attributable to, a parasite (e.g. nematodes). If the fish collected during April were indeed representative of a migrant population, it would appear from these data that resident sheepshead are characterized by a higher degree of histopathological anomalies (or parasitism) than are sheepshead which migrate in and out of the study area for spawning purposes.

Comparisons of condition of sheepshead at the treatment and control structures were based upon specimens subsequently submitted for histopathological and bacterial flora analysis. The data set was reduced to the December 1978 and May 1979 collections, as the sheepshead represented during April were not considered resident fish, and weights were not obtained for the specimens analyzed from August. The length-weight regressions for fish from the two habitats had equal slopes (F = 1.75 at 1 and 16 d.f.); and, although fish from Production Platform 296-B were 10.6% heavier than fish from Satellite 288-5, the differences were nonsignificant (F = 3.79 at 1 and 17 d.f.).

Sheepshead were characterized by the presence of petroleum alkane contaminants in both liver (6.08 ppm) and muscle tissues (4.57 ppm). These levels were lower than that observed characteristic for blennies, but higher than levels observed for fishes not trophically dependent upon the biofouling community for food. No significant trace metal contamination related to BGOF operations was demonstrated (Tillery 1980).

Crested blenny. The blennies are small, "personable" fishes that live in and around rocks, reefs and other hard substrates, particularly barnacle shells. Populations in the BGOF consisted of at least four species--crested blenny (dominant), seaweed blenny, molly miller and the new species noted above. The crested blenny is the most common form on Texas jetties and petroleum platforms of the shallow Gulf.

Characterization--Average density of blennies on BGOF structures dominated by the Mediterranean barnacle ranged from 12 to over 50/m^2 (Workman and Jones 1979, Gallaway and Martin 1980). This compares with a range of 8 to 16/m^2 on platforms offshore Louisiana dominated by acorn barnacles (Gallaway et al. 1979b). Densities of blennies was significantly higher during summer periods than during other seasons, presumably due to recruitment. Spawning of the crested blenny extended from spring to at least August, and the entire life cycle is completed on the structures. Eggs and larvae are brooded in empty barnacle shells. Seasonal size distribution of crested blenny in the BGOF (based upon 1978-1979 data) is shown by Fig. 26.

The crested blenny relied almost entirely on the biofouling community as food (Fig. 27). Hydroids, bryozoans and algae were commonly ingested and small, cryptic species (e.g. amphipods, polychaetes, etc.) were also important food items. During summer 1979, sponge spicules represented 5.1% of the diet. Much of the above "fouling mat" material is probably ingested as the blennies take discrete, cryptic organisms. Barnacles provide not only critical habitat for blennies, but also food, mainly through the work of sheepshead who leave bits of barnacles in the crushed shells during and after feeding.

Based upon the identifiable food contents in the stomachs from samples obtained during 1978-1979, hydroids and barnacle molts were the dominant food items of blennies during summer and fall; amphipods and algae were important during winter, and, during spring, amphipods, hydroids and algae were the dominant foods. The unidentified category is believed to have been primarily of biofouling origin.

Index of fullness values for the crested blenny were highest in winter (52.5) intermediate in spring (36.0) and lowest in summer and fall (29.6 and 28.2, respectively). On a daily basis, stomach contents of specimens collected between 0601 and 1200 h were lower (IF = 27.0) than contents from specimens collected during other periods (IF $\bar{x}$ = 49.0 for period of 1201-1800 h; 49.5 for 1801-2400 h; and 42.0 for 1201-0600 h).

Effects--Blennies exhibited an apparent attraction to the produced water discharge. Highest densities were observed on production platforms and significantly higher densities were observed near the outfall than elsewhere. Based upon *in-situ* investigations, the effluent had no significant effects on recolonization rates of areas harvested of blennies nor were there any significant effects on condition of blennies.

The apparent attraction to the outfall area may have been attributable to the combination of a greater level of habitat availability due to higher densities of both live and dead barnacles in these areas (Howard et al. 1980) and the apparent lack of sensitivity of the crested blenny to produced water (96-h LC50 was 269,000 ppm or about 27% produced water in seawater).

Results of simple bioassays performed *in-situ* by Workman and Jones (1979) confirmed that the crested blenny was tolerant of produced discharge. The experiment was performed by suspending caged blennies just beneath the surface in the area of outfall and beneath a control satellite for an approximate 48-h period. Three of 20 and 22 crested blennies suspended in each of the respective areas died during the experiment. In contrast, all 20 of the seaweed blennies in the cage suspended beneath the effluent died. None of 17 in the control cage were known to have died although 5 specimens were missing (believed to have escaped during a transfer of fish into the cage).

The crested blenny differed little from other BGOF fishes in terms of its bacterial flora. Species of *Vibrio* were the most common taxa during each season; hemolytic *Vibrio* were not isolated from fall specimens. *Moraxella* sp. was apparently a co-dominant with *Vibrio* sp. during spring. There was no marked difference in the bacterial flora of blennies taken from the production platform as compared to those collected at satellite jacket habitats. No diseased blennies were noted in any of the areas sampled.

The crested blenny was a "clean" fish in terms of histopathological anomalies. Other than a light infestation of microsporidean parasites, no significant histopathological anomalies were detected in the specimens which were examined.

However, the average alkane concentration in this fish was 6.79 ppm, higher than the mean levels observed for any other fish from the BGOF (Middleditch 1980). Trace metal contamination of blennies attributable to BGOF operations was not indicated.

Spadefish. The spadefish represents another common coastal food and game fish with little known about its offshore biology. In the United States, its range extends along the Atlantic coast from Cape Cod to Florida and throughout the Gulf of Mexico and into the Caribbean. In Texas, large numbers of small spadefish show-up in the surf along the beach during the spring of each year and remain in nearshore habitats until about fall. Spadefish are generally found in schools and, along the coast, they congregate around jetties, wrecks, pilings and bridges where the average size seldom exceeds 454 g. Offshore, schools are sometimes observed in open water, but spadefish characteristically congregate around structures, particularly petroleum platforms which differ from other reefs in that they extend from the bottom to the surface. Around production platforms, large fish are common, some up to 9 kg. The offshore distribution of spadefish in the Gulf was found by Gallaway et al. (1979b) to be similar to that described for sheepshead above--they were not observed at deep water platforms. Spadefish investigations were conducted during 1977-1978 (Gallaway et al. 1979a) and 1978-1979 (Gallaway and Martin 1980).

Characterization--Based upon results of the mark-recapture studies, spadefish were observed to be habitat faithful; i.e. there was little exchange among populations associated with different structures except for the closely-allied quarters and productions platforms. We believe that the best estimates of seasonal densities of spadefish around BGOF structures were about 0.11 to 0.15 fish/m^3 in summer, ≈0.20 fish/m^3 in fall, ≈0.22 fish/m^3 in winter and about 0.16 fish/m^3 in spring. The seasonal size distribution of spadefish populations appeared to differ by season. During winter and fall, length of individuals ranged from about 210 to 500 mm with fish greater than 400 mm rather common. These large individuals were scarce or absent around the structures during spring and summer seasons (Fig. 28). In spring, the observed length range of spadefish was from about 135 to 385 mm with no apparent size group dominant. Summer populations ranged in length from 175 to 360 mm with at least two different size groups represented (Fig. 28). We believe that relatively high densities observed during fall and winter are attributable to recruitment during fall and to the influx of large fish during winter which were absent (spawning?) during spring and summer.

Recently-spawned spadefish (5-30 mm) were not observed in the BGOF by us during any season. Additionally, results from the ichthyoplankton sampling program of 1976-1978 (Finucane et al. 1979), indicated larval spadefish were not abundant during any season. As described above, young spadefish are abundant in the surf zone of Galveston Island in late May and June. We suspect that the absence of large fish during spring and summer and the relatively large size of the smallest recruits indicates that spawning of this species generally occurs elsewhere.

Food habits of Atlantic spadefish varied seasonally (Fig. 29). During summer, the diet of this species was dominated by a planktonic pteropod, *Carolina longirostris*. During each of the fall, winter, and spring seasons, we were unable to identify most of the material in the stomachs, but suspect that it is primarily of biofouling origin. During winter of the 1979-1980 research year, we were able to obtain a series of stomach contents grading progressively from intact hydroid stalkds to an unidentifiable mass. Food habitat data for spadefish indicate that when plankton were unavailable, spadefish will utilize the biofouling community as a food source. This appeared especially true during the spring when biofouling organisms were being sloughed from the substrate and, as suspended particulates, were harvested by the plankton-feeding spadefish.

Based upon comparisons of Index of Fullness values (IF, Gallaway et al. 1979a) determined from specimens collected by spear, daily feeding periodicity of Atlantic spadefish was not markedly different among seasons. Feeding appeared to have been greatest during the period from mid-morning (≈1000 h) to early evening (≈2000 h), particularly during late afternoon (1600-1700 h). Although patterns of daily feeding were similar among seasons on a relative basis, the magnitude of the IF values varied greatly among seasons. The respective average IF values for specimens speared during summer, fall, winter and spring were 25.7, 3.3, 1.0 and 20.5. The high summer value was associated with plankton-particulate feeding in the upper water column, whereas the low fall and winter levels were believed associated with near-bottom grazing of the biofouling community. As described above, most of the food in the spring samples was also considered to have been of biofouling origin (probably *Tubularia crocea*) but was believed to have been harvested from the water column as opposed to having been grazed from the structures.

During winter of 1977-1978, we observed that spadefish populations in the BGOF experienced a disease epidemic characterized by large, external lesions and varying degrees of fin rot. Based upon bacterial isolates cultured from diseased specimens collected at that time, the fish pathogen *Vibrio* was abundantly represented. Badly diseased fish (those with large lesions and advanced cases of fin rot) were more in evidence at Production Platform 296-B (61% of the sample) than at Satellite 288-5 (25%). The spadefish disease epidemic was also in evidence during the winter period of 1978-1979. In contrast to the previous year, there was little difference among structures (73 and 74% of the spadefish at the Production Platform and control satellite structures, respectively, were badly diseased). In early March practically no diseased spadefish were observed at the V.A. Fogg Liberty Ship Reef which was used as a control against which to compare BGOF populations.

In addition to gross examination, spadefish tissues were collected each season for microscopic examination. Histopathological anomalies in spadefish tissues (gills, intestine, liver, kidney, skin) determined by microscopic examination varied among seasona and habitats. Although larger sample sizes would have been needed to make definitive comparisons, gill hyperplasia was observed to be prevalent during summer, particularly at Production Platform 296-B where each of the 5 specimens collected evidenced the anomaly. Fatty infiltration of the liver was pronounced in spadefish at all sites sampled in the winter and fall, less prevalent during summer, and present in only 1 of 10 fish collected during spring. Fatty infiltration of the liver of spadefish colonizing offshore Louisiana platforms during summer was also observed by BLM investigators (C.A. Bedinger, Southwest Research Institute, pers. comm.). Lesions in skin and fin tissues of BGOF spadefish were restricted to winter samples.

Bacteriological analysis of fish tissues yielded results similar to those of Sizemore (1979) in that *Vibrio* sp. was a predominate genera in all samples, particularly during winter. Potential fish pathogens (*Vibrio* sp., hemolytic; *Seromonas* sp.) were also represented during all seasons. Of these, Sizemore (1979) found only *Aeromonas hydrophila* associated with the four diseased fish he examined.

Spadefish sidease epidemics appear best explained as the result of the actions of opportunistic pathogens during a period of natural seasonal stress for the host. Much of the seasonal stress is presumably attributable to the observed combination of high density, change in habitat (spadefish move from surface waters to the bottom during winter), reduction in apparent feeding efficiency, and the change in food habits from plankton to suspended particulates of biofouling origin (Fig. 30). The observed fatty infiltration of the liver may represent results of a nutritional deficiency of this alternate food source utilized during winter. During the 1978 research year, Atlantic spadefish were characterized by significantly ($\alpha = 0.05$) better condition in summer than in winter (Gallaway et al. 1979a); however, no significant seasonal differences were observed during the 1979 research year (Gallaway and Martin 1980).

Effects--Spadefish showed no evidence of either petroleum or trace metal contamination attributable to BGOF operations, and were characterized by the lowest levels of total alkanes of any fish tested (Middleditch 1980, Tillery 1980). Density levels were found to have been equivalent among the various structure types in the field. The observed disease epidemics seem best explained by natural phenomena. Whereas condition of spadefish was significantly lower during winter than during other seasons as might have been expected, condition did not differ significantly among the habitats sampled during winter.

However, the possibility, although considered by us to be slight, remains that the winter disease epidemics may have been related to the chronic, low-level discharge of contaminants.

Minchew and Yarbrough (1977) found that 96% of the mullet, *Mugil cephalus*, held in ponds subjected to a low-level oil spill (4 to 5 ppm) suffered fin rot whereas only 6% in a control pond developed eroded fins. The primary pathogen considered responsible for the fin erosion was a species of *Vibrio*. Subsequent laboratory work by Giles et al. (1978), confirmed the above results and showed that chronic, low-level exposure of mullet to oil significantly altered the bacteria on the fish, allowing for a large population of potentially pathogenic *Vibrio*. They also suggested that the *Vibrio*, through utilization of the oil, may have acquired an enhanced virulence. Our field studies agree with the findings of the above pond and laboratory experiments in that fish exposed to chronic, low-levels of hydrocarbons in discharges developed external lesions and fin rot which may have been attributable to a *Vibrio* sp.

Red snapper. The red snapper, a highly prized sport and commercially valuable offshore species, occurs in association with hard-bottom habitats throughout the Gulf of Mexico (where it is probably most abundant) as well as in the Western Atlantic and Caribbean Sea. It is believed that red snapper tend to be associated with deeper water (30-65 m) during winter, but that during warmer periods, there is a general movement from offshore to inshore reefs (20-30 m). Spawning occurs between June and October, and juveniles utilize open sand or other soft substrates in waters 10- to 30-m deep as nursery grounds. Red snapper are recruited from the demersal nekton to the reef community at about the end of their first year at which time they have attained lengths of about 140 to 250 mm.

Red snapper investigations in the BGOF were conducted by Workman and Jones (1979), Gallaway and Martin (1980), and during the final research year, 1979-1980, reported herein.

Characterization--All of the tag return data indicated that red snapper were structure-faithful. No tag was returned or taken during a census other than at the location where the fish had been tagged. Population levels of "reef" (≈>180 mm fork length) red snapper at Production Platform 296-B in the BGOF (heavily fished) during the 1978-1980 research years and at a relatively little fished structure in the West Cameron 333 BLM lease block during research year 1980 are shown by Fig. 31. Population levels of reef-sized snapper in the BGOF were highest during the fall and spring seasons, and summer levels typically exceeded those observed during winter, except in 1978. Although some of the population fluctuations of red snapper in the BGOF were undoubtably associated with seasonal movements, we believe most of the reductions were directly attributable to sport-fishing. The difference in population size between the heavily-fished BGOF structure and the relatively unfished petroleum platform in an area with difficult access is apparent (Fig. 31). We received a high rate of tag returns from sportsfishermen and directly observed fishing pressure to have been heavy, particularly during the warm season. We believe that most of the annual recruitment of reef red snapper to the BGOF is harvested by sportfishermen as elaborated under Recreational Fisheries below.

The typical seasonal size distribution of red snapper (including small specimens taken in BGOF trawls) based upon 1978-1979 data is shown by Fig. 32). Within Age Class 0 (after Bradley and Bryan 1976), two size groups were represented in fall, winter and spring--only the larger of these was represented in summer collections. Moseley (1966) stated spawning off the Texas coast extended from early June to mid-September; Bradley and Bryan (1976) provided evidence extending the spawning period from April to as late as November. The latter authors also reported that snapper attain fork lengths of about 200 mm during their first year and grow at a rate of about 75 mm per year after Age or Year Class I. Using the above data as criteria, Age Class 0 fish in the study area during summer of 1978 were probably those of the previous summer's spawn. The small size group of Age 0 fish represented in fall and winter collections were probably spawned in spring of 1978, grew little during the period December 1978-March 1979 and were probably represented by the two specimens between 140 and 155 mm trawled in spring 1979 (Fig. 32). The larger size group of Age 0 fish in fall and winter 1978 collections were probably spawned in early spring of 1978 and were represented by the large Age 0 and small Age I specimens represented in spring 1979 collections. The small size group of Age 0 fish in spring were probably fish spawned the preceding month.

Snapper enter the hook-and-line fishery at about 200 mm (Bradley and Bryan 1976). The red snapper fishery in the BGOF is dominated by Age Classes I and II, no fish older than Age Class IV was represented in our collections (Fig. 32). The dominance of relatively young red snapper in the BGOF fishery also indicates heavy fishing pressure. Fable (1977) found that heavily fished structures and reefs were characterized by smaller and younger (mostly Age Classes I and II) red snapper than were present at less heavily fished banks (Fish up to Age Class V were taken).

The diet of red snapper varied with season with winter appearing to be the most dissimilar in terms of diet (Fig. 33). During winter, red snapper were indicated to feed almost exclusively on squid, although small carangids (probably scad) were also taken. We suspect that the squid was provided by us in the form of bait and that red snapper rely primarily upon other fish as food during the winter season. The mantis shrimp, *Squilla*, was a major component of the diet of red snapper during both the summer and spring seasons with fish also well represented during summer. Shrimp, fish and swimming crabs were the most abundant food items of red snapper collected in the BGOF during fall. Results of our findings generally agree with those of other investigators (Moseley 1966, Bradley and Bryan 1976).

Average index of fullness values of red snapper captured by angling were 68.7, 29.0 and 18.0 for morning (0600-1200 h), afternoon (1201-1800 h) and early evening hours (1801-2000 h), respectively. No specimens were obtained for the period 2000 to 0600 h. These data in combination with the above food habit data could be interpreted to indicate that red snapper feed during the night or early morning over soft bottom away from the platforms. Hastings et al. (1976) obtained similar results for lutjanids in the northeastern Gulf and the Gulf of Mexico Fishery Management Council (1980) reported that most of the benthic prey "consumed by red snapper are not obligate reef or rock dwellers and therefore the inference can be made that the species feeds away from these areas." Red snapper obtained in our study exhibited very little, if any, dependence upon the biofouling community as food.

Effects--Of the 34 red snapper examined for histopathological anomalies, 62% were characterized by gill hyperplasia and 47% by intestinal parasites, usually accompanied by intestinal inflammation, fibrosis and lesions. Gill parasites were believed largely responsible for the observed hyperplasia. No marked difference in the frequency of the various anomalies was observed for production platforms *vs* satellite jacket populations or among seasons. Bacterial flora of red snapper varied seasonally with *Vibrio* sp. usually the dominant form on fish from each of the two habitats sampled. Hemolytic *Vibrio* sp., which include representatives of potential fish pathogens, were well represented on specimens from each structure during each season except fall 1978 when none were isolated from any of the samples. *Aeromonas* sp., which also contains fish pathogens, were isolated from specimens taken at Production Platform 296-B in summer 1978 (27% of the total 26 colonies isolated from snapper tissue were *Aeromonas* sp.) and in spring 1979 (15% of the total 47 isolated colonies). *Aeromonas* sp. were not isolated from red snapper specimens taken at Satellite 288-5 during any season. No evidence of disease or red snapper in poor condition was observed at any location or during any season. Hydrocarbon contamination was variable but typically low (Middleditch 1980); no significant trace metal contamination was observed (Tillery 1980).

Recreational Fisheries

Information provided by Bob Ditton of Texas A&M University (pers. comm.) shows that 50% of all offshore sportsfishing effort along the upper Texas coast is directed at "oil" platforms and that the BGOF receives an estimated 21% of the effort (Fig. 34). Data for the BGOF obtained by Trent et al. (1977) indicated that, weather permitting, the average number of fishing boats in the BGOF ranged between 1 and 6 on weekdays and from 5 to 16 boats on weekend days. Fishing pressure was highest during late summer and early fall.

Of the total number of boats categorized as to type of effort, 77% were bottom fishing, 17% were trolling and 6% were being used as a diving platform. Bottom fishing boats were concentrated around the large production platforms; divers mostly utilized the satellite jackets, perhaps to avoid the bottomfishing. The most fish were caught per fisherman hour by bottom fishing. Of all species reported caught in the bottom fish fishing, red snapper comprised 80% of the catch, Atlantic spadefish 7% and bluefish comprised about 4%. The average bottom fishing boat contained 3.2 people who averaged fishing about 4 h. The number of red snapper caught per fisherman hour ranged from 0.2 (July) to 6.8 (December). Red snapper were also taken in both the trolling and diving efforts. In the former type of effort, the king mackeral was dominant.

We developed a model to simulate the BGOF recreational red snapper fishery based upon the above and the biology of the species. The purpose of the model was to evaluate the observed effort indicated at the BGOF in terms of impact on the commercial fishery and snapper stocks in the Gulf of Mexico. The results of the modeling effort produced projections of marked red snapper stock declines directly attributable to the recreational fisheries associated with petroleum platforms if as few as 100 of these platforms receive the same fishing pressure as a BGOF production platform. The Gulf of Mexico Fishery Management Council (1980) had published data that confirm red snapper stocks are being overfished, and that this condition is directly attributable to the recreational fishery as opposed to the commercial fishery.

Biological Systems Overview

As depicted in Fig. 35, we conceptualize the BGOF as a large sink in the marine environment. The physical presence of the platforms is the major factor controlling, or accounting, for, the three general biotic assemblages which aggregate at these sites--the biofouling, pelagic, and benthic reef fish communities. Of these, the biofouling community is the most complex. The diversity and biomass level of the biofouling community that develops is controlled by the type of perennial shelled animal (in the case of BGOF, barnacle) that dominates. Barnacles (or other shelled organisms) provide habitat diversity, space, and food for other organisms. Barnacles are preyed upon largely by sheepshead and triggerfish, species capable of crushing their protective shells. In their grazing, sheepshead do not always consume all the barnacle and the remains are available to smaller predators such as blennies. Blennies, in turn, are sometimes taken by sheepshead as well as other fish predators, particularly amberjack or almaco jack. Even through cycling is undoubtably high (Gallaway and Margraf 1979), the biofouling community probably obtains most of its food from the environment in the form of plankton and particulates flowing through the system from the environment. Some species are also recruited to the biofouling community from the environment (e.g. stone crab larvae, adult sheepshead). Losses from the biofouling community to the environment include those from reproduction, breaking-off and sloughing, as well as to man (mainly sheepshead, triggerfish, amberjacks).

With the exception of a few plankton-particulate feeding pelagic species which apparently are platform residents, the pelagic predators (e.g. king mackeral, blue runner) and their prey (e.g. scaled sardine), essentially "drift" through the system as do suspended particulates but are characterized by slightly longer residence times. The known aggretory habitats at structures results in their being exposed to increased predation from the top predator from the environment--man. The benthic reef fish community dominated in the BGOF by red snapper, is also subjected to increased predation from man. Red snapper aggregate at platforms, apparently only for purposes of cover since most of their diet is comprised of organisms from the demersal fish and macrocrustacean community.

The direct effects from produced water discharge on the communities appear restricted to only a few meters from the point of outfall due to rapid dilution. Petroleum contamination appears restricted to species within the biofouling community, and there was little or no evidence of any bioaccumulation by any species.

CONCLUSIONS AND RECOMMENDATIONS

Based upon the results of field and laboratory investigations performed over the period 1976-1980, the following major conclusions are supported by the data:

- The major effect of the BGOF has been to provide substrate allowing for the development of a rich and diverse biofouling or artificial reef community.
- The structures and reefs aggregated nektonic species preferring these habitats, as well as those who preyed upon them--particularly man.
- Produced waters were toxic but the direct effects on the biota were restricted to within only a few meters of the outfall.
- Indirect effects of chronic, low-level contaminant discharge, although not known with certainty, were not indicated to have been significant.
- Measurable uptake of contaminants seemed minimal and restricted to those species in the biofouling food chain, there was little evidence of bioaccumulation.
- More concern seems to be in order relative to the effects of the recreational fishery on the fish rather than concern about the effects of the field on either the fish or the recreational fishery.

Based upon subjective evaluations of the certainty of the conclusions, two areas should receive additional investigation. Laboratory and field studies should be directed towards examining the relationship of chronic, low-level contaminant discharges and seasonal fish disease epidemics, and population dynamics studies of red snapper at natural and artificial reefs should be determined as a basis for enlightened management of an apparently dwindling resource.

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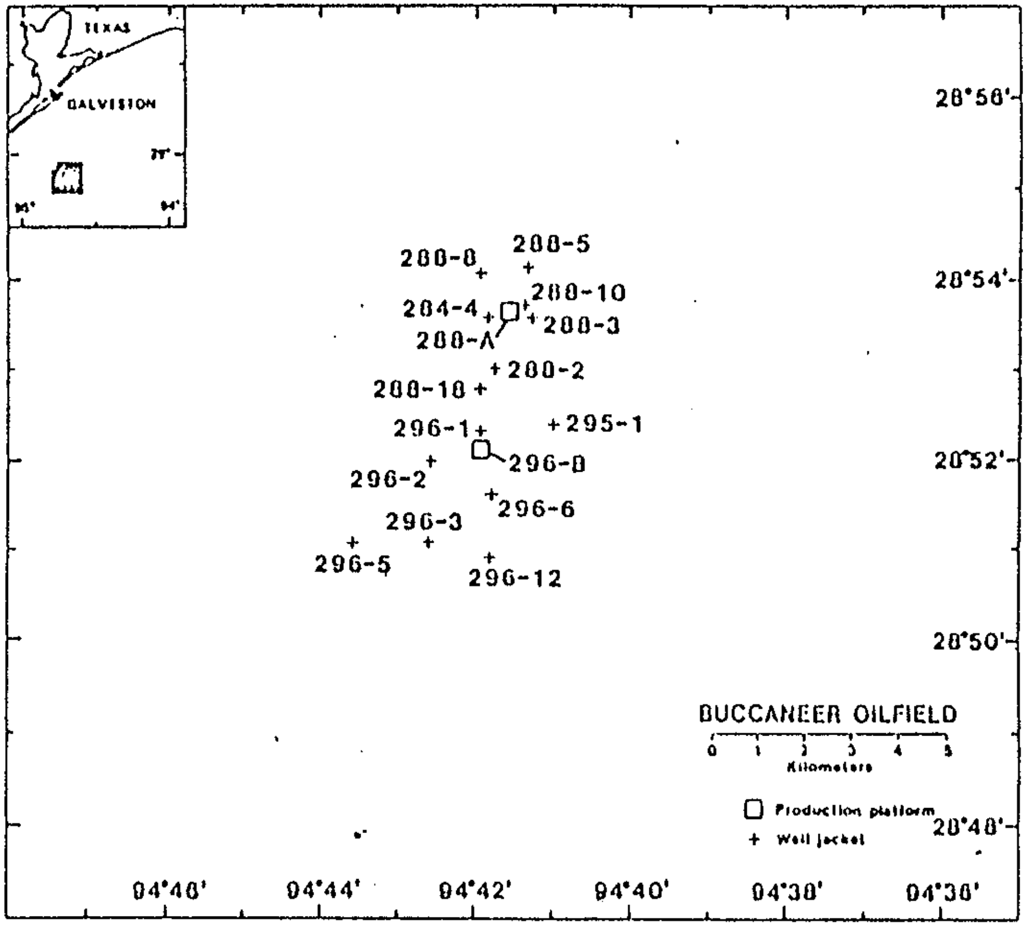


Fig. 1. Map showing locations of production platforms and well jackets in the Buccaneer Gas and Oil Field (after Middleditch 1979).

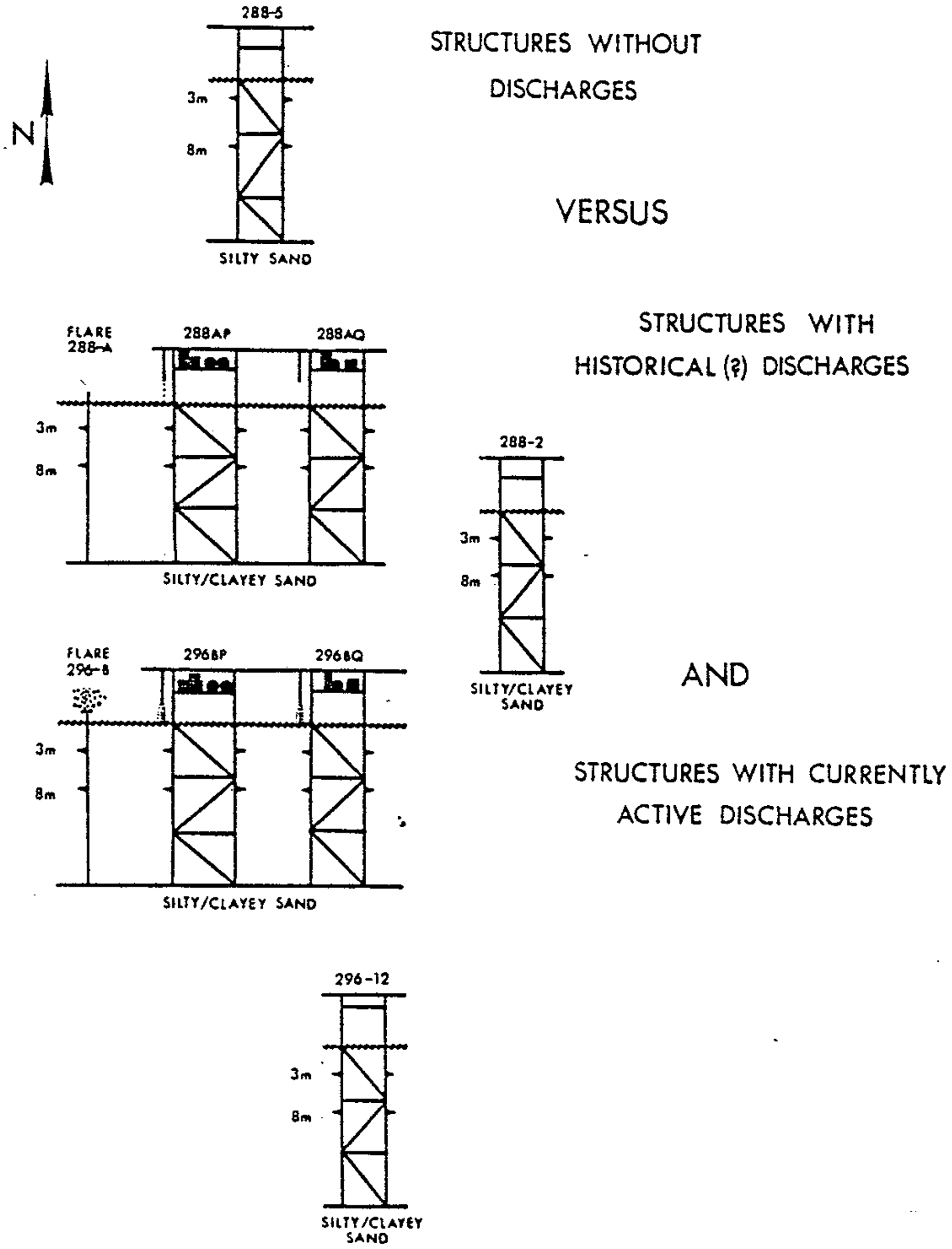


Fig. 2. Idealized experimental design.

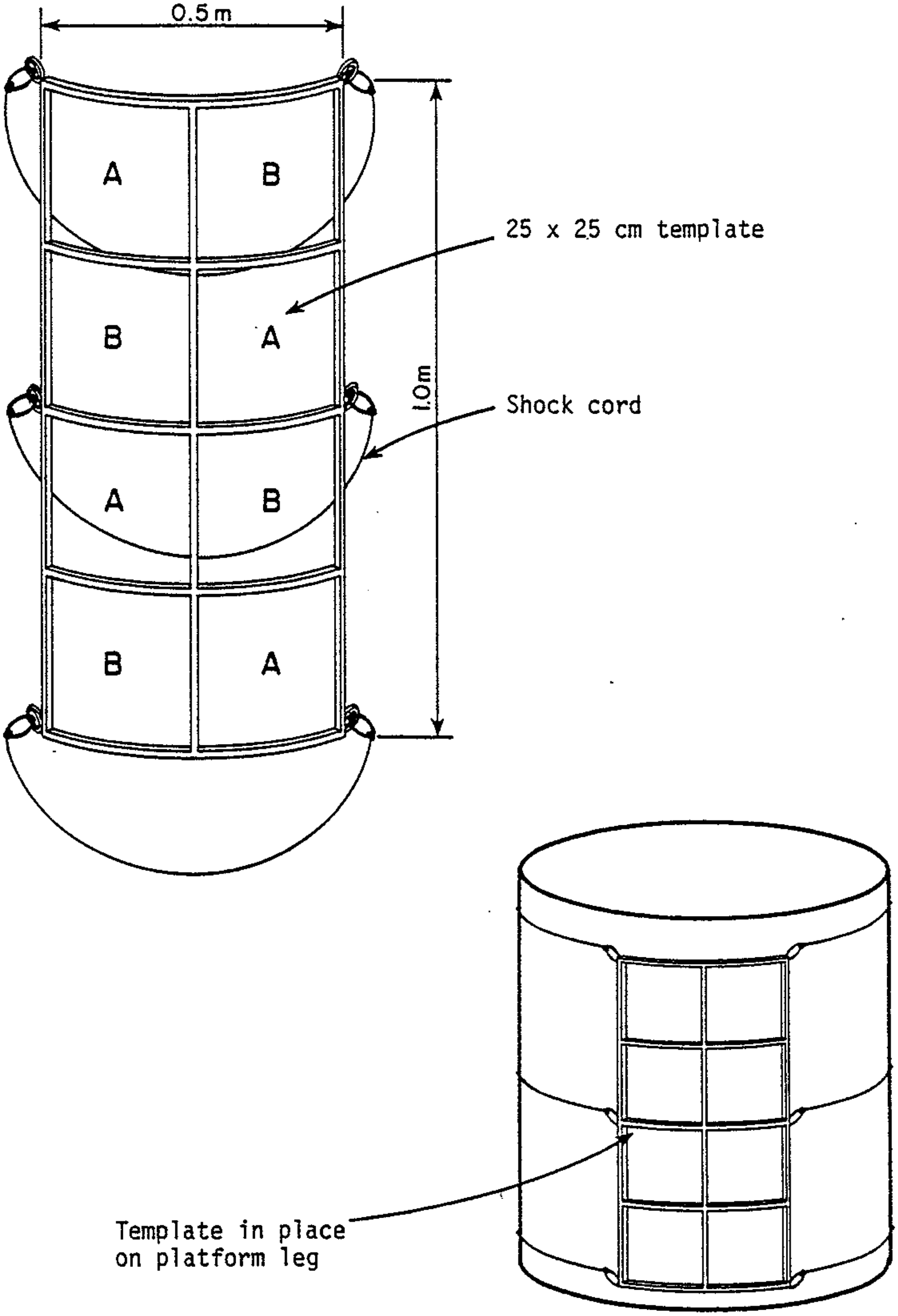


Fig. 3. Diagrammatic representation of scraping templates. Cells labeled A and B represent the two possible sampling schemes.

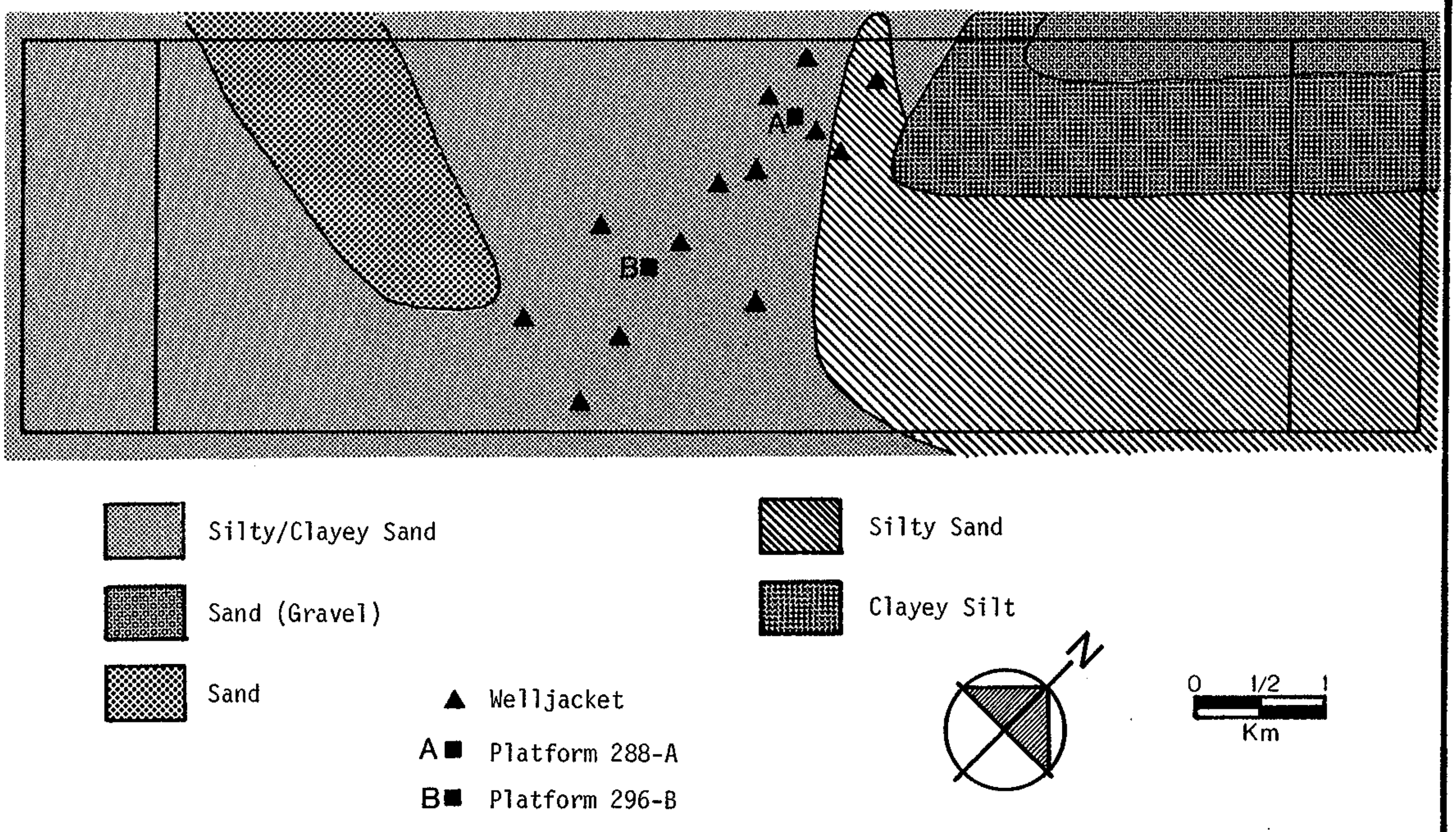


Fig. 4. Sediment distribution in the Buccaneer Gas and Oil Field.

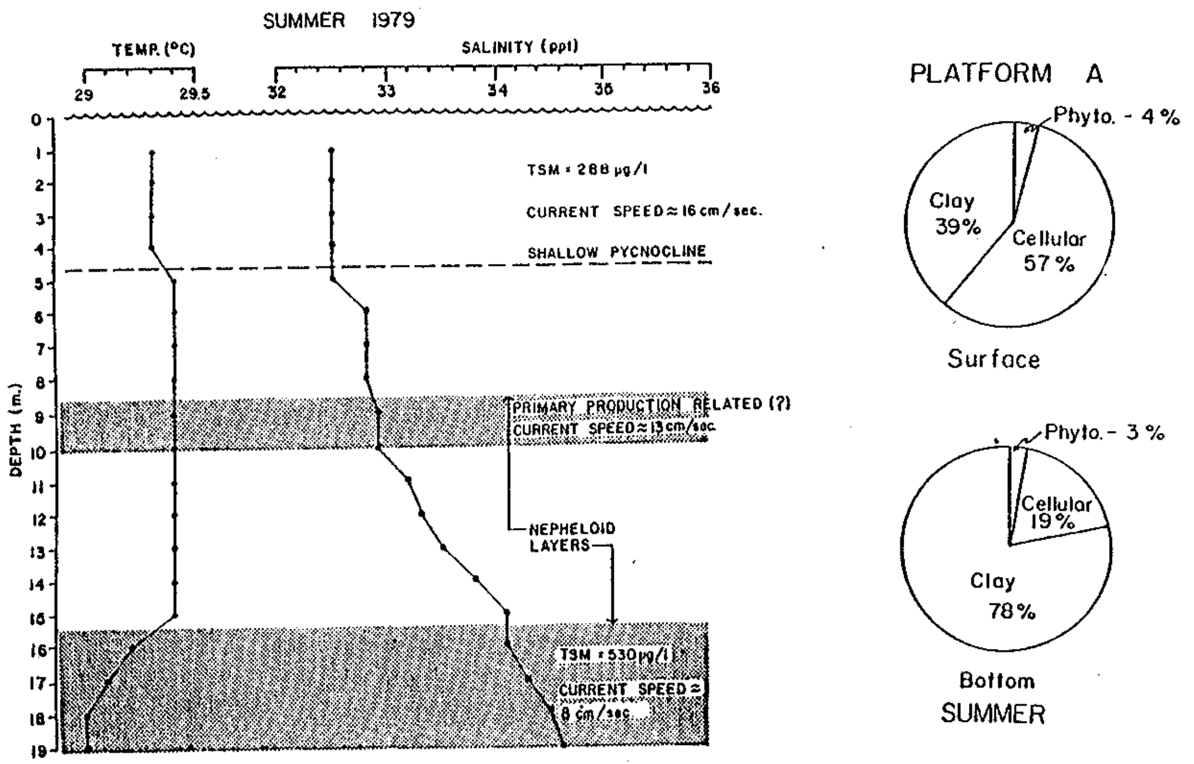


Fig. 5. Characteristic environmental structure observed in the Buccaneer Gas and Oil Field during summer, 1979.

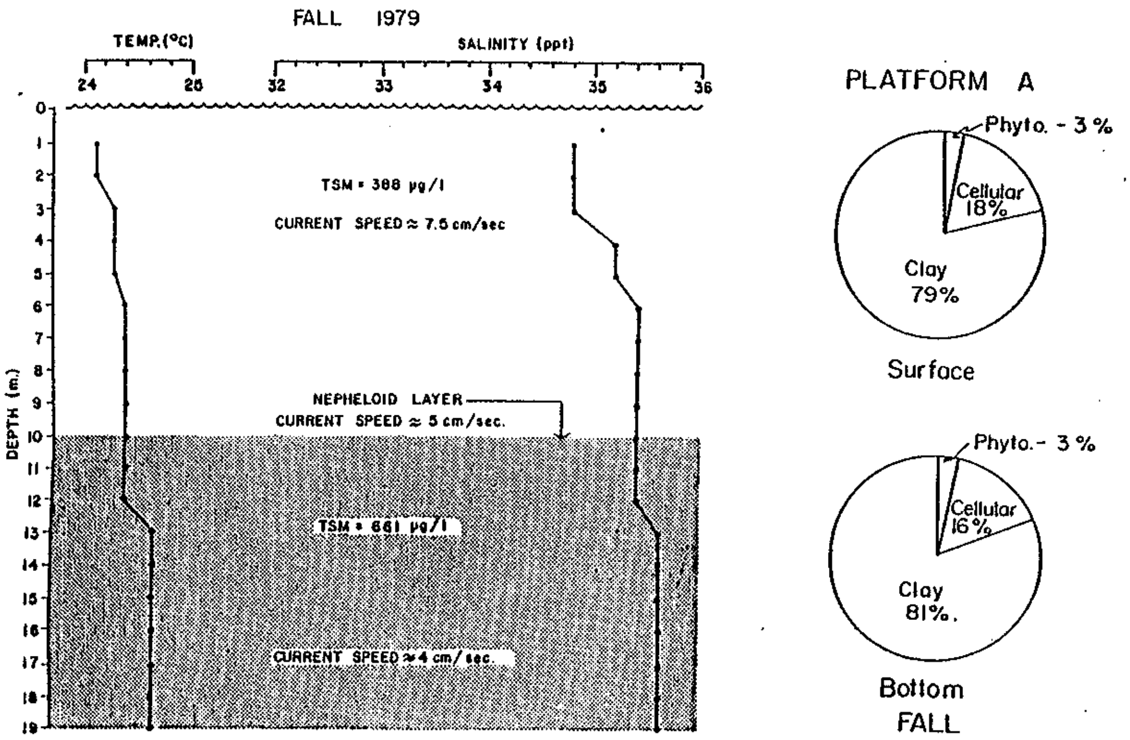


Fig. 6. Characteristic environmental structure observed in the Buccaneer Gas and Oil Field during fall, 1979.

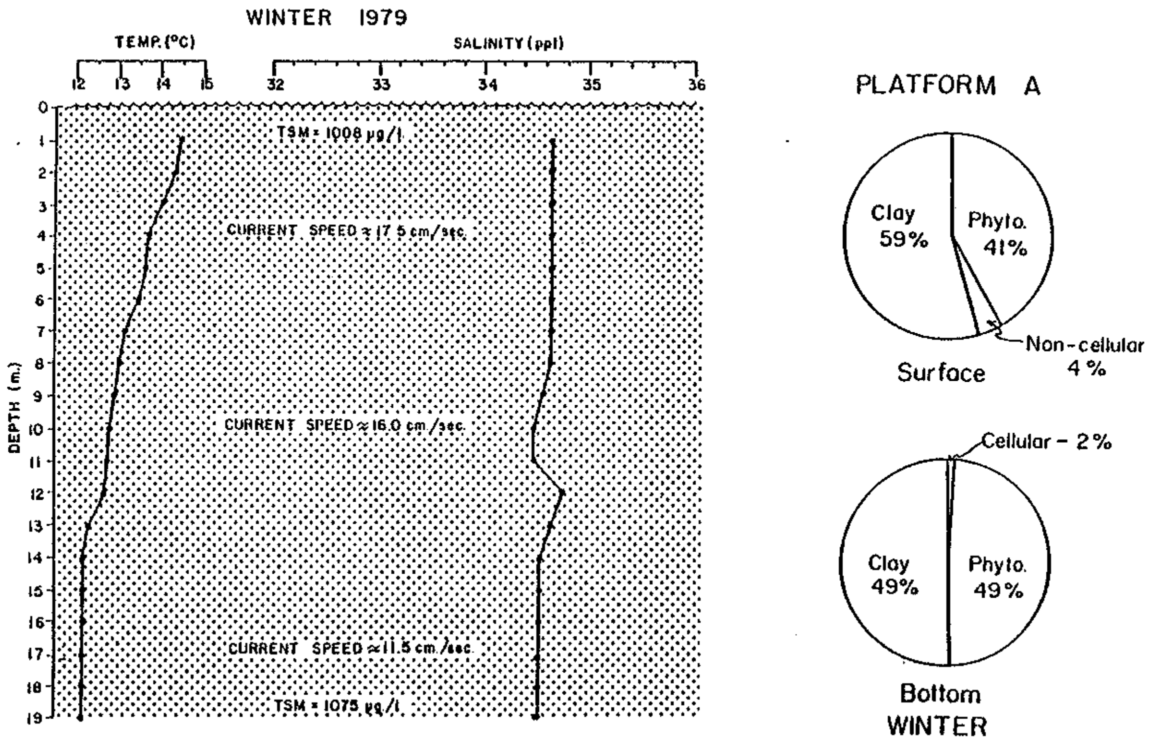


Fig. 7. Characteristic environmental structure observed in the Buccaneer Gas and Oil Field during winter, 1979.

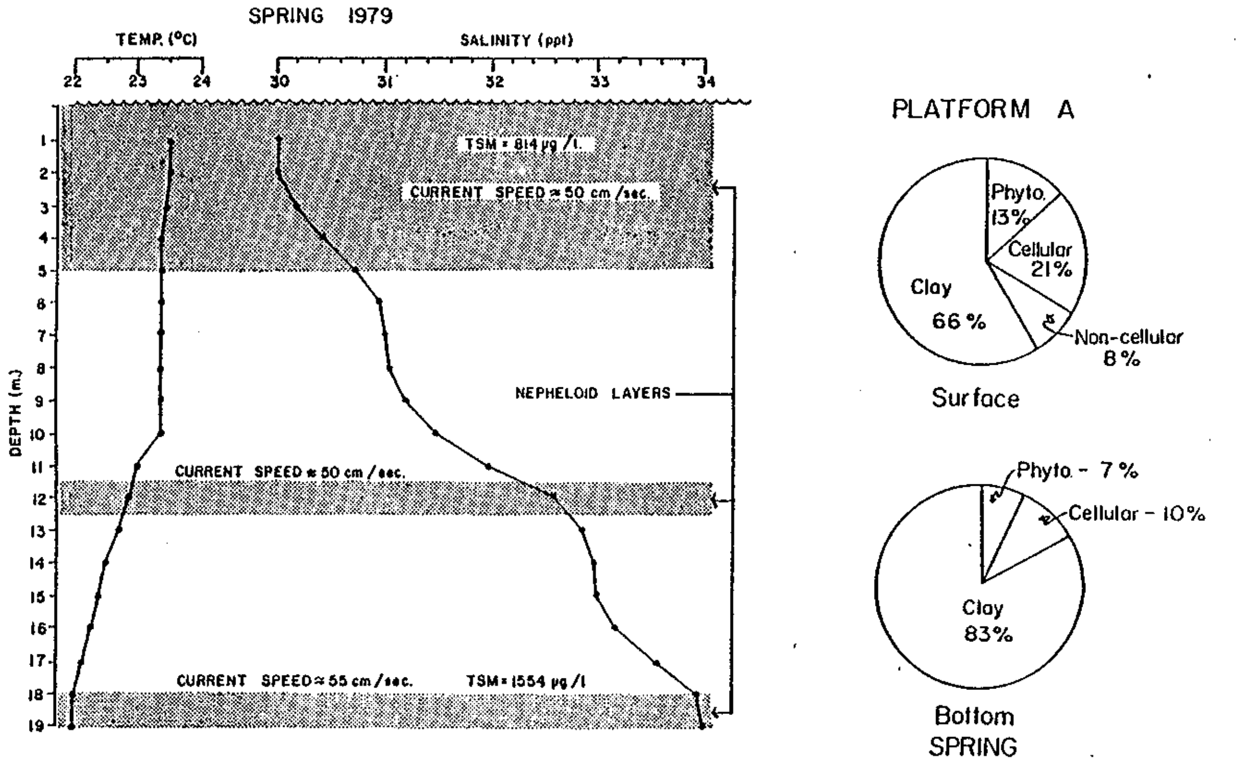


Fig. 8. Characteristic environmental structure observed in the Buccaneer Gas and Oil Field during spring, 1979.

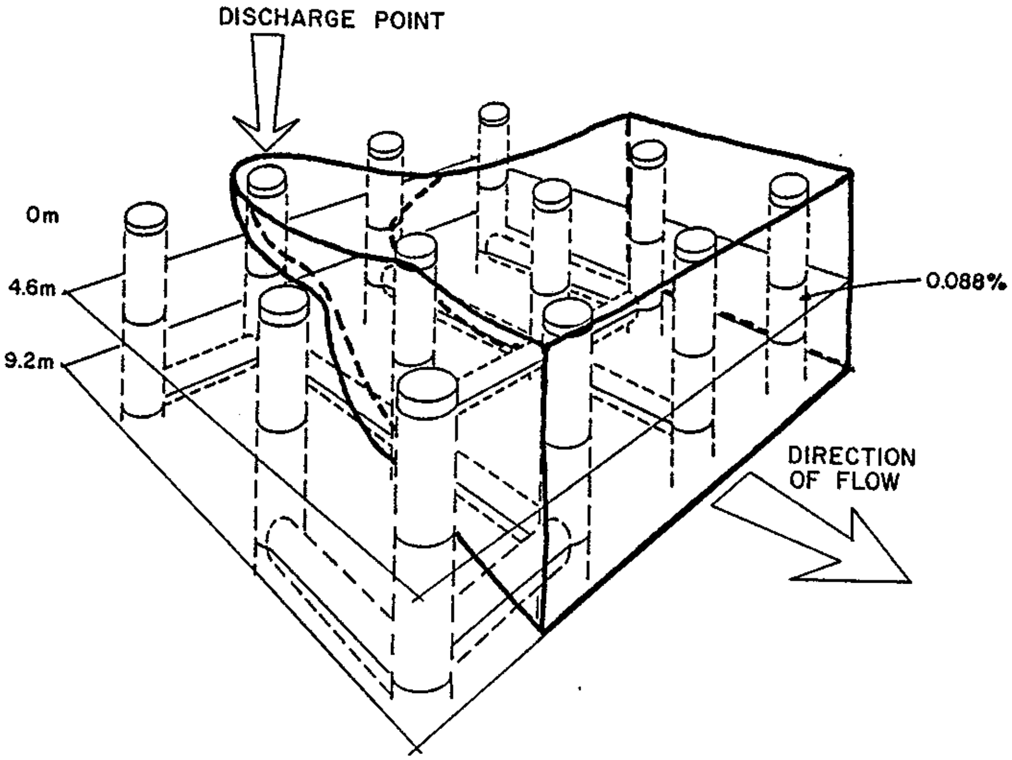
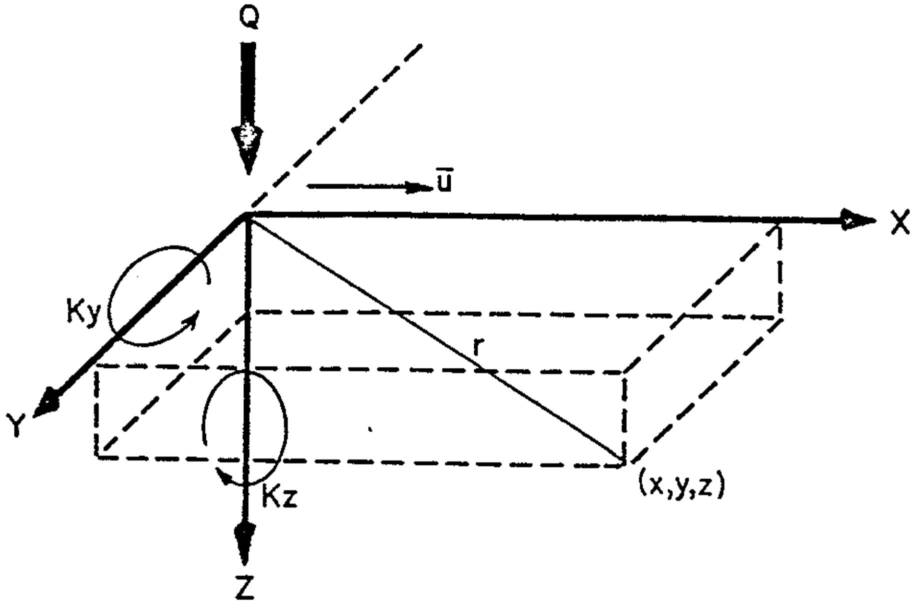
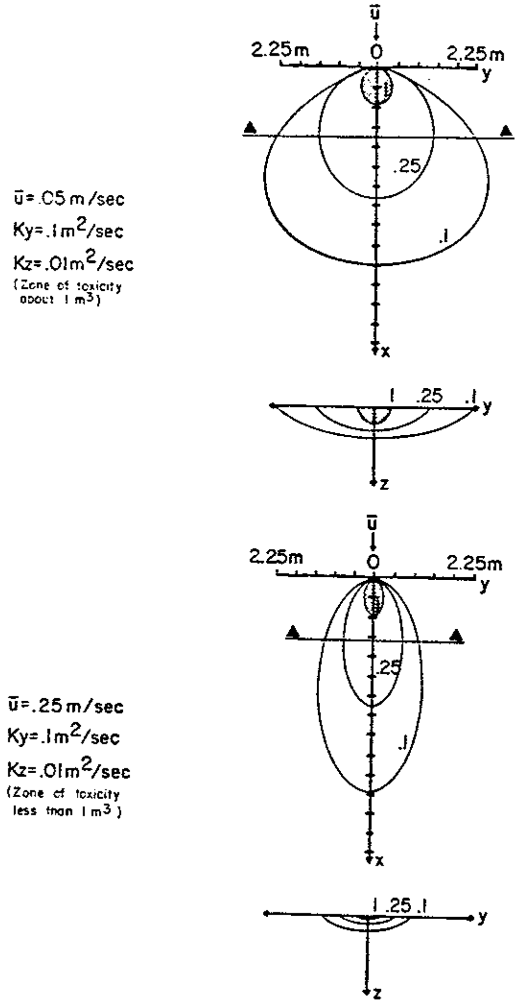


Fig. 9. Hypothetical distribution of produced water in the water column.



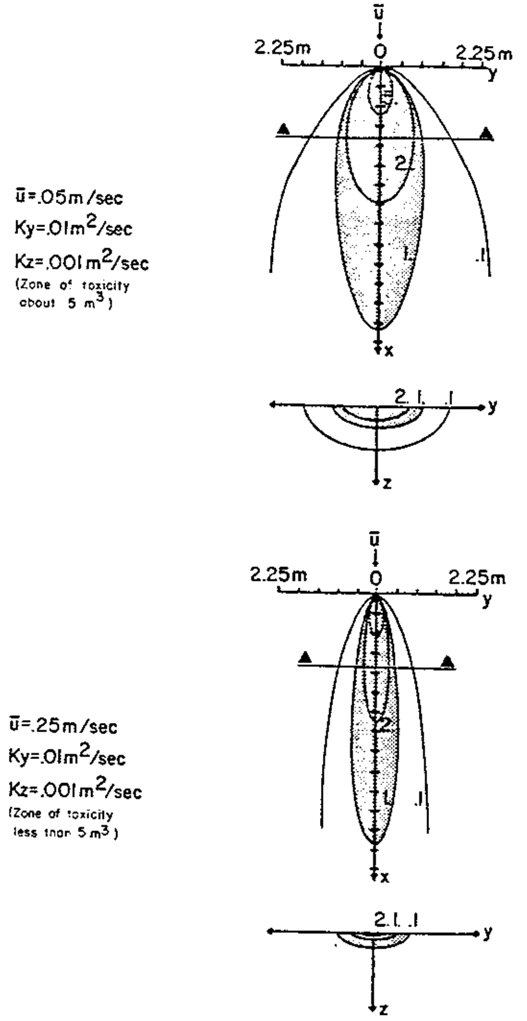
The ambient current is flowing in the x direction with velocity ū (m/sec). Ky and Kz are eddy diffusion coefficients (m^2/sec) in the horizontal and vertical directions respectively. Q is the rate of effluent introduction at the source (m^3/sec). r is the distance (m) from the source to the point (x,y,z).

Fig. 10. Schematic of idealized dispersion from continuous point source of effluent.



NOTE: all contour numbers expressed in % of produced water.

Fig. 11.. Distribution of produced water based upon analytic steady state approximation, conditions 1 and 2.



NOTE: all contour numbers expressed in % of produced water.

Fig. 12. Distribution of produced water based upon analytic steady state approximation, conditions 3 and 4.

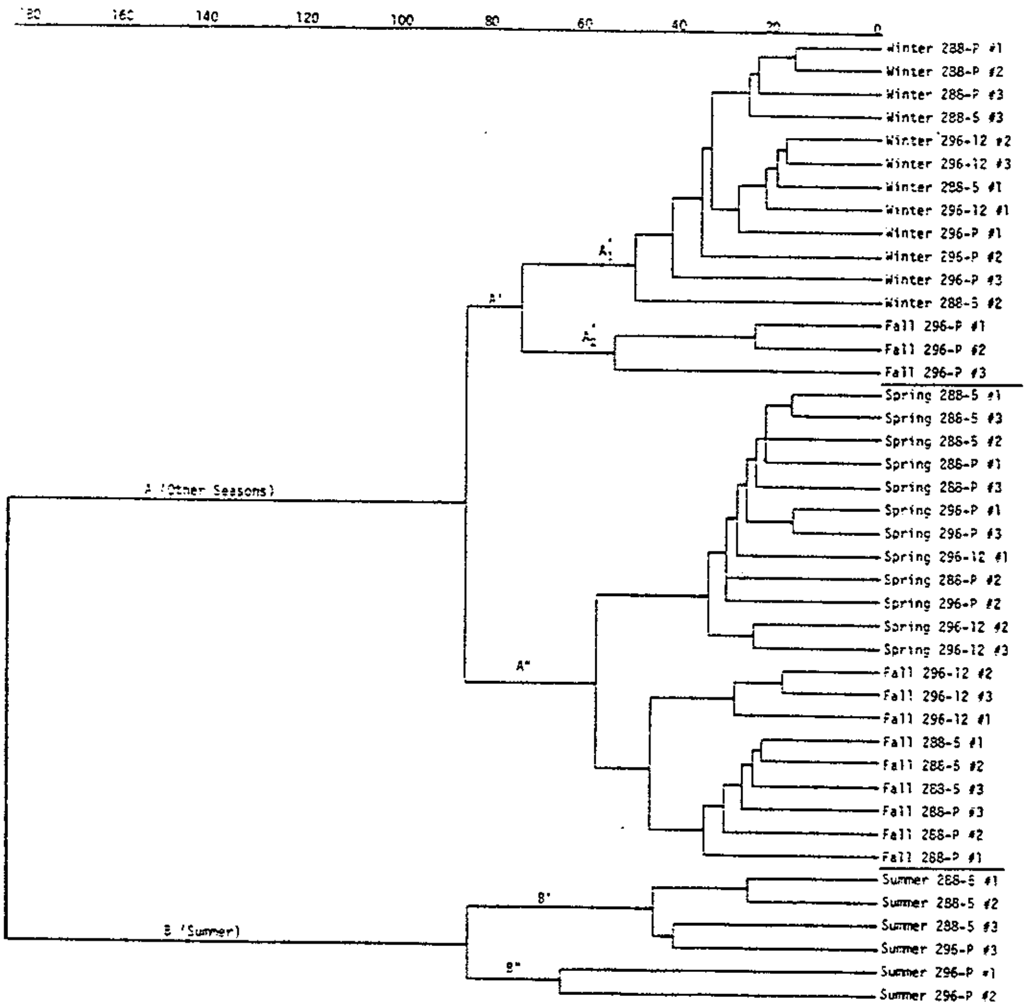


Fig. 13. Normal cluster analysis dendogram for trawl collections made during the 1978-1979 Buccaneer Gas and Oil Field study.

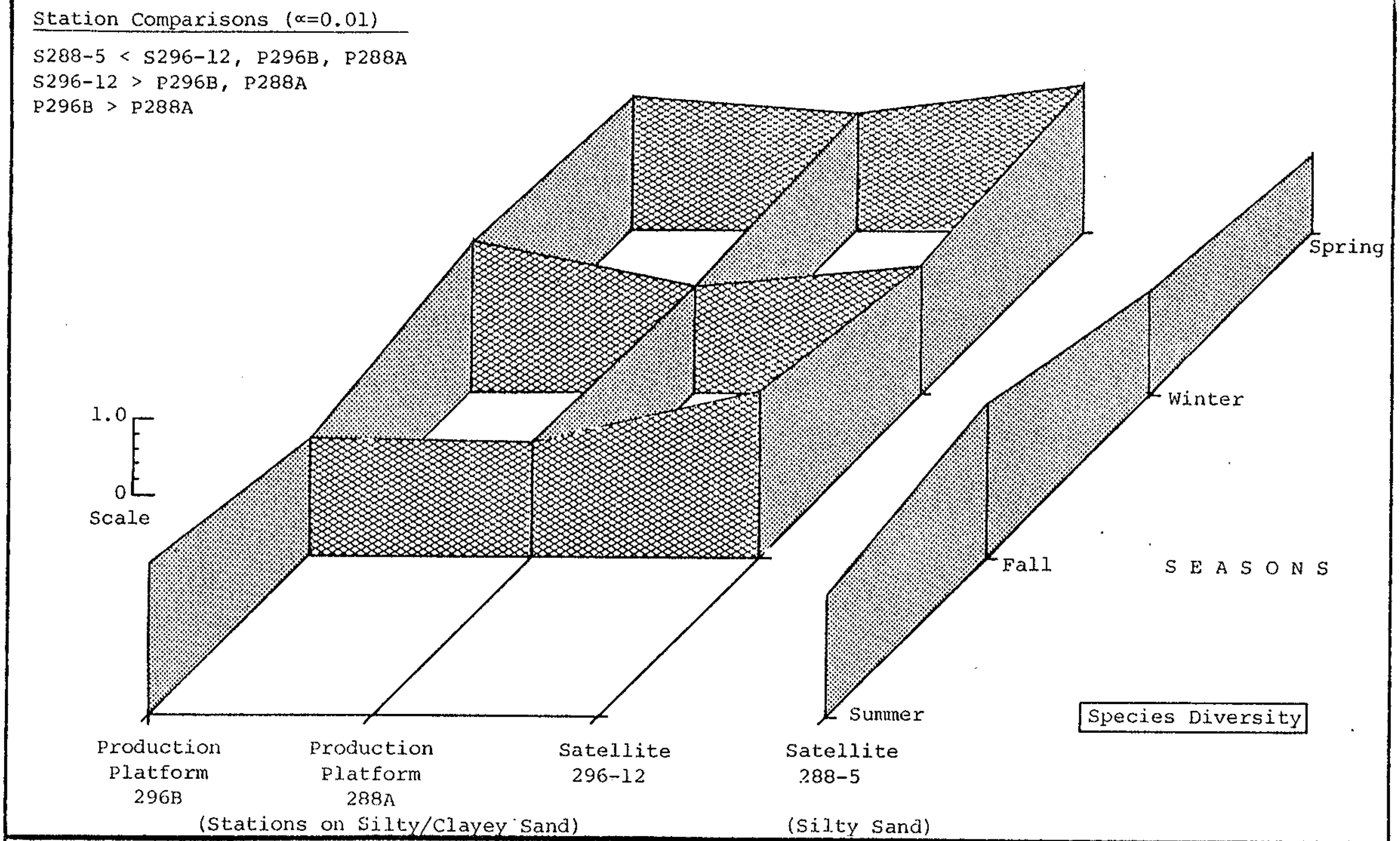


Fig. 14. Comparisons of mean species diversity (H") levels at study area stations or platforms by season.

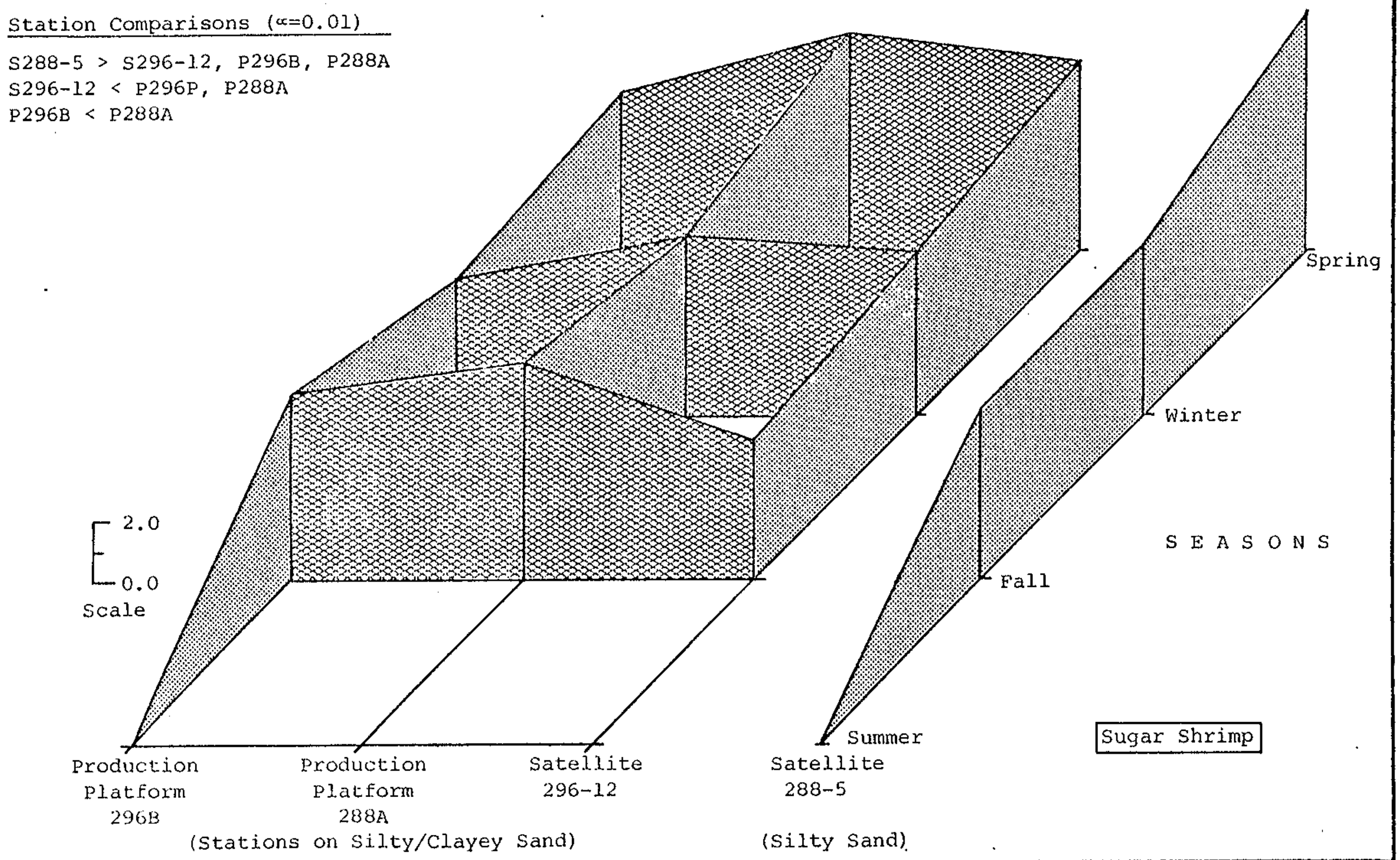


Fig. 15. Comparisons of mean abundance levels [Log_e (n+1)] of sugar shrimp at study area stations or platforms by season.

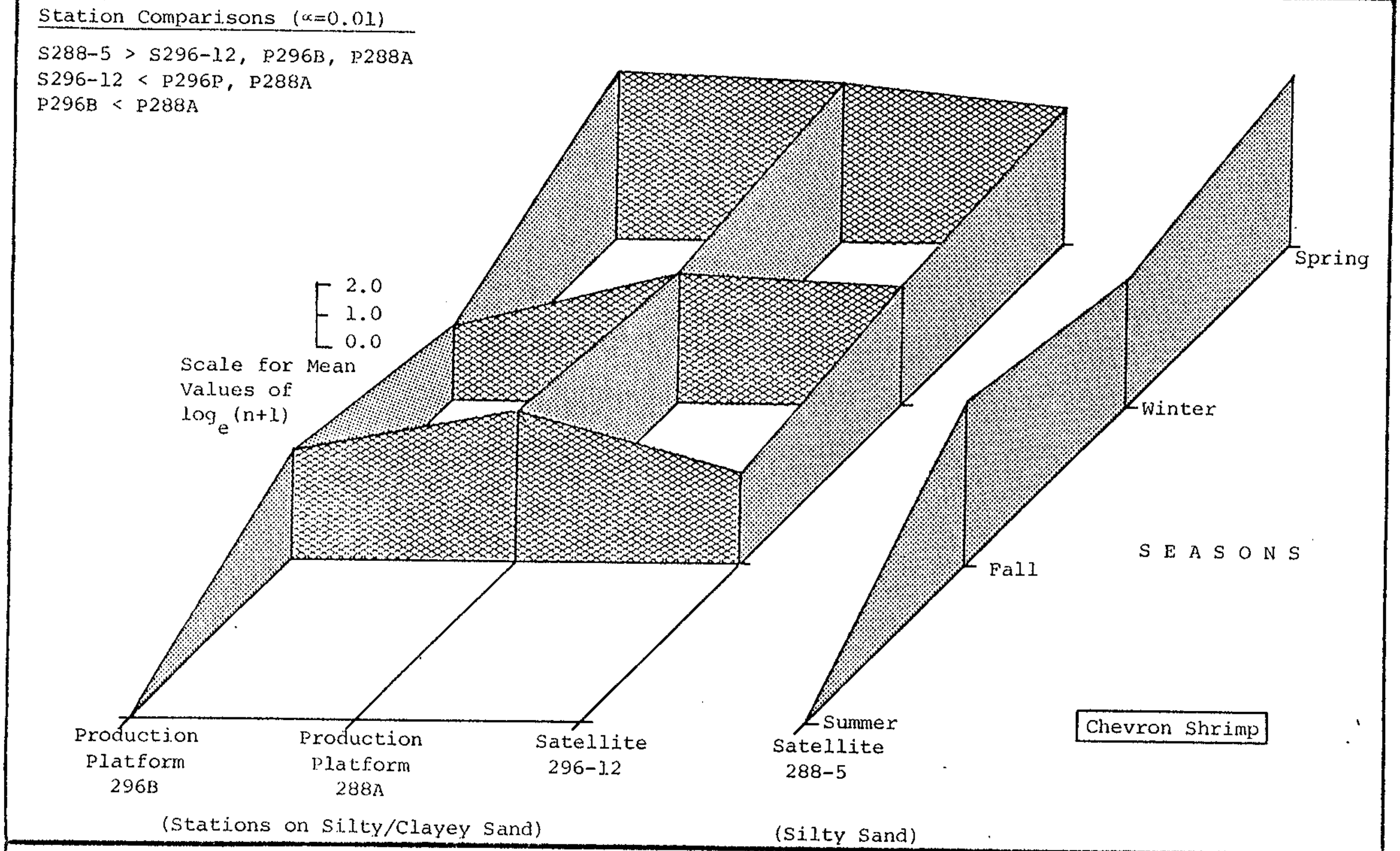


Fig. 16. Comparisons of mean abundance levels [$\log_e$ (n+1)] of chevron shrimp at study area stations or platforms by season.

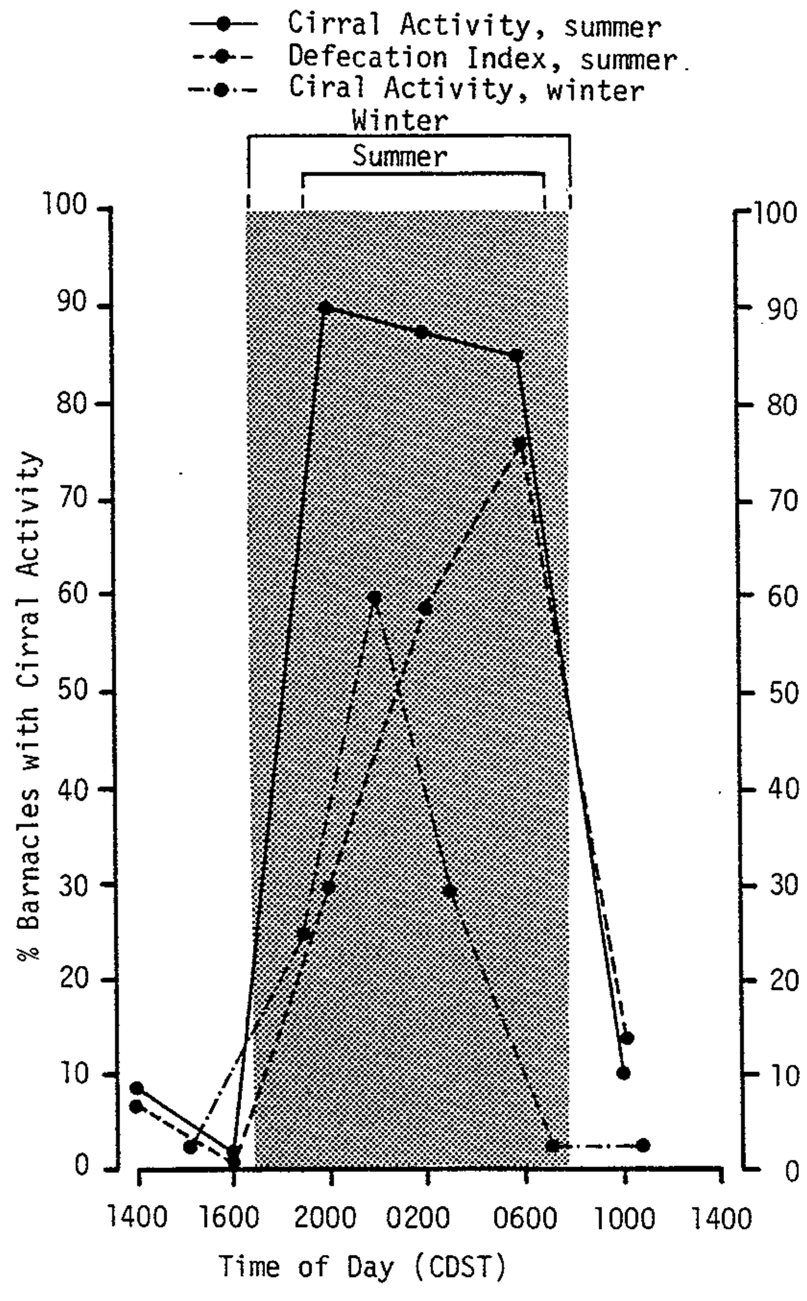


Fig. 17. Diurnal activity of the Mediterranean barnacle, 18-19 August 1978. (Shaded area represents period of darkness.)

HYDROID TIME LAPSE PHOTOGRAPHY

Week 1, March 1979
Healthy colony
1 March 1979

Week 2, March 1979
Colonial biomass decline has occurred

Week 3, March 1979
Degradation progressing

Week 4, March 1979
30 days elapsed
Nearly complete degradation

Fig. 18. Artistic representation of the spring decline of a hydroid colony at 8-m depth on 296Q, as indicated by time-lapse photography.

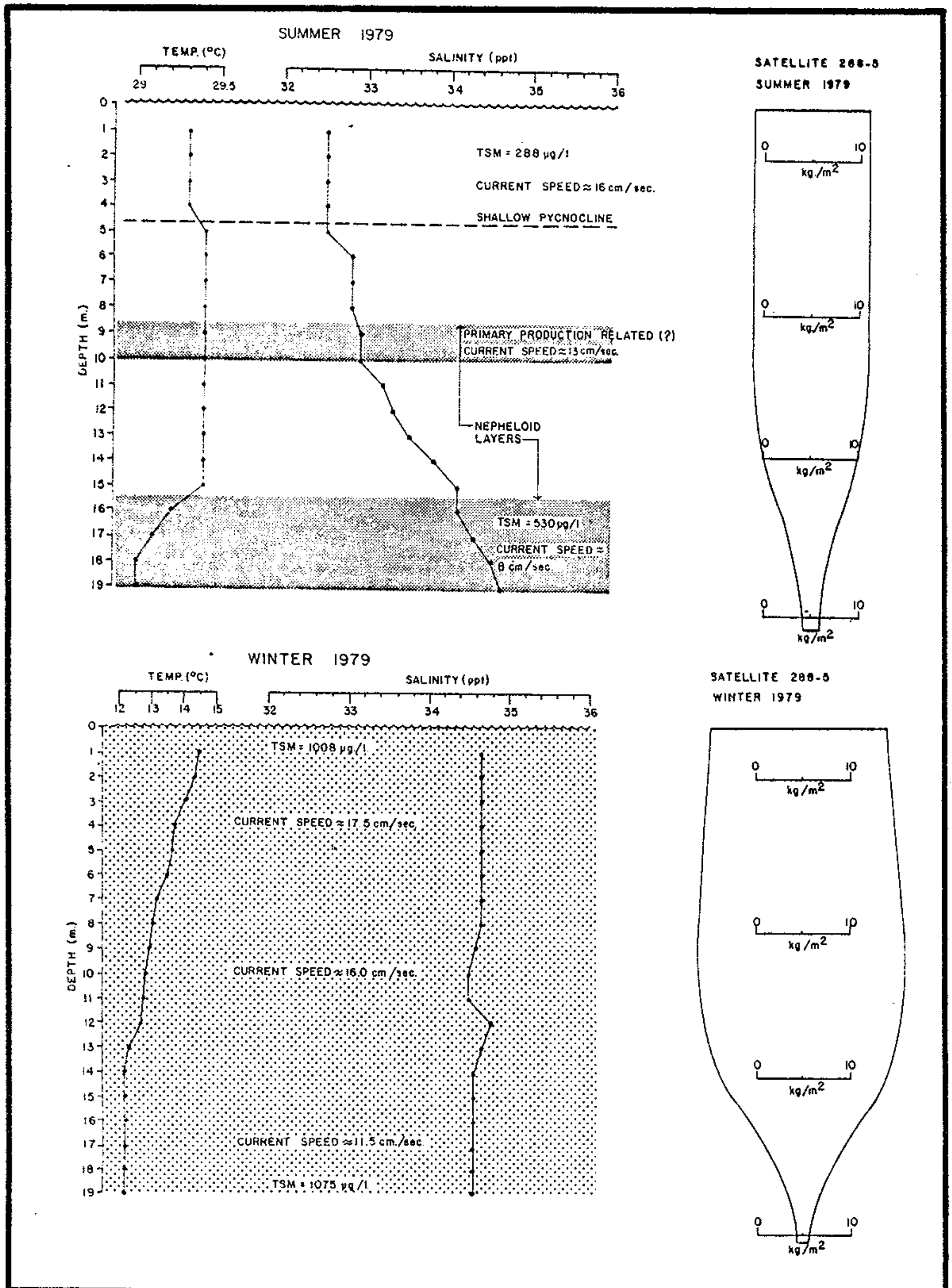


Fig. 19. Seasonal levels of biofouling biomass and characteristic hydrographic conditions.

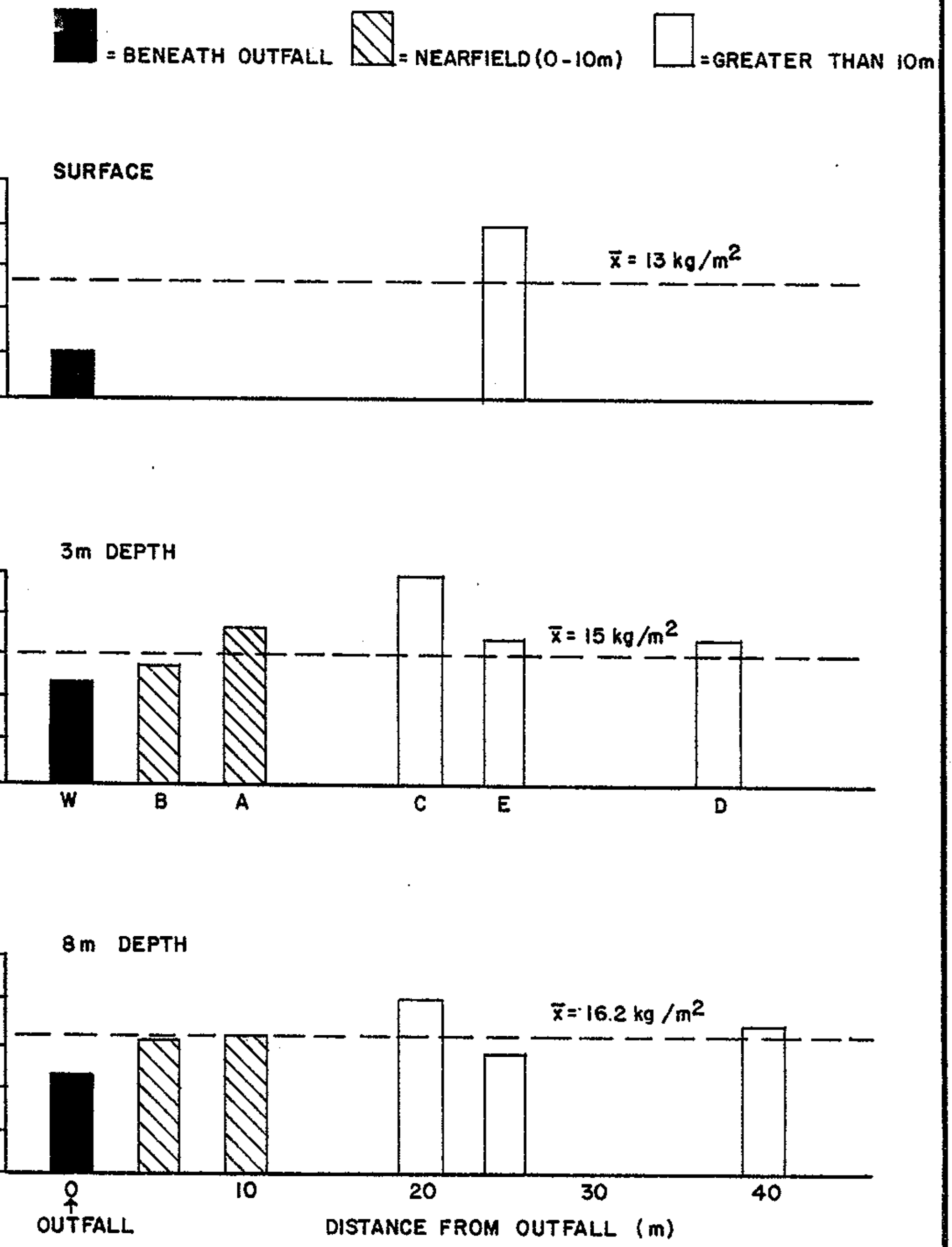


Fig. 20. Standing crop biomass of biofouling community in the Buccaneer Gas and Oil Field, summer 1980.

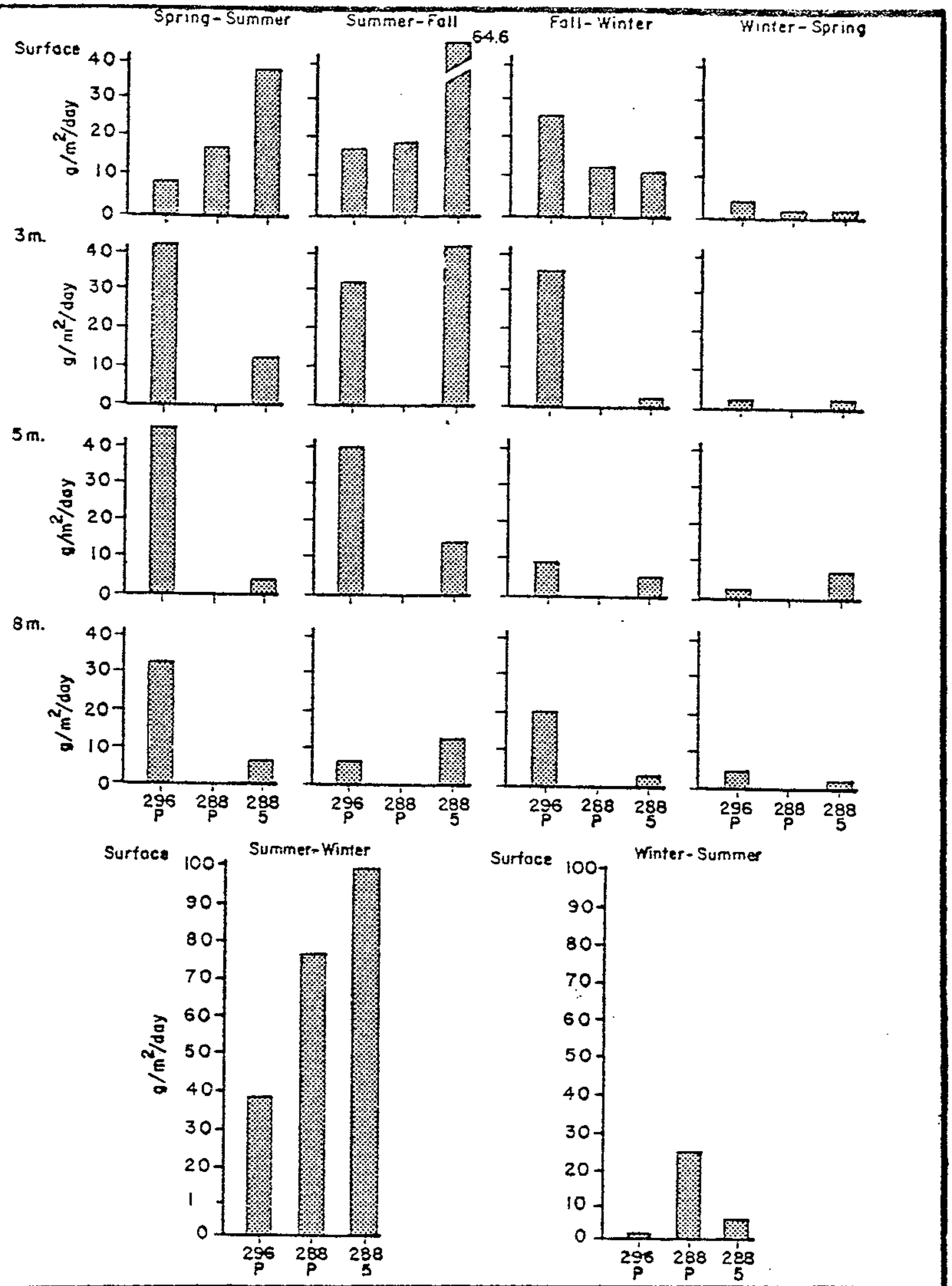


Fig. 21 . Recolonization biomass produced on Buccaneer Gas and Oil Field structures, 1978-1979.

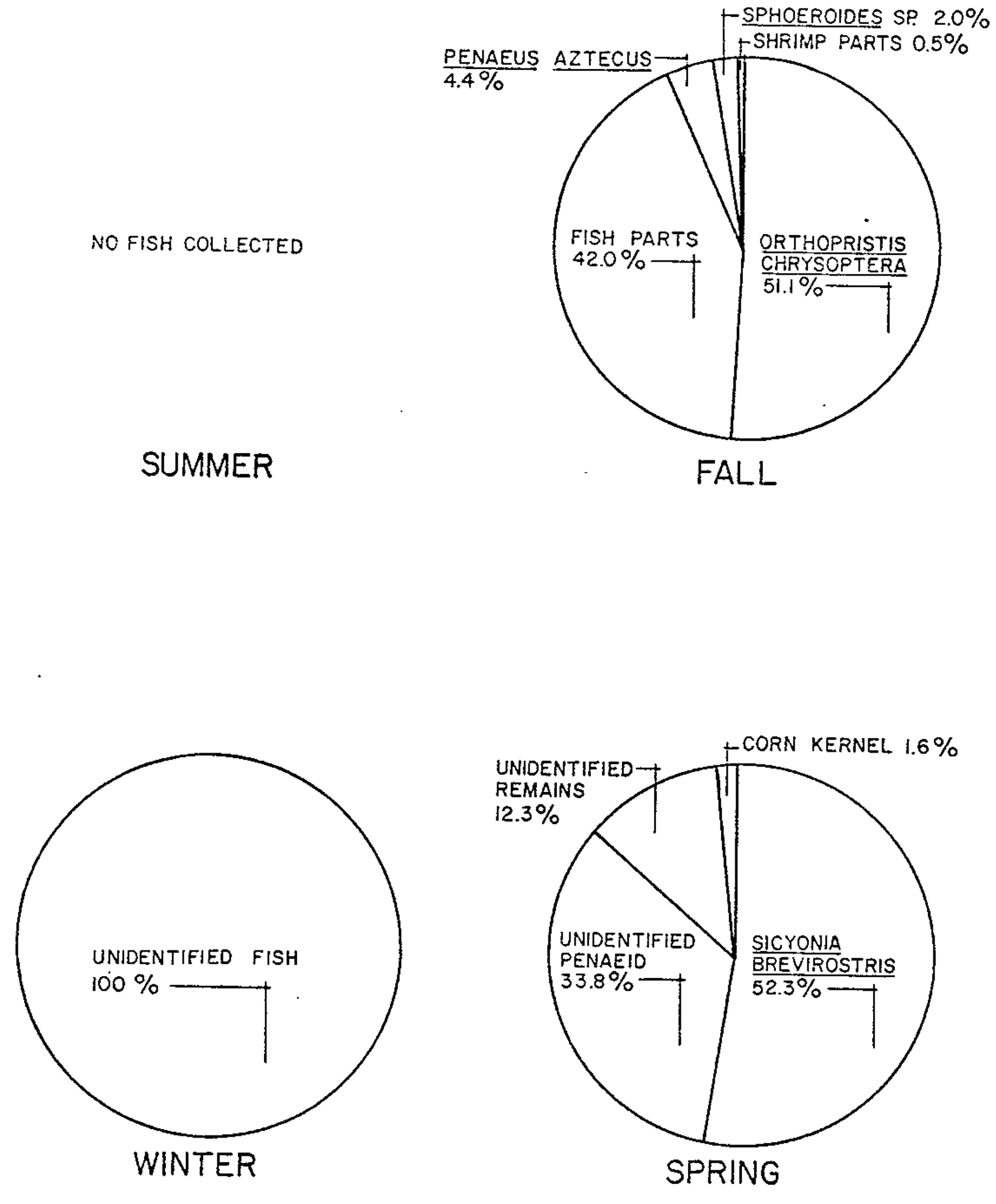


Fig. 22. Seasonal food habits of bluefish in the Buccaneer Gas and Oil Field, 1978-1979.

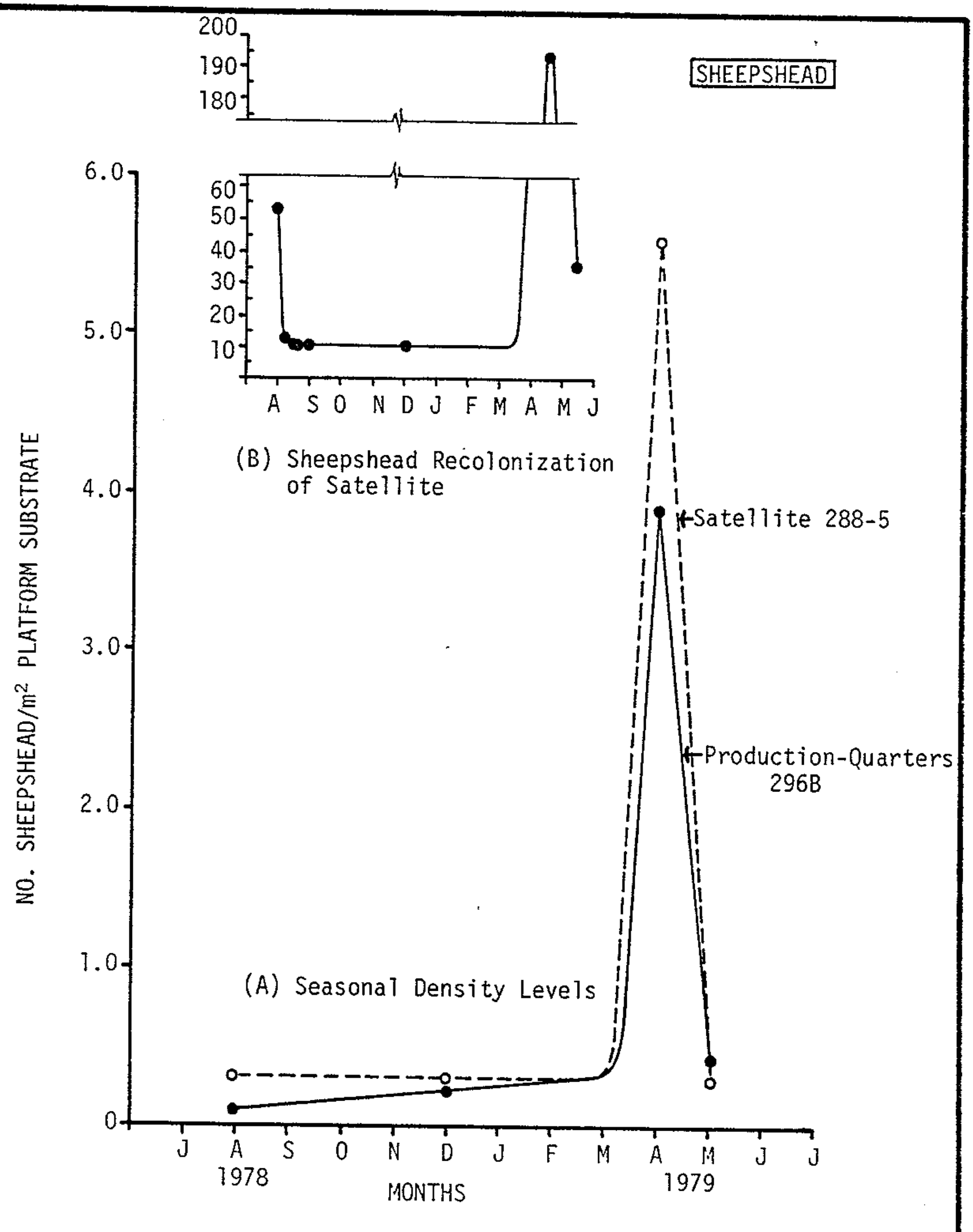


Fig. 23. Seasonal densities of sheepshead at Buccaneer Gas and Oil Field structures, 1978-1979 (A) and population levels (number seen) following harvest of specimens at Satellite 288-2 (B).

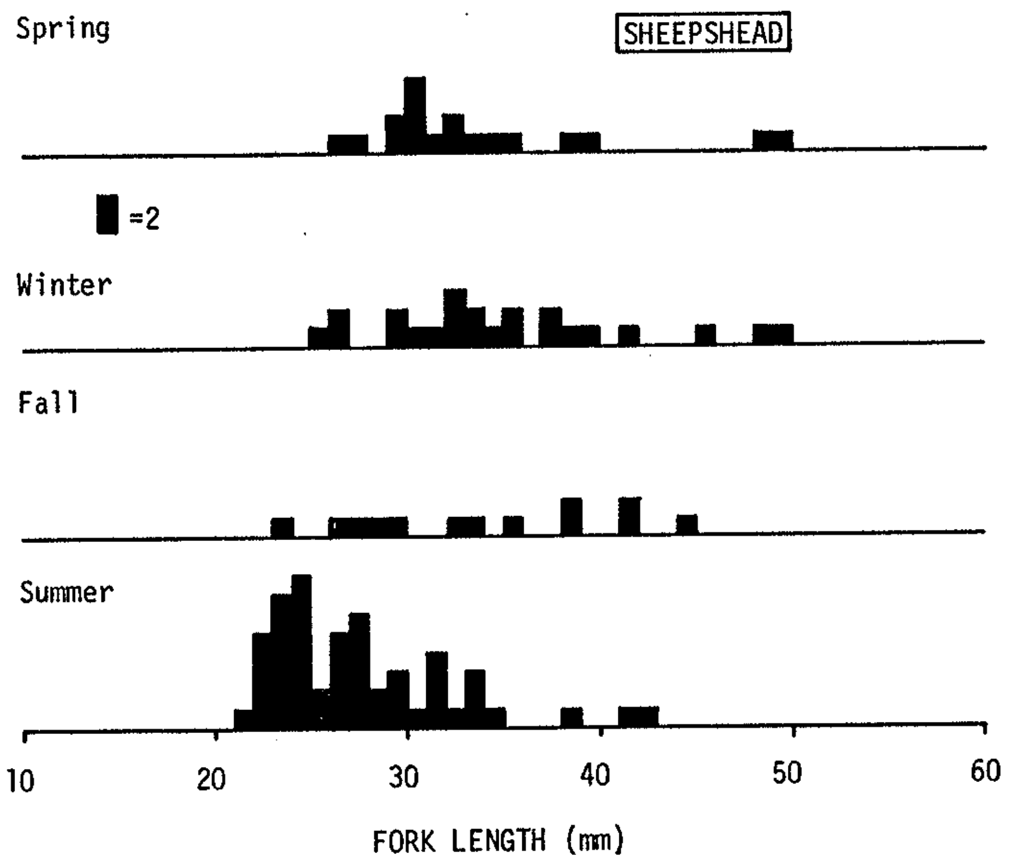


Fig. 24. Size distribution of sheepshead in the Buccaneer Gas and Oil Field, summer 1978-spring 1979.

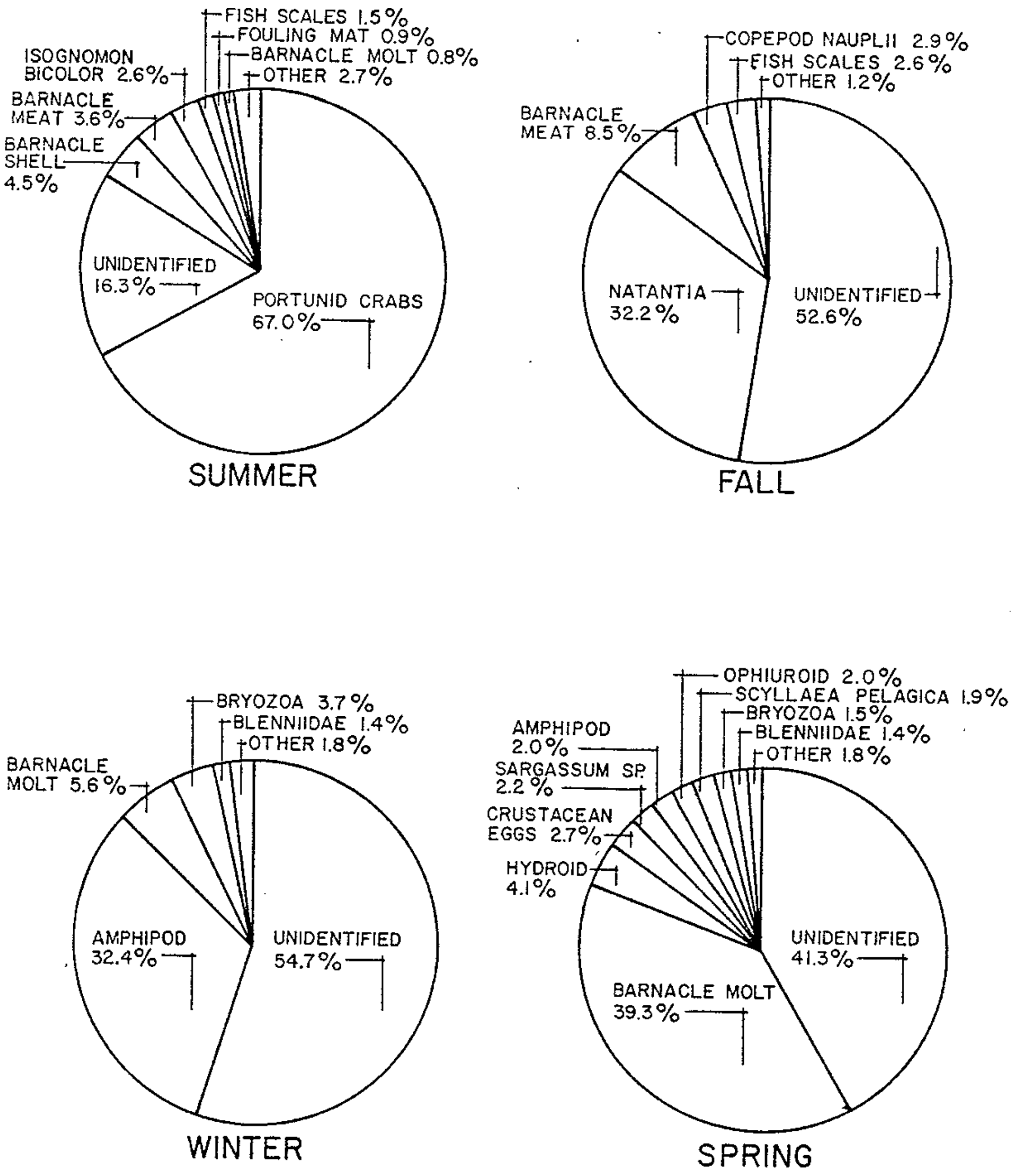


Fig. 25. Seasonal food habits of sheepshead in the Buccaneer Gas and Oil Field, 1978-1979.

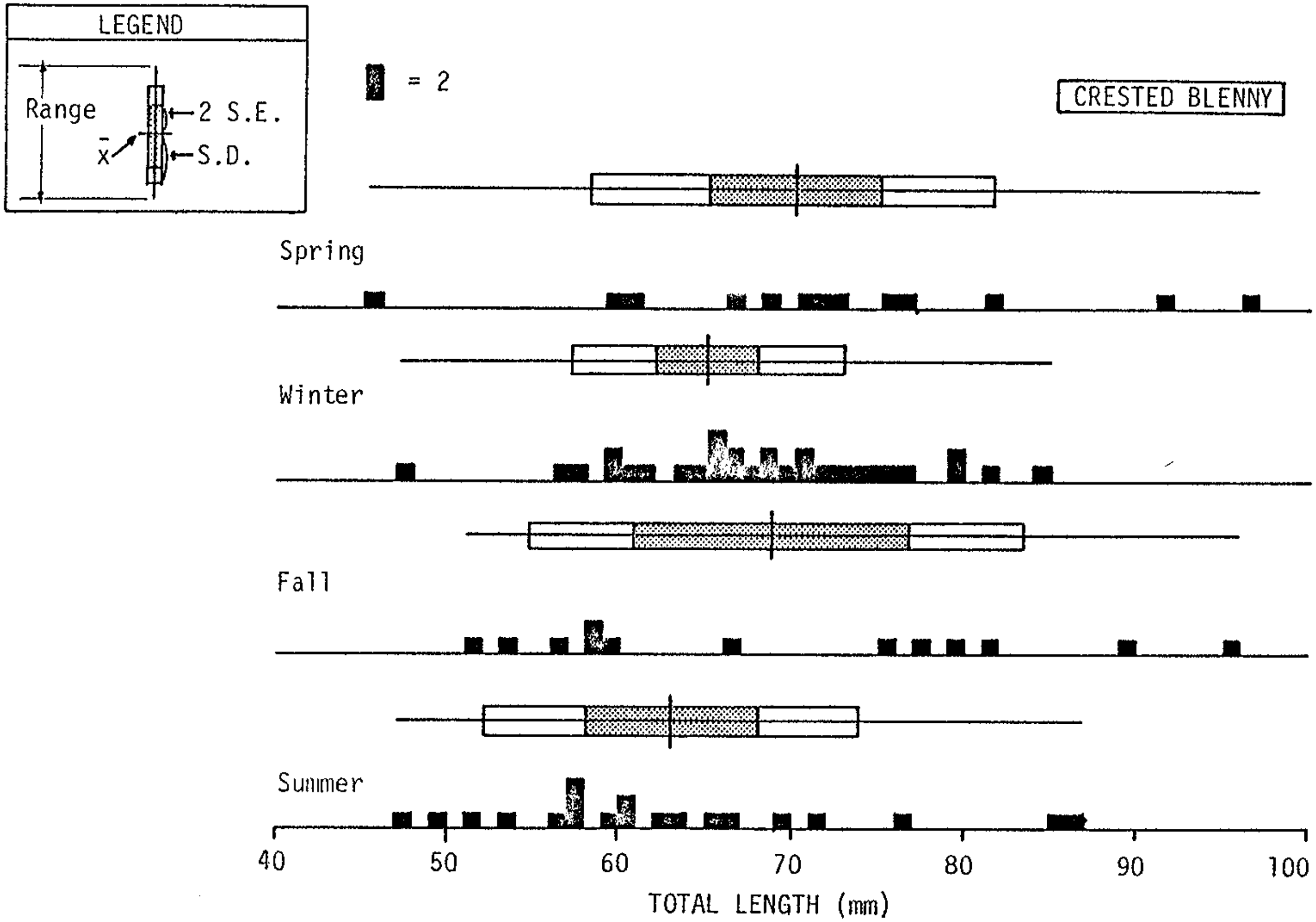


Fig. 26. Seasonal size distribution of crested blenny in the Buccaneer Gas and Oil Field, 1978-1979.

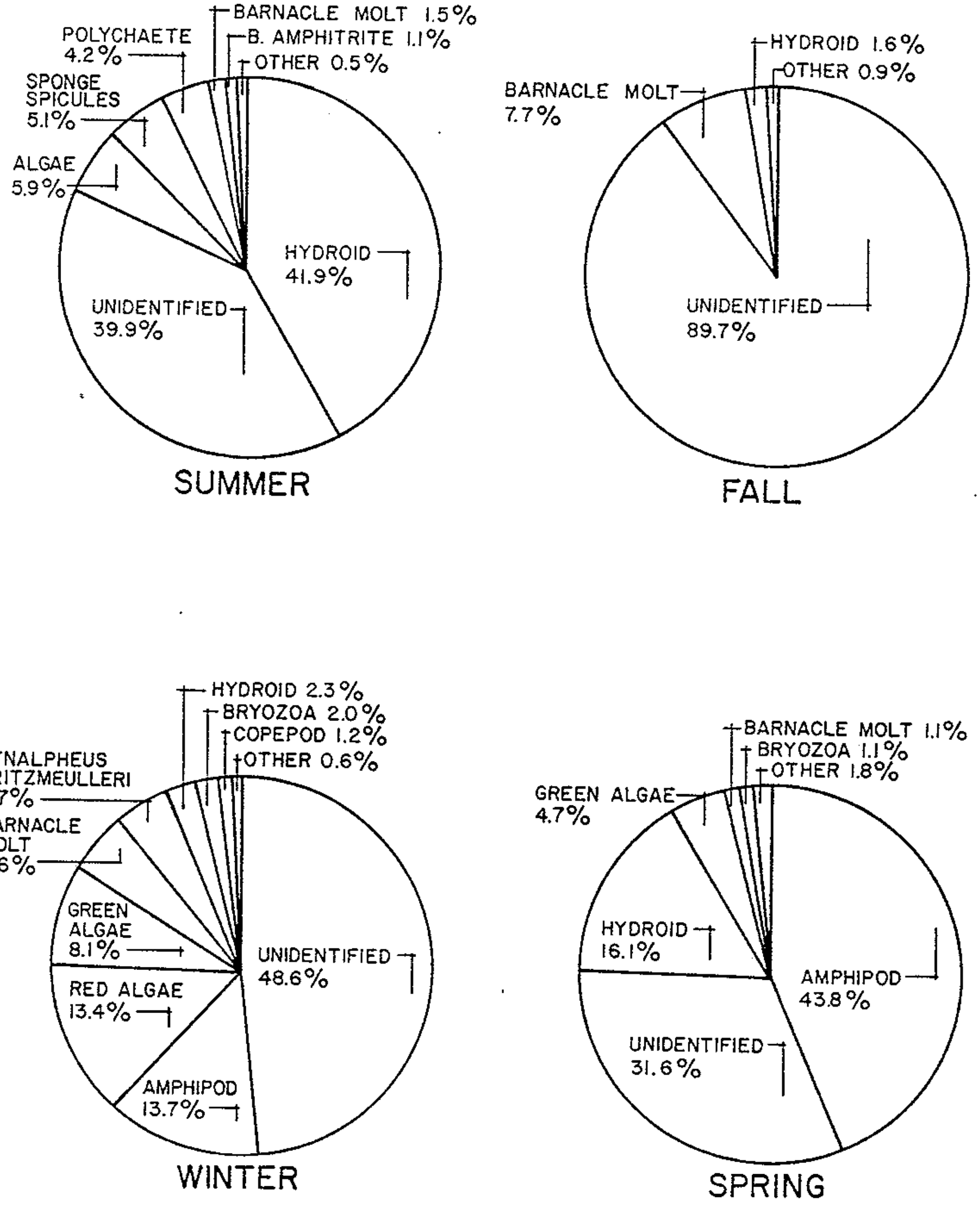


Fig. 27. Seasonal food habits of the crested blenny in the Buccaneer Gas and Oil Field, 1978-1979.

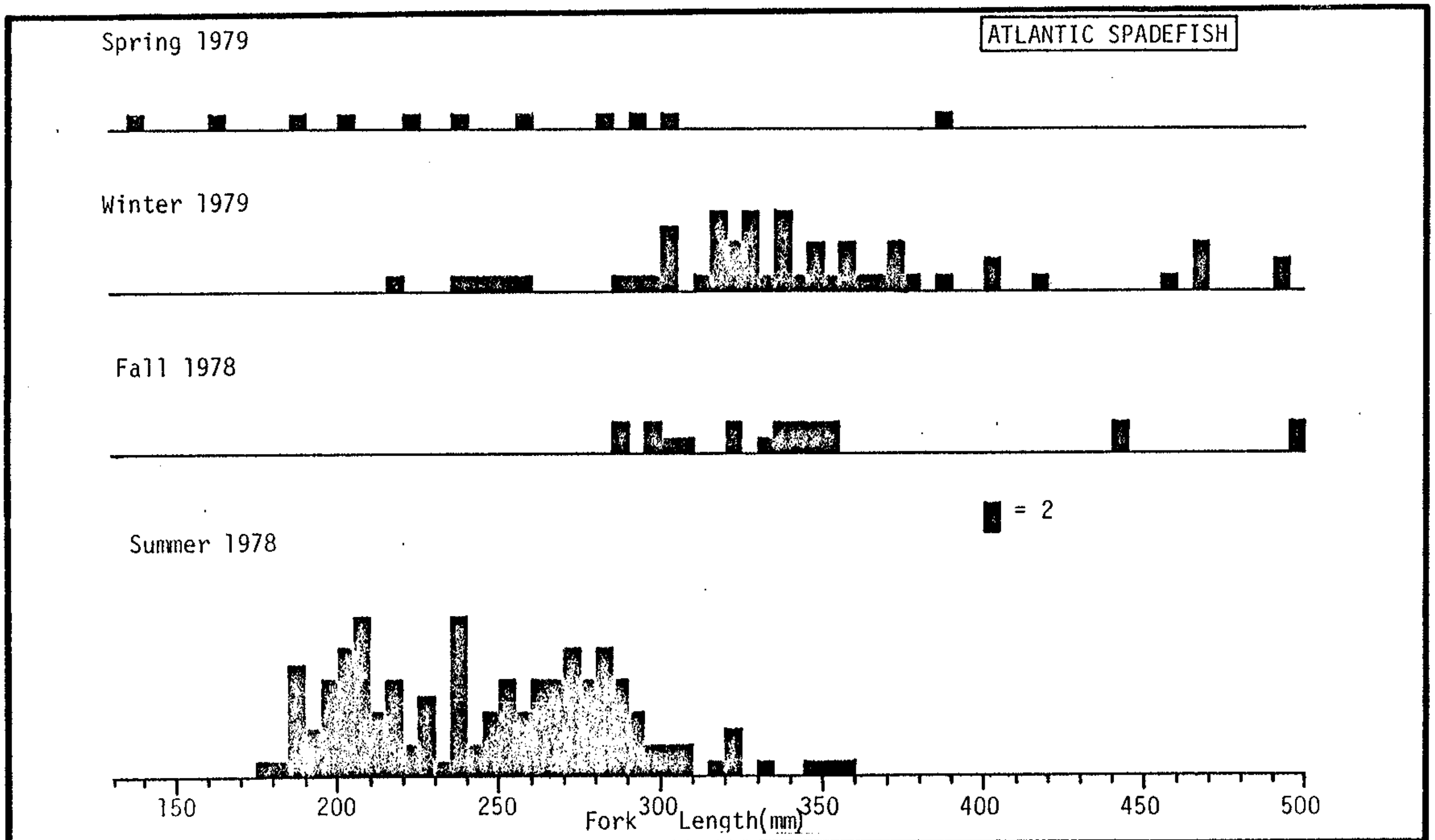


Fig. 28. Size distribution of Atlantic spadefish in the Buccaneer Gas and Oil Field, summer 1978-spring 1979.

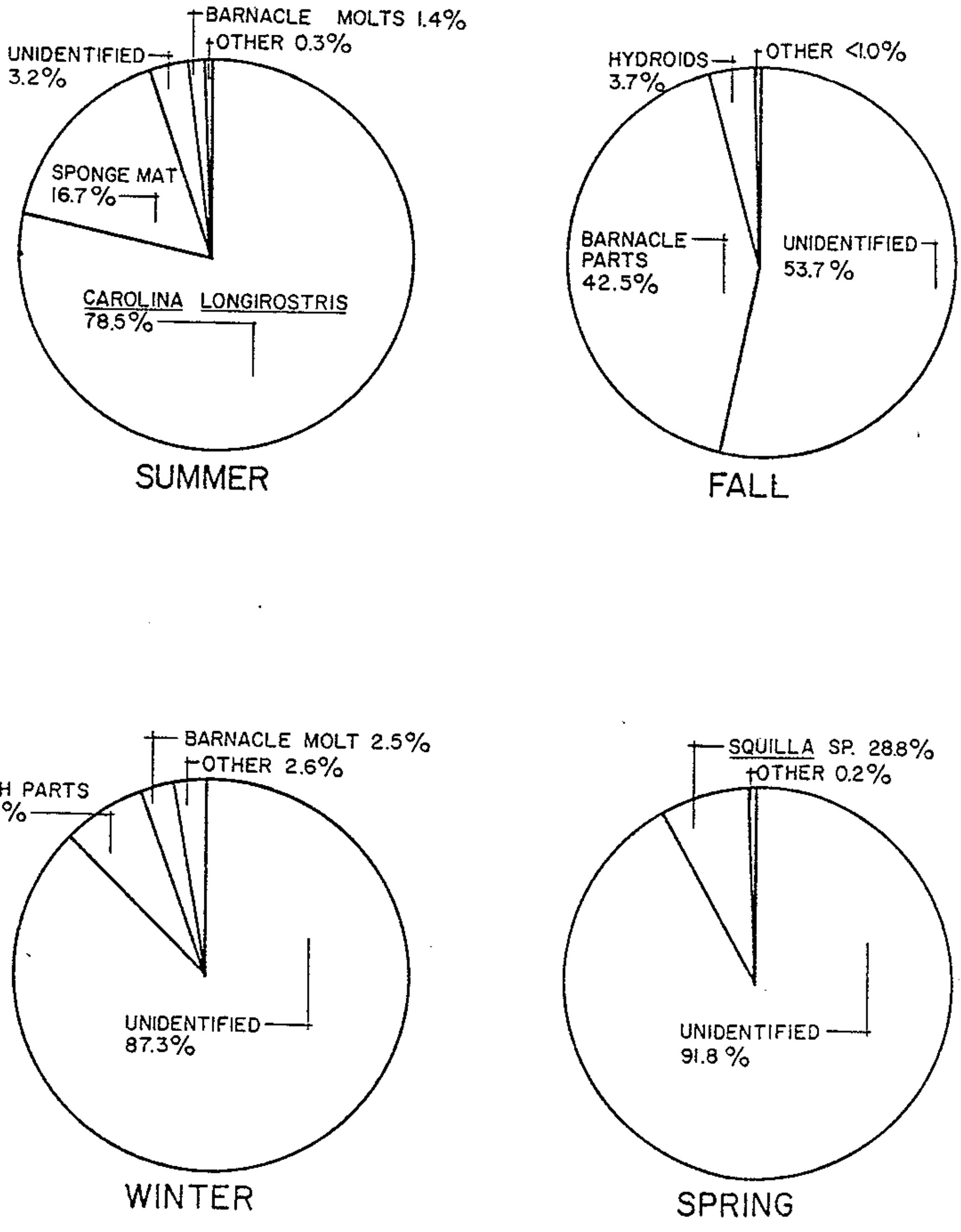


Fig. 29. Seasonal food habits of the Atlantic spadefish in the Buccaneer Gas and Oil Field, 1978-1979.

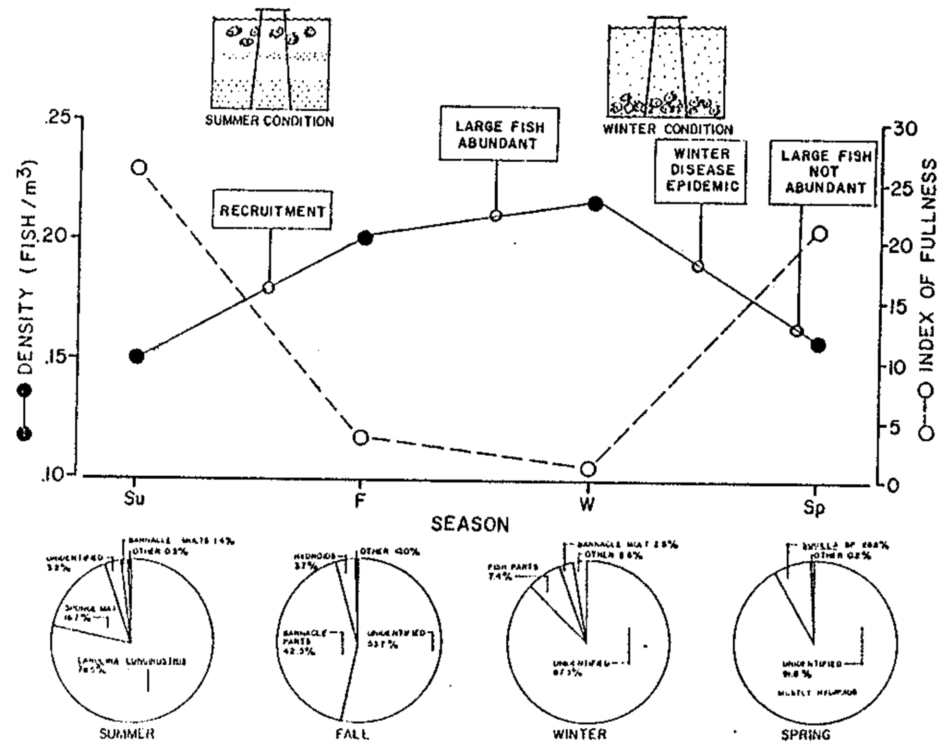


Fig. 30. Seasonal distribution, abundance, foods and feeding patterns of Atlantic spadefish in the Buccaneer Gas and Oil Field.

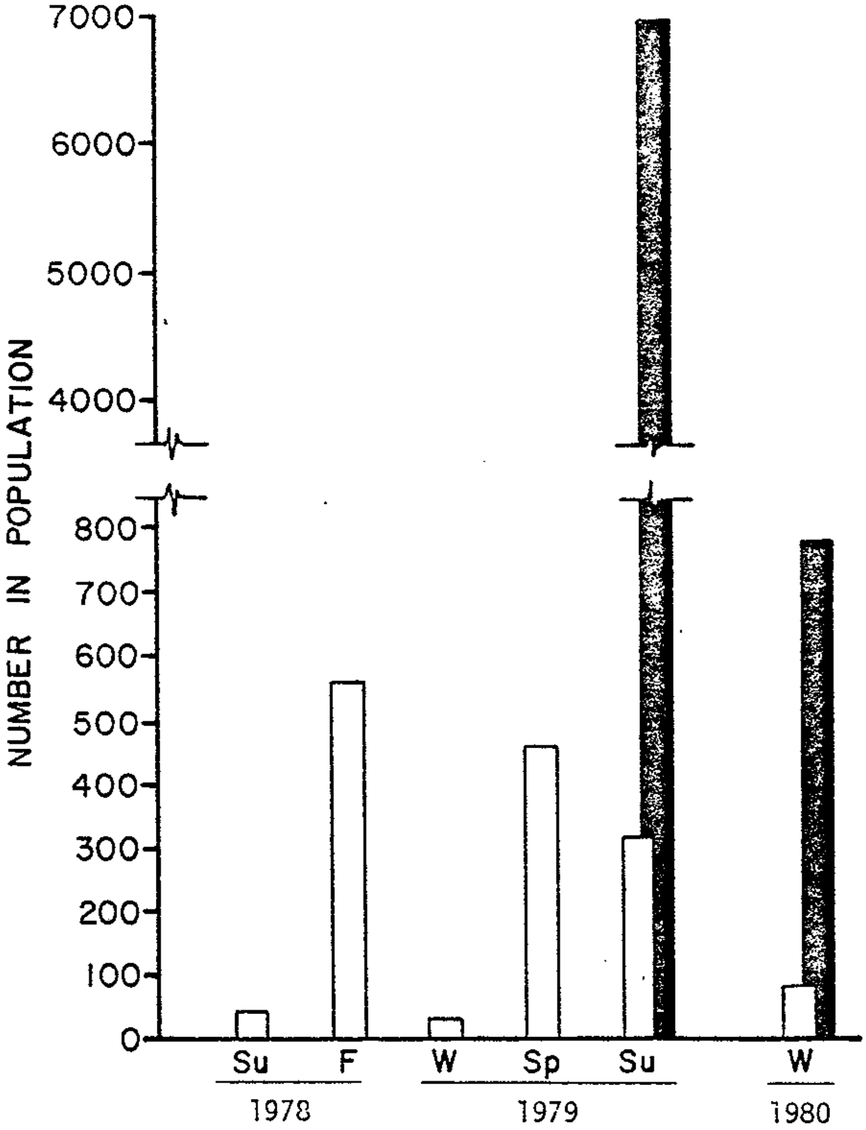


Fig. 31. Seasonal population estimates for red snapper at Buccaneer Gas and Oil Field Platform 296B (open bars) and West Cameron Platform 333A (black bars), 1978-1979.

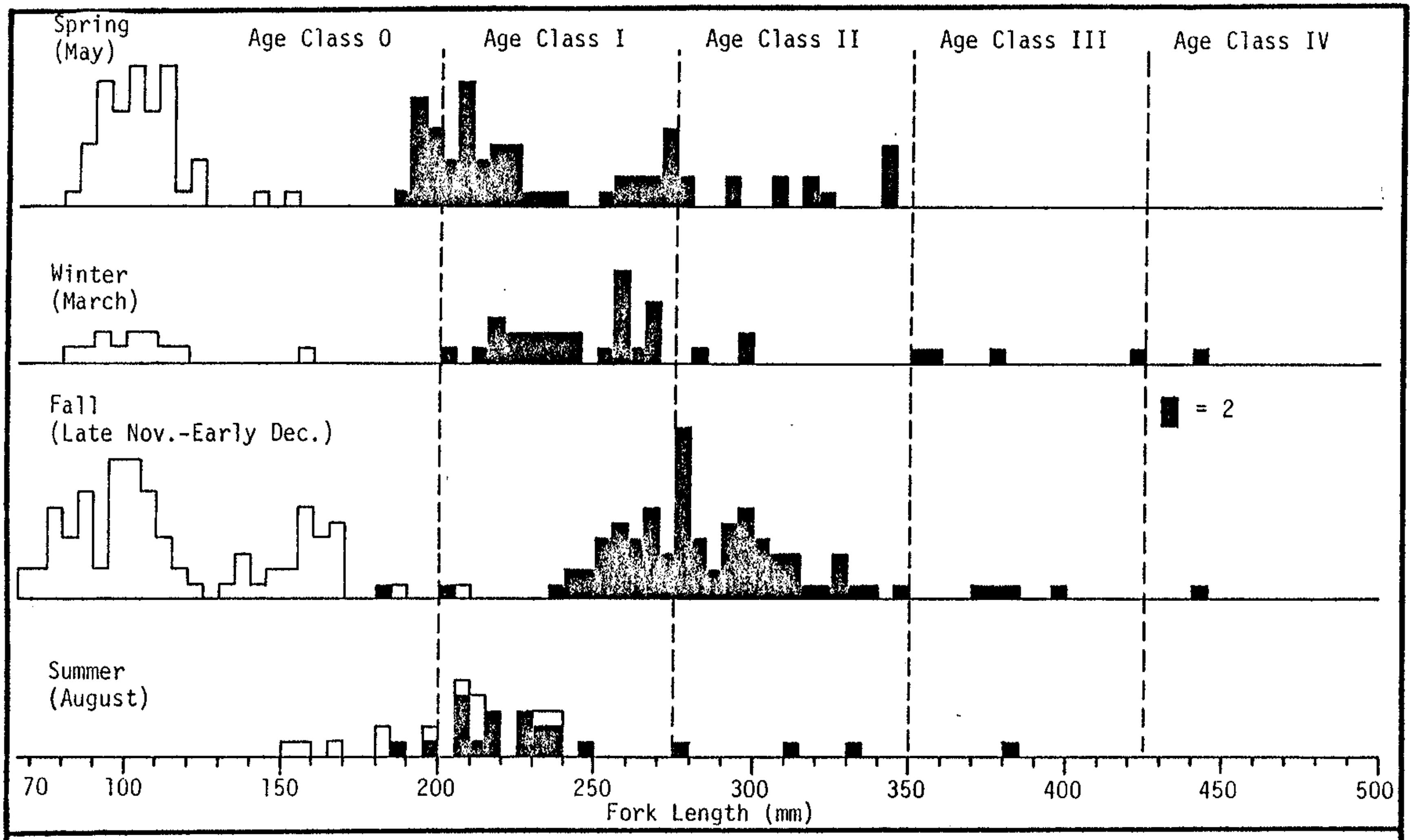


Fig. 32. Seasonal size distribution of red snapper in the Buccaneer Gas and Oil Field, 1978-1979. White bar shows trawled specimens, black bars represent specimens collected by angling or spear. Age class designations are based on Bradley and Bryan (1976).

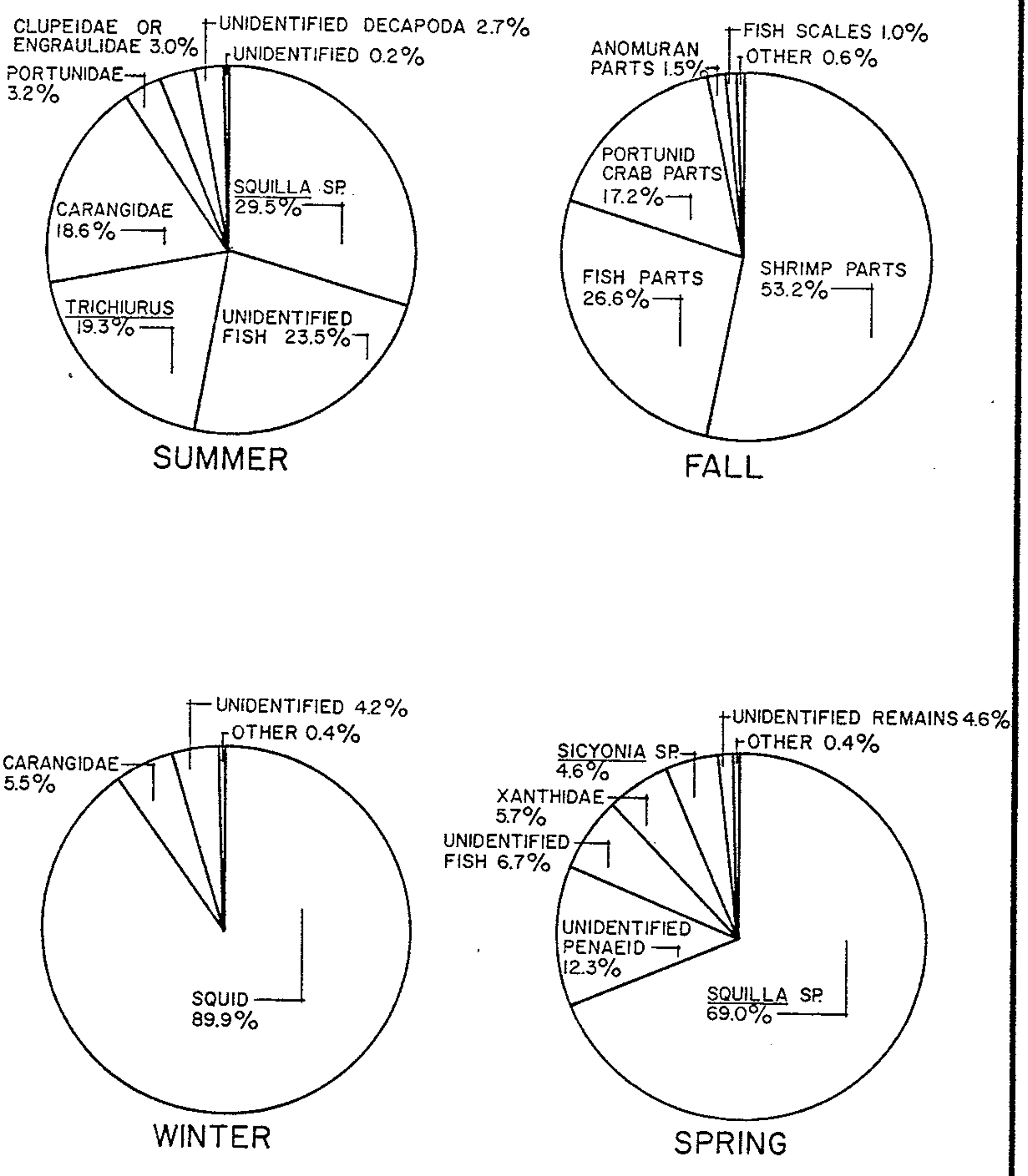


Fig. 33. Seasonal food habits of the red snapper in the Buccaneer Gas and Oil Field, 1978-1979.

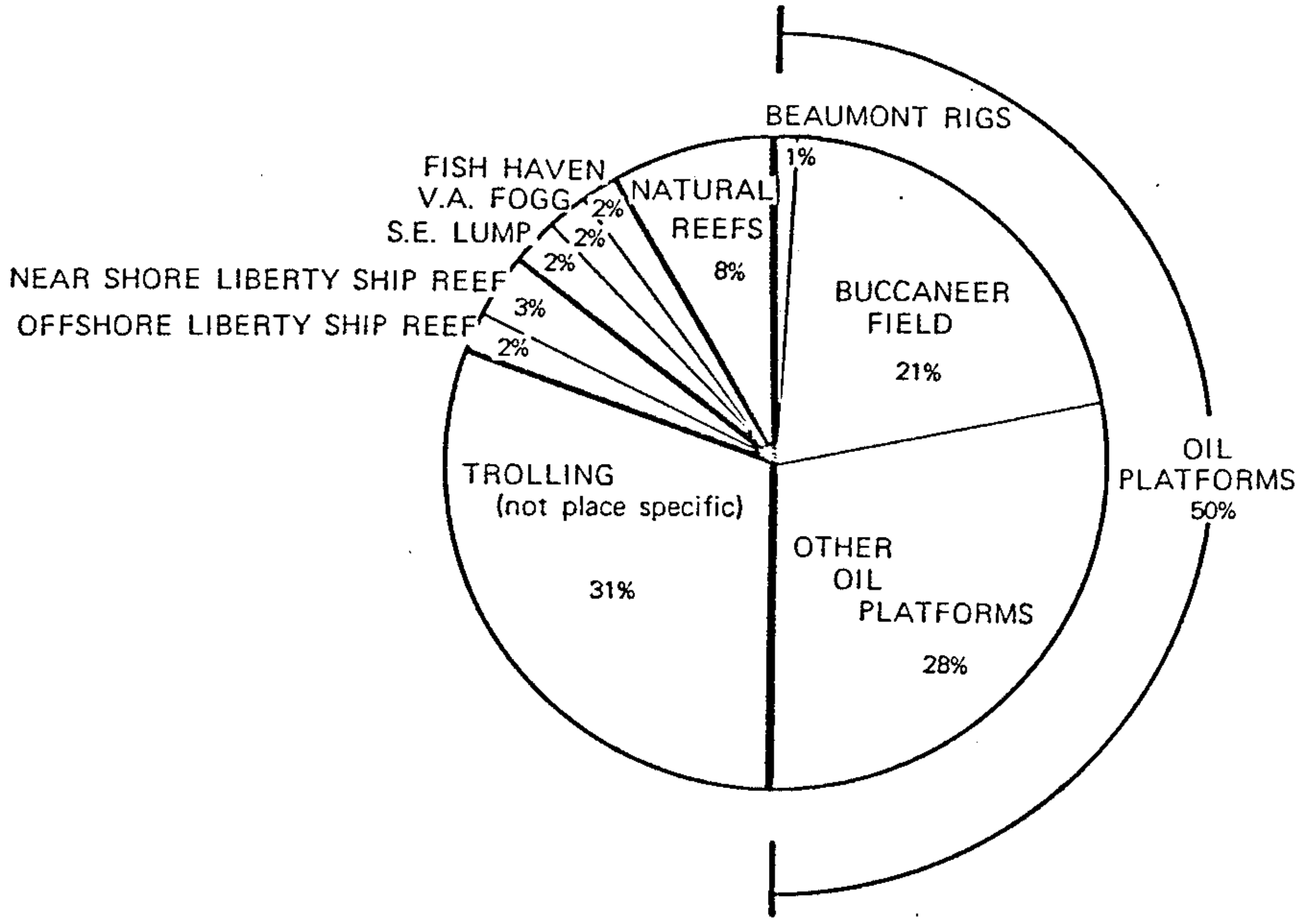


Fig. 34. Distribution of fishing effort offshore Texas coast from Freeport to Beaumont-Port Arthur area.

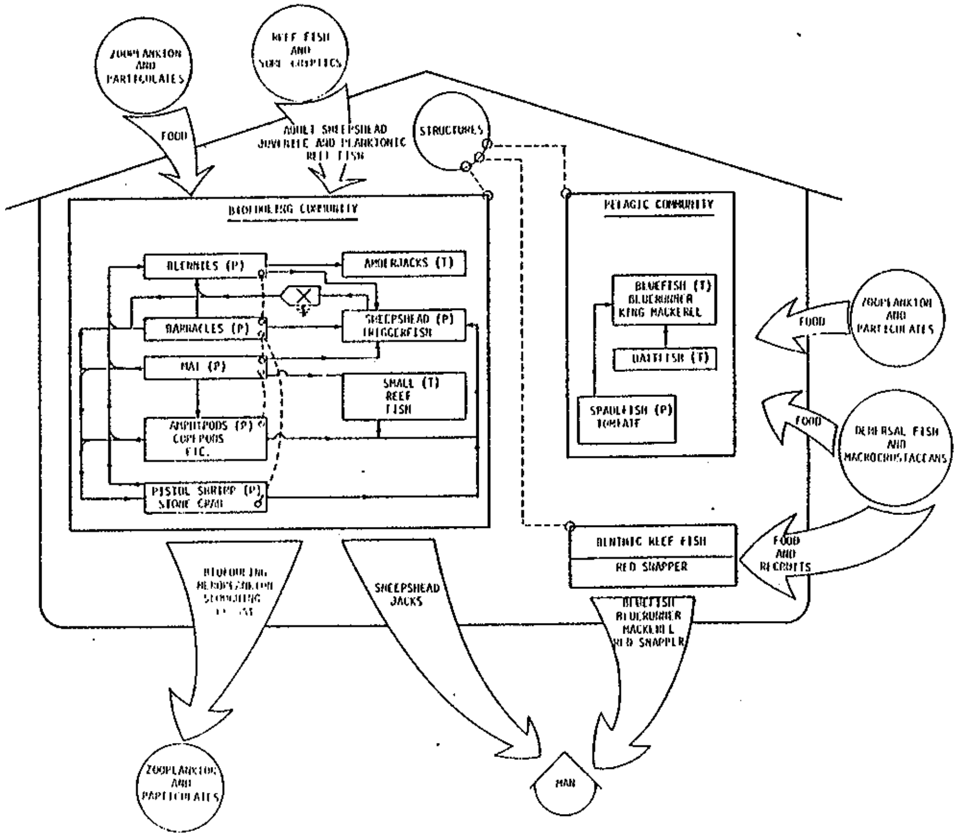


Fig. 35. Conceptual model of a Buccaneer Gas and Oil Field platform community.

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ENVIRONMENTAL EFFECTS OF OFFSHORE OIL PRODUCTION: THE BUCCANEER OIL FIELD STUDY

WEDNESDAY MORNING .... Room 201

8:30 Introduction. **B. S. Middleditch,** University of Houston, Houston, Texas

ORGANIC POLLUTANTS

B. J. Gallaway, Presiding

8:40 (79) Discharge, Fates, and Effects of Hydrocarbons, Biocides, and Sulfur. **B. S. Middleditch,** University of Houston, Houston, Texas.

9:10 (80) Gaseous and Volatile Hydrocarbons. D. A. Wiesenburg, G. Bodennec, R. A. Burke, Jr., and **J. M. Brooks,** Texas A & M University, College Station, Texas.

9:30 INTERMISSION

INORGANIC POLLUTANTS AND SEDIMENTS

D. E. Harper, Jr., Presiding

10:30 (81) Total Organic Carbon and Carbon Isotopes of Sediments. **E. W. Behrens,** University of Texas, Galveston, Texas.

10:50 (82) Trace Metals. **J. B. Tillery,** Southwest Research Institute, San Antonio, Texas.

11:10 (83) Sedimentology and Geochemistry. **J. B. Anderson,** R. R. Schwarzer and R. B. Wheeler, Rice University, Houston, Texas.

11:30 (84) Surficial Sediments and Suspended Particulates. J. M. Brooks, E. L. Estes, C. R. Schwab, **D. A. Wiesenburg** and R. Shokes, Texas A&M University, College Station, Texas.

ENVIRONMENTAL EFFECTS OF OFFSHORE OIL PRODUCTION: THE BUCCANEER OIL FIELD STUDY

WEDNESDAY AFTERNOON .... Room 201

BIOTA I

R. K. Sizemore, Presiding

2:00 (96) Effects of Offshore Oil Field Structures on Their Biotic Environment: Platform Fouling Community. **N. Fotheringham,** University of Houston, Houston, Texas.

2:20 (97) The Effect of Structures on Migratory and Local Marine Birds. **G. D. Aumann,** University of Houston, Houston, Texas.

2:40 (98) Distribution and Abundance of Macrobenthic and Meiobenthic Organisms. **D. E. Harper, Jr.,** D. L. Potts, R. R. Salzer, R. J. Case, R. B. Jaschek, and C. M. Walker, Texas A & M University Marine Laboratory, Galveston, Texas.

3:00 INTERMISSION

BIOTA II

J. M. Brooks, Presiding

4:00 (99) Bacterial Community Composition and Activity. **R. K. Sizemore,** C-S. Hsu and K. D. Olsen, University of Houston, Houston, Texas.

4:30 (100) Effects Upon Platform Fouling Community. **B. J. Gallaway,** LGL Ecological Research Associates, Bryan, Texas.

5:00 (101) Effects Upon Platform Fish Communities. **B. J. Gallaway,** LGL Ecological Research Associates, Bryan, Texas.

ENVIRONMENTAL EFFECTS OF OFFSHORE OIL PRODUCTION: THE BUCCANEER OIL FIELD STUDY

BIOASSAYS

THURSDAY MORNING .... Room 201

R. S. Armstrong, Presiding

8:30 (107) Penaeid Shrimp Bioassays. **Z. P. Zein-Eldin,** National Marine Fisheries Service, Galveston, Texas.

9:00 (108) Acute Toxicity and Aquatic Hazard Associated with Discharged Formation Water. **C. Rose,** Energy Resources Co., Cambridge, Massachusetts.

9:30 INTERMISSION

HYDROGRAPHY AND MODELING

B. J. Gallaway, Presiding

10:30 (109) Water Currents and Hydrography. **L. J. Danek,** Hazleton Environmental Sciences Corporation, Inc., Northbrook, Illinois.

10:50 (110) Hydrodynamic Modeling. **G. Smedes,** Environmental Research and Technology, Inc., Seattle, Washington.

11:10 (111) The Use of Mathematical Models for Environmental Synthesis. **K. W. Fucik,** Science Applications, Inc., Boulder, Colorado.

11:30 (112) Transport and Dispersion of Potential Contaminants. **R. S. Armstrong,** National Marine Fisheries Service, Narragansett, Rhode Island.