

65

# THE JAMES RIVER PUBLIC SEED OYSTER AREA IN VIRGINIA

( A Review of 22 Years of Setting and Population Studies,  
1946 to 1967, and Changes Caused by  
*Minchinia nelsoni* (MSX) after 1960 )

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#### ABSTRACT

The seed-oyster area is located in a low-salinity sector of the James River where seasonal riverflows and resulting salinities vary widely. Low spring salinities, usually below 10 ‰ in April or May, eliminate most predators and diseases. Prior to 1960, spatfalls were regular and moderate in intensity each year. High quality seed oysters 2 to 3 inches in size were produced with 1000 to 2000 thick-shelled oysters per bushel for use by private-ground planters. Following the advent of M. nelsoni (MSX) in Chesapeake Bay in 1959, setting declined to about one-tenth previous levels and there were spatfall failures in many years. Thick beds of fossil shells provided cultch for setting oysters and little repletion by shell planting was attempted.

In the 1950's a gradient of decreasing spatfall with distance from the mouth of the river was observed. Setting was continuous for about 90 days each year with peak spatfalls in late August or early September. After 1960, setting was irregular by years, and sporadic within the seed area, with no patterns. Larvae were scarce and flushing of larvae out of the estuary appeared to require higher brood-oyster populations.

# THE JAMES RIVER SEED AREA

## Table of Contents

1. Introduction . . . . .	1
2. History of setting and seed oystering. . . . .	3
3. Methods . . . . .	4
4. Description of the seed area . . . . .	7
5. Characteristics of the seed area . . . . .	8
6. Predation and competition . . . . .	10
7. Spatfall on natural cultch . . . . .	11
8. Weekly spatfall records . . . . .	12
9. Spatfall on seasonal shellbags . . . . .	16
10. Discussion . . . . .	19
11. Tables . . . . .	28-38
12. Figures. . . . .	39-60

## LIST OF TABLES

1. Seed oyster counts on natural cultch . . . . .	28
2. Spatfalls on natural beds for 25 years . . . . .	29
3. Seasonal distribution of spatfall from weekly tests . . . .	31
4. Example of gradients of setting in seed area . . . . .	32
5. Comparison of setting on two sides of channel . . . . .	33
6. Potential spatfall from summed weekly sets . . . . .	34
7. Seasonal spatfall in shellbags, pre-MSX years . . . . .	35
8. Seasonal spatfall showing decline in 1960's . . . . .	36
9. Seasonal spatfall in post-MSX years . . . . .	37
10. Replication of stations and samples for weekly spatfall, 1967 . . . . .	38

## LIST OF FIGURES

1. James River map with orientation features . . . . .	39
2. Old map of natural oyster beds in James River . . . . .	40
3. Map of seed area with stations and beds . . . . .	41
4. Bar graph of spatfall in shellbags for 16 years . . . . .	42
5. Average spatfall in seasonal shellbags, post-MSX years . .	43
6. Average spatfall in seasonal shellbags, pre-MSX years . . .	44
7. Average spatfall on natural cultch for pre- and post-MSX years . . . . .	45
8-12. Accumulative weekly spatfall for 1963 to 1967 . . . . .	46-50
13-18. Seasonal spatfall for years 1962 to 1967 . . . . .	51-60

# The James River Public Seed Oyster Area in Virginia

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## INTRODUCTION

Recruitment of oyster populations in the James River seed area declined drastically beginning in 1961 and has remained low through 1980. The failure can be attributed to reduced spatfall and not to predation or decreased survival of spat. The change was abrupt and appears to be permanent. The timing coincided with the appearance of an oyster pathogen, Minchinia nelsoni (commonly known as MSX), which destroyed oyster populations in the James River below the seed area (Andrews and Wood, 1967). The evidence that MSX is the cause of the decline in oyster setting is circumstantial but dramatic changes in commercial operations are most readily divided into pre- and post-MSX periods.

The James River is unique for Chesapeake Bay in patterns, intensities and timing of oyster spatfalls. The horizontal salinity gradients are steeper than in other rivers entering Chesapeake Bay (Pritchard, 1952). The drainage basin and runoff are relatively large, providing low-salinity sanctuaries from predators and diseases in most of the seed area. Setting displays gradients of decreasing

intensity and increasing survival from the mouth of the river to upstream areas. Setting is prolonged and always late compared to other areas in Chesapeake Bay (Engle, 1947; Beaven, 1950; Andrews, 1951 and 1954). Little spatfall occurs in July and peaks of setting are reached near the first of September.

The characteristics of spatfall in the James River were described by Loosanoff (1932) and Andrews (1948, 1951, 1954). Setting in pre-MSX periods is compared here with data obtained in the 1960's after the advent of MSX. Discussion of factors and mechanisms controlling larval transport and dispersal is based on 30 years of observation.

Spatfalls in James River have always been light in intensity, thereby creating many single oysters and excellent quality of seed oysters. The sets have never been as heavy as those obtained in South Carolina, Seaside of Eastern Shore of Virginia, Delaware Bay near its mouth, and in the newly-developed Virginia seed areas (1964-66) in the Great Wicomico and the Piankatank rivers. In pre-MSX years, regular light sets occurred every year in the James River, with high survival in the upper seed area compensating for greater initial spatfalls in the lower region where predators levied a toll. Beds in the middle of the seed area are favorably located both for catching and survival of spatfalls, and they produce large quantities of quality oysters. Hundreds of tongers' boats congregate each year in the Wreck Shoal area for the first week or two of harvesting seed oysters (Fig. 1).

## HISTORY OF SETTING AND SEED OYSTERING

The earliest quantitative record of setting in the James River was obtained by Loosanoff in 1931. The level of setting in the seed area was low in that year and testimony of oystermen suggests that periods of poor harvests and relative scarcity of seed oysters occurred prior to World War II. Early descriptive accounts of abundance (catches) and harvests by the Virginia Commission of Fisheries<sup>1</sup> and other observers are obviously influenced by economic conditions and by demand for oysters. Market oysters sold for as little as 25 cents a bushel and at times no strong incentive to harvest existed.

Beginning in 1946, records of setting have been kept every year. In the late 1940's and 1950's river-wide sets each year were typical and seed oysters comprised of three or more yearclasses were abundant. The quality of seed oysters was superb from a planter's viewpoint, with at least 1000 two-inch thick-shelled oysters per bushel. In private planting areas with high salinities ( $> 15$  ‰), where oyster drills were prevalent, most spat and many yearlings were usually killed but older single oysters and small clumps grew into high-quality shucking stocks.

A rapid increase in acreage of private grounds rented after the war created a strong demand for seed oysters. Both Virginia and

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<sup>1</sup>A long series of reports, and beginning in 1941-42 with VIMS laboratory reports appended.



Maryland planters were supplied with low-cost seed from the James River in quantities averaging about 2 million bushels each year. No shell was planted in the river to replace that removed, consequently cultch was provided by live oysters plus some shells dug out of the bottom. During nearly 100 years of tonging, hundreds of intertidal oyster "rocks" were harvested and shell was scattered until now only one reef is exposed at low tides. Probably the oyster beds were increased in acreage by spreading the reefs or "lumps." Many oystering areas in Virginia are characterized by "lumps" or shelly islands surrounded by mud or sand.

#### METHODS

Three kinds of setting data were collected at numerous stations over a 20-year period. Weekly spatfall data refer to short-period exposures of cultch to determine initial intensity and distribution of setting spatially and temporally. Seasonal spatfall in shellbags is a measure of surviving set under optimal conditions of exposure and limitation of competition, predation and fouling. Timing and position of exposure of cultch are important factors. Both weekly and seasonal spatfall involve regulated situations in respect to quality and position of cultch. The third measure of spatfall was taken from samples of natural cultch dredged from oyster bars. Many variables of place and year are involved but these native population samples reflect actual conditions on oyster beds.

Weekly spatfall data were collected from 1947 to 1952 and from 1962 to 1967 (12 years). In the earliest years from 3 to 10 stations

were visited weekly to exchange shellbags or shellstrings. The shellbags contained 20 to 40 clean, paint-marked shells randomized in a quarter-bushel bag of shells. In 1950, shellstrings consisting of 12 to 25 shells, strung face down on a weighted wire, replaced the cumbersome weekly bags. The shellstrings were suspended close to the bottom from stakes. No spacers were used between shells and the strings were rinsed to remove dirt and dried before counting. Counts were made on the inner faces of 3- to 3 1/2-inch flat (right) valves under binocular microscopes. Usually more spat attached to the rough outer surfaces of clean shells than to the inner faces. Counts are usually reported as spat per shellface (one side), but if given as spat per shell or per bushel, the counts are doubled. Examples of replication of samples are given in the appendix (Table 10).

In the 1960's, more intensive efforts were made to monitor weekly distribution of spatfall with 21 stations on five cross-river transects (Fig. 3). Cement board plates (12 x 12 cm) held in suspended frames (Butler, 1954) were exposed at a control stations (Miles Watchhouse) and at VIMS Pier to facilitate comparisons with other investigations. Uniformity of cultch surface, texture, angle and area are desirable features to aid analyses, but unfortunately setting was inadequate in the 1960's for valid comparisons of these factors.

Seasonal spatfalls in quarter-bushel bags of shells were obtained from 1947 to 1952 and 1958 to 1967. The shellbags, 10 inches in diameter and 20 inches long, were filled with hand-selected shells

averaging 3 to 3 1/2 inches in length. All shells were hand-washed or cleaned with a steam jenny. Seasonal shellbags were dropped near stakes on shelly bottoms but were suspended with one end on the bottom at muddy stations. Bags were planted at various times during the setting season from 1 May to 1 September and recovered after setting had ceased for the year. One-hundred shells from each bag were examined for spat with the naked eye in the fall. Often late sets and catching by tongers necessitated removing bags about 1 October (beginning of tonging season) and suspending them at VIMS pier for growth of spat to easily visible size.

Sampling of natural beds gave variable counts and provided only relative abundances of seed oysters. These data are useful for comparisons of population trends by bars and years. A light hand dredge was used to sample the "tops" or best areas of shelly natural "rocks." Samples were taken from approximately the same places on each bar in successive years to reduce variability. All natural seed beds were heavily tonged by oystermen each year, and shells were culled back so the timing of surveys was critical too. James River seed beds are so firm and shelly that rarely were any buried shells caught in a light dredge. Samples varied in size from one-quarter to one bushel, depending on the intensity of spatfall, the amount of shell fragments (cinder) and the time involved in looking for spat because of size. Duplicate samples and those taken in fall and spring were often quite variable, therefore, the data should be examined for trends and patterns without emphasis on individual samples. The Virginia oyster bushel is large and our samples contained full measure

whereas tongers are adept at loosely "filling" a tub. The variability in quality and counts of seed oysters on buyboats anchored near each other on the same day is often astonishing. Hooked mussels (Geukensia demissus) attached to oysters reduced bushel-counts by half some years. This suggests the variability in seed-oyster counts that can be found within the seed area, even on the same bed, by random sampling and by selective tonging and sorting by oystermen.

#### DESCRIPTION OF THE SEED AREA

Familiarity with physical, geographic and biologic features of the James River is necessary to understand the data on oyster setting. The seed area extends from the vicinity of the bridge (J10) to Deep Water Shoal (J24) below Hog Island. Orientation to other areas of the river together with depth contours, channels and landmarks is provided in Fig. 1. Hampton Roads in the lower reaches of the river obtained sets consistently in the 1950's and 1960's, but predation and diseases prevented survival. This area does not produce seed oysters, and data for it are not presented.

The location of natural oyster "rocks" and Baylor Survey lines is shown in Fig. 2. The natural beds have not been surveyed since the late nineteenth century hence may differ considerably in area from this map. (For a recent bottom-type and oyster survey, see Haven et al., 1978.) A sector map of the seed area with channels and depth contours is used to plot spatfall data in visual form.

## CHARACTERISTICS OF THE SEED AREA

The James River exhibits several hydrographic and biologic characteristics that are favorable for seed oyster production. Regular annual spatfalls were the most important attribute prior to 1960. A natural source of cultch supplied by deep shell beds from old oyster reefs is available in shallow waters. Widely fluctuating seasonal salinity regimes control most predators, diseases, and many fouling organisms. This reduces competition and provides seed-oyster stocks free of diseases and predators. Slow growth and poor-quality meats are not usually desirable characteristics of oysters but these attributes promote retention in the seed area until thickened shells are acquired at relatively small sizes. For oystermen planting on predator-infested growing beds, this stunted, thick-shelled seed has great survival value. Unfortunately, several yearclasses of variable sizes are planted together, consequently oysters do not reach marketable size at the same time. Survival after transplanting depends upon the firmness of planting grounds to avoid smothering and low salinity levels to prevent predation and diseases. Regular, moderate setting and constant handling (tonging) also improve seed quality by keeping clusters small, shape uniform, and counts of oysters per bushel high. James River seed is preferred over that from areas with heavier sets, such as the Piankatank and the Great Wicomico rivers, because well-shaped oysters result that are more easily handled for shucking. Shape, size of oysters and clusters, and amount of fouling are important in bushel measurements for sale of seed and for subsequent yields of market oysters. Counts of seed oysters and

yields of meats per bushel in market oysters are important to oyster farmers.

The size and kind of cultch also affect the quality of seed oysters. In the James River seed area, cultch is comprised of live oysters and shell fragments dug out of old reefs. In years of good sets (pre-MSX period), live oysters provided most of the cultch but the proportion of shell has increased in the 1960's. Oysters and shells are typically larger at the lower end of the seed area (Brown Shoal) than at the upper end (Deep Water Shoal). This corresponds with growth rates today and in the past which exhibit a gradient from lower to upper river. Small shells or cinder in the upper river, particularly at Deep Water Shoal, tend to give excessively high comparative spat counts because they fit more compactly in sample tubs than clumped oysters and shells. The surface area per unit of volume is greatly increased by cinder which is measured by volume.

Survival of oysters is affected by fresh water runoff and by silt deposition. Oysters at Deep Water Shoal and to some extent in the upper river Horsehead-Point of Shoal area are subjected to fresh-water kills in the spring of wet years. Storms roil silt on the shallow bottoms of all seed beds and deposit it on oysters and shells which affects setting and survival.

## PREDATION AND COMPETITION

Predators and competitors (fouling organisms) affect setting and survival along the salinity gradient of the seed area. Oyster drills inhabit the lower edge of the seed area and seriously reduce or eliminate spatfalls in the Brown Shoal area. In 1948 and 1949, for example, wet years almost eliminated these predators from the downriver sector of the seed area, whereas the drought years of 1963 to 1967 brought a slow advance of drills to the channel edge of Wreck Shoal, but serious damage was limited to the area below Gun Rock. Stylochus, the oyster "leech," is a serious predator of newly set spat in natural waters. Survival of spat improves greatly in the low salinities of the upper seed area probably because of scarcity of Stylochus and other predators such as mud crabs. The role of blue crabs is probably important but hard to document.

Epifaunal species tolerant of low salinities affect setting and survival in the seed area. The chief competitors for space and food are barnacles, sea squirts, mussels and bryozoans. Beaven (1947) described some fouling organisms of upper Chesapeake Bay. The sea squirt Molgula manhattensis often covers much of the available cultch surface from Wreck Shoal downriver and as far up as Horsehead in dry years. Sea squirts set from May to September and grow very rapidly to nearly an inch in diameter in six weeks. Sea squirts are more serious pests on objects suspended or projecting above the bottom. Spatfall is impeded in the upper half of the seed area by regular intensive sets of Balanus improvisus. B. eburneus is not an important fouling

organism in the seed area although it may become abundant on intertidal and off-bottom substrates as it did in 1968. The hooked mussel Geukensia recurvus becomes a serious pest of oysters in some years but is relatively short-lived and subject to sudden mortalities, hence interferes little with oyster setting most years.

#### SPATFALL ON NATURAL CULTCH

Counts of seed oysters for typical years from the major natural beds are given in Table 1. The totals of live oysters per bushel probably exceed the counts found in tonger's catches because the samples were from selected areas of the best rocks. However, our samples were uncultured, whereas tongers are required to "rough cull" or remove shells without oysters. In years of good setting, as in 1947 to 1949, up to 90% of the catch on the major rocks was on oysters and shell fragments with oysters attached. The distribution of yearclasses and sizes in Table 1 shows that the tonger's catches were comprised of several ages of oysters. The current year class was finger-nail size or smaller and mostly attached to larger oysters. Many spat were smothered or killed by predators when transplanted to private grounds. Therefore, "small" oysters made up the effective seed stock planted, and counts of these in Table 1 approximate the useful seed obtained by planters.

Spat counts in samples from natural cultch for a period of 25 years are given in Table 2. Despite all the variables previously discussed and many gaps in the data, the outstanding feature of the seed area was regularity of setting. The years 1947, 1953 and 1958



were notably strong in the upper end of the seed area. No failures occurred prior to 1961 although the upper and lower ends of the seed area varied much more than the middle sector. The poorest sets were encountered in 1931 and the post-MSX years after 1960.

Abundance of spat was greatest in the middle of the river at Wreck Shoal where conditions appeared to be optimal both for setting and survival year after year. This abundance of oysters in the middle sector has long been recognized by tongers who work this area first and continuously each year. The greatest fluctuations in counts occurred at the upper and lower ends of the seed area where both survival and setting intensity were involved. Weekly records indicated that the heaviest sets occurred in the lower seed area but survival was lower than upriver. Cultch exposed for a second week usually exhibited mostly new spat in the lower seed area because those that set in the first week were smothered or killed by flatworms.

#### WEEKLY SPATFALL RECORDS

##### 1. Pre-MSX Period

The primary purpose of weekly monitoring of spatfall was to determine seasonality and duration of setting for recommendations on timing of shellplanting. A second purpose was to compare initial and surviving spatfalls by periods and locations. Continuous setting for about 90 days made surveillance of particular larval broods impractical, consequently, no effort was made to monitor larvae for prediction of setting. The industry is not able to plant shells in short periods even if predictions were feasible. Rather, effort was

expended looking for patterns of spatfall over many years in the belief that enough regularity would be found to choose times and places for shellplantings from past experience. This has been a useful approach (Andrews, 1951). Unfortunately, by 1963 when Virginia began serious programs of shellplanting in James River, setting had declined to a low level.

Weekly spatfalls on clean test shells are given in Tables 3, 4 and 5 for three years. Setting occurred in James River throughout August and September with peaks varying, but tending to cluster around the first of September (Andrews, 1951). Significant setting was always spread over several weeks and involved several broods of larvae. For example, in 1949 setting was persistent from 26 July to 20 September, whereas in 1950 three weeks in September accounted for a large proportion of the spatfall (Table 3). Prolonged duration of spatfall implies regular mechanisms for conserving and distributing larvae rather than chance, one-shot survival from erratic winds, currents and predator activity.

Setting was not localized but occurred throughout the river simultaneously with a pattern of decreasing intensity with distance upriver. From week to week changes in intensity of setting were usually in the same direction at all stations (Tables 3 and 4). This implies that larval swarms were widely distributed in the seed area by tidal currents. However, strong linear gradients of declining spatfall from lower to upper river, as exhibited in 1950, are typical for most years. Level of setting by stations probably reflects

variations in density and distribution of larval swarms, consequently duration of opportunity for spatfall. That is, more setting-size larvae are probably available for longer periods over beds in the lower than in the upper seed area. Tidal excursions are obviously involved in distributing and dispersing larval swarms throughout the river during the 10-14 day planktonic period.

Weekly shellbags and shellstrings are compared inconclusively as to relative efficiencies in catching spat (Table 3). Also, an attempt was made to demonstrate lateral gradients of spatfall in 1952 by monitoring shellstring stations on opposite sides of the channel. The evidence for cross-river gradients is too weak to be convincing, with many possible variables.

## 2. Post-MSX Period

Failure of setting in post-MSX years (Andrews, 1982) quickly revived interest in monitoring, occurrence and distribution of larvae and spatfall. After the first set failure in 1961, it was not anticipated that greatly reduced setting would continue for twenty consecutive years. Beginning in 1963, some 40 stations in the seed area and Hampton Roads were monitored weekly for setting.

Intensive monitoring for five years revealed three important changes in setting in the seed area. Most important was the drastic reduction in level of setting (Figs. 8 to 12). Only two of eight years (1964 and 1966) had light sets in the seed area. Total weekly spatfalls for key stations best reveal the severity of the decline (Table 6). Total weekly sets in pre-MSX years were 10 to 100 times as

great as in post-MSX years. In the years of failure, most stations had less than one spat per shell per season of initial set on clean shells. No reduction in mortality of spat from predation and smothering was observed in these post-MSX years. The proportion of losses may have increased.

A second characteristic of post-MSX setting is that it occurred almost entirely in September. Since oysters were observed to have spawned regularly in July and August, it appears that late setting was a consequence of survival and distribution of larvae upriver being more favorable in late summer. Also, the light sets of 1964 and 1966 were provided mostly by one or two broods of larvae in contrast to pre-MSX years with continuous setting for three months.

The pattern of distribution of weekly setting in the seed area in post-MSX years is quite different from the gradient type described for earlier years. Spatfall occurred throughout the river but appeared to be heaviest inshore and upriver. This contrasts sharply with earlier patterns. The swarms of mature larvae appeared to enter the seed area on the northeast shore and subsequently passed down the southwest shore to Hampton Roads (Figs. 19 to 22). This pattern was observed only for 1964 and 1966. The other years were spatfall failures except for a few spat in a small wedge area adjacent to the channel above the bridge in 1963, for example.

## SPATFALL ON SEASONAL SHELLBAGS

Seasonal shellbags were used in most years to obtain estimates of surviving spatfall under more optimum conditions than natural cultch provided. Timing of exposure, control of predators and fouling, and bag-induced turbulence of bottom currents all favored greater intensity of setting than usually occurred on bottom cultch. Shellbags were placed on beds at times when larvae were known to be setting or expected to do so. Thus, much spring and early-summer fouling was avoided. Prediction of setting from known broods of larvae was not feasible by the methods used in Pendrell Sound, British Columbia (Quayle, 1957, 1964, 1969; Bourne, 1979). It was learned by experience that cultch exposed in early August and often as late as early September obtained maximal surviving spatfalls.

Control of predators was not complete even in shellbags suspended off the bottom. The drills Urosalpinx and Eupleura have only limited access to spat on shells in wire bags, but the flatworms Stylochus often killed newly set spat. These predators are tiny plankton-derived specimens about the size of spat that appear in early July, and they penetrate all crevices in shellbags whether suspended or on bottom.

Seasonal shellbags provided one method of testing timing of planting with some control of fouling and predation. With significant setting usually continuing over most of three months, the only practical approach was to select a propitious period for planting and accept the results over a period of years. It is now recommended that

commercial shellplanting begin about 1 August and that it be completed by 15 August each year. Optimum timing is to be planting shells when the period of peak setting is in progress. In normal years in James River there is considerable leeway in timing because of prolonged periods of setting. May-June and September are typically the most serious months for fouling, particularly barnacles, with sea squirts (Molgula) most intensive in late spring but continuing throughout the summer at temperatures above 20°C.

A serious problem with late-setting (Sept.) spat in the James River is their failure to grow appreciably the first fall. Many spat winter as tiny pinhead-size individuals, consequently they are susceptible to smothering by winter storms as well as losses from predation, competition and low winter-spring salinities. Furthermore, many spat on larger oysters are transplanted to inferior private grounds during the seed-oyster season from October to May with further losses occurring from smothering following replanting.

The patterns of setting from 1947 to 1960 are considered normal for the seed area. Counts of spat per shell in seasonal shellbags for the first six years of this period are given in Table 7. Average numbers per shell including replicate bags show the distribution of spatfall in the river and the variations among samples. During these years only hard, shelly seed rocks were used with the bags lying on the bottom near stakes. Smothering and fouling were not serious problems although this series of bags was planted in early June. Higher counts usually occurred in bags planted in August. The highest

surviving sets occurred in the middle of the seed area with reduced survival downriver and lower initial sets upriver accounting for this pattern. Drill activity reduced the survival at Nansemond Ridge and Brown Shoal every year, but counts of drilled spat have little meaning because the heaviest mortality occurs on very tiny spat immediately after setting from flatworms.

The drastic change in spatfall in seasonal shellbags in post-MSX years is shown in Fig. 4 and Table 8. Three important rocks representing the major seed area types of lower, middle and upper river are shown with average counts in shellbags. The reduction in spatfall was equally serious at all levels of the river. Low sets for eight consecutive years of data is indicative of a serious change in the ecosystem in regard to oyster reproduction.

From 1963 to 1967, seasonal shellbags were suspended at each of the 21 transect stations used for weekly spatfall. The data confirm the riverwide scarcity of spatfall previously noted, with light sets in 1964 and 1966 (Table 9). Oyster beds were utilized where possible but some soft bottom stations had to be used, therefore suspension of shellbags and other variables such as depth, fouling and sometimes smothering became involved. Some shellbags were lost and time of planting varied although most were exposed about the first of August. The data are given in spat per hundred shells on maps of the seed area (Figs. 13 to 18). It is apparent that sets in the 1960's (Fig. 5) were far below those of normal years (Fig. 6). Furthermore, the failures were generally riverwide with only two years (1964 and 1966)

showing appreciable sets. There was a tendency for the best spatfalls to occur inshore and upriver. For example, in 1967 the best surviving set occurred at the Deep Water Shoal station at the upper end of the seed area.

## DISCUSSION

The regularity of spatfall in the James River in the past implies a mechanism or system of larval transport that functions effectively despite many biotic and physical variables. A prolonged two- to three-month setting period precludes a chance shotgun approach in which one or more of many spawnings is successful but most fail. Predation and flushing, both of which are undoubtedly limiting factors, never succeed in destroying whole broods for continuous setting is the rule.

The James River is an open-circulation system in comparison with St. Mary's River (Manning and Whaley, 1954) and other seed oyster areas in Chesapeake Bay which are relatively enclosed, self-contained systems with sills or other barriers to free exchange of water with the Bay. Manning and Whaley reported high counts of mature larvae in St. Mary's where weak tidal currents permitted southerly winds to push larvae towards the head of the stream. The Great Wicomico and Piankatank are similar rivers with little fresh-water inflow that also exhibit intensive spatfalls in the upper reaches but face different directions than St. Marys River. All three rivers have deep, tortuous channels and strong mechanisms for transporting larvae upstream with subsequent intensive sets. In contrast, James River has low larval



counts, comparatively light sets and the most effective setting period is August and September rather than July. The James River succeeds when similar rivers (York, Rappahannock and Potomac) fail or obtain much lower sets.

The massive effort required to monitor larvae in a large open-flushing river is not to be undertaken lightly. VIMS has tried it only twice in the past 35 years. The experience of taking weekly and even daily plankton samples containing no oyster larvae during a period of intensive spatfall is warning enough of the complexity of larval distribution. Experience showed that James River is not a place where large numbers of mature and eyed larvae can be taken--even with samples as large as 500 liters (cf. Carriker, 1951). Consequently, efforts to understand the system and make predictions have been directed primarily towards spatfall and clues to the mechanisms of transport have been sought from long-term records.

Unfortunately, a dramatic decrease in the level of setting occurred in James River after 1960. Spatfall essentially failed in all but two subsequent years in the 1960's and the 1964 and 1966 sets were only about one-tenth the magnitude of normal years. The causes are not confirmed. Decline in production of oysters from the James River beds was slower and less serious economically than expected due to a series of events explained elsewhere (Andrews, manuscript; Haven et al., 1978). Explanations for this reduced reproduction have not been proven, but they may be a guide to subsequent investigators.

Records of seasonal shellbags and weekly shellstrings were sporadic because research efforts were diverted to pressing oyster disease problems.

A series of facts and concepts is the basis of this analysis of decline of setting. 1) A new disease caused by Minchinia nelsoni (MSX) destroyed millions of bushels of private and public oysters in lower Chesapeake Bay between 1959 and 1961. 2) Included in the destruction were large private stocks of oysters in Hampton Roads from Brown Shoal downstream in the James River. Nansemond River, Hampton Bar and Willoughby Spit were the major areas involved. Therefore, oyster broodstocks in Hampton Roads, the broad, deep sector of the James River, were severely depleted after 1960. No replanting occurred and the private beds were abandoned.

The remaining concepts are concerned with setting patterns in the James River seed area. 3) Spatfall declined drastically beginning in 1961 and low setting persisted through 1980. This is referred to as the post-MSX period and the implication of cause and effect can not be denied. 4) In pre-MSX years, setting exhibited a longitudinal gradient with heaviest initial spatfall in the lower seed area and progressive declines in the upper half. Evidence for a gradient of decreasing set from near channel to inshore areas was found also. 5) Post-MSX setting in two years of significant spatfall was river-wide with a tendency for the intensity to be greatest inshore and upriver. 6) Survival of spat is greatest in the Wreck Shoal (middle area) and upper areas, with predation in the lower seed area and occasional fresh-water kills in the upper part reducing survival. 7) Typically,

spatfall occurs late in the summer compared to other seed areas in the Chesapeake Bay region.

Two patterns of larval origin and dispersal are hypothesized from this information. The predominant pattern that produced good spatfalls in pre-MSX years is dependent upon salt-wedge penetration of the seed area with subsequent mixing upstream and laterally. Brood stocks in the deeper waters of Hampton Roads appeared to be the major source of spawn. Probably seed oysters on the relatively shallow beds (mostly < 10 feet) above the bridge also provided spawn which was carried by net downstream surface currents into Hampton Roads. In late summer, Hampton Roads shows little vertical density stratification, therefore, it becomes a big mixing bowl in which larvae get into deeper channel waters and are carried upriver. Larval swarms tend to reach all levels of the seed area in tidal excursions but setting gradients indicate much reduced densities in the upriver and inshore fringes of swarms. After 1960, the density of swarms was so reduced that little setting occurred above the bridge. Consequently the gradient setting pattern has not operated in twenty consecutive years. Since no major changes in hydrography are known, destruction of brood stocks in Hampton Roads by disease is implicated as the cause of failures and reduced intensity of oyster spatfalls.

The second pattern of sporadic spatfall involves brood stocks within the seed area and inshore retention of larval swarms over the shallow seed oyster beds during late stages of their pelagic phase. Some decline of brood stock in the seed area has occurred in the

1960's because catch has decreased to 1/4 to 1/3 of pre-MSX years and some lower beds have become unproductive due to diseases (e.g., Brown Shoals). However, reduced spatfall was accompanied by increased growth and fattening of unharvested oysters from 1963 to 1966 due to higher salinities. This last trend has not persisted for poor growth and small oysters characterized the years 1967 to 1969 and through the wet 1970's. In terms of oyster spawn produced within the seed area, the post-MSX years appeared relatively unchanged from normal years through 1966 because fewer but larger oysters produced more sex products. Circumstances which could retain or trap larvae in the shallow inshore waters of the seed area for more than a few days cannot be explained. Regardless of source of brood stock, larvae probably are imported from the Hampton Roads mixing bowl and carried inshore by wind-induced currents. Occurrence of sporadic, low-intensity spatfalls in only two of eight years suggests special and erratic conditions of short duration. It is probably significant, too, that the post-MSX spatfalls were apparently each from one or a few larval swarms mostly confined to setting within two weekly, sampling periods. Therefore, the 1964 and 1966 sets have all the attributes of irregular circumstantial events rather than true transport systems or patterns.

The implication is that both systems were working prior to 1960 but that the salt-wedge method was most regular and most important. The pre-MSX years, when relatively sporadic patterns were important, may be recognized by relatively heavy sets throughout the river but especially on the upper bars. Years in which this pattern with

intensive spatfalls was pre-dominant or important are 1947, 1953, 1957, and 1958. High survival and cindery cultch (many small shell fragments) tend to distort comparative counts on natural beds in the upper river.

A full two decades of inadequate setting in the James River seed area have severely stressed this fabulous oyster-producing river. Production has been reduced to less than one-third pre-MSX yields despite increased shell planting. Almost no cultch was planted prior to 1963. The river now appears almost deserted at times by oystermen with reductions in numbers of tongers to about one-fifth those of the 1950's.

The fecundity of marine invertebrates with pelagic larvae is phenomenal and repletion of stocks by single yearclasses occurs inexplicably at times. Examples include oysters in the Potomac River in 1963, and in Long Island Sound in 1966 and 1968 (MacKenzie, personal communication). It is hazardous to predict the future of oyster setting in the James River. However, it appears that the broodstock required to produce spatfalls of the magnitude of the 1950's is no longer available in the James River. Flushing of larvae appears to require very large stocks of spawners, despite relatively steep salinity gradients that indicate vigorous salt-wedge penetration of seed areas in some seasons. Additional studies of hydrography and larval transport are needed to learn how to distribute more efficiently those oysters remaining for maximum reproduction of the species.

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Table 1. Counts of seed oysters and shells in dredged samples of natural cultch, James River seed area, 1947-1949

Bar	Per Bushel						
	Live Oysters				Shell Reserve		
	Market	Small	Spat	Total	Blank Shells	Other Shells	Cinder %
				<u>1947</u>			
Wreck Shoal	56	966	1464	2486	54	90	8
Horsehead	0	784	1428	2212	20	104	25
Deep Water Shoal	<u>74</u>	<u>320</u>	<u>6024</u>	<u>6418</u>	<u>64</u>	<u>456</u>	<u>65</u>
Average	43	690	2972	3705	46	217	33
				<u>1948</u>			
White Shoal	61	1113	960	2134	55	24	-
Gun Rock	39	900	1335	2274	32	16	-
Blunt Point	40	1136	328	1504	72	8	2
Wreck Shoal	33	1648	1399	3080	22	1	6
Rainbow Rock	4	2732	380	3116	20	8	-
Point of Shoal	28	1412	260	1700	124	4	40
Horsehead Rock	4	1994	686	2684	40	12	-
Deep Water Shoal	<u>7</u>	<u>359</u>	<u>388</u>	<u>754</u>	<u>211</u>	<u>19</u>	<u>35</u>
Average	27	1412	717	2156	72	12	21
				<u>1949</u>			
White Shoal	36	600	1912	2548	4	16	2
Thomas Rock	60	928	2320	3308	24	20	3
Wreck Shoal	13	1603	2971	4587	67	36	12
Rainbow Rock	8	1880	1872	3760	16	8	8
Point of Shoal	24	1156	548	1728	12	4	35
Horsehead	0	1416	2656	4072	8	24	25
Deep Water Shoal*	—	—	—	—	—	—	—
Average	24	1264	2047	3334	22	18	14

\*Deep Water Shoal omitted from calculation for 1949 because freshwater prevented much set and killed many small oysters; hence, there was no harvesting on this bar in 1949-50.

Table 2. Spat counts per bushel in samples of uncultured natural cultch. Pre-MSX and post-MSX averages are given for comparison.

	<u>(1931)</u>	<u>1944</u>	<u>1945</u>	<u>1946</u>	<u>1947</u>	<u>1948</u>	<u>1949</u>	<u>1950</u>	<u>1951</u>	<u>1952</u>
Brown Shoal		27	1200	335	48	256	1834	734	1836	1460
Gun Rock		1288	780	168		1335	2320		1692	1253
White Shoal						960	1912		1072	1196
Wreck Shoal	420	927	500	395	1464	1399	2971	1772	2754	1502
Rainbow Rock						380	1872	1584	1728	996
Horsehead	275	400	60	280	1428	686	2656		1460	1084
Point of Shoals		146		42		260	548	348		336
Deep Water Shoal	260	78	0	83	6024	382	216	354	928	132
Average	318	478	508	217	2241	707	1801	958	1639	995
	<u>1953</u>	<u>1954</u>	<u>1955</u>	<u>1956</u>	<u>1957</u>	<u>1958</u>	<u>1959</u>	<u>1960</u>	<u>Averages 1944-60</u>	
Brown Shoal	356	184	1396	296	700		428	438	720	
Gun Rock		936	480	400	1436	524		220	987	
White Shoal		576	728	176	1048	2116			1086	
Wreck Shoal		877	3056	227	1164	2332	2424	644	1526	
Rainbow Rock		708	716	428	1204		684		1030	
Horsehead	4312	580	34	396	2030	4116	872		1360	
Point of Shoals		336							288	
Deep Water Shoal	2468	796	36	180	1080		144		860	
Average	2379	624	921	307	1237	2272	910	434		

Table 2. (continued)

	<u>1961</u>	<u>1962</u>	<u>1963</u>	<u>1964</u>	<u>1965</u>	<u>1966</u>	<u>1967</u>	<u>Averages 1961-67</u>
Brown Shoal		113	166	83	15	11	0	64
Gun Rock		118	38	76	24	16	0	45
White Shoal		140	72	42		68	2	65
Wreck Shoal	132	201	157	937	62	148	0	234
Rainbow Rock		16	56		74	158	12	63
Horsehead	68	8	7	234	16	783	4	160
Point of Shoals		42	0	364		436		211
Deep Water Shoal	10	20	10	500	24	380	42	141
Average	70	82	63	319	36	250	9	

Table 3. Weekly spatfall, James River  
(Spat per day per 100 shellfaces)

Year	1949		1950			
Type of collector	Shellbags		Shellbags		Shellstrings	
Oyster bar	Brown Shoal	Wreck Shoal	Brown Shoal	Wreck Shoal	Brown Shoal	Wreck Shoal
Period of exposure						
28 Jun- 5 Jul	0	2	0	0	0	0
5 Jul-12 Jul	49	25	0	0	0	0
12 Jul-19 Jul	83	30	0	1	2	0
19 Jul-26 Jul	0	12	11	13	3	4
26 Jul- 2 Aug	106	85	97	30	37	20
2 Aug- 9 Aug	213	255	49	28	-	-
9 Aug-16 Aug	465	235	45	48	29	17
16 Aug-23 Aug	419	265	15	21	17	36
23 Aug-30 Aug	415	260	61	48	93	49
30 Aug- 6 Sep	200	100	617	557	-	766
6 Sep-13 Sep	154	90	652	460	1417	1159
13 Sep-20 Sep	66	105	335	194	299	197
20 Sep-27 Sep	16	62	62	90	-	-
27 Sep- 4 Oct	14	3	30	38	-	-
4 Oct-19 Oct	0	1	14	5	-	-

Table 4. Weekly spatfall, James River shellstrings, 1950  
(Spat per day per 100 shellfaces)

Oyster bar	Brown Shoal	Gun Rock	White Shoal	Wreck Shoal	Rainbow Rock	Horsehead Rock	Point of Shoal	Deep Water Shoal	Total
Location*	J11E	J13E	J13C	J17E	J19E	J21E	J21E	J24E	
Period of exposure									
5 Jul-11 Jul	0	0	0	0	0	0	0	0	0
11 Jul-17 Jul	2	0	2	0	0	0	0	0	4
17 Jul-26 Jul	3	0	0	4	0	1	0	0	8
26 Jul- 2 Aug	37	9	9	20	0	1	0	0	76
2 Aug- 9 Aug	-	4	7	-	1	1	0	1	14
9 Aug-16 Aug	29	16	13	17	14	0	-	0	89
16 Aug-23 Aug	17	20	9	36	16	4	-	7	109
23 Aug-30 Aug	93	34	11	49	6	-	-	1	194
30 Aug- 6 Sep	-	511	73	766	179	63	4	19	1615
6 Sep-13 Sep	1417	-	647	1159	207	30	-	6	3466
13 Sep-20 Sep	<u>299</u>	<u>93</u>	<u>109</u>	<u>197</u>	<u>37</u>	<u>1</u>	<u>-</u>	<u>0</u>	<u>736</u>
Totals	1897	687	880	2248	460	101	4	34	6311

\*J11E indicates Brown Shoal is 11 nautical miles from the mouth of the river on the east or left side of the channel. J13C indicates White Shoal is on a bar in the middle of the river between two channels.

Table 5. Weekly spatfall, James River, 1952

(Spat per day per 100 shellfaces)

Oyster bar *	Brown Shoal	Dog Shoal	White Shoal	Wreck Shoal	Days Point	Deep Water Shoal	Point of Shoal
Location	J11E	J11W	J13C	J17E	J17W	J24E	J21W
Period of exposure							
9 Jun-27 Jun	0	0	0	0	0	0	0
27 Jun- 2 Jul	0	0	0	0	0	0	0
2 Jul- 9 Jul	14	16	6	4	1	0	0
9 Jul-16 Jul	53	173	10	24	3	0	0
16 Jul-23 Jul	80	60	27	46	11	6	4
23 Jul-30 Jul	40	27	6	14	1	6	3
30 Jul- 6 Aug	30	53	23	27	11	1	4
6 Aug-13 Aug	177	170	20	67	5		1
13 Aug-20 Aug	76	147	21	21		10	3
20 Aug-26 Aug	8	12	13	12	0	5	5
26 Aug-10 Sep	141	98	45	73	27	5	1
10 Sep-16 Sep	383	147	28	50	20	3	8
16 Sep-26 Sep	106	71	33	111	22	6	3
26 Sep- 6 Oct	2	14	3	1	6	0	0
6 Oct-10 Nov	<u>1</u>	<u>0</u>	<u>0</u>	<u>-</u>	<u>0</u>	<u>0</u>	<u>0</u>
Totals	1111	988	235	450	107	42	32

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\*Stations are arranged by pairs in order of distance from mouth of river.

Table 6. Total weekly spatfalls in James River seed area by years<sup>1</sup>  
(Spat per shell per season)

Year	Stations			
	Brown Shoal	Wreck Shoal	Horsehead	Deep Water Shoal
1931 <sup>2</sup>	-	-	-	-
1947 <sup>3</sup>	-	313	-	31
1948	-	170	-	
1949	311	215		9
1950	281 (265+) <sup>4</sup>	215 (315)	(14)	6 (5)
1951	-	80	-	-
1952	177	80	-	7
1963	28	1	1	0
1964	14	9	4	3
1965	0	1	0	0
1966	14	8	7	6
1967	1	1	3	2

<sup>1</sup>Totals for years through 1952 are for shells in wire bags. Those in parentheses and all figures for the 1960's are based on shellstrings.

<sup>2</sup>In 1931, Loosanoff monitored setting weekly at Miles' Watchhouse. Calculations give a total of 9 spat for the season in a period of drought.

<sup>3</sup>Station at Nansemond Ridge had 113 spat per shell.

<sup>4</sup>Shellstring for one week lost during peak of setting.

Table 7. Seasonal survival of spat in shellbags (spat per shell) exposed from early June to November in a period of "normal" years, James River. Counts from replicate bags given for comparisons.

Oyster Shoal	Years					
	1947	1948	1949	1950	1951	1952
Nansemond Ridge	2.9* 2.6*		3.1 1.1	2.5 1.9	5.5	
Brown Shoal			3.3	4.8 5.7	6.8 8.0	5.7
White Shoal			4.2	4.3 3.6	4.9	3.3
Thomas Rock					6.0 3.7	
Wreck Shoal	11.6 14.6	7.9 8.0 8.6 8.1 9.6	14.1 16.5		6.9 7.4 9.0 6.6 8.0	5.8
Rainbow Rock			6.2 4.2	6.0	4.1 5.6	3.8
Horsehead			4.1 3.1		5.3 2.6	1.8
Point of Shoals			1.6 1.7		1.4 1.9	1.1
Deep Water Shoal	6.9 7.1		0.9 1.1	0.5	2.3	0.4

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\*Many drilled spat not counted.



Table 8. Spatfall in shellbags, James River  
(Spat per shell for season)

Date	Location		
	Brown Shoal	Wreck Shoal	Horsehead Rock
1947	4.5	14.4	8.7
1948	3.8	9.0	6.5
1949	12.0	17.0	3.6
1950	5.2	13.3	1.7
1951	7.4	7.6	3.9
1952	5.7	6.4	1.8
1958	21.0	28.7	6.9
1959	-	9.6	-
1960	7.0	3.0	9.2
1961	0.8	3.6	-
1962	1.6	1.2	0.5
1963	2.1	0.3	0.1
1964	1.5	2.7	1.5
1965	0.7	0.1	0.0
1966	0.6	0.4	0.4
1967	0.1	0.2	1.0

Table 9. Spatfall on seasonal shellbags in post-MSX years.  
Spat per shell on bags planted about 1 Aug each year.

Station <sup>1</sup>	Year				
	1963	1964	1965	1966	1967
1	0.6	1.2	0.6	0.6	-
2	2.1	1.1	0.7	0.7	0.1
3	-	0.3	0.1	0.2	0.0
4	-	4.3	0.2	1.4	0.2
5	-	0.5	0.2	1.2	-
6	0.7	0.2	0.1	1.7	0.0
7	0.3	3.6	-	0.4	0.1
8	0.1	0.2	0.0	0.8	-
9	0.1	2.3	-	0.6	0.1
10	0.2	2.7	0.1	0.4	0.2
11	-	0.2	0.0	0.7	0.1
12	0.0	3.3	0.0	0.2	0.1
13	-	-	0.0	0.1	0.4
14	-	1.7	0.1	1.1	0.2
15	0.1	1.3	0.1	0.6	0.6
16	-	0.6	0.0	0.4	0.2
17	0.1	-	0.0	0.9	0.3
18	0.1	1.5	0.0	0.4	0.8
19	-	0.2	-	0.6	0.5
20	-	0.3	-	1.1	1.4
21	0.2	0.5	0.1	0.1	-

<sup>1</sup> See Fig. \_\_\_ for stations and transect locations

Table 10. Replication of stations and samples for weekly spatfall per 10 shellfaces, James River, 1947<sup>1</sup>

Dates of exposure <sup>2</sup>	Nansemond Ridge				Wreck Shoal				Deep Water Shoal			
	Sta. 1		Sta. 2		Sta. 1		Sta. 2		Sta. 1		Sta. 2	
May 23-30	0	0	0	0	0	0	0	0	0	0	0	-
May 30-Jun 12	0	0	0	0	0	0	0	0	0	0	0	0
Jun 12-19	0	0	0	0	0	0	0	0	0	0	0	0
Jun 19-27	0	0	0	0	0	0	0	0	0	0	0	0
Jun 27-Jul 3	0	0	0	0	0	0	0	0	-	-	0	0
Jul 3-11	0	1	0	0	0	0	0	0	0	0	0	0
Jul 11-18	4	4	3	1	17	28	21	13	0	0	3	0
Jul 18-25	8	7	4	4	11	7	12	18	0	2	0	0
Jul 25-31	13	13	12	0	58	63	42	36	2	3	1	2
Jul 31-Aug 8	16	25	7	9	56	70	71	104	23	19	13	16
Aug 8-15	121	113	97	68	154	124	144	147	5	4	12	18
Aug 15-22	157	138	188	198	261	306	263	303	6	8	7	12
							163	268				
Aug 22-29	33	40	15	23	302	322	304	325	56	53	17	32
Aug 29-Sep 4	91	128	80	106	405	343	274	187	62	52	32	19
Sep 4-12	81	60	66	82	132	188	316	239	38	24	25	28
Sep 12-19	33	51	51	75	125	126	56	53	8	2	3	5
Sep 19-27	5	18	7	6	68	47	36	19	8	5	0	6
Sep 27-Oct 2	2	2	0	2	16	20	34	17	2	3	1	1
Oct 2-9	0	1	2	1	1	1	17	10	0	0	1	0
Oct 9-16	-	-	-	-	0	0	0	1	0	0	0	0
Oct 16-24	0	0	0	0	0	0	0	0	0	0	0	0
Oct 24-Nov 6	0	0	0	0	0	0	0	0	0	0	0	0

<sup>1</sup>20 clean shells randomly mixed in tub with one-quarter bushel of shells before filling shellbags. Replicate bags at stakes some 50 yards apart.

<sup>2</sup>Dates of exposure were regularly one or two days earlier at Wreck Shoal and Deep Water Shoal.

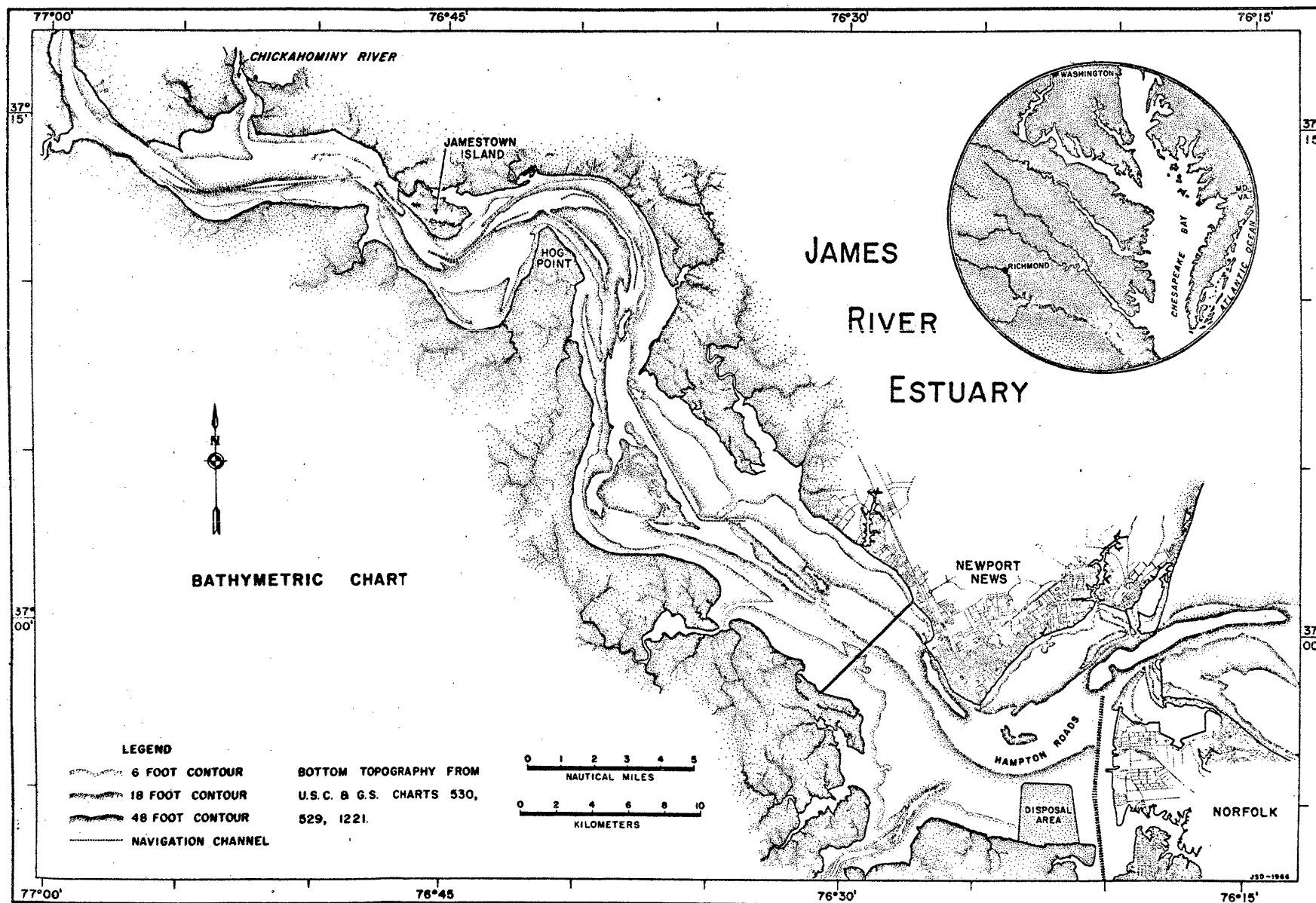


Fig. 1. Map of James River in Virginia, showing small tributaries and Hampton Roads bounded by cities. The famous seed area begins at nautical mile J10 near the James River Bridge at Newport News and extends to J24 below Hog Point. Wide seasonal variations in freshwater runoff occur in this river which extends into the Blue Ridge Mountains and drains a large area, completely in Va.

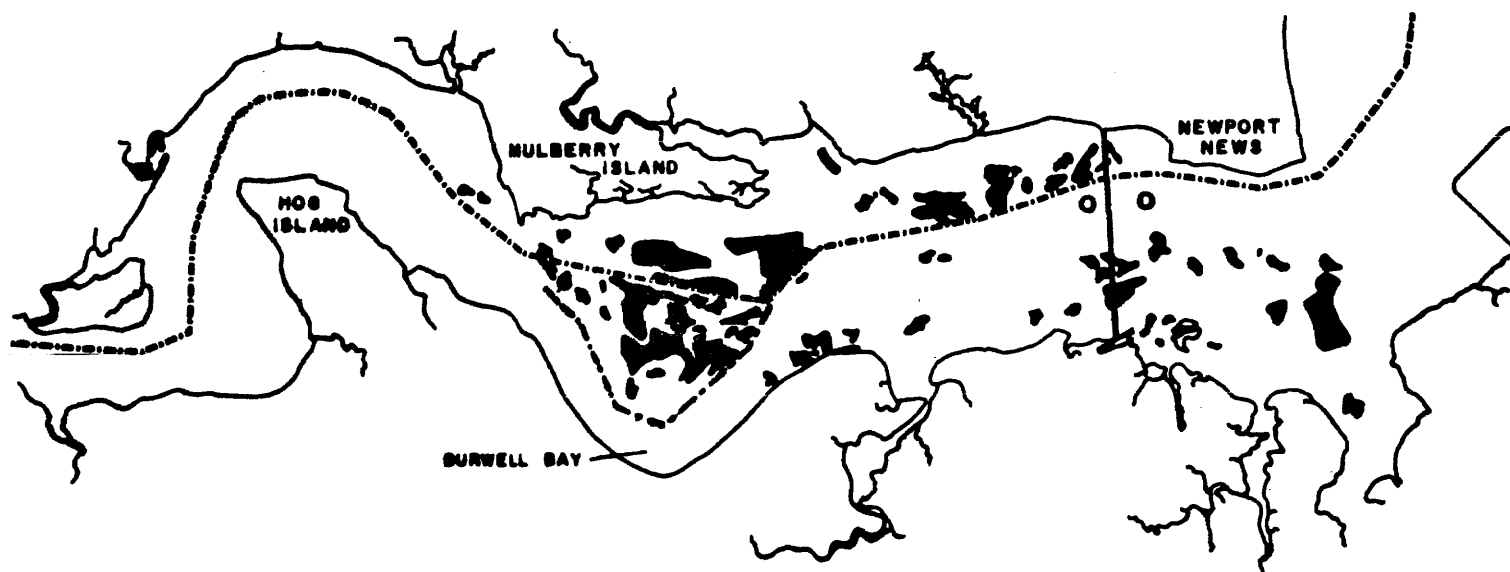


Figure 2. Public oyster beds of the James River seed area as determined by the Baylor Survey, 1896. Most natural beds are located on the eastern side of the old natural channel which follows around Burwell Bay. The James River Bridge above Newport News marks the approximate boundary of predator and disease activity at salinities of 15 to 18 ‰ in late summer.

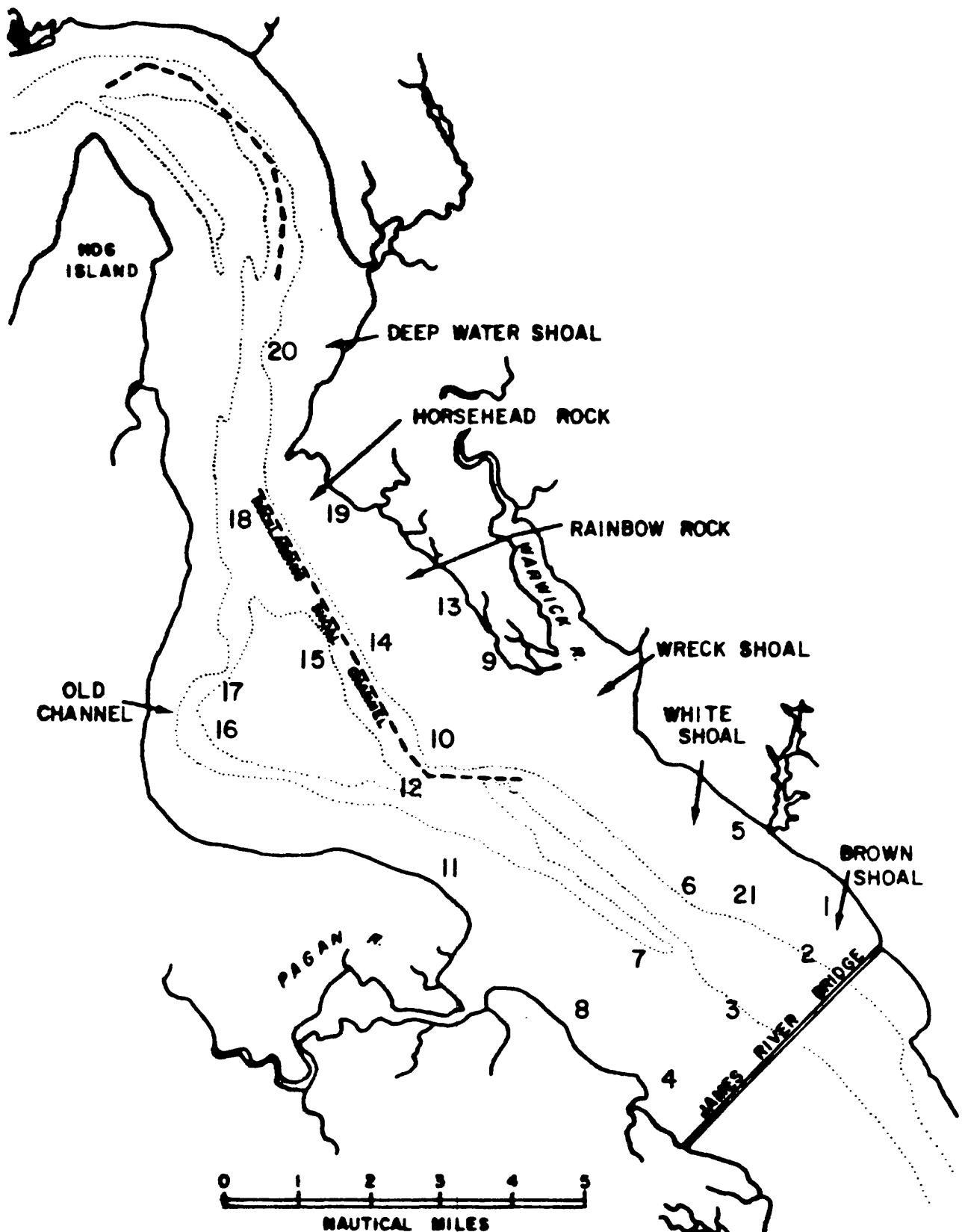


Figure 3. Map of James River seed-oyster area from J.R. Bridge (J10) to Deep Water Shoal (J24), last up-river bed. Stations on five cross-river transects, plus Deep Water Shoal, and Miles Watchhouse near station 5, were chosen to represent inshore and offshore sites of oyster spatfall. The old channel on Burwell Bay is partly filled with silt limiting ship traffic, yet it carries far more water than the artificial, narrow Rocklanding shoal which transects deep shell beds for transportation purposes.

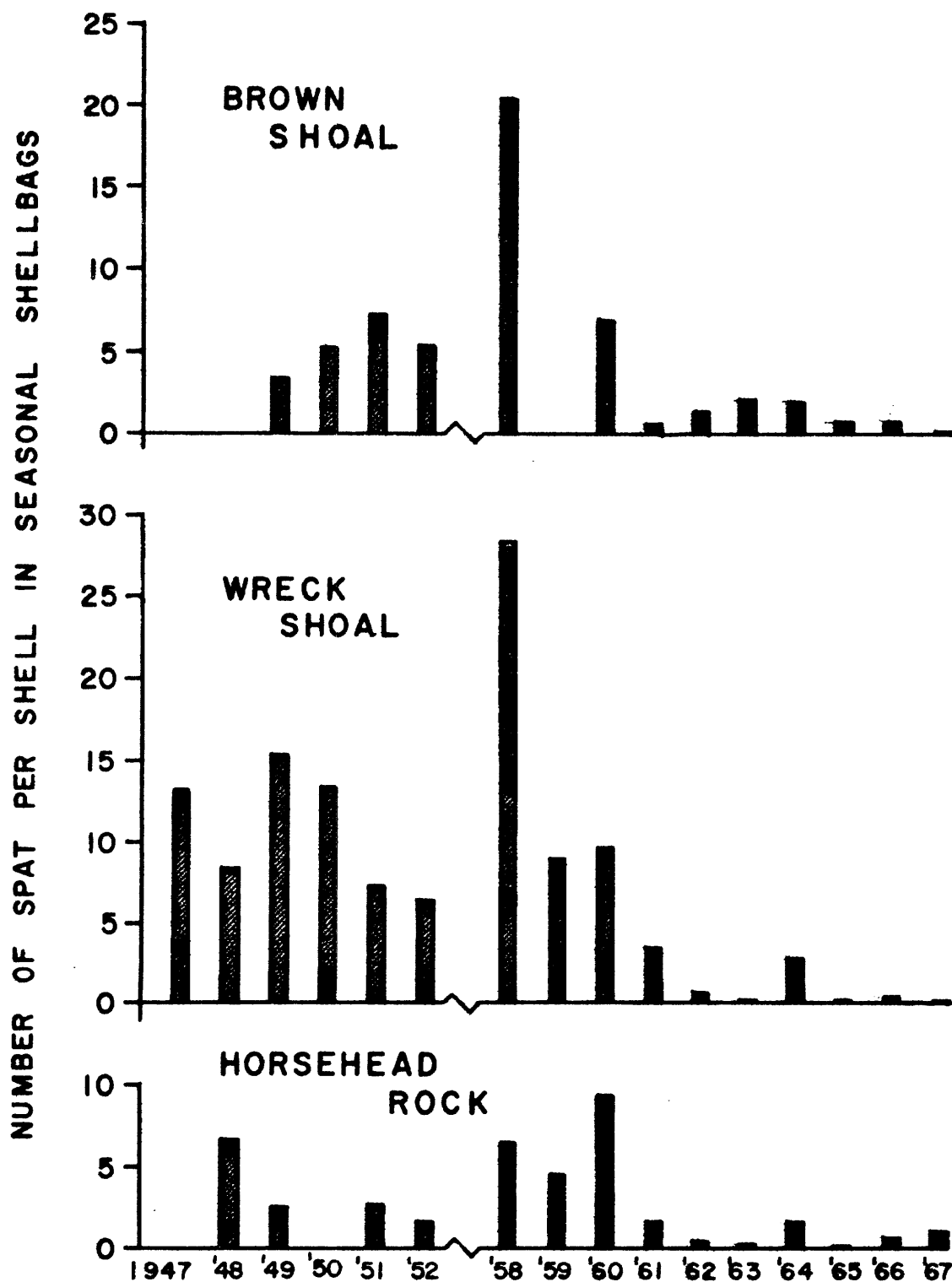


Figure 4. Spatfall in seasonal shell bags on three major oyster beds in James River in pre-MSX (1947-60) and post-MSX (1961-67) years. Brown Shoal, Wreck Shoal and Horsehead Rock are located at the lower end, middle, and upper end of the James River seed area.

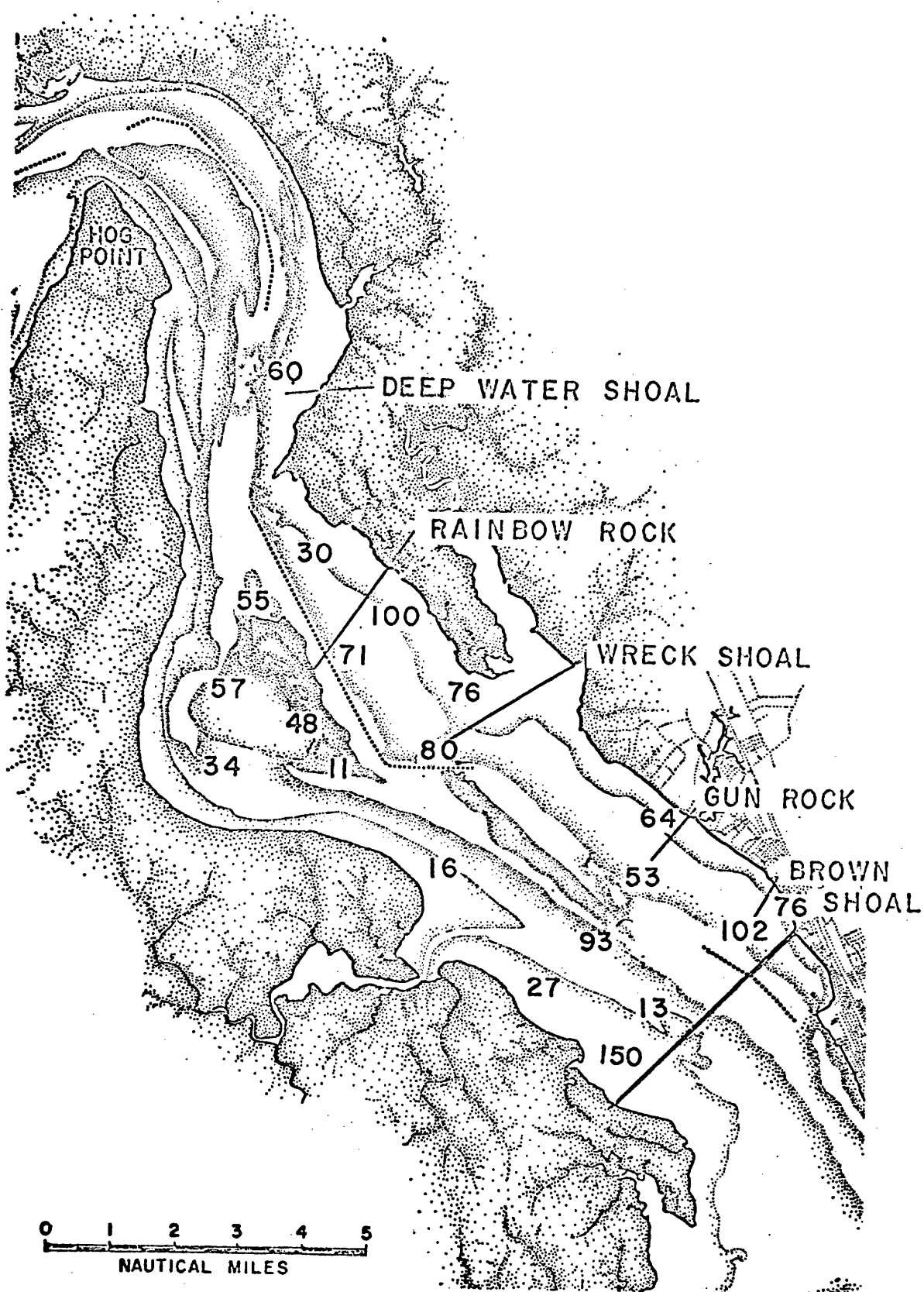


Fig. 5. Average spatfall per 100 shells in seasonal shell bags for post-MSX years. 1963-1967.



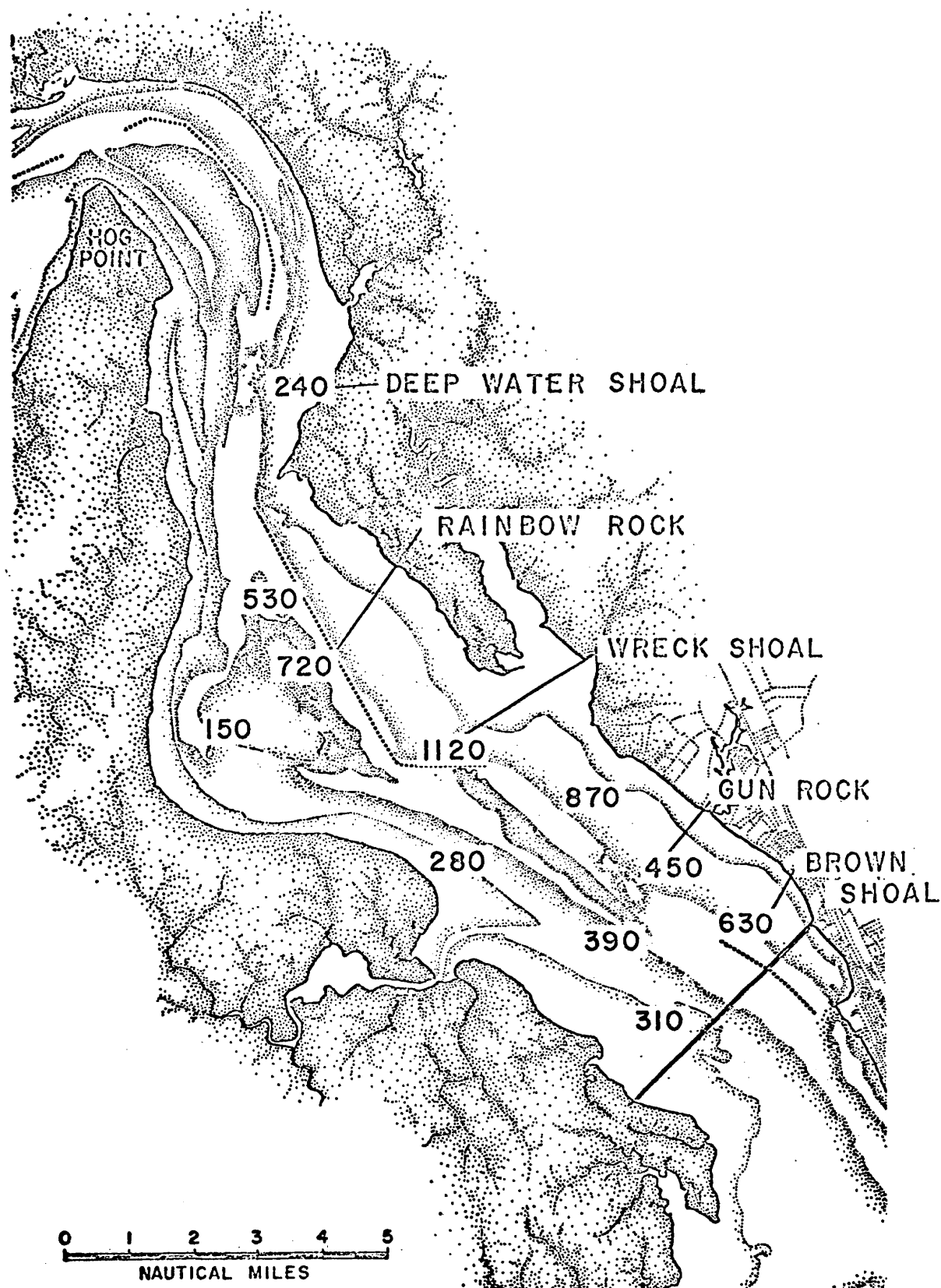


Fig. 6. Average spatfall per 100 shells in seasonal shellbags, 1947-1952 and 1958-1960. "Normal" years.

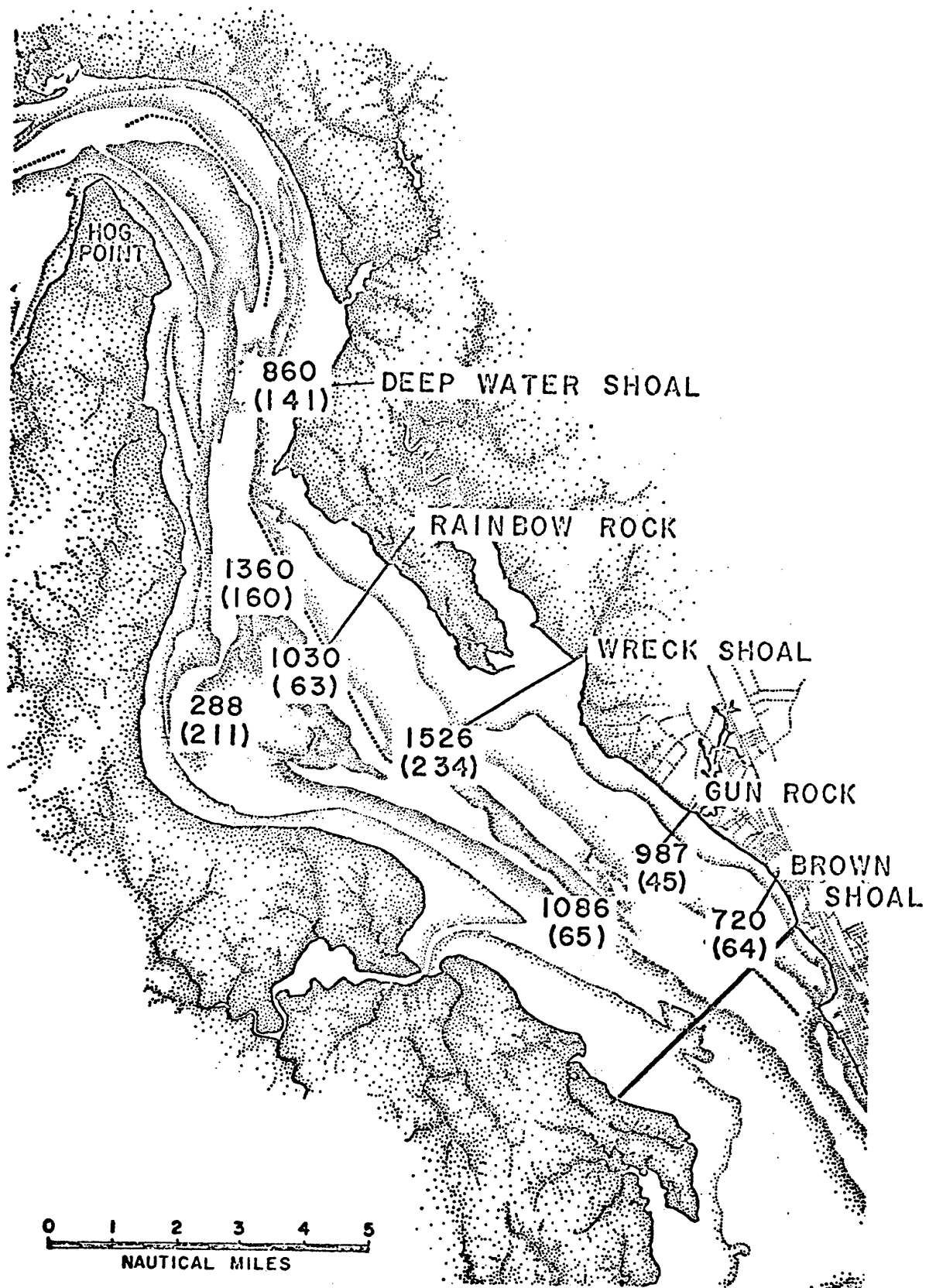


Fig. 7. Average spatfall per bushel on natural cultch for "normal" years and post-MSX years (parentheses)

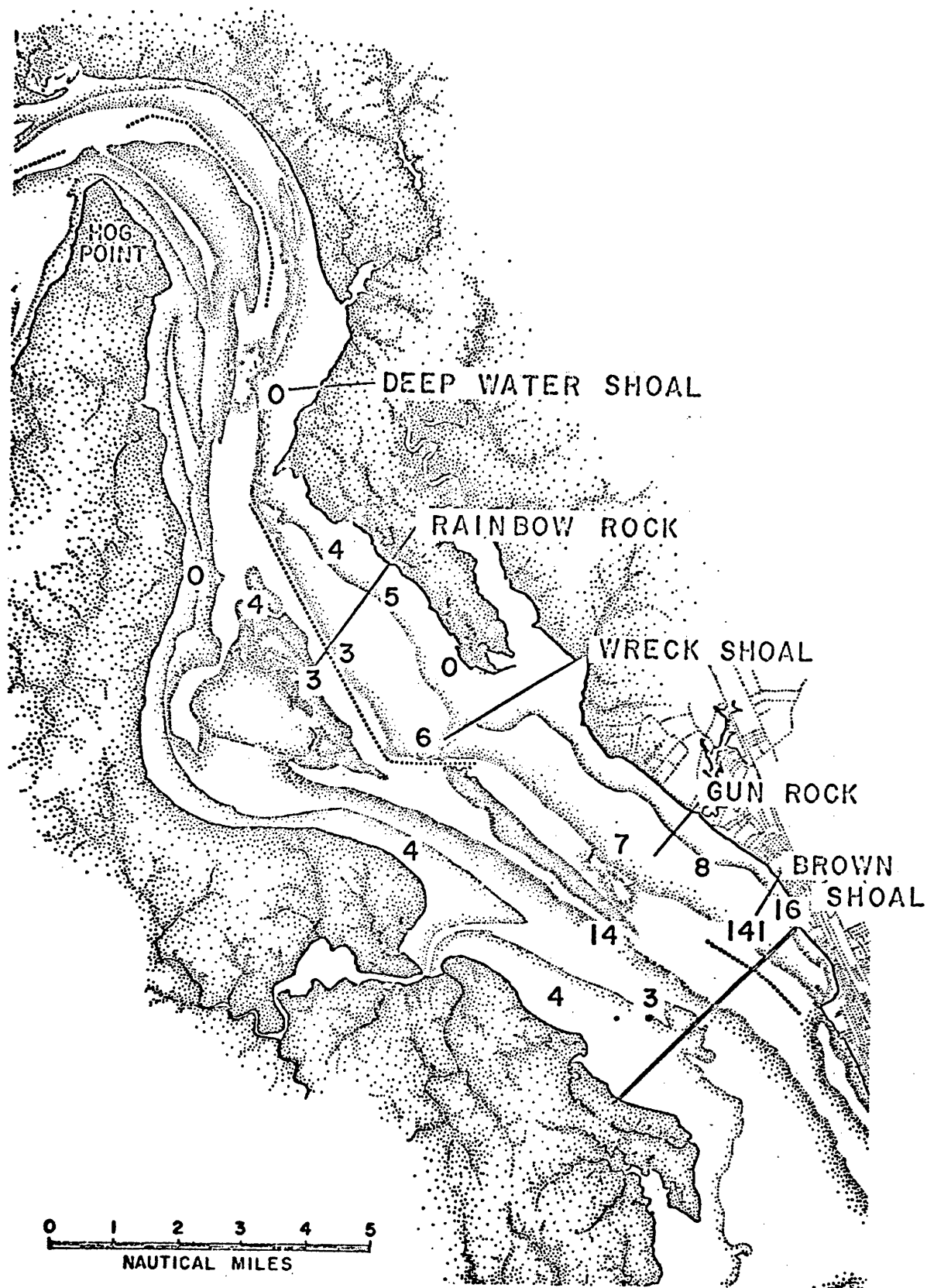


Fig. 8. Accumulative weekly spatfall per 10 shell faces for 1963.

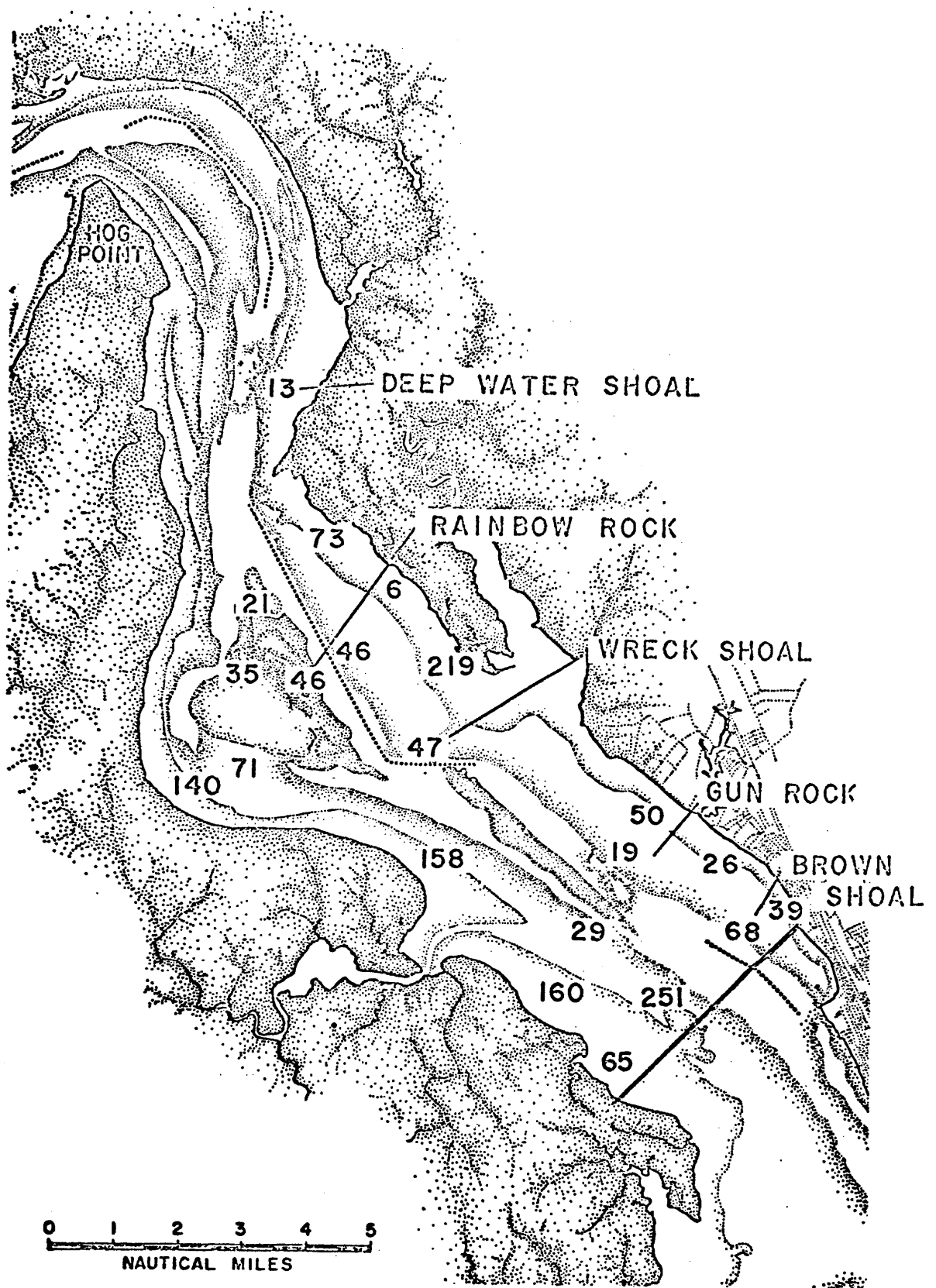


Fig. 9. Accumulative weekly spatfall per 10 shell faces for 1964.



48

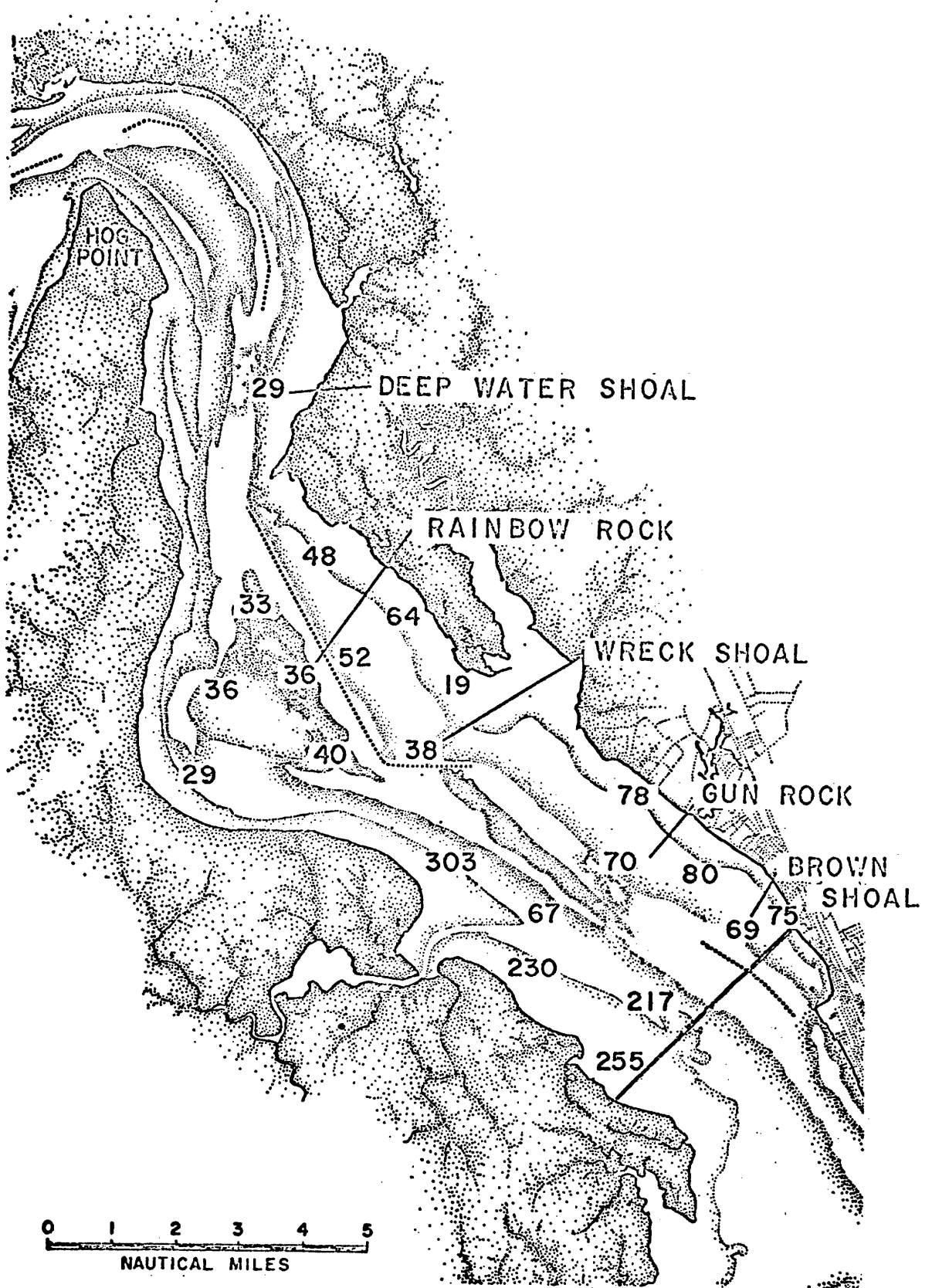


Fig. 11. Accumulative weekly spatfall per 10 shellfaces for 1966.

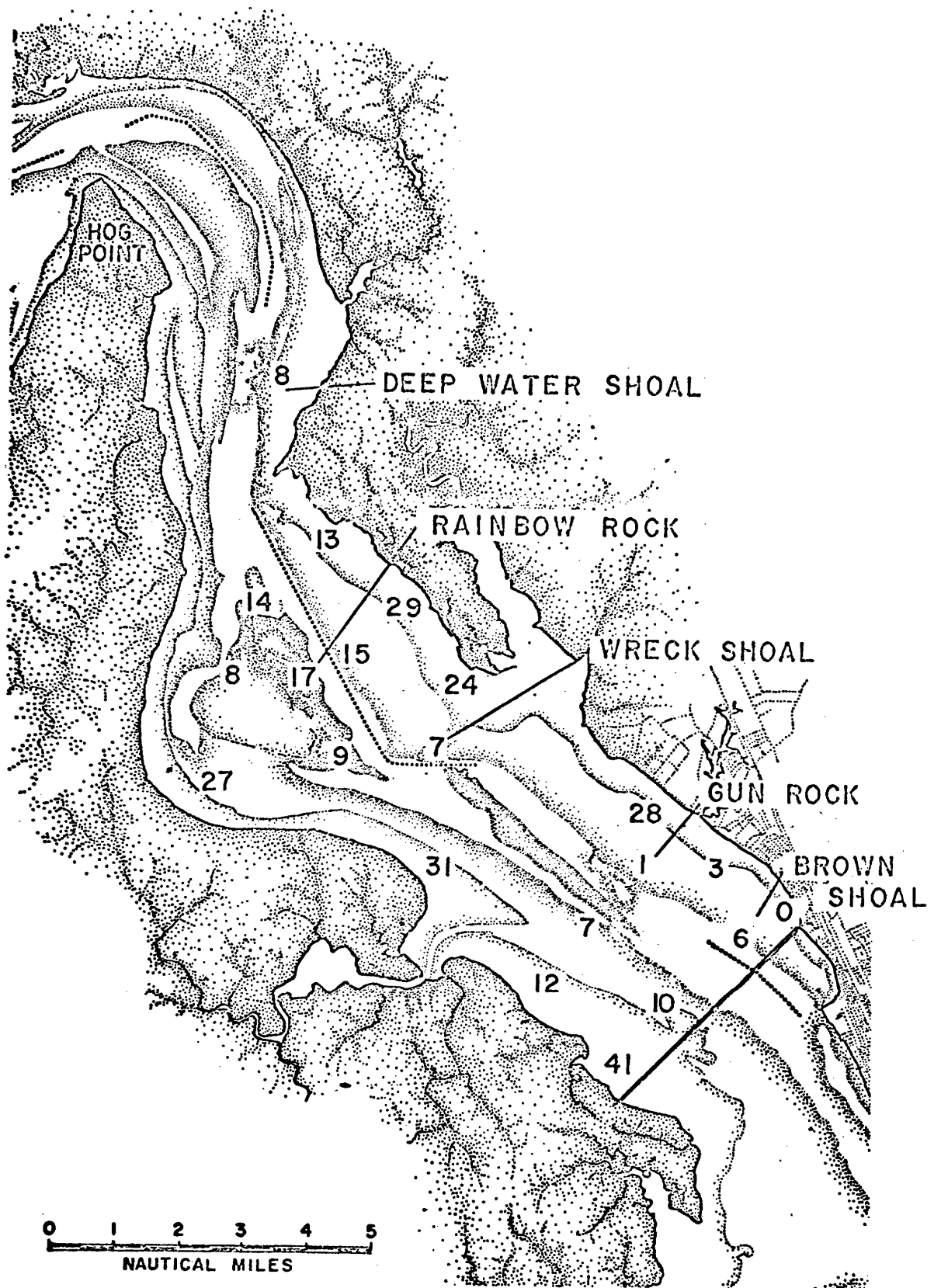


Fig. 12. Accumulative weekly spatfall per 10 shellfaces for 1967.

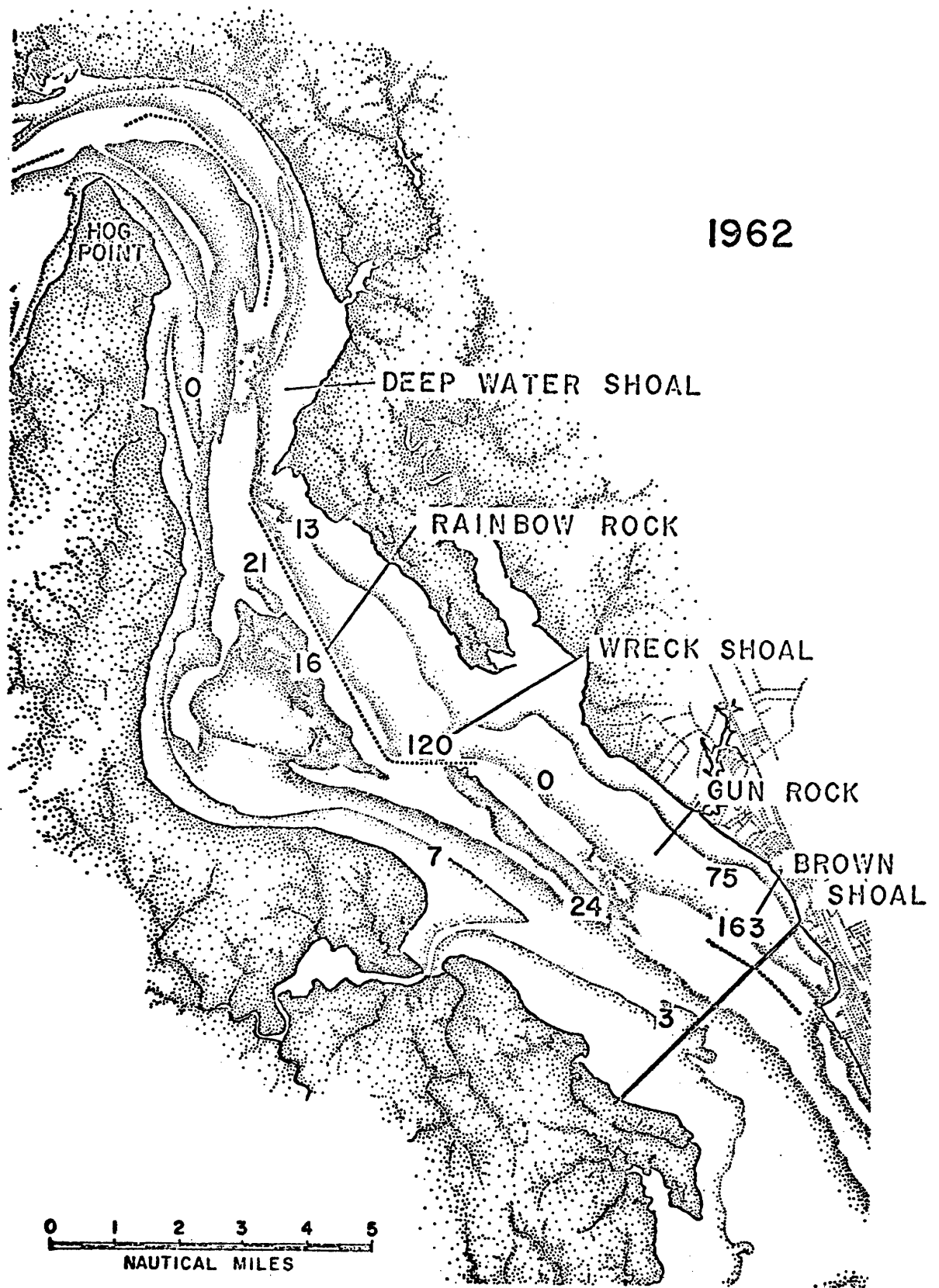


Fig. 13. Spat per 100 shells in seasonal shellbags.



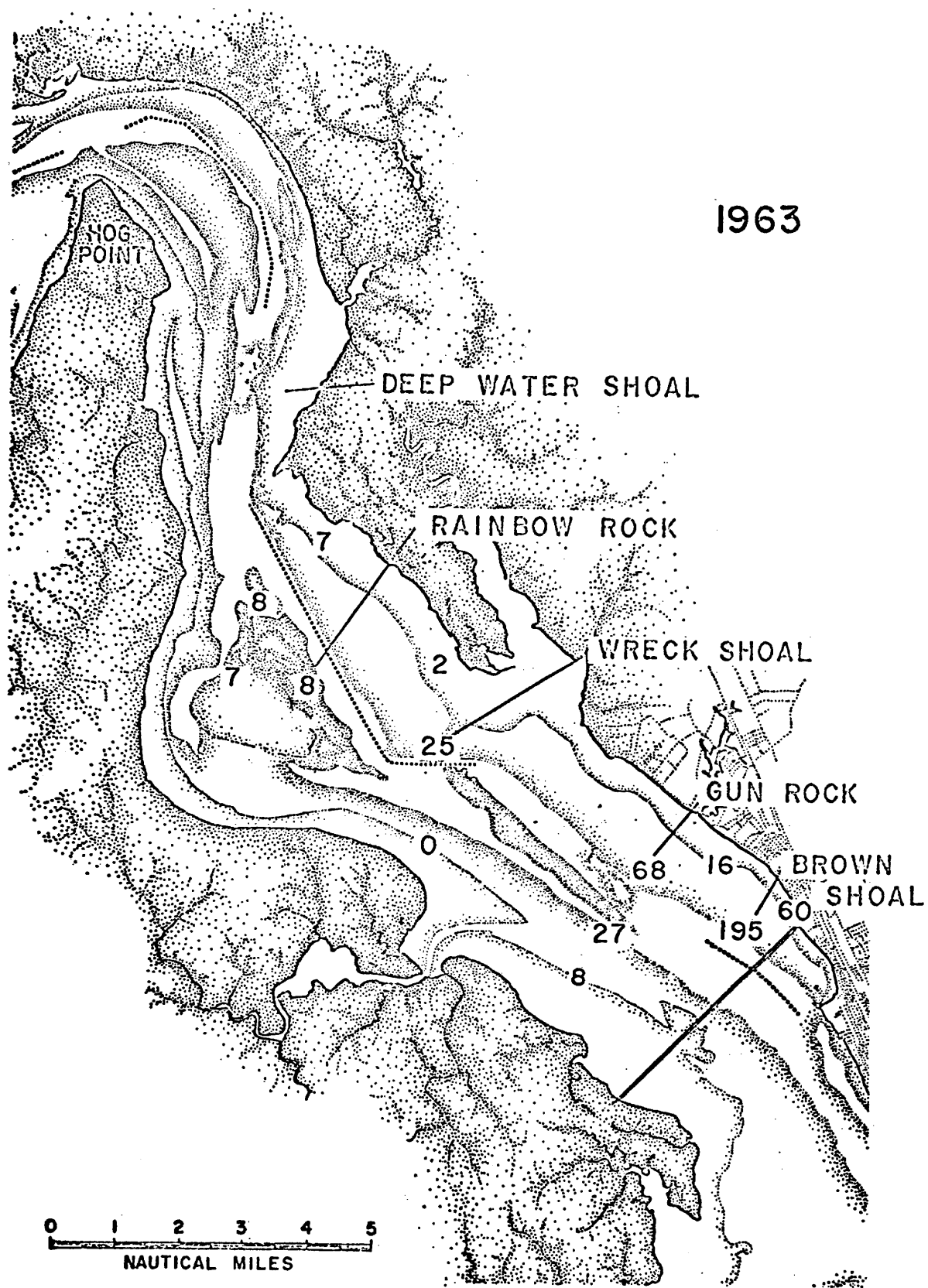


Fig. 14. Spat per 100 shells in seasonal shellbags.

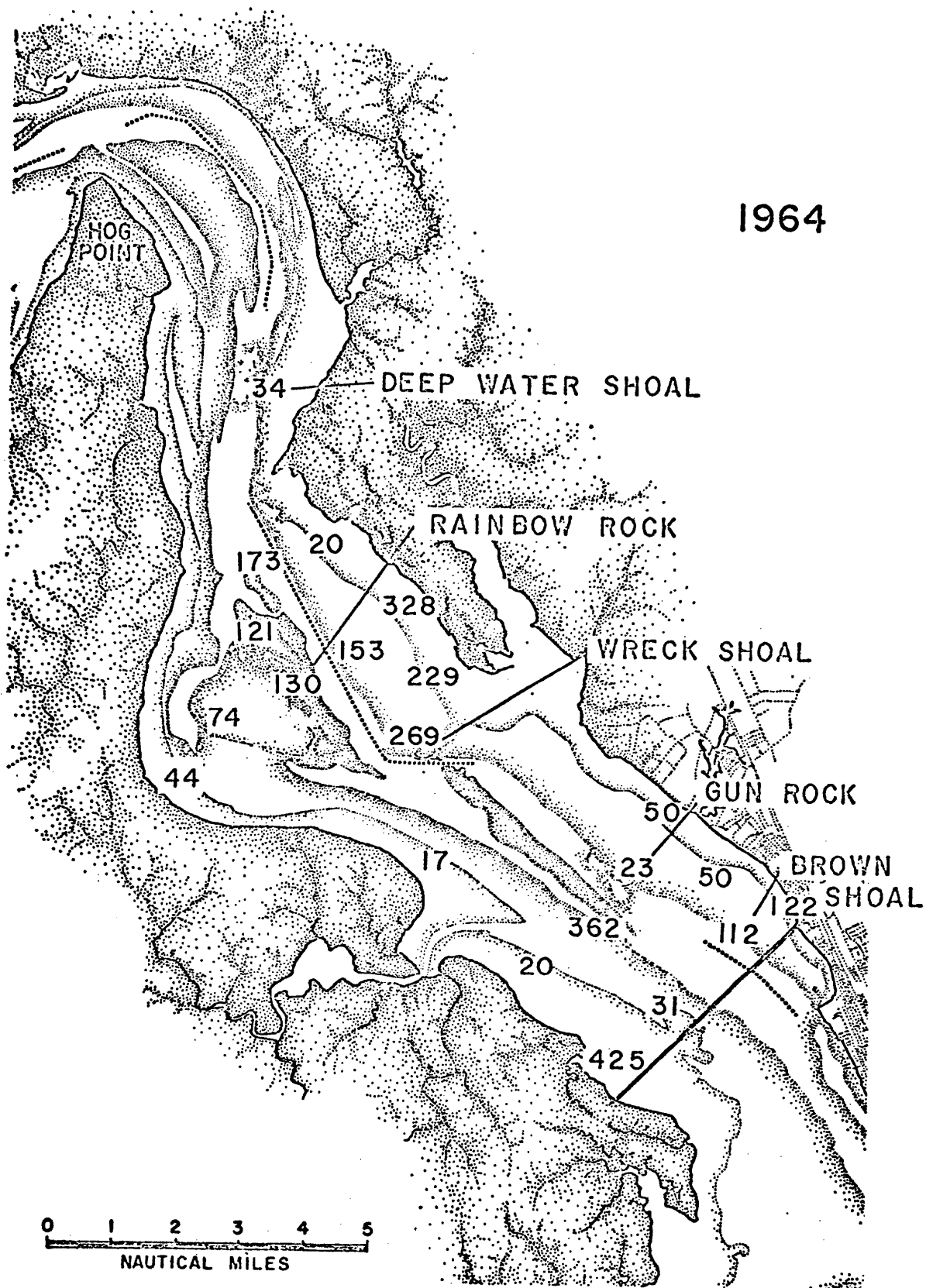


Fig. 15, Spat per 100 shells in seasonal shellbags.

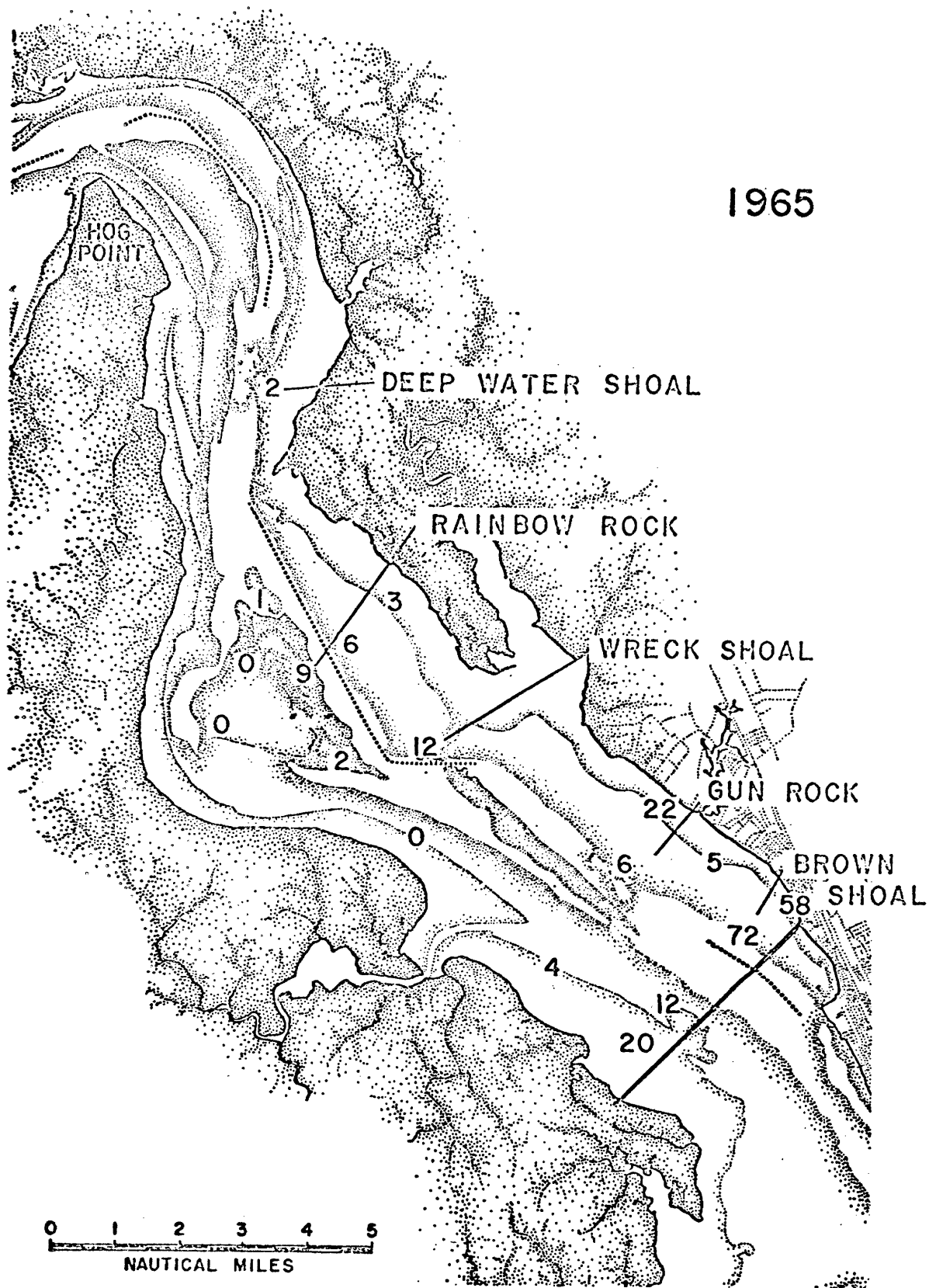


Fig. 16. Spat per 100 shells in seasonal shellbags.

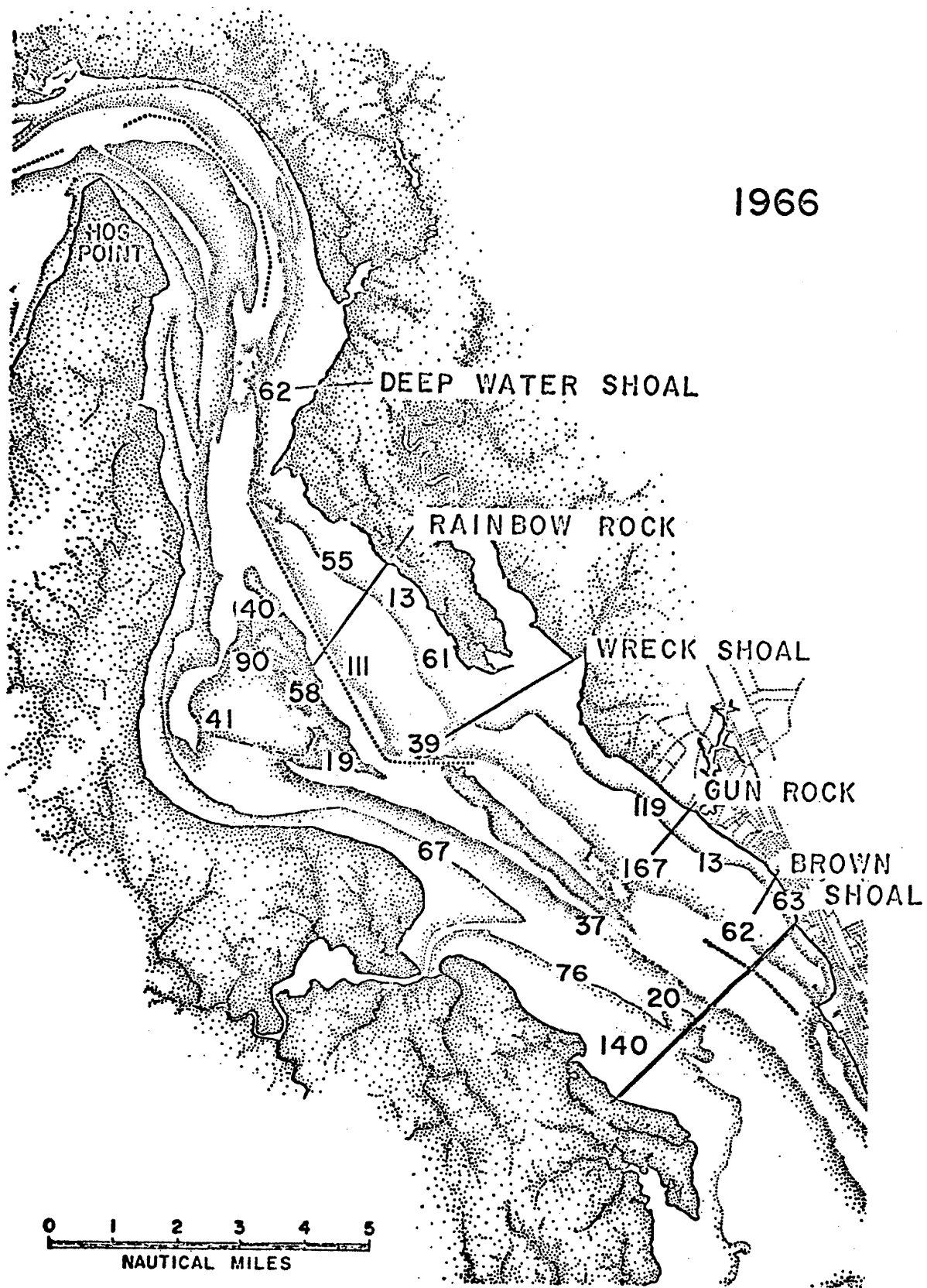


Fig. 17. Spat per 100 shells in seasonal shellbags.

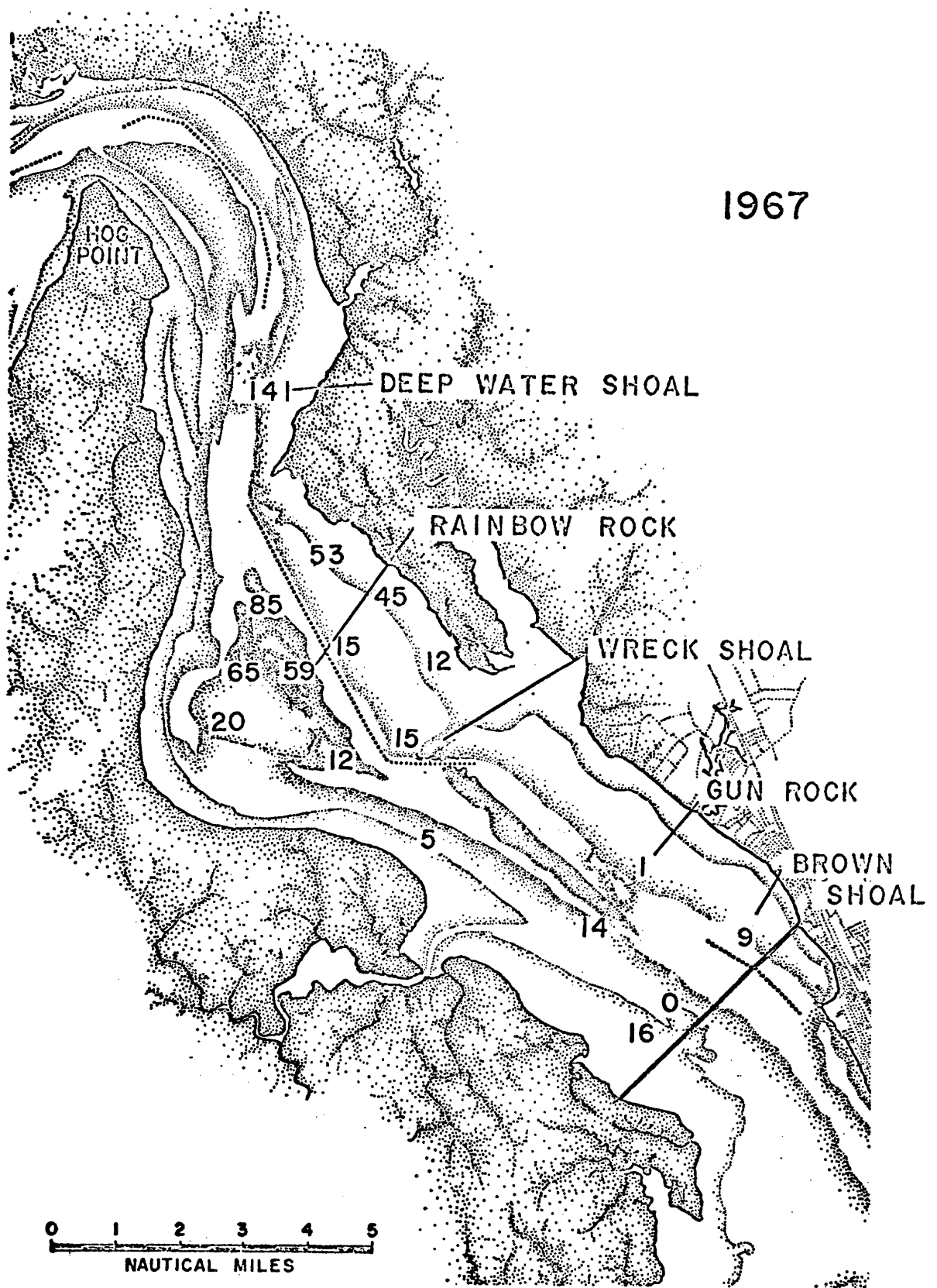


Fig. 18. Spat per 100 shells in seasonal shellbags.

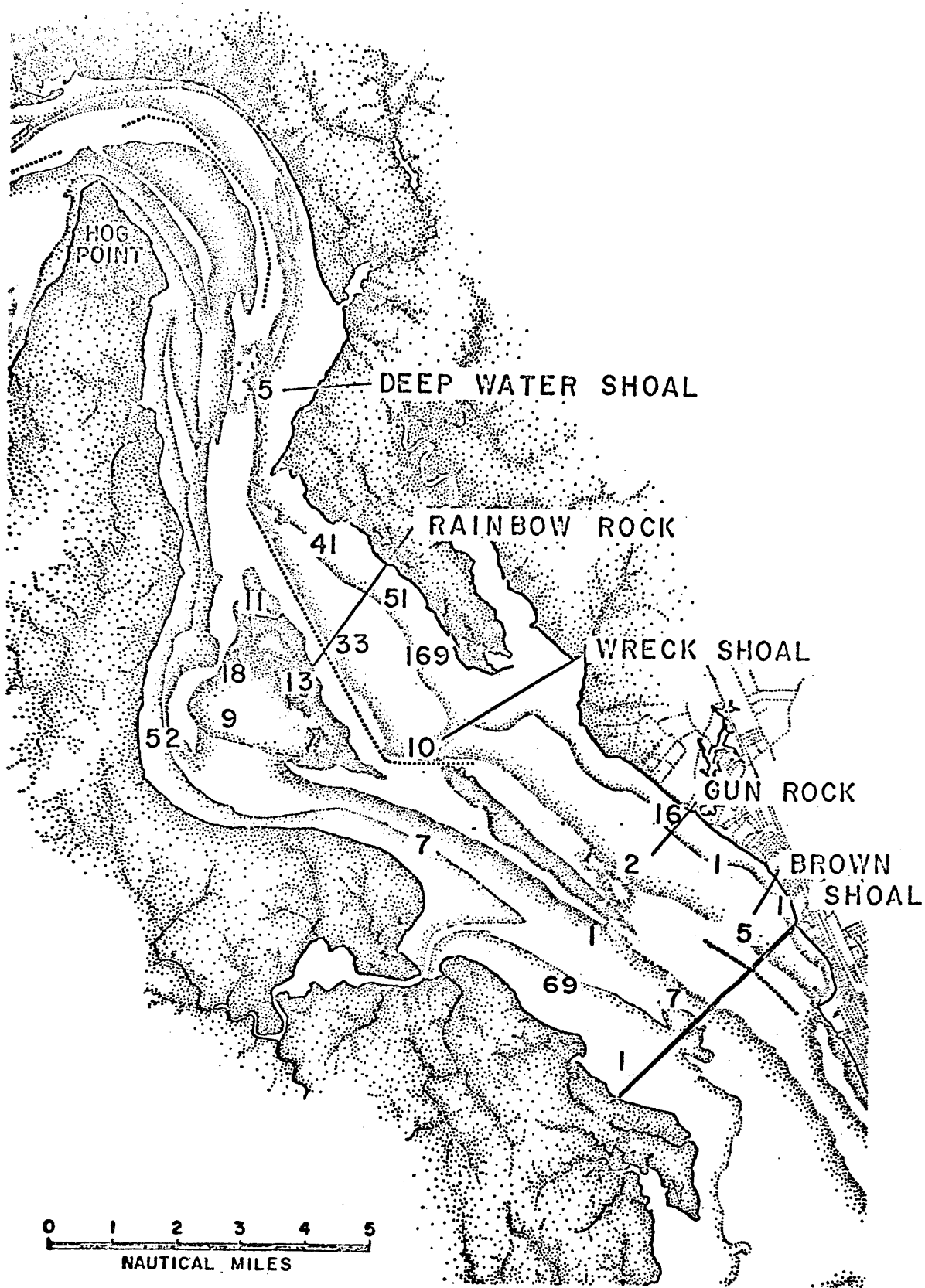


Fig. 19. Spatfall for week of 25 August to 2 September, 1964, in spat per 10 shellfaces.

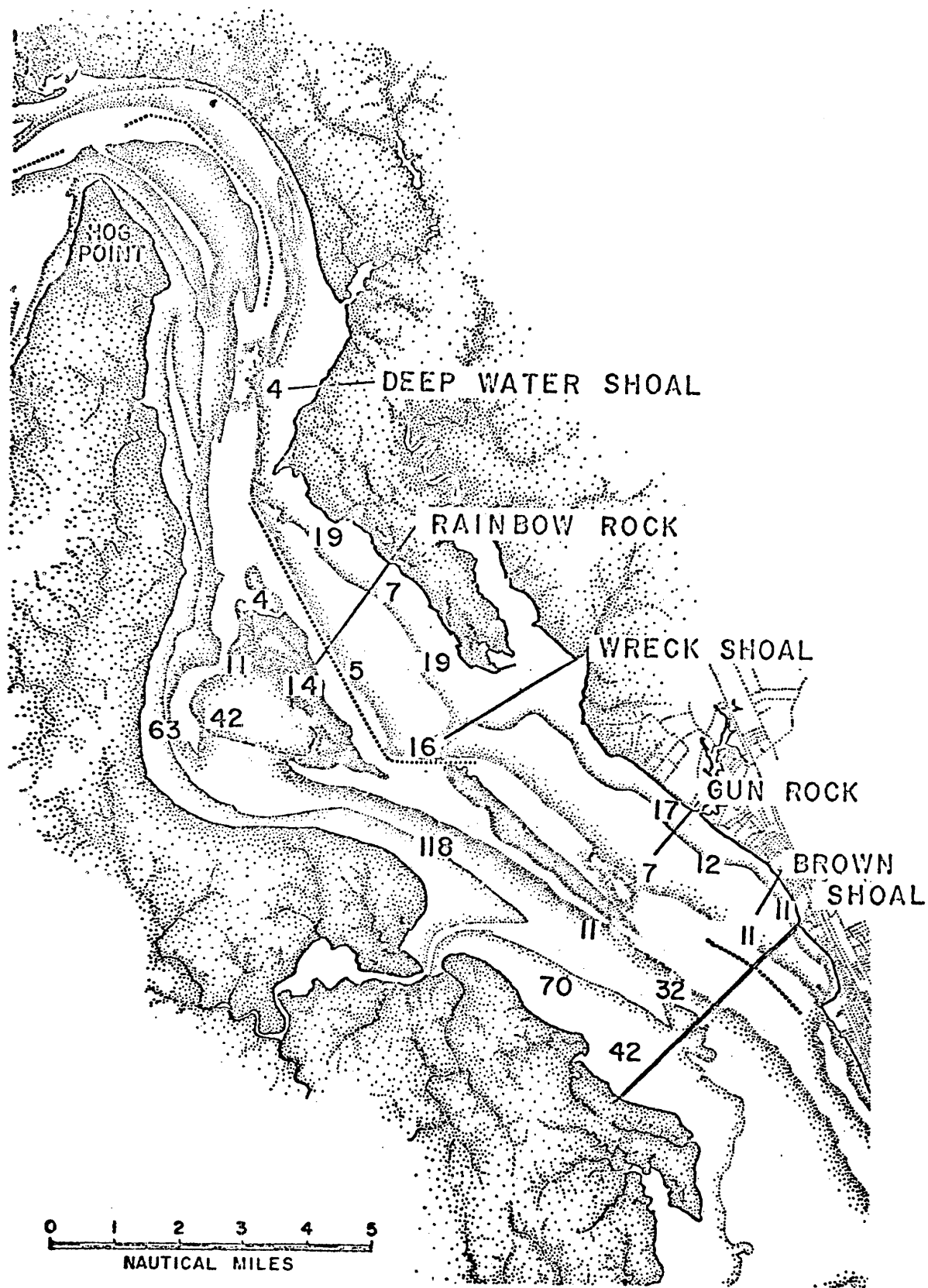


Fig. 20. Spatfall per 10 shell faces for week of 2 to 8 September, 1964.

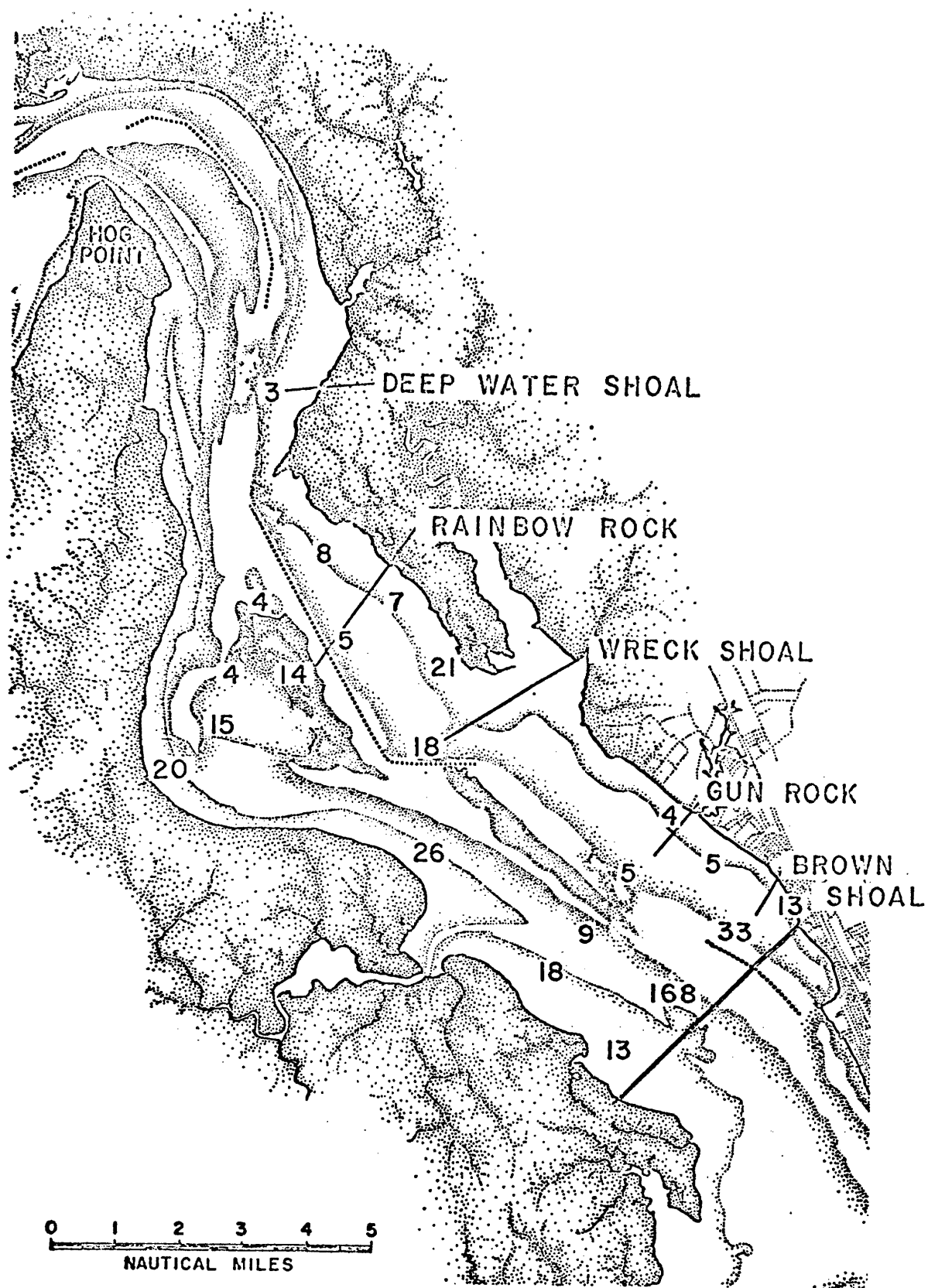


Fig. 21. Spatfall per 10 shell faces for week of 8 to 15 September, 1964.



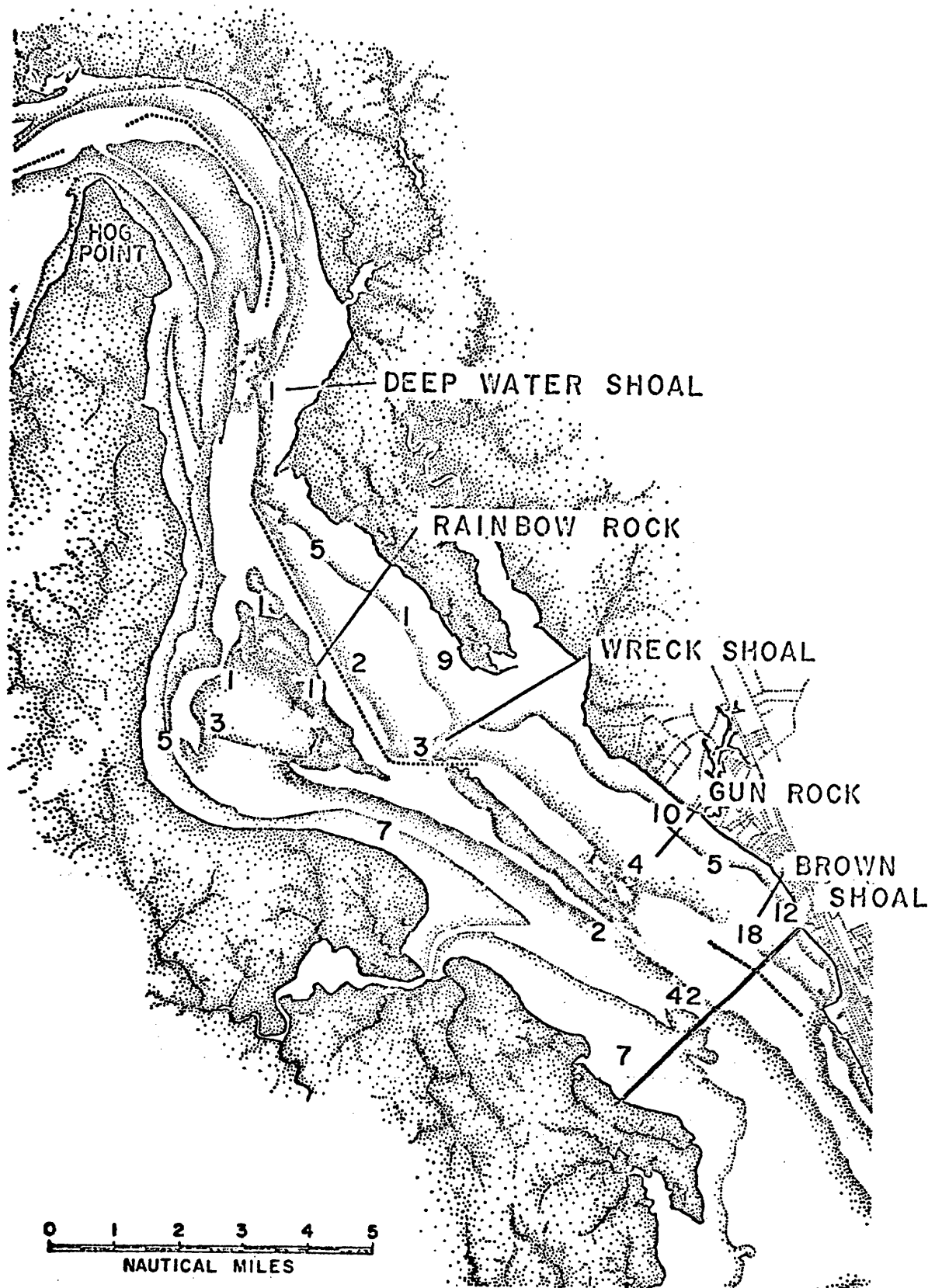


Fig. 22. Spatfall per 10 shell faces for week of 15 to 24 September, 1964.