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Title: THE MIGRATORY PATTERN OF ADULT SOCKEYE SALMON (ONCORHYNCHUS NERKA) IN BRISTOL BAY AS RELATED TO THE DISTRIBUTION OF THEIR HOME-RIVER WATERS

Abstract approved: Redacted for privacy
Carl E. Bond

The individual stocks of sockeye salmon that make up the annual spawning migration to the Bristol Bay region of Western Alaska are produced in the lakes and streams of ten major river systems, which discharge into the bay over a shoreline distance of 120 miles. The hypothesis adopted in this study was that the bay distribution of the waters from these river systems and controlling factors such as tide, wind and bottom topography determine the distribution of the individual stocks of sockeye salmon in Bristol Bay. This hypothesis was based on the premise that mature sockeye salmon return to their river system of origin to spawn and in doing so utilize recognizable characteristics of their home-river waters to guide them to its source.

Hydrographic studies were carried out in upper Bristol Bay to determine the seaward course and distribution of the waters of major

sockeye salmon-producing river systems draining into Bristol Bay. These studies included determination of the vertical and horizontal salinity distribution in the upper bay, tracking and plotting the distribution and course of individual river waters, which had been tagged with Rhodamine B dye, during flood and ebb tide and plotting the seaward course of plastic drift cards released at various strategic locations in upper Bristol Bay. From the results of these studies the course and distribution of the waters of each major sockeye salmon-producing river system was described for upper Bristol Bay.

The distribution and migration routes of the individual stocks of Bristol Bay sockeye salmon were determined from analysis of the results of exploratory fishing operations carried out by research vessels of the United States and offshore and inshore adult sockeye salmon tagging studies conducted by the United States and Japan. The results of this analysis showed that the main migration route of all stocks of Bristol Bay sockeye is in the offshore waters of the southern half of the entrance to the bay and in the bay itself. All stocks remain in the offshore waters until within 20 to 50 miles of their home-river systems. They were, however, already beginning to segregate according to river of origin in the offshore waters when still as much as 150 miles from the mouths of their home-river systems. From this point to the head of Bristol Bay there was a progressive segregation of sockeye salmon stocks according to their river of origin. From these studies the general distribution and migration route of all major stocks of Bristol Bay sockeye salmon was described and illustrated on a chart of the area.

Comparison of the distribution of the major river-system waters with that of their respective sockeye salmon stocks showed that the distribution of river water in outer Bristol Bay did not conform to the distribution of sockeye salmon whereas in the upper bay the individual sockeye stocks assumed a distribution which was very similar to that of their river-system waters. The conclusions reached were that the migration route, distribution and initial segregation of sockeye stocks in the clear offshore waters of Bristol Bay are not influenced by the distribution of river water, but once in the turbid upper bay these features must somehow be related to the distribution of home-river waters and the recognizable properties they contain.

The Migratory Pattern of Adult Sockeye Salmon (*Oncorhynchus nerka*) in Bristol Bay as Related to the Distribution of Their Home-river Waters

by

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I. INTRODUCTION

Salmon management in the Pacific Northwest has long been based on the premise that salmon homing to various river systems or principal tributaries of river systems constitute individual production units, and that each unit must be managed separately insofar as it is practical to do so. Basic to this premise is the belief that each unit or stock,[1] by virtue of its reproductive isolation and attendant adaptive processes, has its own unique requirements for spawning, incubation of eggs, rearing, and survival.

Thus, management of Pacific salmon stocks in North America has resulted in a multiplicity of regulatory districts, each of which is associated with a major river, bay, or strait. Ideally, the exploitation of salmon within each district would be limited to times and places such that individual salmon stocks would be harvested independently of others, each in accordance with its own requirements.

In pursuit of this ideal, fishery biologists have directed their efforts toward determination of the routes and times of spawning

[1] The term "stock" as used in this thesis is applied to the population of salmon of a given species inhabiting a specific river system or main tributary during the spawning and rearing stages of the life cycle. This use of the term is, for the most part, consistent with current management practices.

migration[2] of major stocks. These efforts have revealed that there are few areas and times when specific salmon stocks are completely separate from others, except when they eventually become segregated in the spawning tributaries.

Thus, the establishment of fishing areas, the determination of times when fishing may be permitted, and the assessment of the effects of exploiting simultaneously several salmon stocks having differing levels of productivity remain especially vexing problems. This is particularly true for the important sockeye salmon area of Bristol Bay in Western Alaska. Here the catch is made in five regulatory districts, three of which are associated with single-river systems, the Togiak, Egegik, and Ugashik rivers (Figure 1). Four major rivers discharge into Nushagak Bay (Nushagak District) and three discharge into Kvichak Bay (Naknek-Kvichak District).

Over the years, the boundaries of each fishing district have undergone a number of changes, which generally reduced the size of the areas where fishing was permitted and confined the fishing fleets close to the river mouths. The earliest changes were made on the largely intuitive assumption that the fish nearest to a river mouth were fish produced in that river system.

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[2]With the exception of the troll fisheries for king salmon (<u>Oncorhynchus tshawytscha</u>) and silver salmon (<u>O. Kisutch</u>), the inshore salmon fisheries are prosecuted on adult salmon returning to fresh water to spawn.

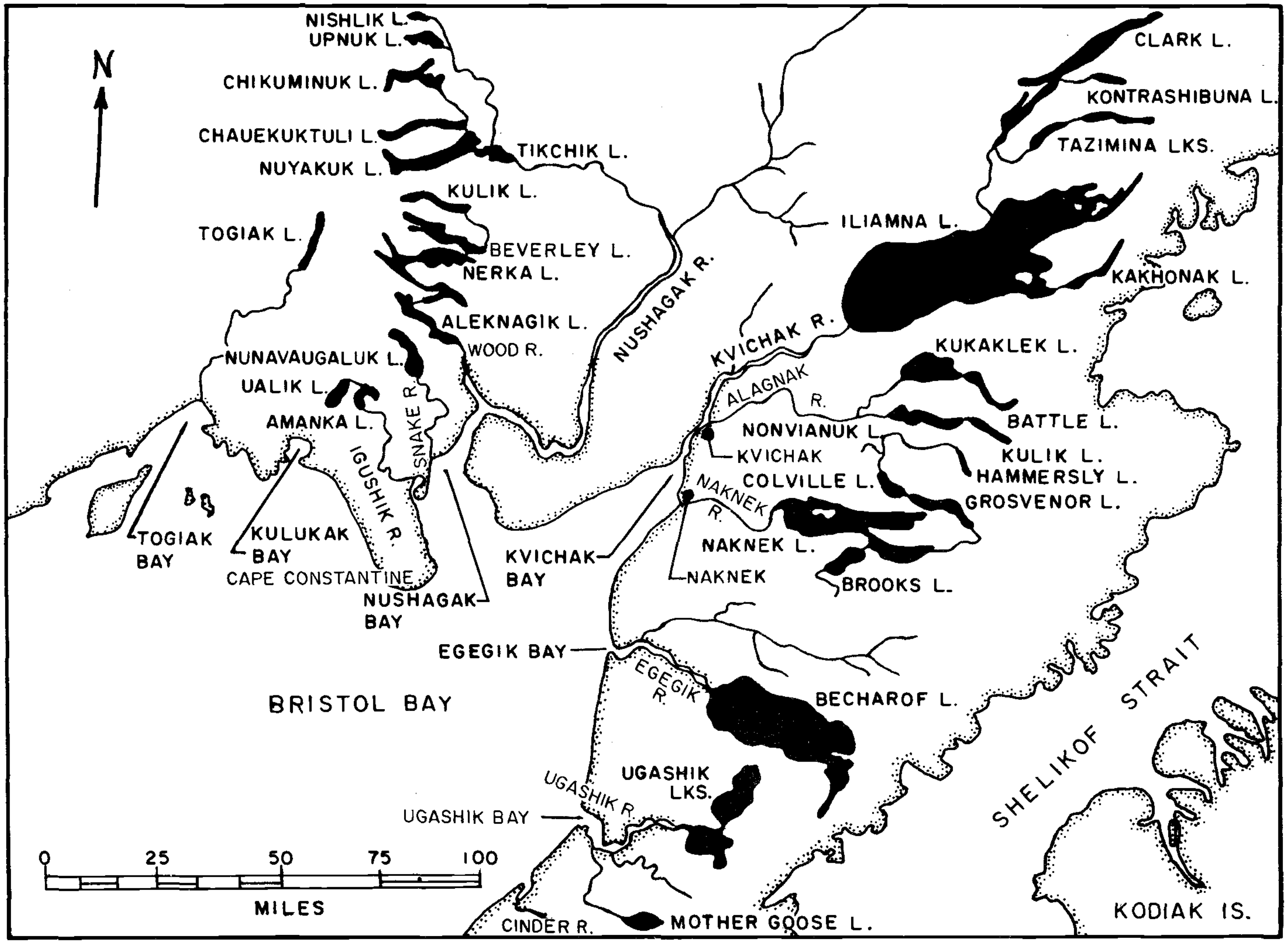

Figure 1. Bristol Bay, showing the principal sockeye salmon-producing river systems.

In later years several mark-and-recovery experiments were carried out in the upper region of Bristol Bay by various agencies (Bureau of Commercial Fisheries, Fisheries Research Institute of the University of Washington, and Alaska Department of Fish and Game) to define areas of concentrations of major stocks. The most extensive of these were conducted from 1955 through 1959 under my direction.

In 1965, 1966, and 1967 I supervised a series of studies to determine the physical characteristics of the upper end of Bristol Bay and the distribution of water masses associated with the more important sockeye salmon-producing rivers. Information from these studies is presented here to show (1) current pattern and direction of seaward transport of the water masses associated with each major river system discharging into Bristol Bay; (2) migration routes of the major sockeye salmon stocks; and (3) the relation between the distribution of individual sockeye salmon stocks and that of their respective home-river waters. Various hypotheses concerning the mechanism of homing of salmon are discussed.

II. THE BRISTOL BAY SOCKEYE SALMON FISHERY

Sockeye salmon runs to Bristol Bay are among the largest on the North American Continent. More than 50 million adult salmon have returned to spawn in the river and lake systems of this area in a single year.

The commercial sockeye salmon fishery in Bristol Bay began in 1888, but a rapid expansion of the fishery did not take place until after 1900. By 1912 the annual catches had risen to 20 million fish. The fishery, however, did not reach a peak until the 1936-38 period, when the annual catches exceeded 22 million fish. Since then a progressive decline has taken place. In the 12 years from 1956 to 1967, the annual catch of sockeye salmon averaged approximately 8.2 million.

In spite of the apparent depressed state of the stocks in this area, the sockeye salmon fishery remains an important element in the economy of the State of Alaska. In peak years it is worth up to $20 million to the fishermen and $50 million to the salmon packing industry.

The individual stocks of sockeye salmon that make up the annual run to Bristol Bay are produced in the lakes and streams of ten major river systems, which discharge into the bay over a shoreline distance of 120 miles (Figure 1).

The spawning migration of sockeye salmon to Bristol Bay starts in early May. Salmon move directly toward the Aleutian Islands passes from their feeding grounds in the North Pacific and then eastward in the Bering Sea to Bristol Bay at a rate of about 30 miles per day (Hartt, 1962). The run is of relatively short duration in Bristol Bay systems as compared with other sockeye salmon-producing river systems, such as the Karluk River on Kodiak Island, Alaska, and the Fraser River in British Columbia, which have spawning migrations extending over a period of 4 months. The run passes through the upper bay fishing areas during a 4- to 6-week period. Small numbers of fish are on the fishing grounds by mid-June, and the run usually reaches peak proportions between July 1 and 10. By late July most of the fish have entered their respective river systems and few are left on the fishing grounds.

The upper bay region is divided into a number of fishing districts. These districts have the effect of confining the catch of salmon close to the mouth of the producing river system, thereby permitting more effective control in allotting desired escapements to individual river systems.

Commercial fishing is done almost entirely with gill nets. The nets, which drift with the tide, are set from one- or two-man boats or are staked or anchored along the beaches. The fishery is so intense and efficient that it takes almost all of the fish in a given district during an open fishing period. Because of this, the fishery in each district is closed periodically so that spawners from all segments of the run can escape to the stream.

The day-to-day progress and size of the run through each fishing district is carefully monitored by the Alaska Department of Fish and Game, which exercises control over Alaska fisheries. Test-fishing gear is operated during the closed periods and in closed fishing areas both upstream and seaward of the fishery to obtain immediate indices of the numbers of fish entering and escaping the fishery. Finally, sample counts are made from observation towers located on each bank of all the major rivers entering the bay to obtain an accurate estimate of spawning escapements.

III. OCEANOGRAPHIC FEATURES OF BRISTOL BAY

Climate and Physiography

For the purpose of this thesis, Bristol Bay is considered to include that part of the Bering Sea east of a line drawn from Cape Sarichef on Unimak Island to the Kuskokwim River (Figure 2). Unimak Island and the Alaska Peninsula bound it on the south and east and separate it from the North Pacific Ocean. Bristol Bay is the southeast terminus of the shallow continental shelf of the Bering Sea.

Precipitation over the area occurs mostly in July through September, with August being the rainiest month (U.S. Coast and Geodetic Survey, 1964). The mean annual rainfall is 30 to 40 inches and the mean air temperature is approximately 35° F. Fog occurs in every month of the year at most localities. Depending on the severity of winter temperatures, ice begins to form along the shores of the bay in October or November and expands seaward throughout the winter until March. Although the ice pack usually begins to break up and melt in the spring (April), compact fields of drift ice may occur offshore as late as late May.

The plain bordering Bristol Bay and extending inland from 10 to 50 miles is of low relief along the coast (elevation 50-250 feet) and inland rises to an elevation of 300-500 feet (Wahrhaftig, 1965). It

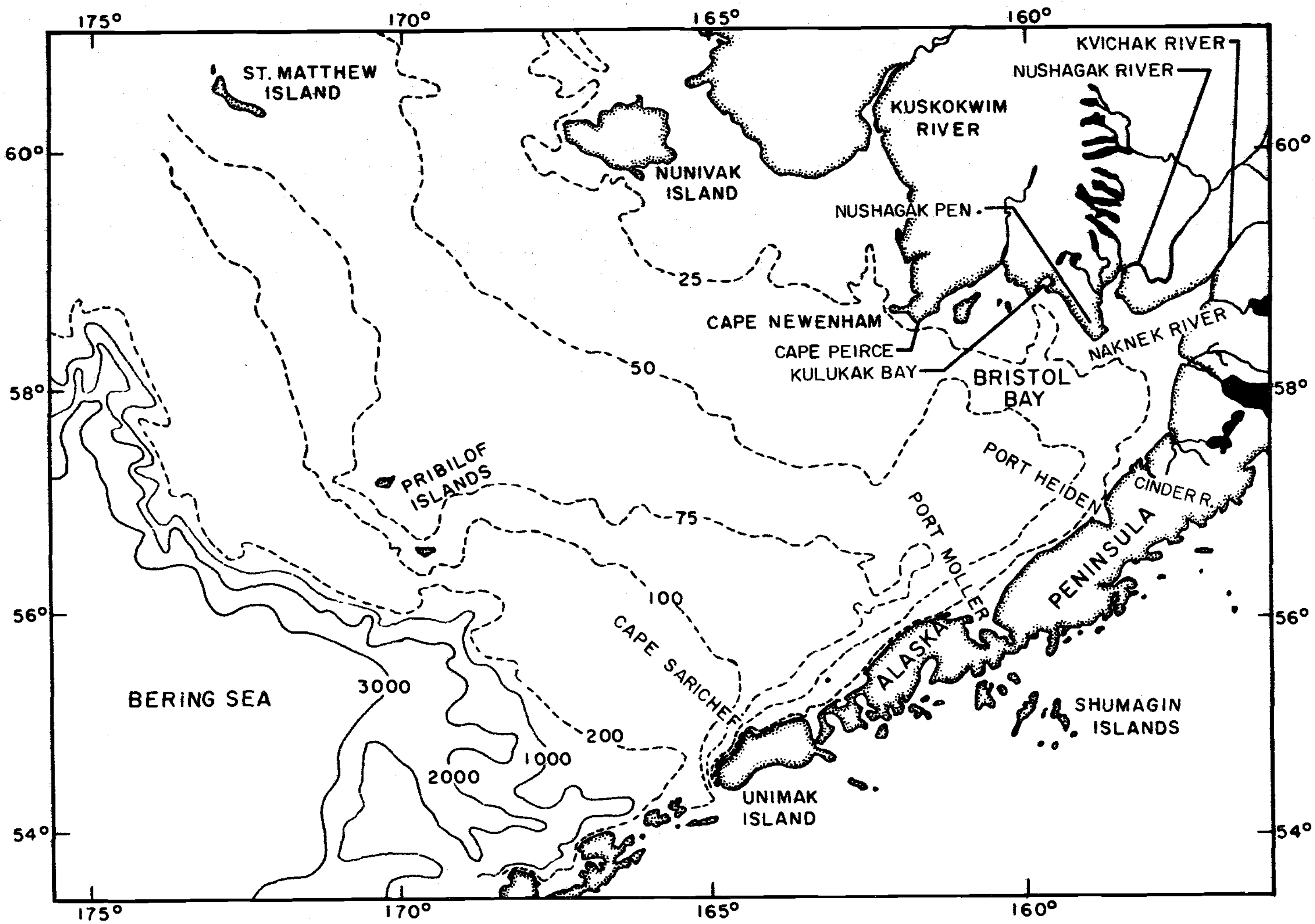

Figure 2. Area chart of Bristol Bay and the eastern Bering Sea. (Contours of bottom topography in meters. Redrawn from: Dodimead, Favorite, and Hirano (1963).)

comprises largely glacial outwash and morainal deposits and lies in a region of sporadic permafrost, which in places is several hundred feet deep. Its surface has numerous thaw and morainal lakes, most of which do not have any surface drainage.

Numerous rivers cut through the coastal lowlands. The largest of these are the Togiak, Wood, Nushagak, Kvichak, Naknek, Egegik, and Ugashik rivers. The watersheds draining into Bristol Bay cover an area of 38,000 square miles. The rivers discharging directly into Bristol Bay are from 10 to 50 miles long and rise in large lakes whose basins were scoured out by ice during the glacial period. Inland, the drainage pattern consists of numerous tributaries extending into the foothills and mountain ranges that surround the Bristol Bay lowlands. Receding glaciers still persist in many of the high headwater valleys and cirques of the Alaska and Aleutian mountain ranges.

Discharge Pattern of Rivers

The annual river discharge pattern is determined by snow melt, glacier melt, rainfall, and the storage capacity of natural lakes. Tributary streams which drain the foothills receive runoff largely from snow melt and rainfall (U.S. Department of the Army, 1957) and have maximum flows in late May and June. Tributaries which head in mountain ranges receive runoff from glacier melt as well and generally have maximum flows in June and early July.

The many large lakes which intercept the tributaries have a combined surface area of nearly 3,000 square miles, and the deepest lake basins are 1,000 feet deep or more. Collectively these natural lakes have an enormous storage capacity that serves to regulate runoff into trunk rivers that discharge directly into Bristol Bay. Flows in the trunk rivers peak in late July and August some weeks to several months later than in the headwater tributaries.

During freezeup the trunk rivers derive runoff largely from lake storage and ground water. From late August to early September until May of the following spring, water levels in the trunk rivers gradually recede as the natural storage is used up.

Thus the freshwater discharge into Bristol Bay is not subject to wide or sudden fluctuations. The annual pattern of discharge is one of minimum flows in April or May followed by gradually increasing flows until August, and then a gradual recession until the following spring.

Sediment Load of Rivers

Nearly all tributaries carry a heavy load of silt, sand, and gravel in the spring of the year during high water. After the thaw, however, they run clear except those that head in glaciers or flow through unconsolidated volcanic deposits. These generally carry a heavy load of glacial flour and pumice throughout the summer months.

Virtually all tributaries discharge into lakes which act as settling basins and allow very little of the sediment derived from erosion of upland areas to reach the sea.

Trunk rivers generally run exceptionally clear from the lake outlets to the upper limits of tidal action. Tidal influence extends up the rivers for 18 to 40 miles; within this zone the river banks are deeply undercut in places and undergo rapid erosion. Hence the lower reaches of the rivers are heavily charged with sediment derived from the outwash plain. This material is deposited with the inner bays and estuaries on bars and shoals which form vast expanses of exposed flats at low tide.

Erosion of low cliffs, which are common along the shoreline of Bristol Bay, by waves during severe storms and by the thawing of exposed permafrost also adds large amounts of sediment to the bay.

Current Patterns

The movement of water in Bristol Bay is affected by ice, run-off, winds, tidal currents, and the movement of oceanic water off the continental shelf. Over much of Bristol Bay the winds are from the northeast from October to March, and from the southeast during the spring, summer, and early fall. The average wind velocity is 15 knots at Port Heiden, in outer Bristol Bay, and about 10 knots at Naknek, at the head of the bay. The funnel-shaped configurations of the bay and of the river entrances create very strong tidal currents with velocities to 6 knots at times. The tides and currents in the bay are of the mixed type in which two highs and two lows occur during a tidal day, generally with a significant diurnal inequality. The diurnal range of tide averages about 18 feet at the river entrances.

Little information on oceanographic conditions at the time of the adult sockeye salmon migration is available for the upper region of Bristol Bay where this study was conducted and where most of the commercial fishing takes place. Previous oceanographic investigations were conducted primarily seaward of a line between Cape Constantine and Egegik Bay (Figure 1). Dodimead, Favorite, and Hirano (1963) present a review of this work and of the conditions in this area from May through August, the period of the annual sockeye migration. Characteristic features of this area which bear directly on this study, particularly with reference to currents and river water distribution, are taken from their review and discussed here.

The distribution of salinity (‰) and sigma-t[3] shows that the

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[3]The symbol ‰ refers to salinity expressed as parts per thousand by weight of dissolved materials. The density of sea water is commonly expressed as the quantity sigma-t. This is the density of the water sample when the total pressure on it has been reduced to atmospheric (i. e., the water pressure equals zero), but the salinity and temperature are as _in situ_.

movement of water in Bristol Bay is counterclockwise (Figure 3). On the basis of current meter readings, Hebard (1959) deduced a net or average flow of less than 0.1 knot for this current, or about 2 miles per day. Surface current measurements, obtained from drift-stick observations, provide a comprehensive picture of the tidal currents in the bay (Figure 4). The water in the bay oscillates in a northeast-southwest direction; velocities exceed 2 knots along the shore but decrease in the central part of the entrance of the bay.

The horizontal temperature distribution in the bay indicates a sharp separation between the inshore and offshore areas. Surface temperatures during May and June (Figure 5), show a marked temperature front along a line from Port Heiden to Cape Peirce. Seaward of this front a counterclockwise flow is indicated. Shoreward of the front the isotherms show the presence of another more pronounced counterclockwise gyre. Surface salinities obtained during the same period also show this feature (Figure 6). The absence of this inshore gyre is indicated in both the bottom salinity and temperature distribution and indicates that it is confined to the surface. Apparently the warm dilute river runoff from the land is contained eastward of Cape Peirce and forced to recirculate shoreward of this front. By August this feature disappears, and the peripheral counterclockwise flow is evident again (Figures 7 and 8). Dodimead, Favorite, and Hirano (1963) obtained vertical distributions of salinity

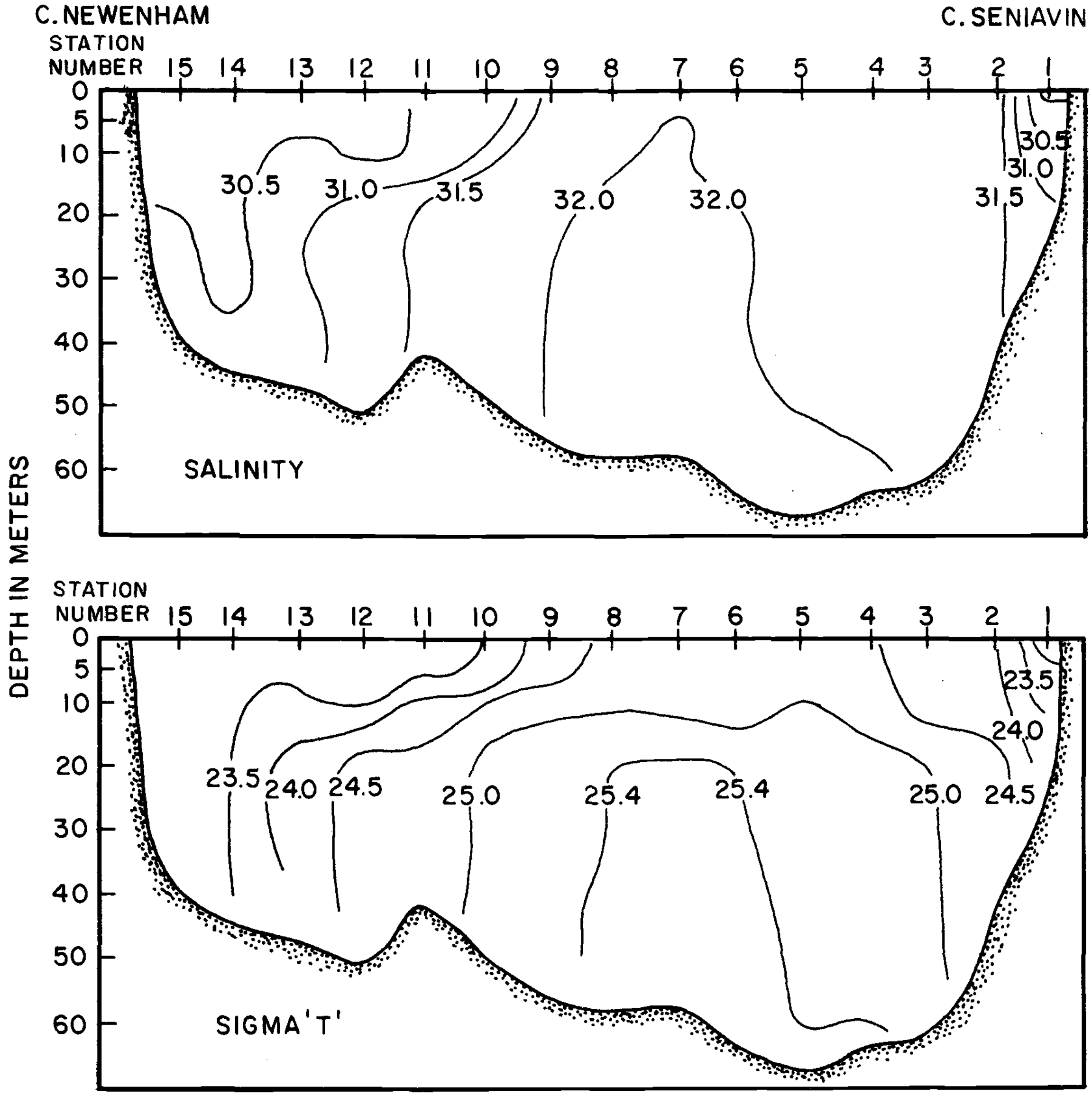

Figure 3. Vertical profiles of salinity and sigma-t between Cape Seniavin and Cape Newenham, August 1938.

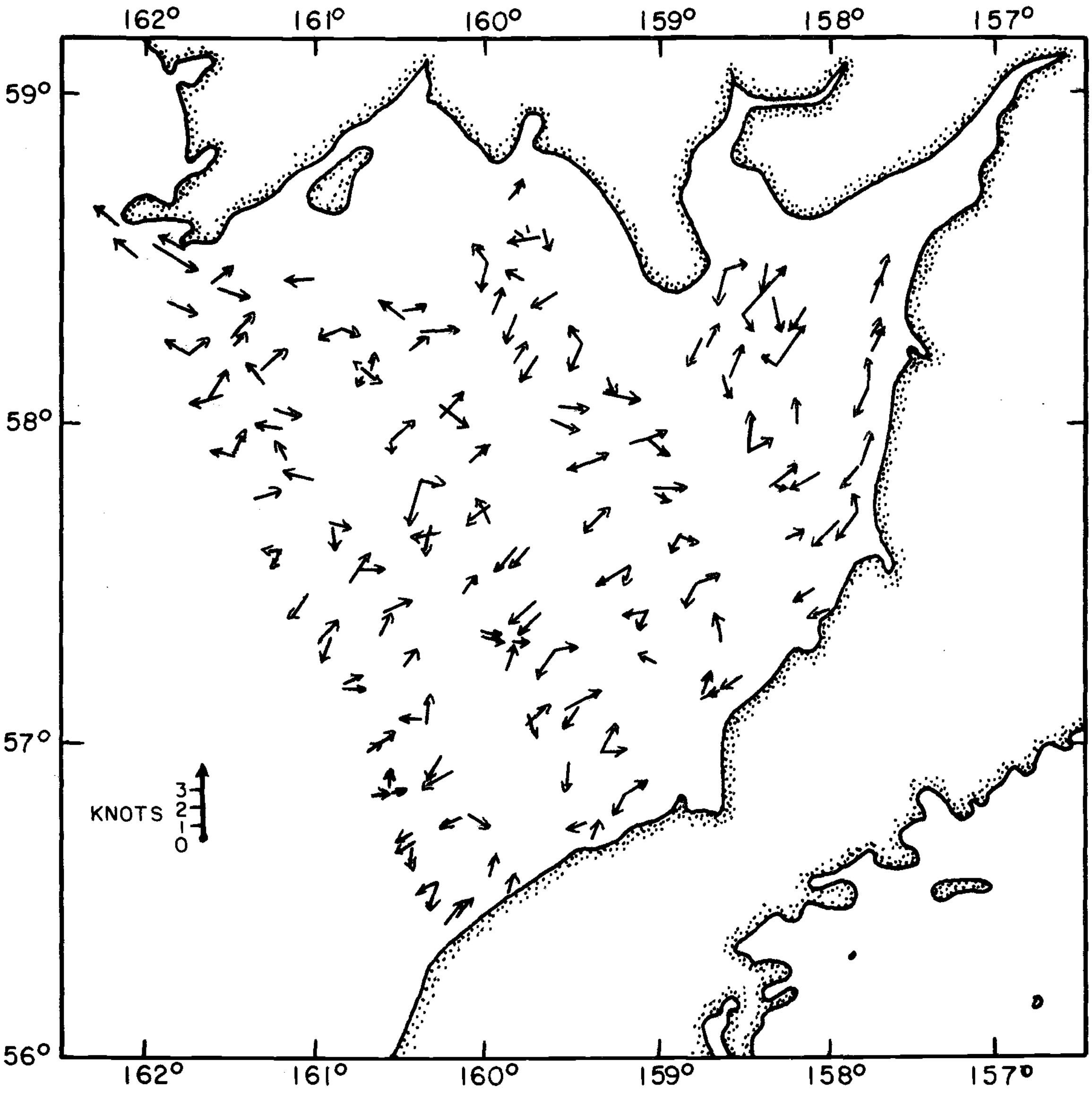

Figure 4. Surface drift-stick observations, 1939.

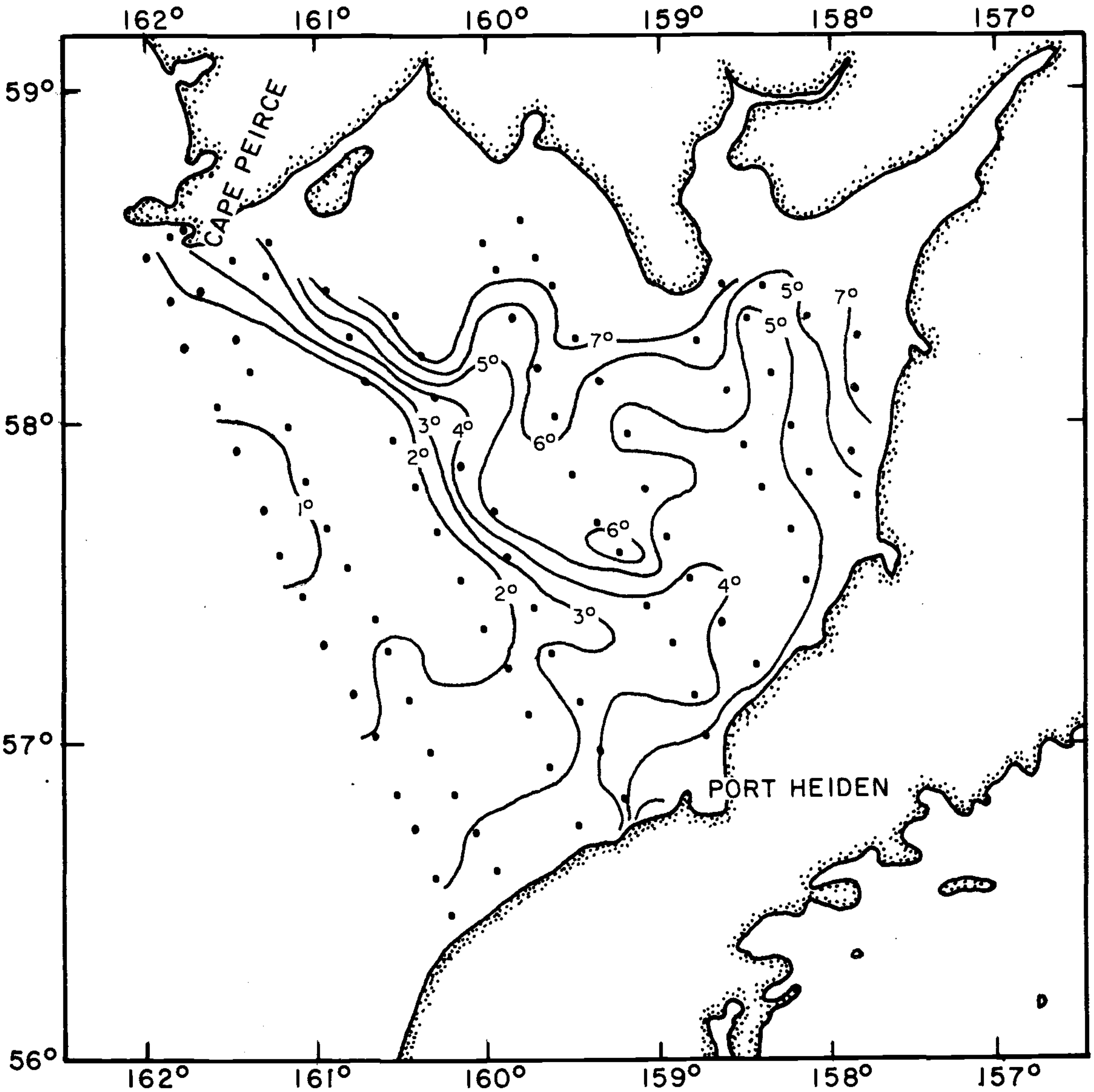

Figure 5. Surface temperatures (°C.), May-June 1939.

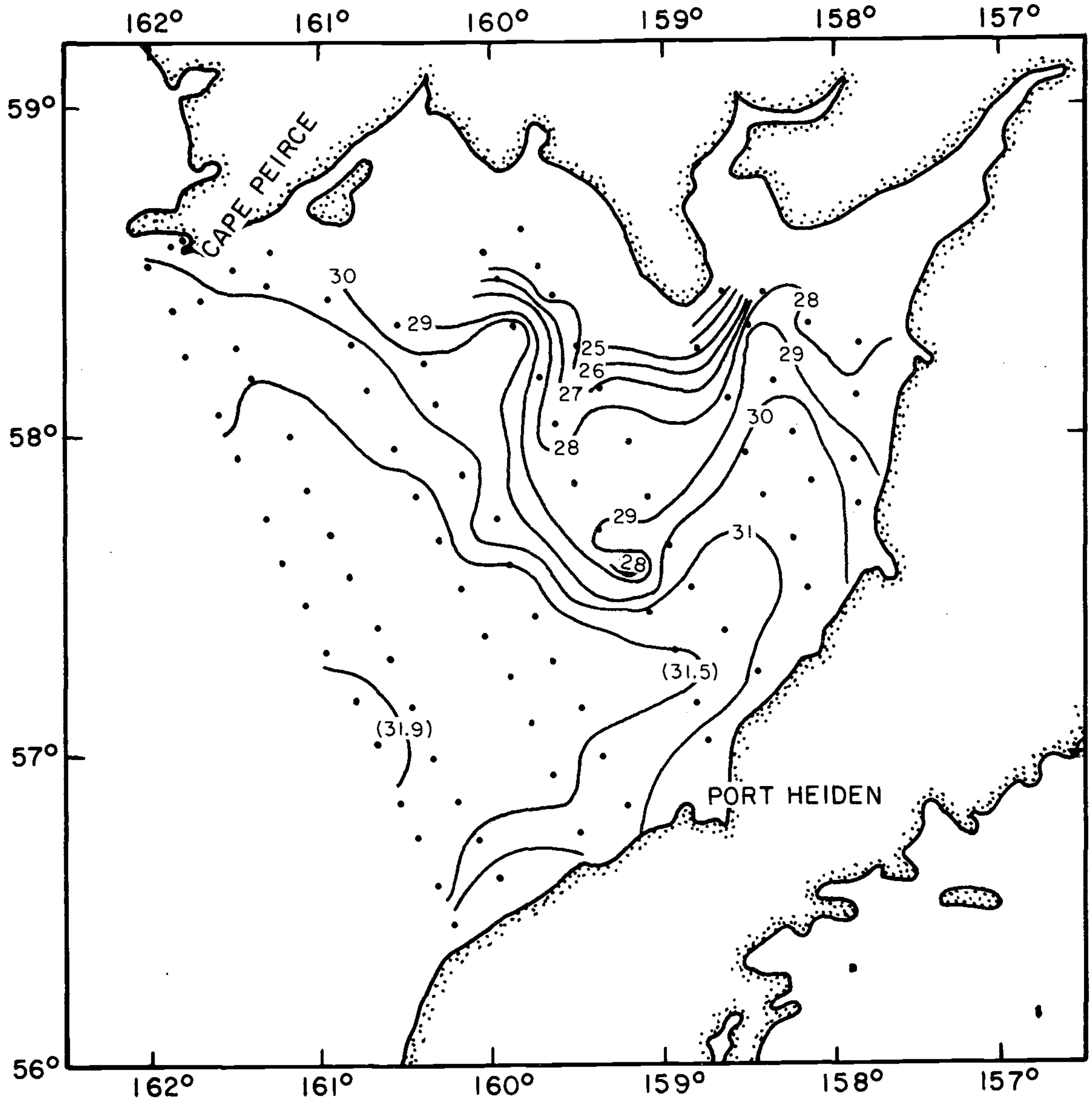

Figure 6. Surface salinity (‰), May-June 1939.

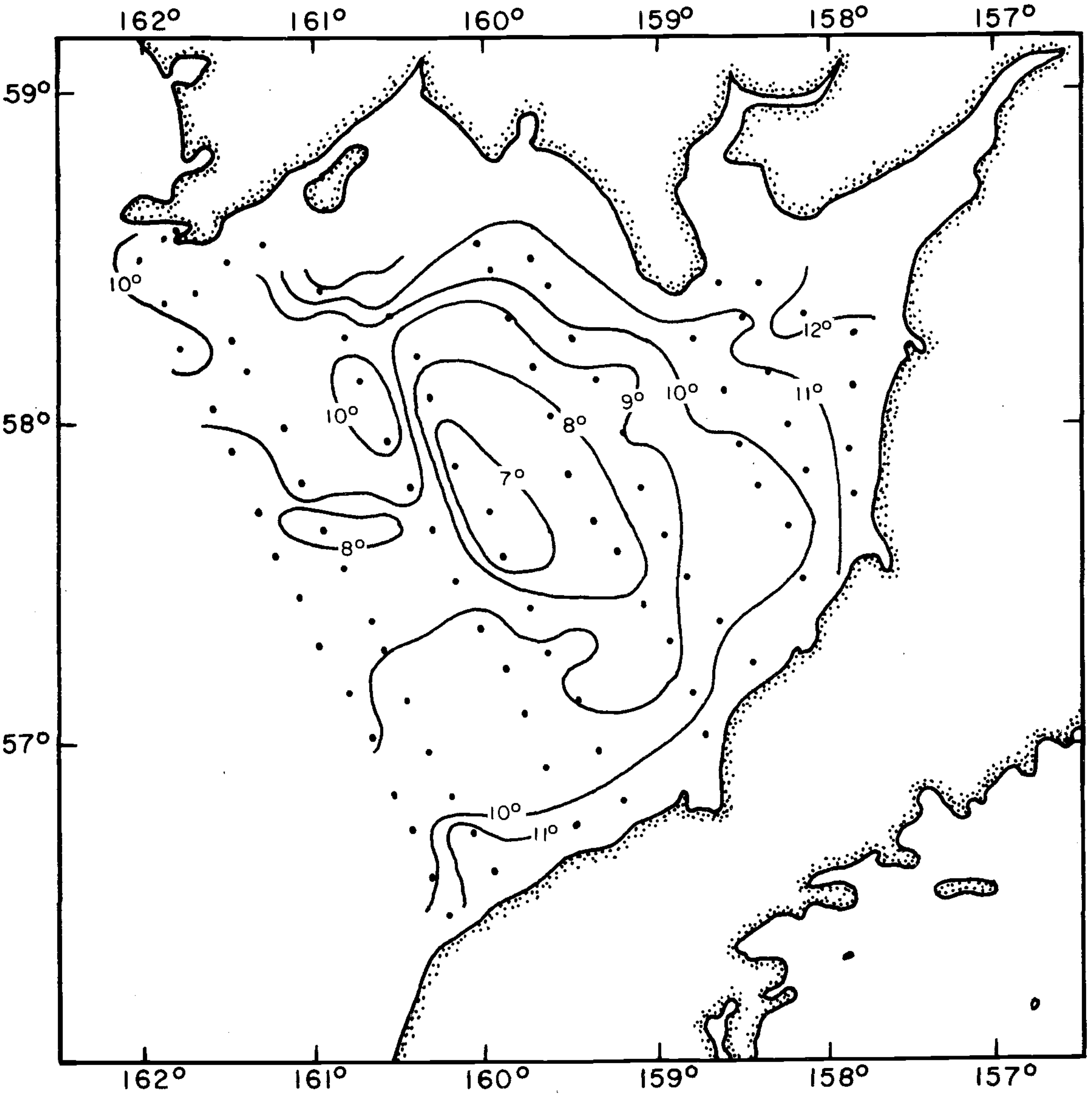

Figure 7. Surface temperatures (^{o}C.), August 1939.

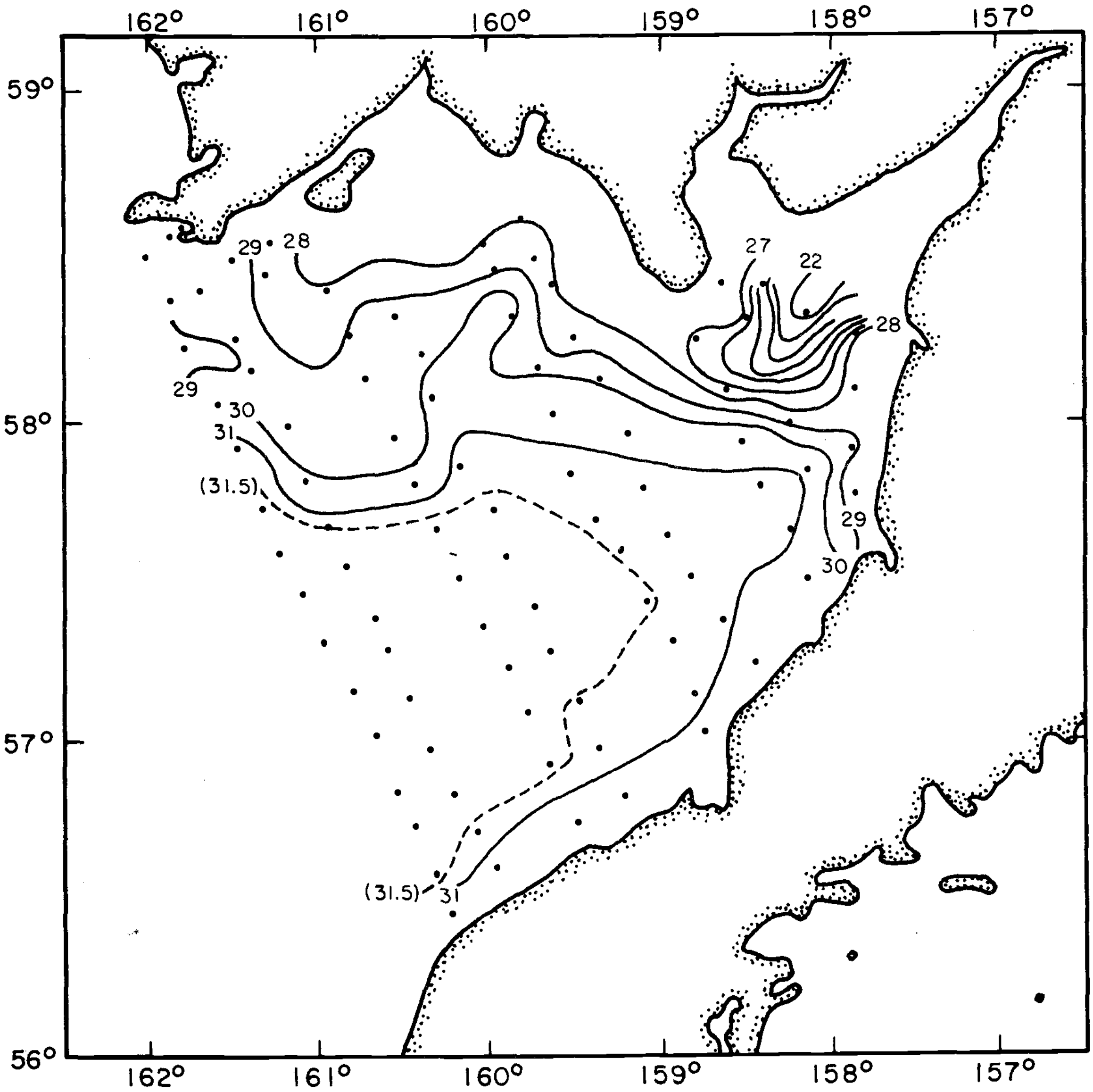

Figure 8. Surface salinity (‰), August 1939.

during June, July, and August, 1939, at three stations between the entrance and upper end of Bristol Bay. They state that in August, the river runoff moved counterclockwise along the north and northwest coastline and did not extend to the central part of the bay (Figure 9). Their explanation is as follows:

> At location A the water column was isohaline at about 31.8‰ during all three months. At B, which was further inshore, isohaline conditions also prevailed. Dilution occurred in July, but in August more saline conditions were encountered. This is due to an intrusion from the southwest which is evident in the horizontal distribution that follows. An adjacent station reflected the progressive dilution characteristic of the inshore area, which was clearly reflected in the values at C during August. By late August, the temperature reached a maximum and began to decrease; however, there is evidence that further dilution occurred after this period. The absence of an appreciable halocline offshore at Position A implies that the river runoff moved counterclockwise along the coastline and did not extend to the central part of the bay.

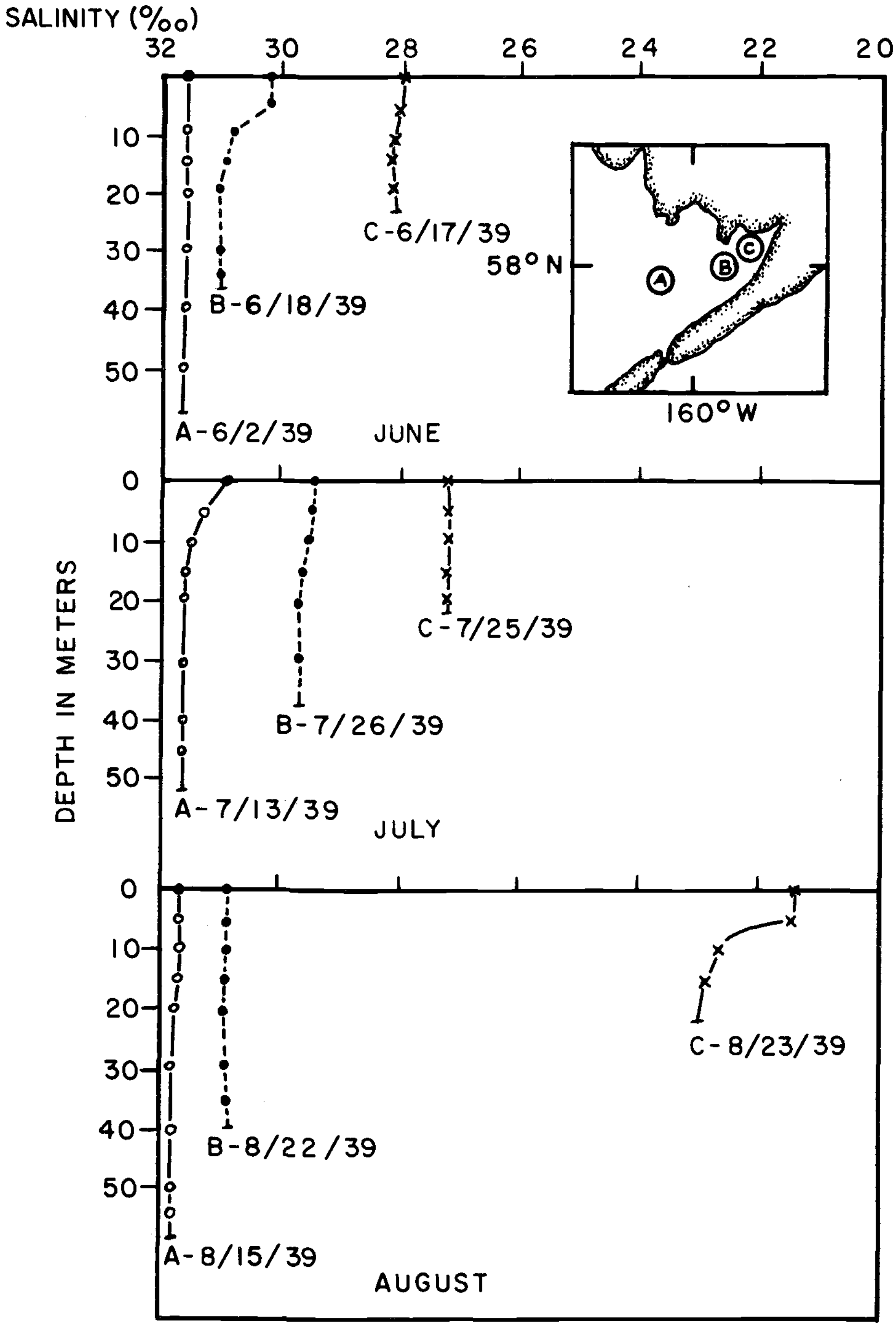

Figure 9. Vertical salinity structure at three selected stations, 1939.

IV. REVIEW OF HOMING THEORIES

Most fishery biologists believe that Pacific salmon, when mature, return to the river system of their origin to spawn. This homing tendency, recognized as early as 1738 (Krasheninnkov, 1754) was given formal expression as the "home-stream theory" in the early 1900's (Chamberlain, 1907). Over a period of many years, evidence to support this theory was obtained from marking experiments from Central California to Alaska.

Acceptance of the home-stream theory leads one to hypothesize that the distribution of home-river water masses in inshore areas influences the migration route of sockeye salmon stocks. If this is so, what properties of the water are used as cues by the salmon stock seeking the mouth of its home-river system?

Much research has been done on the homing of salmon. Hasler (1966) summarizes previous hypotheses that have been advanced to explain the mechanism by which adult salmon find their home stream. He discusses gradients of temperature (Ward, 1921a, 1921b, 1939a, 1939b), of carbon dioxide (Powers, 1939; Powers and Clark, 1943; and Collins, 1952), and of inorganic compounds, such as chlorides. The gradient theories are largely discounted by Hasler for two reasons: (1) the relatively steep gradients required by fish in order to receive continuous information from the environment, and (2) the necessity for fish to recall instantly the latest level of a particular physicochemical characteristic of the water while passing in and out of a gradient-carrying current.

An impressive amount of experimental evidence, gained both in the laboratory and in the field, has been amassed in support of the theory termed the "odor hypothesis" by Hasler and Wisby (1951) and Hasler (1966). In essence, the theory is that each stream has a characteristic odor which provides a meaningful cue to the fish which originated in that stream. Salmon, by means of olfactory perception, may be able to detect their home stream and track it to its source.

Laboratory and field experiments demonstrate that salmon can discriminate between stream odors (Hasler and Wisby, 1951; Wisby and Hasler, 1954). They also showed that seasonal changes in stream waters had no effect in altering a fish's response to the water of a given stream. In addition, they found that reaction to stream odors was indeed dependent on the olfactory system. This has been further verified for salmon in more recent studies in the field and laboratory (Collins, Trefethen, and Groves, 1962; Fagerlund et al., 1963; Hartman and Raleigh, 1964; and Hara, Ueda, and Gorbman, 1965).

Hasler and Wisby (1951) showed in the laboratory that the odorous substance to which trained fish were responding was organic in nature. Hasler (1966) suggests that:

> Odorous substances are probably carried into a stream by runoff from the vegetation and soils of a watershed and

> combined with the bouquet of the aquatic flora and fauna, lend to the stream a distinctive scent which can be perceived, learned, and recognized again by fishes after a protracted period of nonexposure.

If home-stream odors influence the orientation of salmon migrations, the salmon's early association to the odor must be retained during its life at sea. This is the prime requisite of the odor hypothesis. Hasler and Wisby (1951) showed that laboratory-trained fishes were capable of retaining their learning of odors for a considerable period of time. For salmon, Donaldson and Allen (1957) and Carlin (1963) offer convincing evidence in support of imprinting of fry and fingerling salmon by home-stream water as the determinant in the choice of spawning streams. In addition, the electroencephalographic studies of homing salmon by Hara, Ueda, and Gorbman (1965) support the theory of environmental imprinting of young salmon by stream odors.

Thus far the discussion of the odor hypothesis has dealt primarily with tributary stream homing of salmon, or that occurring in fresh water. In sockeye salmon, which generally spawn in the tributary streams of lakes, on lake beaches, or in the outlet of lakes, what part does olfactory perception and other senses play at sea in the selection of the correct river system? This question is pertinent to the situation in Bristol Bay where the ten major sockeye salmon-producing river systems, each of which has many spawning tributaries, discharge into the bay in close proximity.

Hasler (1966) states:

> Among species of salmon which spawn in large rivers near their outlets to the sea, the odor hypothesis could account adequately for the selection of the home river. In this instance the spawning ground is close enough to the coastline that odor-carrying currents could reasonably be expected to reach the sea.

Hasler (1966) discusses Huntsman's (1936) suggestion that the presence of freshets attracted salmon to a river. This is discounted, however, because it does not explain the specific selection of one river system over another. Hasler also mentions Heath's (1960) studies of the assemblages of salmon at the coastal outlets of two blocked creeks in California. Heath showed that creek water seeped into the sea through the bars blocking the creeks. He concluded that there was sufficient chemical influence in the sea to cue the salmon to the stream beyond the bar. Hasler (1966) states that:

> From this evidence one might postulate that the "chemical influence" could be an odor, and although, as we have already suggested, it seems improbable that the odor of a distant spawning ground would reach the salmon in the sea, still it is possible that the salmon have also become conditioned to a second odor--the combinations of odors at the river mouth.

Manzer (1956), Manzer and Shepard (1962), and McInerney (1964) found that salmon smolts lingered in the estuarine waters at the ocean-river junction for several weeks, which is sufficient time for imprinting (Carlin, 1963). The return to the main river by adult

Atlantic salmon which were released as smolts into the tidal zones of the ocean just beyond the river mouth (Carlin, 1955) supports the theory that odor is a possible cue by which a fish locates the mouth of the correct river system while he is some distance at sea.

The exceptional acuity of the eel's olfactory perception of some chemicals was demonstrated by Teichmann (1957). He showed that young eels conditioned by training were able to detect three parts of B-phenylethyl alcohol in 10^{18} parts of water, and calculated that at this dilution, two or three molecules would be in the eel's olfactory sack at one time. Hasler (1966) discusses Wright's (1964) work in which he calculated dilution factors of the water with its odor-bearing constituents from small salmon tributaries of the Fraser River, and attempted to determine the relative concentration of any individual stream odor at the river mouth. Wright concluded that a comparatively modest addition of scent from a home stream could put its mark on the whole downstream area and be present at the river mouth. In Bristol Bay the distance a fish must travel between the marine environment and the freshwater spawning grounds for all rivers is short in comparison with the distance most Fraser River sockeye salmon stocks must travel. In addition, the number of spawning streams (with their distinctive odors) which drain into a given Bristol Bay river system is not as great as the total number of spawning streams which eventually drain into the Fraser River. Therefore, there is a strong likelihood that an individual Bristol Bay spawning stream could impart its mark on the whole downstream river system and be detected at the river mouth and perhaps some distance at sea. There is an equal possibility that salmon smolts could be imprinted with a "second odor" or that of the river mouth, as suggested by Hasler (1966).

Hasler (1956) also suggested that a home-river system might be detected by the unique conformation of each sea-river junction--the tactile and sound vibrations arising from the movement of shallow water through the unique topography may provide a characteristic cue which is recognized by a fish of that river system.

On the basis of the foregoing evidence, I hypothesize here that the distribution of home-river system waters and the controlling factors such as tide, wind, and bottom topography determine the distribution of individual stocks of sockeye salmon in Bristol Bay.

V. EXPERIMENTAL APPROACH

I consider the ideal approach to a study of this kind would be to determine the distribution and discreteness of major river waters in the upper region of Bristol Bay. This information would then be used to select locations where sockeye salmon would be captured, marked, and released. The recoveries in individual river systems of these marked fish would be used to determine the migration route and relative discreteness of the individual stocks from various locations in Bristol Bay. Finally, river water distribution would be compared with stock distribution to learn if migration routes of individual stocks correspond to the distribution in the bay of their home-river system waters.

This study, however, was carried out in reverse order to what I considered the ideal approach. The tagging studies in 1955 were designed to meet urgent management needs; fishing interests were suggesting the relocation of boundaries of some fishing areas and the opening of areas formerly closed to fishing. Thus, the sites for the capture-and-marking experiments were selected with little or no prior knowledge of individual river water distribution. For most experiments, marking sites were selected primarily on the basis of previous and existing fishing district boundaries.

To obtain a general knowledge of river water distribution in the upper bay, investigations were carried out on a number of river systems in 1965, 1966, and 1967. The four river systems selected for study were the Naknek, Kvichak, Egegik, and Ugashik (Figure 1). They were selected because, on the average, their combined production is more than 70 percent of the total annual Bristol Bay run and because a considerable amount of inshore mark-and-recovery data were already available for stocks of salmon occurring along the southeast side of the upper bay where several of these rivers enter. Knowledge gained from the study of these four rivers might be used to explain the inshore distribution of other stocks of Bristol Bay sockeye salmon.

In essence then, I have used all available and pertinent mark-and-recovery data and supporting age composition data to present a synoptic picture of the distribution of the major stocks of sockeye salmon making up the Bristol Bay run. For the river systems mentioned, the river water and stock distributions are compared at various locations in the bay to see if, and to what extent, they are correlated. Conclusions drawn are used to explain the distribution of other sockeye salmon stocks in the bay. Suggestions are made for additional needed research.

Distribution of River Water

The important processes which determine the distribution of river water in the upper bay are the overall circulation pattern, oscillatory tidal motion, and the force and direction of local winds. The circulation pattern is determined by the amount of fresh water entering the area, the width and depth of the area, and the force and direction of prevailing winds. The direction and velocity of the resulting currents of this pattern are modified by frictional forces and the rotation of the earth, which tends to turn the moving current to the right in the northern hemisphere.

Several methods were used to determine the distribution and relative discreteness of river waters of individual systems in upper Bristol Bay. These consisted of (1) determining the vertical and horizontal salinity distribution of the area, (2) tracking river waters tagged with a fluorescent dye-tracer through the upper bay, and (3) plotting the course followed by drift cards released in the rivers and at other strategic locations in the bay.

Salinity Distribution

As has been pointed out in the review of Bristol Bay oceanography, river runoff moves seaward along the right side of the bay, but few data are available for the upper region of the bay. Because the upper region is an estuary, some knowledge of the hydrography was necessary in order to predict the course of individual river waters. This was obtained by conducting hydrographic surveys to determine the vertical and horizontal temperature and salinity distribution of the area. I expected that these data would show features consistent with those of the offshore area. In addition, I reasoned that these data would not only show the general course followed by river runoff but also might show something of the course followed by river waters of an individual system and the possible effect of tidal action on the mixing of these waters.

Vertical temperature and salinity were measured in 1965 and 1966 at hydrographic stations along parallel transect lines at 5- and 10-mile intervals across upper Bristol Bay (Figure 10). Measurements were made at low and, in most cases, high stages of the tides. Stations were located at 5-mile intervals along the offshore transects and at 1- and 2-mile intervals along the inshore transects.

Because the area is essentially an estuary and subject to large semidiurnal tides, the salinity of the water along any given transect varies with the stage of the tide. It should return, however, to substantially the same value successively on similar tidal stages, provided the river flow and the winds are not changing. In other words, there is a quasi-steady-state distribution of salinity and consequently of the diluting river water. Ideally, a hydrographic survey of this

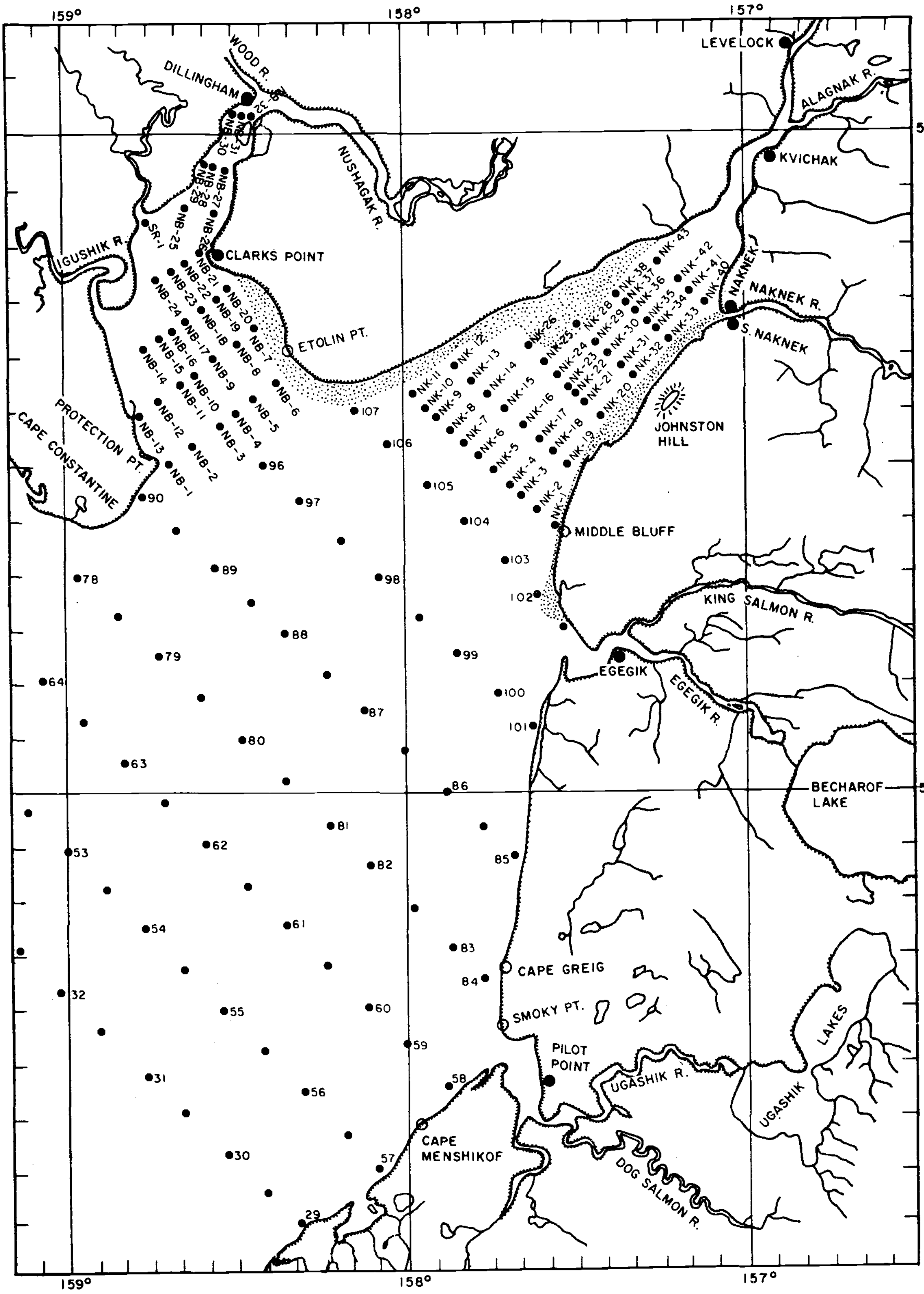

Figure 10. Hydrographic station plan, Bristol Bay, 1965 and 1966.

area in a single day on a given stage of the tide would have been desirable. Only one vessel was available for this work, however, and the survey was conducted over a period of a month. There is, consequently, some error in the interpretation of the results. The error would be in the correct positioning of a given mixture of fresh and sea water on given stages of the tide. Because of this, measurements at stations along given transects were confined to periods when the tide and wind conditions were as nearly similar as possible. No estimate of changes in the amount of freshwater runoff during the survey period was possible because stream gauges were lacking on most river systems. The survey was carried out, however, during the period (July and August) of greatest annual river discharge.

For the most part, the data used in this study were collected on consecutive days in late July and August 1966 during periods when tidal conditions were as nearly similar as possible (Appendix Table 1). Because these days had the greatest tidal ranges, the maximum differences between high and low tide conditions and the effects of tidal currents on the distribution and mixing of river water should become more apparent in the resulting plots of the data. Although transects could not always be made on the desired tide, because of inclement weather and darkness, they could usually be run on the lowest and highest tides of the day. The run of stations along a transect line was normally started between 1 and 1-1/2 hours before the low or high tide. The vessel was kept on a constant compass course along a given transect line as it traveled between stations so that it moved toward the head of the bay or seaward at a rate which depended on the velocity of the tidal current. In this way the vessel was expected to remain in that section of water along a given transect line at a given time, i. e., at high or low tide. In addition, to reduce the effect strong winds would have on the mixing of river waters and on the drift of a vessel, transects were normally run when the wind velocity was less than 10 to 15 knots. Wind speeds greater than 13 knots caused waves to become unstable and break into whitecaps, with a resulting increase in the mixing of the surface waters (Johnson, 1959). Inclement weather and the small size of the vessel prevented the coverage desired in the more seaward portion of the study area and at high stages of the tide.

Temperature and salinity were measured at stations *in situ* at the surface and at 1-meter and 2-meter intervals thereafter to the bottom. A Model RS 5-A portable induction salinometer manufactured by Industrial Instruments, Inc. (now Beckman Instruments) of Cedar Grove, New Jersey, was used for this work. This instrument measures and provides a readout in conductivity and temperature with accuracy of ±0.5 millimhos/cm. and ±0.5° C. respectively. These two measurements are combined in a computer circuit of the instrument to provide a readout in salinity with an accuracy of

±0.5‰. This degree of accuracy was considered adequate for the objective of this study. All three measurements at a given depth could be taken and recorded in less than one minute.

Fluorescent Tracer Studies

A supplemental and more direct method to determine the course and discreteness of given river waters is to tag them with an artificial or external tracer and follow their course offshore.

The introduction of artificial tracer materials, particularly fluorescent types, into natural waters has been useful in studying a variety of hydrologic phenomena. Artificial tracer methods have had their widest use in pollution investigations to predict the distributions of wastes in estuarine systems and coastal waters. These studies were designed to: (1) evaluate empirically the distribution in time and space of a contaminant; (2) study the mechanics of dispersions of the material by turbulent mixing processes; and (3) follow the gross net movement of a mass of water that has been tagged with a tracer in order to provide an average value of velocity over the path of movement. Seligman (1955) describes the use of fluorescein in studies on the discharge of radioactive waste products into the Irish Sea. Moon, Bretschneider, and Hood (1957) used fluorescein as a tracer in estimating eddy diffusion in coastal embayments; they felt the method was superior to other methods of obtaining such estimates. Pearson (1959) compares the characteristics of tritium (Hydrogen 3), fluorescein (sodium fluorescein), and orzan (dried spent sulfite liquor) for use in field tracing of water movements. He concluded that orzan was the most practical tracer for general estuarine waste disposal studies because the low cost of the material compensated for its low sensitivity of detection. Feuerstein and Selleck (1963) found that fluorescein had a large photochemical decay rate, a drawback that restricts its use to short-term studies.

A new tracer technique utilizing Rhodamine B dye, a fluorescent organic pigment, was used by Pritchard and Carpenter (1960) for the direct observation of the movement and dispersion of water in various parts of Chesapeake Bay. A very stable and compact fluorometer is used to detect the pigment. Fluorometric detection provides one of the best methods presently available for tracer studies because it is quite sensitive, simple, and straightforward and makes possible the rapid analysis of water samples. The pigment has a maximum absorption spectrum of 550 millimicrons which allows its molecule to be strongly excited to fluorescence by the green (546 millimicrons) line of mercury. Special optical filters cause the green mercury line to be isolated so that nearly monochromatic exciting light is easily filtered from the emitted path and the effects of scattering are almost eliminated. The long wavelength of the exciting light reduces the absorption and scattering by dissolved and suspended materials found for the shorter wavelength ultraviolet light commonly used for fluorescent analysis, and aids in reducing the background. This was of particular importance in the study area where waters are heavily laden with suspended material.

Since the initial work of Pritchard and Carpenter, the technique has also found wide application in water movement and dispersion studies in reservoirs (Nickerson, 1961); rivers (Fisher, 1962, 1963; Gallagher, 1963a, 1963b; and Buchanan, 1964); and the open ocean (Okubo, 1962, 1965; and Stevenson, 1966).

<u>Characteristics of Rhodamine B as a Tracer</u>. Rhodamine B (Alkyl aminophenol derivative) is an organic pigment which has long been recognized as one of the most efficient fluorescing compounds. Several qualities make it desirable as a tracer in estuarine studies: (1) It is easy to handle and release; (2) it is nontoxic to human beings and harmless to aquatic life; (3) it is essentially unaffected by light; (4) its fluorescence is nearly independent of pH values between 5 and 10; and (5) its fluorescent intensities are only slightly affected by the values of salinities encountered between fresh and oceanic water (Pritchard and Carpenter, 1960; Feuerstein and Selleck, 1963).

Certain qualities of Rhodamine B make it less desirable as a tracer in some studies where the determination of the exact concentration of dye is required. These include its adsorption on suspended material (Feuerstein and Selleck, 1963) and the reduction of fluorescence with increasing temperature (Pritchard and Carpenter, 1960).

Because the principal objective of my study was simply to plot the course of individual river waters, I did not need to determine exact dye concentrations. The effects of temperature and adsorption were only important in the rate to which they reduced fluorescence below the minimum detectable level; once the dye concentration reached this level, the dye patch was reinforced by the addition of more Rhodamine B.

Location of Tracer Studies. Tracer studies were conducted on the Naknek, Egegik, and Ugashik rivers during July and August 1965 and 1966 (Appendix Table 2). Dye was not released in the Kvichak River, which was also the subject of this investigation, because I thought that the course and distribution of Kvichak River water in upper Bristol Bay could be logically deduced from results of the Naknek River study and hydrographic surveys. Only two rivers, the Naknek and Kvichak, enter at the head of Kvichak Bay (Figure 1), and knowledge of the course and distribution of one of these rivers provides the information needed to show the same information for the other river.

Method of Tracer Release. Ideally, release of a tracer into a given river on a continuous flow basis for a period of time long enough for the tracer to achieve an equilibrium with its environment would have been desirable. Steady-state conditions are seldom attempted with external tracers in field studies, however, because of the large quantity and high cost of tracer material and the extensive study period required. The limited objectives of my study could be met by the instantaneous release of enough Rhodamine B to trace its course over one or two tidal cycles.

A limitation in the use of tracers is that the results obtained are specific to the conditions at the time of observation. The same conditions which influence the salinity distribution (tidal currents, wind direction and velocity, and variations in river runoff) will also have an effect on patterns of dye dispersion. In the short-term studies in my investigation, the effects of wind on mixing and dispersion of the tracer were considered to be most important; tracer studies were therefore carried out on days when wind velocities were less than 15 knots.

As mentioned previously, no measure of the amount of freshwater runoff is available for rivers draining into Bristol Bay. The tracer studies were conducted during the same months (July and August) as the hydrographic surveys, however, and therefore the results obtained by both approaches as they pertain to the course and distribution of river water should complement one another.

The Rhodamine B dye, which was purchased from E. I. Du Pont de Nemours and Company in Portland, Oregon, was a 40 percent (by weight) acetic acid solution. Because the density of the solution was greater than that of the water into which it was to be released, to ensure rapid and complete mixing the dye was adjusted to a specific gravity of 1.000 at the prevailing air temperature by the addition of methyl alcohol.

I found that the most efficient way to introduce the Rhodamine B tracer rapidly was to pour it from plastic containers (2-1/2- or 5-gallon) into the propeller wash of the tracking vessel while traveling at a speed of 5 knots (Figure 11). The tracer mixed almost instantaneously with the water to a depth of 2 meters; within 1 hour after release it had mixed to a depth of 4 meters.

The dye tracer was released in a continuous line 10 feet wide across the main channel of the river. The channel was crossed three or four times with a line of dye laid down about 50 feet upstream from the previous line. Usually within 1 hour the individual lines of dye had diffused horizontally and merged with one another, producing a visible patch across the channel 200 feet or more wide.

Before this study little was known of the vertical salinity, and thus the density distribution, of the study area. The topography and tidal currents of the area and the results of oceanographic

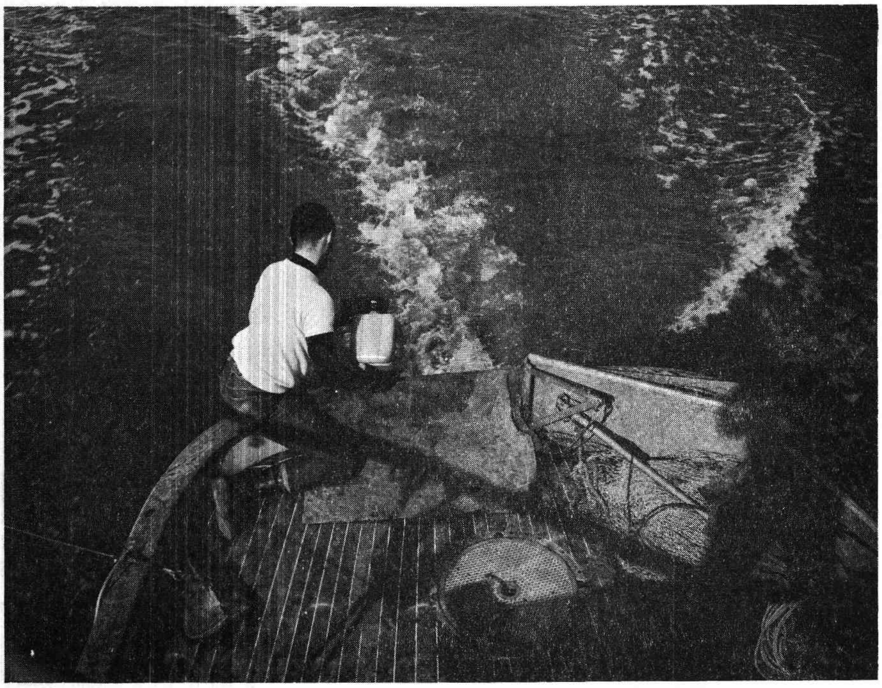

Figure 11. Introduction of Rhodamine B dye tracer into Naknek River by pouring it into propeller wash of tracking vessel, July 1965.

investigations in the offshore regions of Bristol Bay cited earlier suggested, however, that salinity in this area should be essentially vertically homogeneous. A survey of the Naknek River at high slack water prior to the initial dye releases in 1965 showed this to be true; there was a vertical salinity gradient (Figure 12), but it was not great enough to be considered stratified. The greatest range in salinity in the Naknek River at the time of my survey was about 4‰, which can be considered as almost vertically homogeneous.

Because the water movement in vertically homogeneous estuaries does not vary with depth (Pritchard, 1959), the presence of dye throughout the water column in the river under study was not necessary in order to follow and plot its offshore distribution. The course and distribution of given river waters were therefore determined from tracking dye in the surface layers.

Initial dye releases were made upstream from the river mouth or at the entrance to Bristol Bay within 1 hour after high slack tide. The course and distribution of these releases were tracked offshore during the ebb tide and back inshore during the following flood tide. Successive dye releases at high tide were made farther downstream and offshore over a course assumed to be the seaward limit of the previous dye release. The course and distribution were again followed farther offshore. The offshore distribution and course of river waters were thus determined in stages, a procedure which required

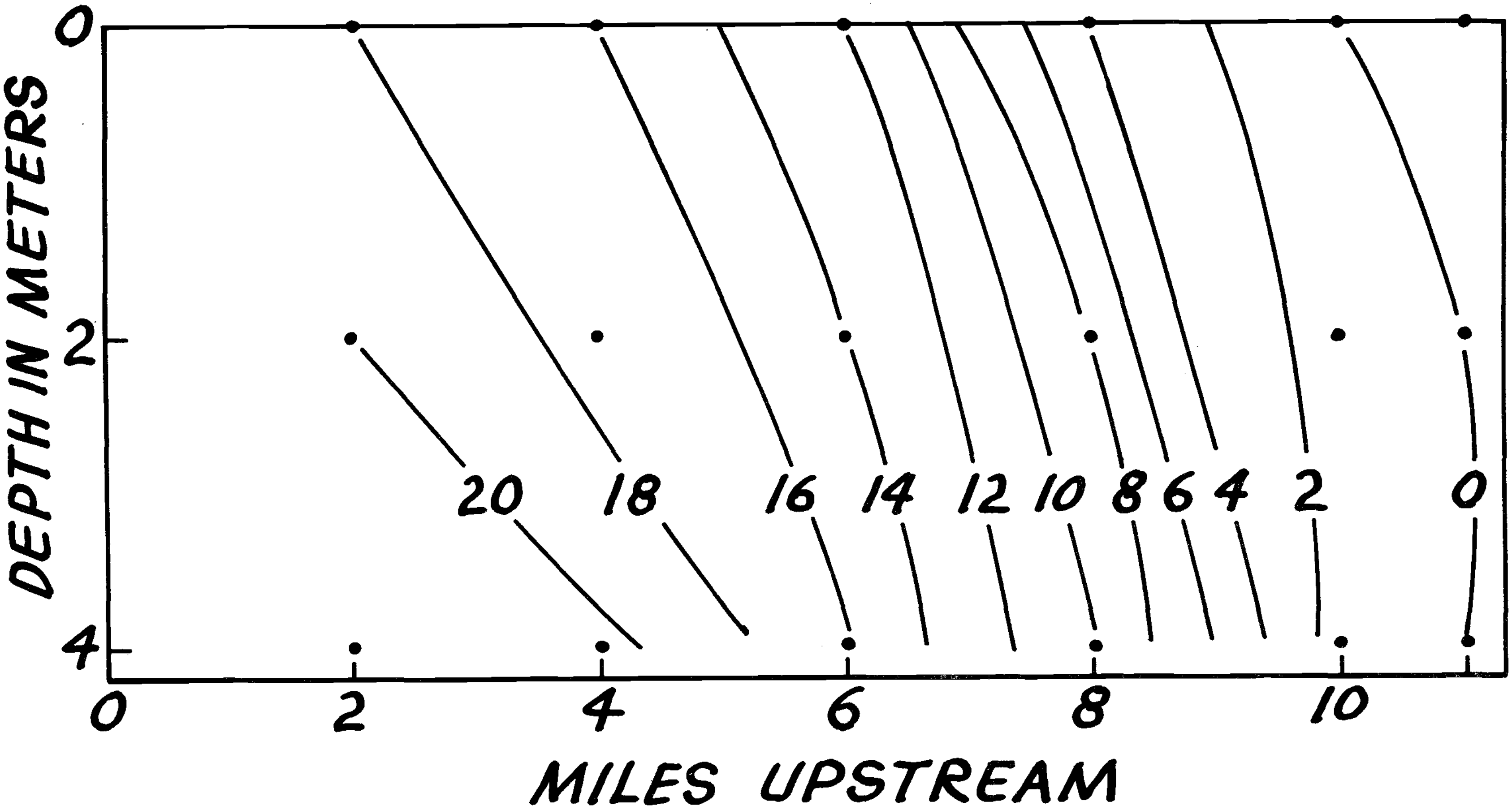

Figure 12. Salinity (‰), mouth of Naknek River to 11 miles upstream at high tide, July 5, 1965.

much less dye than would have been used by any other method. Dye was also released just before and at low slack water to study the course followed by river water during the flood tide.

Selleck and Pearson (1960) state that the quantity of tracer needed to study a given region should be at least equivalent to the amount required to give a uniform concentration at low water equal to the minimum that can be detected significantly, and preferably should be twice this amount. Although this would have been desirable, I felt it was unnecessary in this study. The amount of Rhodamine B dye used was based on the width of the area to be tagged: enough dye was used to put at least three and sometimes four visible lines across the main channel, or course, followed by a river. In some studies, when the dye reached the minimum detectable level, additional dye was released over a course already containing tracer material.

Tracer Detection. The instrument used to detect the Rhodamine B tracer was the Turner Model 111 Fluorometer (Figure 13) manufactured by G. K. Turner Associates of Palo Alto, California. It includes a fluorescence detector and readout system and was equipped with a Rustrak recorder to record the sample readings on a strip chart. The fluorometer is basically an optical bridge, which measures the difference between light emitted by the water sample and that emitted from a separate calibrated light path.

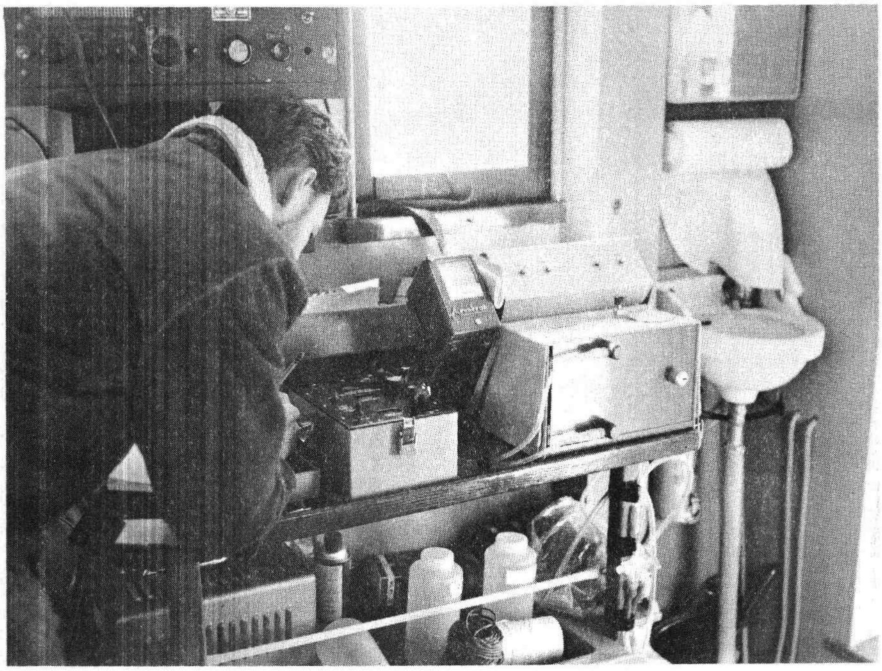

Figure 13. Turner Model III fluorometer installed aboard tracking vessel and fitted with continuous-flow curvette door for underway monitoring of water for fluorescence, Bristol Bay, 1965.

The instrument has four operating ranges to give it a large range of sensitivity. Each range is defined by the size of the aperture emitting excitation energy to the sample from the light source. The results are indicated on a dial calibrated from 0 to 100 percent, the reading being proportional to the amount of light leaving the sample. The dial is accurate to about ±0.5 units. The instrument was calibrated by obtaining dial indications for known concentrations of Rhodamine B dye (Appendix Table 3).

Both discrete-sample curvette and continuous-flow curvette doors are available for the fluorometer, but I used one equipped with the continuous-flow curvette so that continuous records of fluorescence could be obtained by pumping samples through the instrument while traversing a dye patch.

Tracer Sampling Procedures. For about 1 to 2 hours after dye was released, it could be followed visually before it lost its identity. Thereafter it was followed by use of the fluorometer. Continuous underway sampling was carried out with the fluorometer to obtain recorded profiles of the dye distribution.

Water samples were drawn from a depth of 1 meter and pumped through the fluorometer while the tracking vessel was traveling at a speed of 3 knots. The water sampling gear consisted of a 30-foot piece of polyethylene tubing, one end of which was attached to a brass rod

1 meter long (Figure 14). The other end of the rod was fitted with a Spongex float. The rod-float arrangement was attached to the wire cable of the hydrographic winch in such a manner that it would move freely up and down the cable when in the sampling position. A 45-pound depressor was attached to the end of the cable. To put it into sampling position, the whole apparatus was swung off to one side of the vessel with a boom, and the depressor was lowered to a depth dependent on sea conditions. When swells were large or when the tracking vessel was run in a direction that caused it to roll excessively, the depressor was lowered deeper than under calm sea conditions. In this way, the depth of sampling was kept constant because the sampling tube was moving independent of the cable, which was subjected to the pitch and roll of the vessel. The other end of the sampling tube was attached to a small laboratory pump which brought the water from depth to the continuous-flow curvette of the fluorometer. Fluorometer dial indications were recorded on the strip chart of the instrument recorder (Figure 15).

Reference was made to prominent landmarks, marker buoys, and bottom topography for accurate positioning of the vessel when plotting the distribution of dye. Navigational charts of the area and a fathometer were used as a check on proper positioning of the vessel. Under the low wind conditions in which these studies were conducted, only the tidal currents affected the position of the tracking vessel.

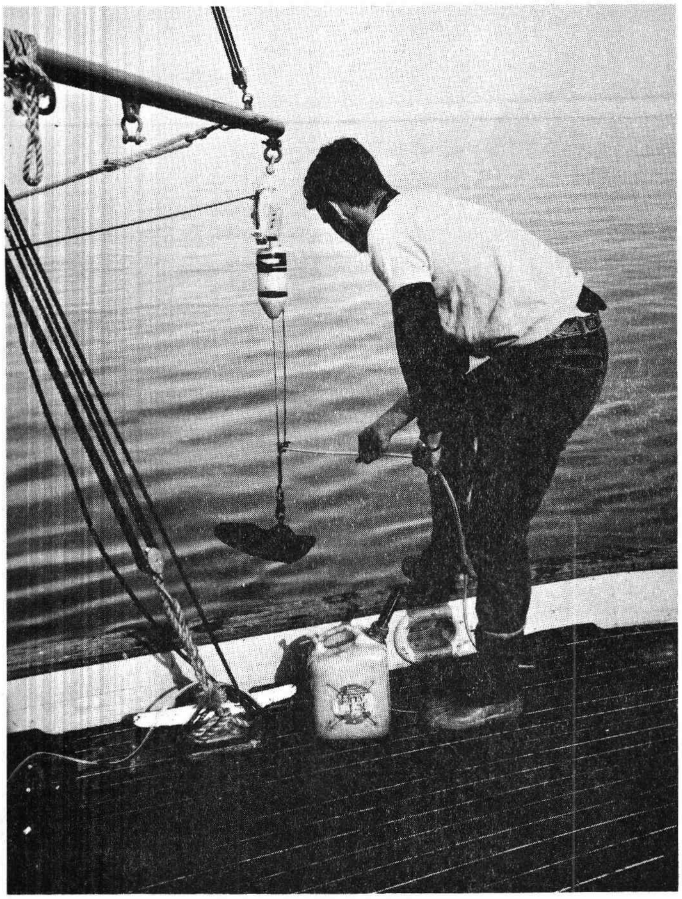

Figure 14. Apparatus used for underway sampling of water for Rhodamine B dye, Bristol Bay, 1965.

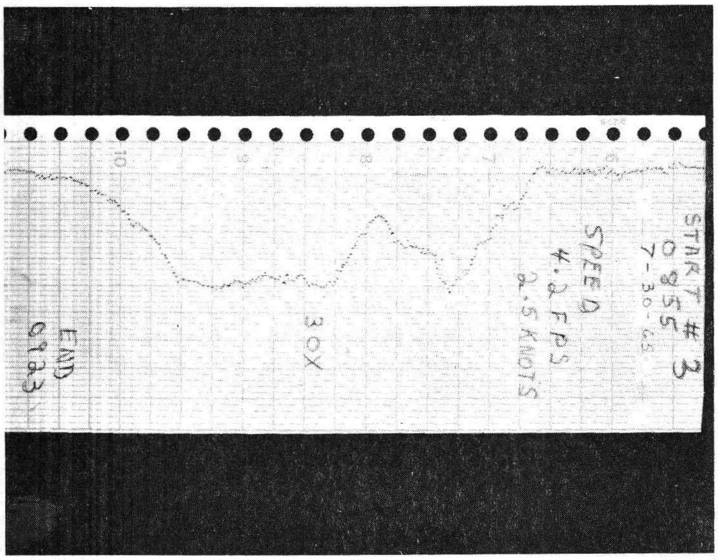

Figure 15. Strip chart record of fluorometer dial indications, Bristol Bay, 1965.

In this manner then, the dye patch was continuously crossed and its course during the ebb and flood obtained. When crossing a dye patch, continuous reference was made to the dial indicator of the fluorometer; and the vessel's position, the depth of water, and the time were noted. When the vessel left the dye, it was turned 180° from its previous heading so that it crossed the dye patch again. The speed of the vessel was kept constant by reference to a sensitive speedometer, and each crossing of a dye patch was timed.

Preliminary Survey of Background Fluorescence. Background fluorescence is the natural fluorescence of water plus false readings due to turbid water. Before the tracer studies were started, a sample of pure river water from each of the rivers to be studied was run through the fluorometer to determine the level of possible interfering background fluorescence. In addition, the offshore portion of the study area was surveyed to determine what level of fluorescence might be encountered in these waters. As a final check on the background level, waters along the course of the proposed tracer release were sampled immediately before the release. Corrections for background fluorescence were applied to fluorometer readings during the tracking phase of the tracer studies.

Drift Card Studies

A third method used to study the circulation pattern and course followed by individual river waters in upper Bristol Bay was to release drift cards at various locations and to chart their subsequent distribution.

At the beginning of this study in 1965, the use of drift cards or bottles was considered as a possible method to use in studying the distribution of river waters. However, a drawback to the use of drifting objects in an area as remote as Bristol Bay is the lack of a means of obtaining sufficient recoveries. Fishing vessels which might encounter drift cards or bottles are only abundant in the bay from mid-June to late July, and then are generally restricted to the vicinity of the river mouths and bay entrances. Recoveries of introduced drifting objects would therefore be limited to these areas and provide little information on the course and distribution of river waters.

A new type of plastic drift card was selected for use in this study in 1967 for the following reasons:

1. Their design permits recoveries from beaches even after they have been afloat for extended periods of time.
2. They would extend the range of observations of river water course and distribution beyond that shown by the tracer studies.

3. Their distribution could be used to verify conclusions reached from the salinity distribution of the area.

Description of Drift Cards. Drift cards used in this study were developed by John Martin of the Bureau of Commercial Fisheries and are being used for studies of the coastal currents of southeastern Alaska. The following description and illustration of these cards is taken from Martin (1967).

> The card [Figure 16] is printed on a rectangular sheet of plastic (22x28 cm), international orange in color. Each sheet is numbered and folded in half lengthwise. A float of expanded polystyrene (0.8x2.5x7.5 cm) is attached along the inside of the fold, near one end, with two galvanized staples (stainless steel staples are recommended for longer term studies). A 3.5-g lead weight is attached with a staple inside the fold, at each of the two corners diagonal from the float. The two edges opposite the fold are kept apart by the float and the resilience of the plastic along the fold.
>
> The folded drift card measures 11x28 cm and weighs about 22 g. It floats with about 3 cm of the folded edge above the water and the top corners of the opposite edges just under the water [see Figure 16]. The exposed triangular portion of the card rotates into the wind. At the same time, the edges of the card opposite the fold are forced farther apart as the card moves downwind through the water. The position produces maximum drag in the water.
>
> The outer surface of the card bears printed instructions to the finder. One part is an addressed, postpaid postcard (which must be cut out by the finder) with appropriate instructions and space for recording data.

In preliminary tests with these cards, Martin (personal communication) found that the galvanized staples holding the lead weights

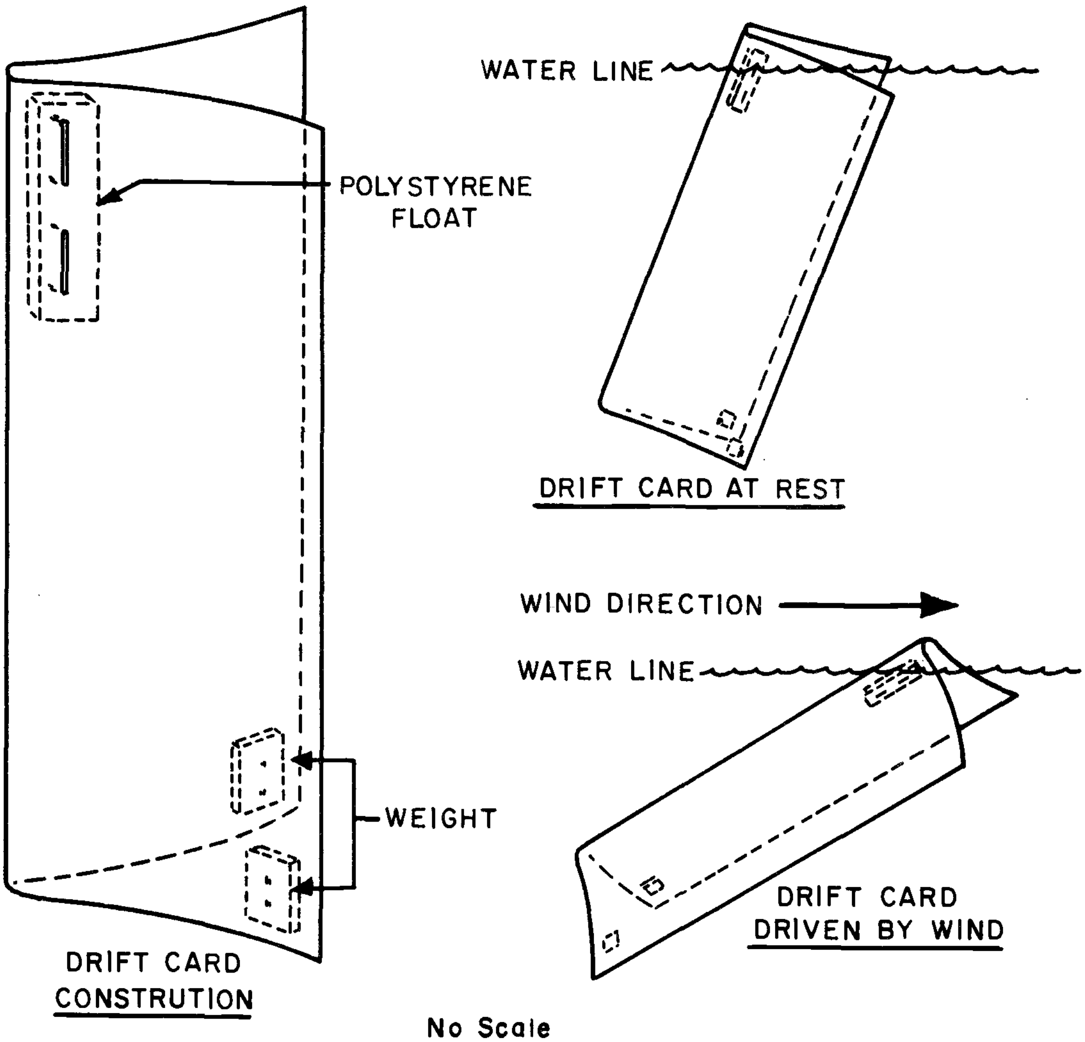

Figure 16. Plastic drift card construction and operation.

to the card corroded away in about 6 weeks. This caused the card to float on its side, which made it more subject to the effects of the wind. This aspect of their construction causes the cards to be blown ashore, where they can be recovered easily.

Location and Method of Drift Card Release. The locations selected for release of drift cards were based on the distribution of river water as shown by the results of the tracer studies and the salinity distribution of the area. In addition, the release locations were in the same general area where sockeye salmon were captured, tagged, and released during tagging studies (to be discussed later).

A total of 1,007 serially numbered drift cards were released in upper Bristol Bay on June 2, 1967. They were released (in groups of ten) from an aircraft in a line across the mouths of the Kvichak and Naknek rivers, at the entrances to Egegik and Ugashik bays, offshore for a distance of four miles at Cape Chichagof, at the 58° parallel of latitude, and off Cape Greig and Cape Menshikof (Appendix Table 4). The aircraft was flown at a speed of 80 miles per hour and an altitude of 300 feet. Cards were released during ebb tide from one to two hours after high slack tide so that those released in the river mouth and bay entrance areas would move immediately out into the bay. In this way they had less chance of being picked up by local people living in the villages near the river mouths and bay entrances.

Method of Drift Card Recovery and Presentation of Results. Card recoveries came from two sources. First, commercial salmon fishermen using set and drifting gill nets recovered cards which happened to drift into their area of operation. Each person returning a card was sent the location and date the card was released. Second, I recovered cards from beaches during aerial surveys conducted six weeks or more after the cards were released. I anticipated that by this time a significant number of cards would have lost their lead weights and drifted ashore. The beaches along the southeast side of Bristol Bay between the village of Kvichak and 25 miles south of the Cinder River (Figure 1) were surveyed by air for drift cards on July 17 and 27, 1967. The northwest beaches of the bay between the village of Kvichak and the entrance to Kulukak Bay were surveyed on July 26 and August 9, 1967. A Piper super cub and Cessna 180 aircraft were used in these surveys. They were flown at altitudes of 75 to 100 feet and a speed of 80 miles per hour. Drift cards not covered by sand, grass, or other debris could be seen easily because of their bright orange color. When a card was observed, the plane was landed on the nearest suitable beach to recover it.

The location of each recovery was noted on a map and in the appropriate space on the card itself. Recoveries from each location of release were plotted on maps of the upper bay to show the direction of drift and thus the course and distribution of river waters.

Distribution and Migration Pattern of Bristol Bay Sockeye Salmon

Since the advent of high seas fishing by the Japanese in 1952, a great deal of research has been carried out under the auspices of the International North Pacific Fisheries Commission[4] to determine the continent and specific area of origin of salmon on the high seas. Tagging studies conducted by the United States (Hartt, 1962 and 1966) and Japan (Kondo *et al.*, 1965) have shown that sockeye salmon aggregations south of the Alaska Peninsula and in the central Bering Sea include fish from all river systems of Bristol Bay. There is no detectable segregation of individual stocks of Bristol Bay sockeye salmon on the high seas.

In this study I considered it necessary to establish whether individual stocks of Bristol Bay sockeye salmon segregate according to river of origin and if they did, to determine where such segregation occurred. The logical location to begin this study was at some point in the Bering Sea well outside Bristol Bay where most of the spawning migration would be encountered. From here to the river mouths the migration pattern and distribution of individual stocks of sockeye salmon were determined on the basis of the available data.

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[4]The Commission was established in 1953 by convention between Canada, Japan, and the United States for the conservation of the fishery resources of the North Pacific Ocean.

The area selected for study was east of long. 170° W. and south of lat. 60° N. This region is east of the most important passes of the Aleutian Islands through which Bristol Bay sockeye salmon enter the Bering Sea (Hartt, 1962 and 1966). Studies of the scale characters, morphological characteristics, and parasite infestations of Asian and North American stocks of sockeye salmon (Margolis et al., 1966) have shown that in June and July mature fish in this region resemble those of Western Alaska (mainly Bristol Bay). Investigations of the direction of movement of fish caught in gill nets (Barnaby, 1952) and purse seines (Hartt, 1962) show that most sockeye salmon in this area are moving east toward Bristol Bay. The tagging experiments of United States (Hartt, 1962 and 1966) and Japan (Kondo et al., 1965) showed that most mature sockeye salmon in this region were indeed bound for Bristol Bay rivers.

The distribution and migratory pattern of sockeye salmon in this region are discussed under two headings, "Offshore Distribution of Sockeye Salmon" and "Inshore Distribution of Sockeye Salmon." The offshore region includes that area of the Bering Sea east of long. 170° W. and south of lat. 60° N. to a line drawn between Nushagak Peninsula and the Cinder River (Figure 2). The inshore area includes the remaining area to the river mouths.

Materials for study of the distribution of sockeye salmon in the offshore area were taken largely from the published results of recent investigations carried out by the United States and Japan under the auspices of the International North Pacific Fisheries Commission and from earlier studies by the Bureau of Commercial Fisheries. Unpublished data resulting from tagging experiments and related studies carried out under my supervision were used in the study of inshore distribution.

Offshore Distribution of Sockeye Salmon

The relative density of sockeye salmon in the offshore area along north-south transects was determined from results of exploratory fishing operations carried out by research vessels of the United States. Recaptures in Bristol Bay of sockeye salmon tagged by the United States and Japan were analyzed to determine if individual sockeye salmon stocks were segregated in the offshore area.

Exploratory Fishing. Periodically over a period of 28 years research, vessels of the United States have carried out exploratory fishing operations in the offshore waters of the Bering Sea. The principal objective of these investigations was to determine the availability, abundance, distribution, and direction of movement of salmon in this region. In addition, samples of the salmon taken were used in racial studies to determine their continent of origin. In most cases gill nets of various lengths and mesh sizes were the principal form of fishing gear used, although purse seines and long lines were also used.

The results of eight years of exploratory fishing with gill nets in the offshore area were analyzed in this study. The year, location, and dates of fishing and source of these data are listed in Appendix Table 5. The years shown were selected because (1) fishing was carried out during June and July, the period of the spawning migration when sockeye salmon are most abundant; (2) fishing was fairly systematic, usually on consecutive days at stations located along given section lines (Figure 17); and (3) the section lines fished provided the most extensive coverage available.

The catch of sockeye salmon per gill net set at locations along given section lines in each year of fishing is illustrated in histograms to show the distribution of fish across the approaches to and in outer Bristol Bay. In some years fishing was carried out along a given section line two or three times. In these cases, catch data are illustrated so that a visual comparison of sockeye salmon distribution can be made for each time period a given line was fished. This makes it possible to draw some general conclusions regarding the consistency of the distribution at various times during the spawning migration. Fishing was also carried out along long. 170° W. in three different years, making possible a comparison of sockeye salmon distribution between years with runs of different magnitude.

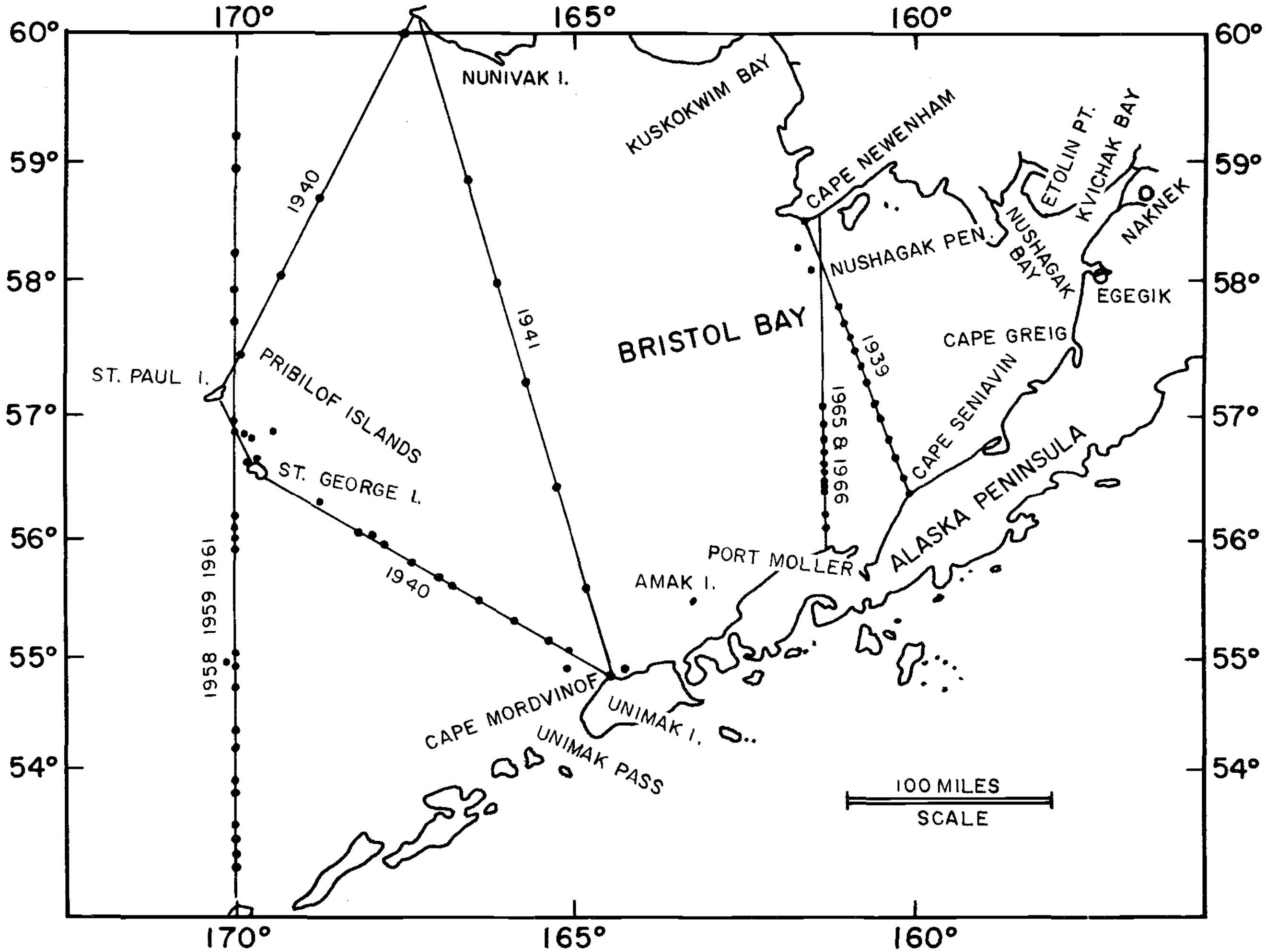

Figure 17. Year and location of exploratory fishing for salmon in the eastern Bering Sea and Bristol Bay, Alaska.

On the basis of the distribution shown by the eight years of catch data, the relative density of sockeye salmon in the offshore area is illustrated on a chart of the region. Areas having the greatest abundance of sockeye salmon are illustrated on the chart by dark shading and those with lesser abundance by lighter shading.

Offshore Tagging. The published results of eight years of salmon tagging carried out at various locations in the Eastern Bering Sea and outer Bristol Bay (Figure 18) are analyzed in this study. These years were selected because many of the sites of tagging were east of long. 170° W. in the area covered by the exploratory fishing previously discussed. The country conducting the tagging, the year and inclusive dates of tagging, the type of fishing gear and tags used, and the source of the recovery data are listed in Appendix Table 6.

These tagging experiments had various and specific objectives. Those carried out by the United States and Japan in 1957, 1958, 1960, and 1961 were designed primarily to provide information on the ocean movements and continent of origin of salmon. Major objectives of the tagging by the United States in 1964 and 1965 were to determine the feasibility of estimating terminal natural mortality by tagging salmon during their last few weeks of ocean life and to estimate growth over the same interval. The objective in the 1922 and 1925 experiments by the United States was to determine the destination of sockeye salmon

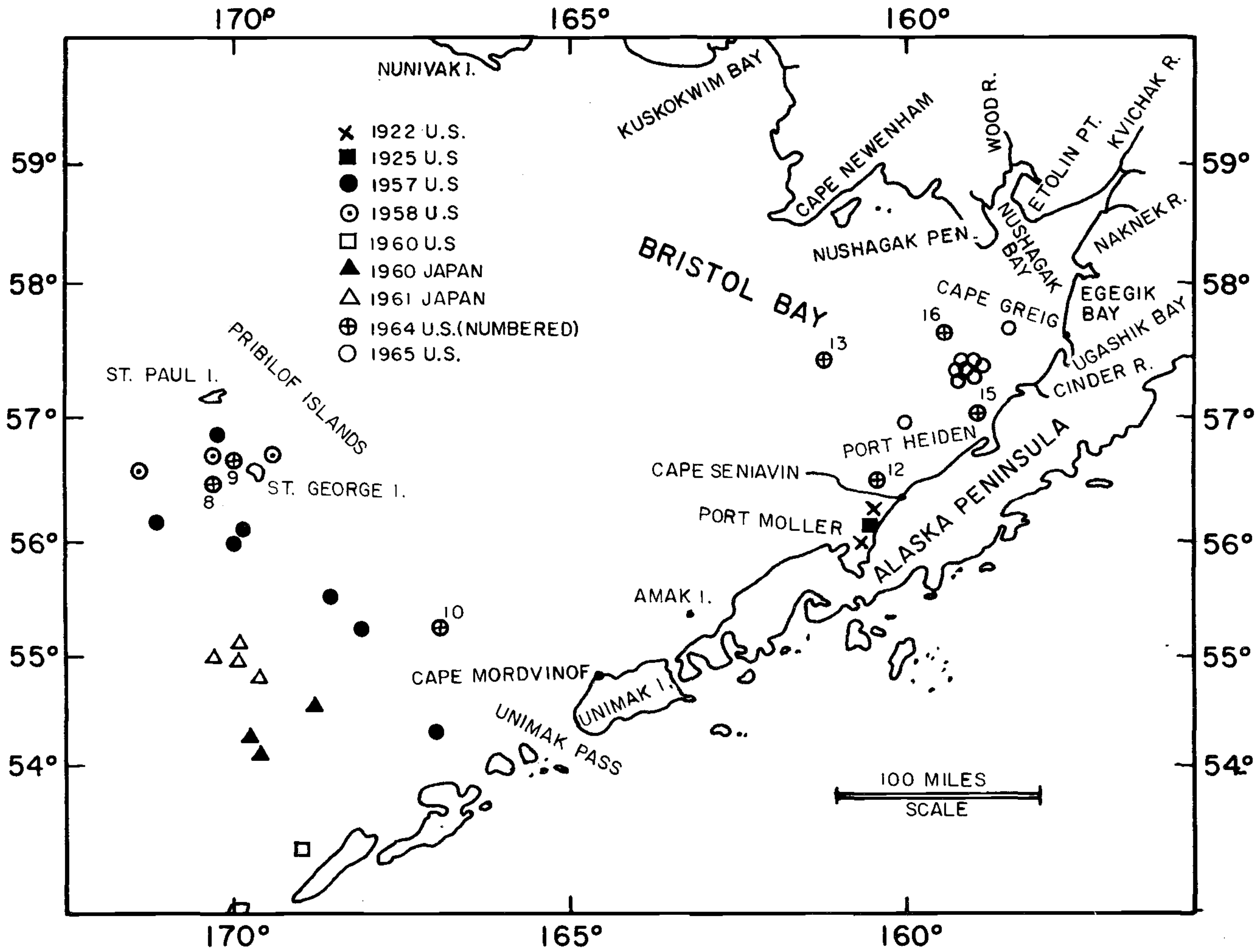

Figure 18. Location, by year, of salmon tagging in the eastern Bering Sea and outer Bristol Bay, Alaska.

in the coastal area just north of Port Moller (Figure 18).

In this thesis I use the tag-recapture data resulting from these experiments to determine the offshore distribution of individual stocks of sockeye salmon. This was possible because of the rather wide distribution of tagging sites over the approaches to Bristol Bay and the fact that tagged sockeye salmon from most sites were recaptured in the Bristol Bay fishery.

In this analysis, tag recoveries are grouped by fishing district, i.e., Nushagak, Naknek-Kvichak, Egegik, and Ugashik. The sockeye salmon migrating to each district are treated as individual populations even though several major river systems discharge into some of the districts. In Nushagak Bay (Figure 1) for example, the fishery is prosecuted on sockeye salmon destined for the Igushik, Snake, Wood, and Nushagak river systems. Therefore, in analyzing the offshore tagging, the Nushagak district stocks are treated in aggregate. The Naknek-Kvichak district includes much of Kvichak Bay through which pass the sockeye salmon bound for the Naknek, Kvichak, and Alagnak river systems. The Egegik and Ugashik districts include the areas around the entrances and portions of Egegik and Ugashik bays respectively.

The assumption is made in the analysis that tagged fish recaptured in a particular fishing district were actually bound for the major river systems entering that district. The validity of this assumption probably varied inversely with the size of the individual fishing district, i. e., the smaller the area of the district, the greater the likelihood that the assumption is true. This was indicated by the results of inshore tagging (to be discussed in a later section). These results showed a mixing of sockeye salmon stocks, in some areas formerly open to fishing, which were bound for river systems outside the fishing district in question.

The results of inshore tagging also showed little mixing in most districts between stocks of sockeye salmon bound for the rivers entering on the southeast and northwest side of the bay. This occurrence made it possible also to study the offshore distribution of sockeye salmon originating in the rivers entering on the southeast and northwest side of the bay. For analysis, tag recoveries from individual or groups of release sites were grouped according to whether they came from the southeast or northwest side fishing districts. The southeast side districts included the Naknek-Kvichak, Egegik, and Ugashik districts. The northwest side included only the Nushagak district. These grouped recoveries were analyzed in the same manner as the recoveries grouped by individual fishing districts.

In analyzing the recovery data, I adopted the hypothesis of like offshore distributions for all sockeye salmon stocks of Bristol Bay origin, i. e., sockeye salmon tagged at the various offshore sites occurred in the same proportion as they did in the total run to Bristol

Bay. I used chi-square analysis to test this hypothesis, comparing the actual with the expected tag recoveries in the individual and southeast and northwest side fishing districts. Probability values of less than P = 0.05 were considered to indicate unlike distribution or segregation of sockeye salmon stocks offshore. Tests on the recovery data grouped by southeast and northwest side fishing districts involved only 1 degree of freedom. In these tests 0.5 was subtracted from the absolute values of the deviations in the chi-square calculations as suggested by Snedecor (1956). This was to correct for the bias which would occur when the probability value was taken from Snedecor's chi-square table.

The expected number of tag recoveries from individual or grouped fishing districts was computed from the equation,

$$\hat{R}_i = C_i P_i \sum_{i=1}^{n} R_i \quad /W$$

where

R_i = expected number of recoveries from the i^{th} fishing district

C_i = proportion of the i^{th} district population caught in the fishery

P_i = proportion of the total Bristol Bay sockeye salmon run consisting of fish from the i^{th} district population

R_i = actual tag recoveries from the i^{th} district

W = total commercial catch of sockeye salmon for Bristol Bay divided by the total run

n = number of districts

Data used in the calculations on the size of the sockeye salmon run and commercial catch are listed by fishing district for each year of tagging in Appendix Tables 7-12.

The assumption is made in interpreting the results of this analysis, that tagged fish were equally as vulnerable to fishing as untagged fish. Several factors inherent in the fishery could cause tagged fish to be more vulnerable to fishing than untagged fish.

Commercial fishing in all districts in Bristol Bay is entirely by means of gill nets. Peterson (1954) showed that gill nets of the type and mesh size (5-3/8 stretch measure) used in Bristol Bay were selective for size of fish. Differences in the size composition of the commercial catch and the escapement indicate that the gill nets used in Bristol Bay are selective to the larger .3 fish.[5] Apparently a higher proportion of the smaller .2 fish are able to pass through the gill nets and escape.

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[5] .2 and .3 refer to the number of winters a salmon has spent in the ocean. The use of this method (European method) for designating the age of adult Pacific salmon in reference to marine life only was proposed by Koo (1962).

The size composition of the sockeye salmon runs to each fishing district varies from year and year and between districts in a single year. In some years the run to a given district may be composed largely of the smaller .2 fish. In other years the larger .3 fish may predominate.

Plastic disc tags, which were used in varying proportions in most of the offshore tagging (Appendix Table 6), have the disadvantage that they make the fish more vulnerable to gill nets than are untagged fish because the twine catches under the disc (Ricker, 1958). I have observed this on several occasions in the gill net recapture of sockeye salmon tagged in upper Bristol Bay. Because of the tag, the .2 fish, which were better able to pass through the gill nets, were more vulnerable to capture than .3 fish. The larger .3 fish were usually gilled (held in the net by the gills). The result is that a greater proportion of the smaller .2 tagged fish are captured. Large differences between districts in the proportion of .2 and .3 fish could lead to error in the interpretation of tagging results because of the differences in the vulnerability of these two size groups. No adjustments have been made for the selective action of gill nets in calculating the expected number of tags from each district.

Inshore Distribution of Sockeye Salmon

The inshore distribution and migration routes of the principal stocks of sockeye salmon in Bristol Bay were determined from tagging studies carried out in upper Bristol Bay in 1955-57 and 1959. These studies were conducted under my supervision and represent the most extensive tagging carried out to date in upper Bristol Bay. They were designed primarily to provide immediate information for regulation of the commercial fishery in each district. Specific objectives were to determine (1) when the various sockeye salmon stocks pass through each fishing area, (2) the length of time they remain available to the fishery, (3) their migration routes within the fishing district, and (4) the areas in which individual stocks intermingle.

Location of Inshore Tagging. The locations for capture and tagging of sockeye salmon were selected within and adjacent to each major fishing district (Figures 19-22). The fishing district boundaries (Figure 19) remained the same during the four years of tagging.

As pointed out earlier (Page 55), the locations for the release of drift cards were selected partially on the basis of former tagging sites. Some of the tagging sites were in areas which I would have selected for the tagging of sockeye salmon if prior knowledge of the bay distribution of the major river system waters had been available. Unfortunately there was a large area in the middle of upper Bristol Bay where no sockeye salmon were tagged. In analyzing the tag

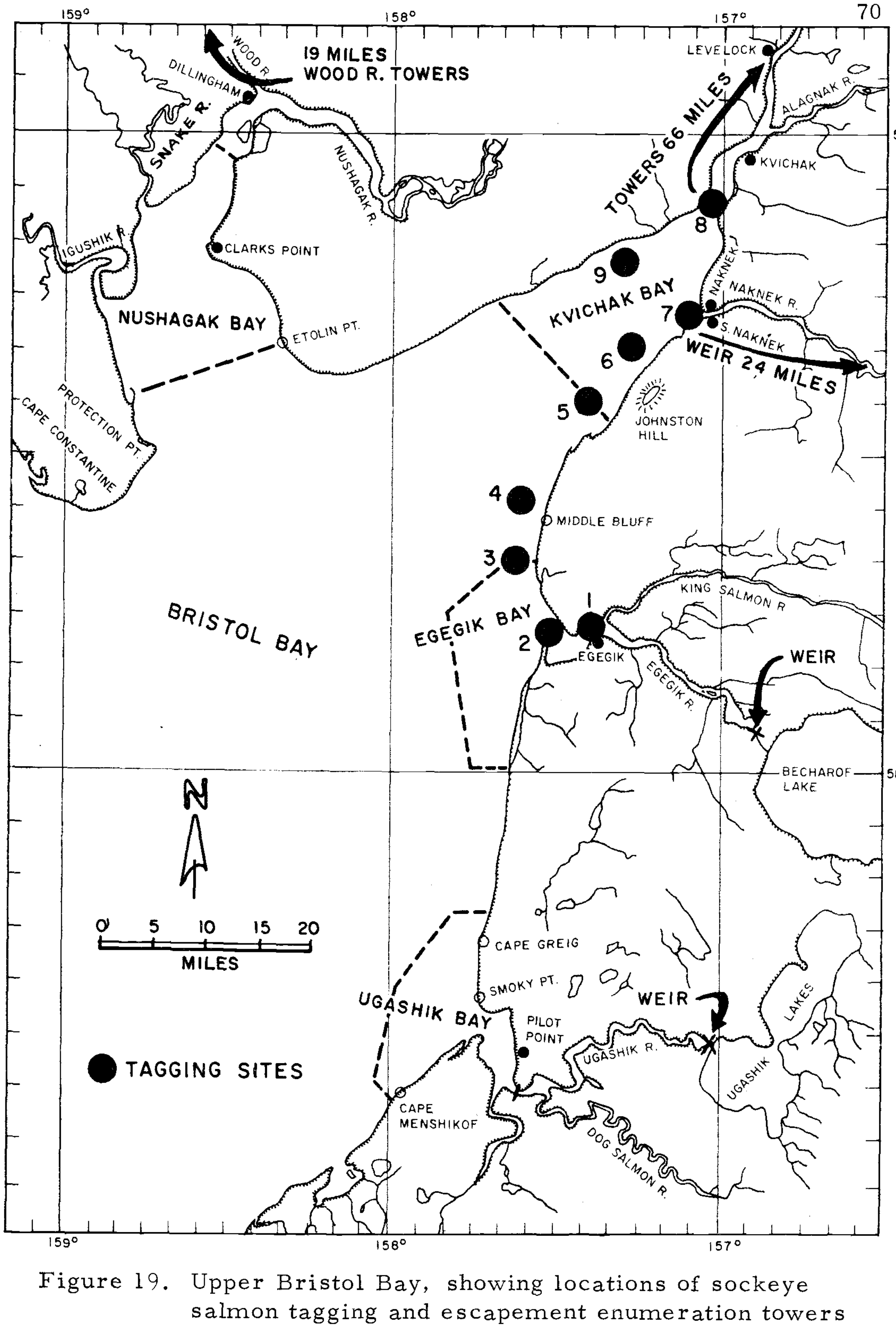

Figure 19. Upper Bristol Bay, showing locations of sockeye salmon tagging and escapement enumeration towers and weirs, 1955.

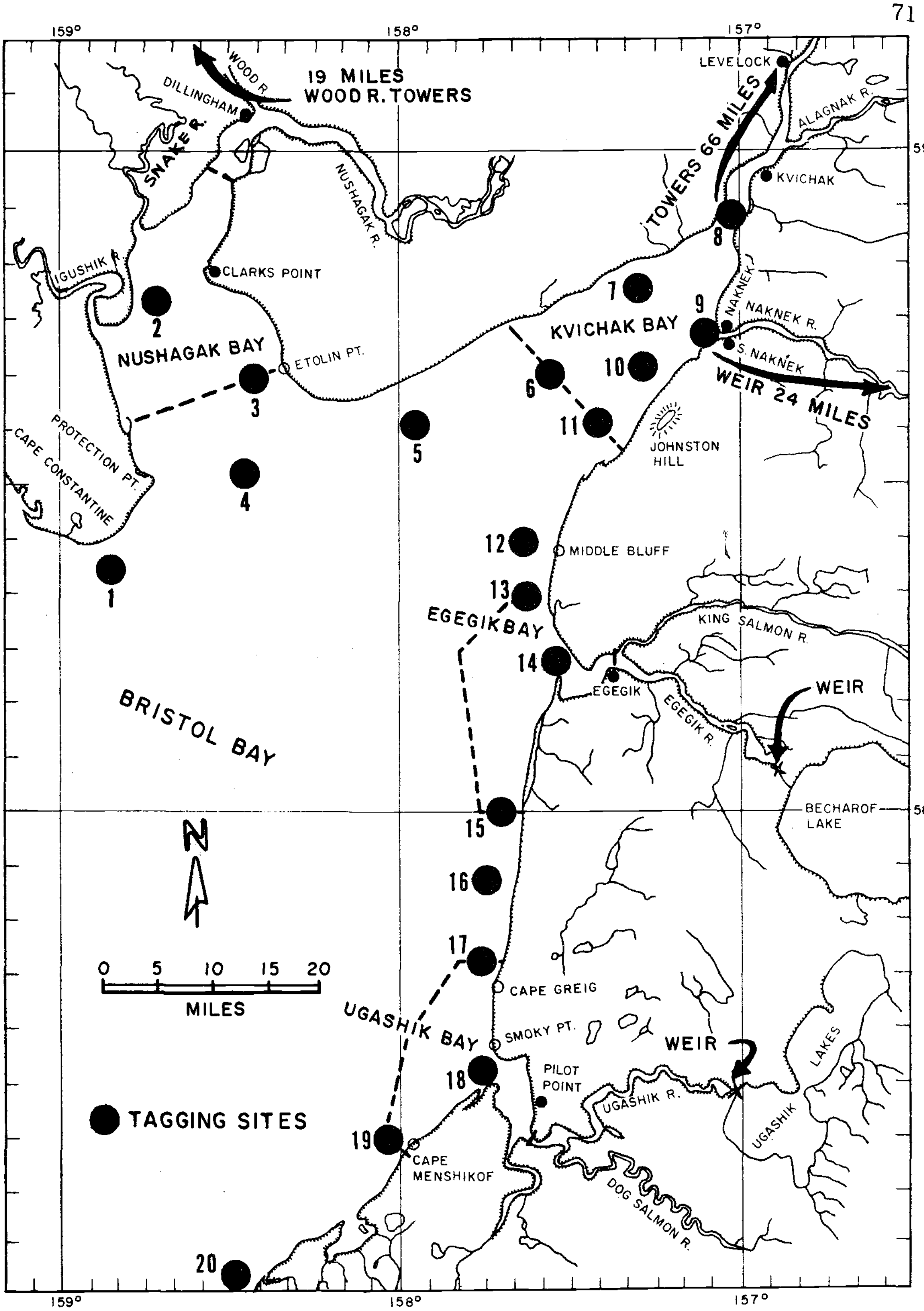

Figure 20. Upper Bristol Bay, showing locations of sockeye salmon tagging and escapement enumeration towers and weirs, 1956.

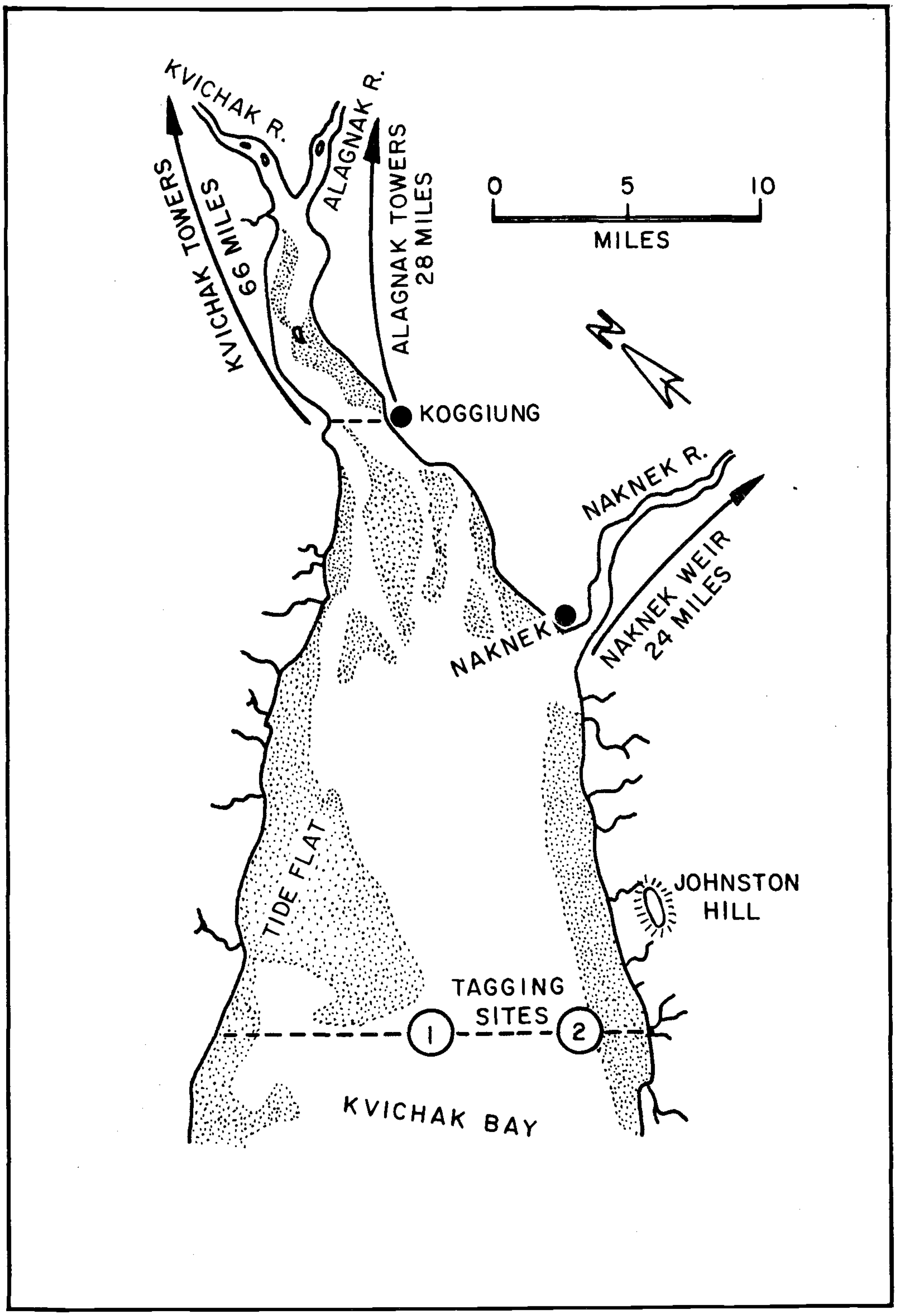

Figure 21. Kvichak Bay, showing locations of sockeye salmon tagging and escapement enumeration towers and weirs, 1957.

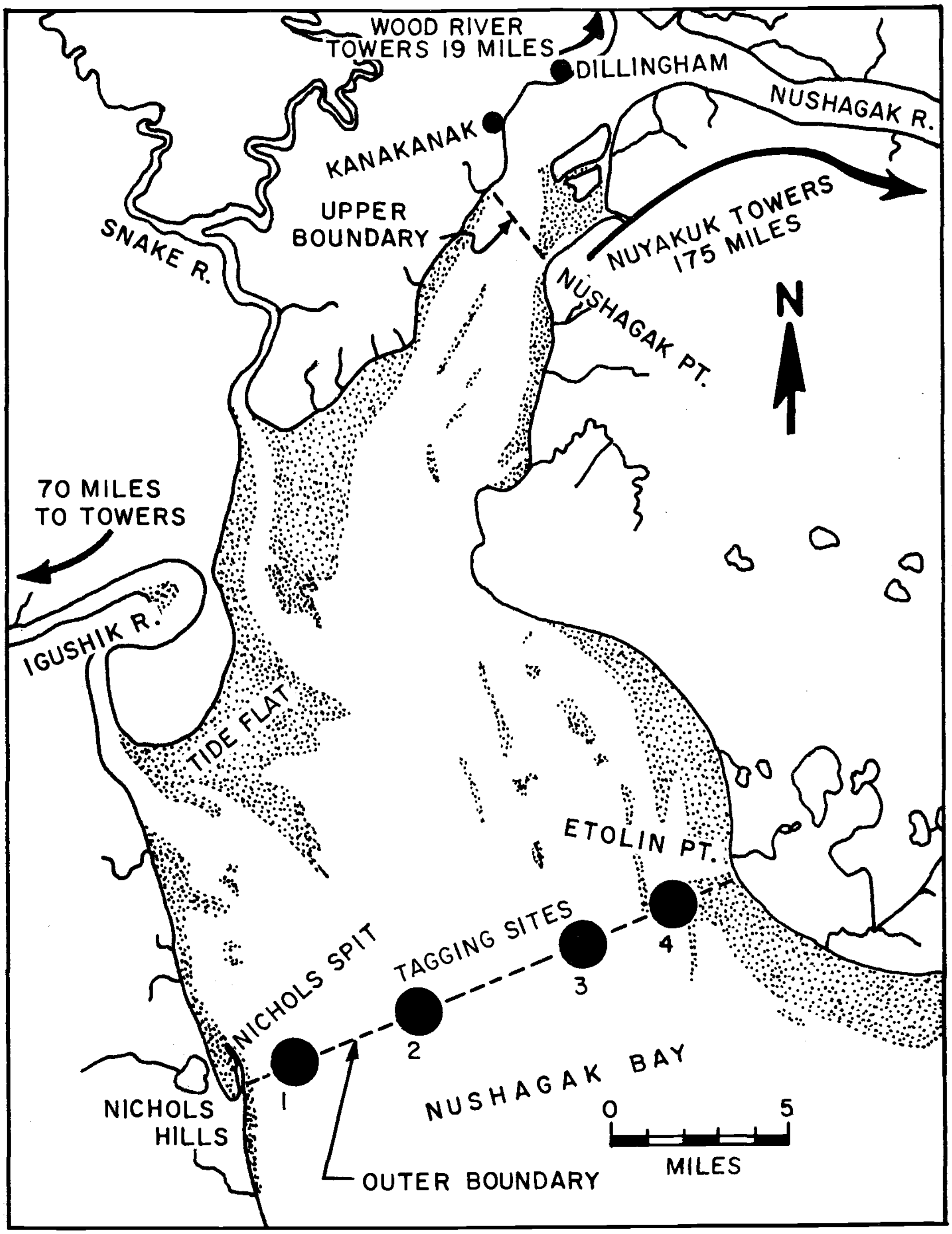

Figure 22. Nushagak Bay, showing locations of sockeye salmon tagging and escapement enumeration towers, 1959.

recovery data, I had to infer the stock composition of fish in this region from the results of both the offshore and inshore tagging.

Method of Capture, Tagging, and Handling. Sockeye salmon were captured in linen and nylon drift gill nets of the type and mesh size (5 1/2-inch stretch measure, 28 meshes deep) commonly used in Bristol Bay during the years of tagging. The length of net and the fishing time depended on the abundance of fish. When fish were abundant, only a small amount of net was fished; fishing time varied from 5 to 20 minutes. Every precaution was taken to minimize injury to fish, including cutting the mesh when necessary.

In the tagging studies in 1956, 1957, and 1959, standard type drift gill net boats, equipped with power rollers to assist in hauling the nets, were used for the fishing and tagging operations (Figure 23). In 1955 trunk cabin type "monkey boats"[6] were used for this work and nets were hauled by hand. As the gill nets were brought aboard the boat, the fish were freed and put into a life raft holding-pen tied alongside (Figure 23). Tagging began when all fish were removed from the net.

Red, blue, green, white, and yellow Petersen disc tags 3/4-inch (1955, 1956, and 1957) and 1-inch (1959) in diameter were used

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[6] "Monkey boat," type of vessel used to tow sail gill net boats to and from the fishing grounds.

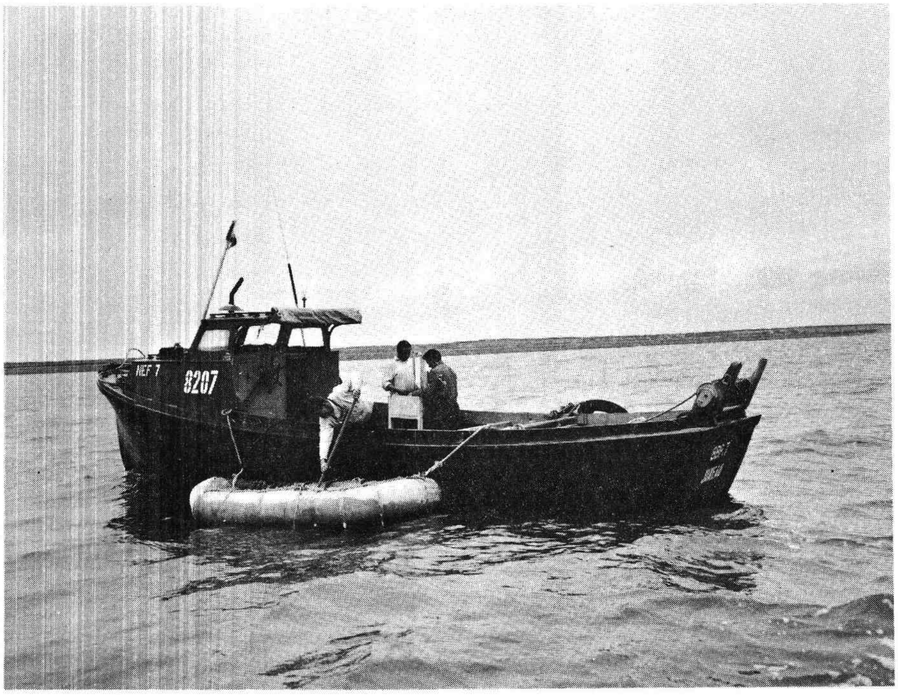

Figure 23. Standard drift gill net fishing boat used in inshore tagging studies, showing salmon holding-pen, Bristol Bay, 1959.

in various combinations, so that the date and location of tagging could be determined from visual observation of tagged fish in the spawning escapement. One disc tag was attached on each side of the fish with a 1 3/4-inch pure nickel pin which was inserted through the fleshy part of the back just beneath the dorsal fin. The right tag contained a serial number and reward notice and the left tag was blank. The number of sockeye salmon tagged with each color combination are listed by location and date of release for each year of tagging in Appendix Tables 13-16.

Tag Recoveries. Recoveries of tagged fish included visual sightings as well as actual recaptures. Actual recaptures were obtained from the commercial gill net fishery operating in each district, the personal-use gill nets operating on the major rivers above the fishery, and the spawning grounds.

To facilitate recoveries from the fishery 50 cents was paid in 1955 and 1 dollar in 1956, 1957, and 1959 for each set of disc tags turned in. Before the beginning of the commercial fishing season, posters advertising thetagging studies, which noted the cash reward offered for tags and where to send them, were distributed to all places where fish landings were expected. These posters were also displayed in prominent places in most villages in the Bristol Bay area. Maps of the fishing district on which to mark the location of capture, and envelopes on which to record the recovery information were distributed to all canneries and "tally" scows and to as many individual fishing boats as possible. The information requested included the tag number, date, time, and place of capture, type of fishing gear used, and the finder's name and address. Cannery bookkeepers accepted tags from fishermen, recorded the recovery data when necessary, and facilitated payment of tag rewards. In addition, Bureau of Commercial Fisheries personnel in the field were provided with cash for "on-the-spot" payment of tag rewards; they personally contacted as many fishermen as possible.

Weirs built across some of the major rivers and observations towers located on each bank of other rivers were used in Bristol Bay to enumerate the spawning escapement. Observations were made from these structures of tagged fish in the escapement to each major river system during the daily enumeration of the escapement. Placards displaying tag color combinations were placed at the counting gates of each weir and at each tower to assist in positive identification of tagged salmon. For the river systems whose escapements were not observed from weirs or towers, spawning ground and personal-use gill net recoveries of tagged fish provided information on the source of the fish.

The coverage of the major river systems by weirs and towers as well as the methods of enumerating the escapement varied for the different years of tagging.

In 1955 and 1956, sockeye salmon escapements to the Naknek, Egegik, and Ugahik river systems were enumerated at weirs (Figure 19) operated by personnel of the Bureau of Commercial Fisheries. The escapements to the Wood and Kvichak river systems were enumerated from observation towers located on both banks of these rivers. The towers were manned by personnel of the Fisheries Research Institute of the University of Washington. The Igushik, Snake, and Nushagak rivers discharging into Nushagak Bay and the Alagnak River discharging into Kvichak Bay were covered by aerial survey.

In 1957, the Fisheries Research Institute operated the towers on the Wood and Kvichak rivers as it had in 1955 and 1956. The Bureau of Commercial fisheries operated towers on the Alagnak, Egegik, and Ugashik rivers and a weir on the Naknek River. The Igushik, Nushagak, and Snake river escapements were not enumerated from towers or weirs in 1957.

In 1959 the Bureau of Commercial fisheries operated towers on the Igushik, Nuyakuk, Alagnak, Naknek, Egegik, and Ugashik rivers. The Fisheries Research Institute again operated the towers on the Wood and Kvichak rivers as in previous years.

A total count of the daily spawning escapement was made at all weirs in 1955. In 1956 sample counts were made at the Naknek and

Egegik weirs during periods of heavy migrations. Sample counting of the daily escapement was conducted at the Naknek River weir in 1957. Sample counting was also carried out at the towers located on the various river systems in all years.

Although sample counting periods varied in length at the towers and weirs, the method of weighting tagged fish sightings made during these sample periods were essentially the same for all years. At weirs the number of tags observed during the sample counting period was multiplied by the fraction of the hour counted to furnish the estimated hourly tag count. Hourly estimates were totaled daily and for the season to furnish an estimate of the total number of tagged fish in the spawning escapement. In 1956 when sample and total counts of the escapement were both made at the Naknek and Egegik weirs, the weighted sample counts were added to the total counts to furnish an estimated daily and seasonal tag count for these river systems. On the river systems covered by towers tags sighted during the sample counting periods at each tower were weighted in a similar manner. The individual estimates for each tower were totaled to provide a daily and seasonal estimate of the number of tags in the escapement to these rivers.

For the Kvichak River in 1955 and the Nushagak River in 1959, I had to rely largely on the recaptures of tagged fish taken by the personal-use gill nets located downstream from the observation towers to provide information on the major source of tagged fish in the escapement. This was because too few fish were positively identified during the sample counting periods at the towers.

The Snake River escapement was not usually enumerated, but in 1959 it was unusually large (200,000 sockeye salmon--unpublished data on file with the Bureau of Commercial Fisheries, Auke Bay, Alaska) and the spawning grounds were therefore surveyed for tags.

Treatment of Tag Recovery Data. I used the distribution of tag recoveries in the commercial fishery and observations of tags sighted in the escapement to show the distribution of the stocks of sockeye salmon from the various rivers in upper Bristol Bay. The distribution of fishery recaptures and escapement observations of sockeye salmon tagged at each site for each year of tagging are illustrated in histograms and on charts of the upper bay. These illustrations are used to depict graphically the distribution and migration route of the individual river system stocks of sockeye salmon in upper Bristol Bay.

As mentioned earlier (Page 65), the results of the inshore tagging in upper Bristol Bay showed that the commercial catch of sockeye salmon within the four fishing districts was composed of mixed stocks, some of which were bound for river systems outside the district in question. For this reason the distribution in the escapement (regarded as a pure or unmixed stock) of fish tagged at each site is probably a better indication of the final destination of tagged fish released at various sites in upper Bristol Bay than is the distribution of fishery recaptures. Tagged fish recaptured in the fishery have been included in the analysis, however, because they serve to complement the results shown by the distribution of tags in the escapement. When viewed with the escapement tag distribution, the distribution of tags in the fishery aids in interpreting the movement of individual sockeye salmon stocks within the fishing districts. In addition, both tag recovery distributions indicate that the mixing of several nondistrict stocks within a given fishing district was not serious enough to prevent interpretation of the distribution and migration routes of individual sockeye salmon stocks in upper Bristol Bay.

Several assumptions are made in interpreting the tag recovery data. First, sockeye salmon of each river system are assumed to be tagged in proportion to their abundance in the area of tagging. If significant mixing of stocks of two different ocean age groups (2 or 3 years in the ocean) occurred in the area of tagging, the selective action of the gill nets (Page 67) used to capture fish for tagging could have resulted in a larger proportion of the 3-ocean fish being caught than were actually present. In general, the recovery distributions resulting from taggings at several of the same locations but in different years were similar. The magnitude of the run as well as the size composition varied between fishing districts in these years. The similarity of distributions for different years indicates that such mixing of stocks of different ocean age was not serious enough to prevent interpretation of the distribution of individual stocks in upper Bristol Bay.

A second assumption is that the proportion of each stock at a given tagging location remained essentially the same throughout the duration of the sockeye salmon run into Bristol Bay. This assumption is necessary because to provide sufficient numbers of tags for analysis, particularly in 1955, 1956, and 1959, I have grouped the recoveries from all taggings at each site regardless of the date when the fish were tagged. The distribution of individual stocks of sockeye salmon may change at times because of tide and wind conditions. For example, I have personally talked with commercial fishermen who have stated that when winds are strong from the southeast, good catches can be made on the northwest side of Kvichak Bay. If such changes in stock distribution occur they may be of short duration and are probably due to violent environmental changes. Their occurrence during the four years of tagging would not be apparent in my analysis, however, because of the grouping of tag recoveries.

In most years and at most tagging sites, the majority of fish were tagged during a two-week period (Appendix Tables 13-16) during which the sockeye salmon runs to each fishing district reached their maximum strength. Appendix Tables 17 to 20 show the commercial sockeye salmon catch by fishing periods for each fishing district and for each year of tagging. These tables give the period when the runs to each district reached their greatest abundance. Because most of the fish were tagged during this period, the distribution of the individual sockeye salmon stocks in upper Bristol Bay is representative of the major portion of the run to each district.

A third assumption made in analyzing the tagging data is that tagged fish recaptured in each fishing district had an equal likelihood of being reported to investigators. There was no reason to expect a variation in reports from fishermen in each district of the tagged fish captured and therefore in the validity of this assumption.

The final assumption made in the analysis is that each tagged fish in the spawning escapement had an equal likelihood of being observed and identified as to location of tagging. As mentioned earlier, it was necessary to ascertain the color of the tag on each side of the fish to identify the location at which the fish was tagged. At weirs this was a relatively simple task. Here an observer sat directly over an opening through which fish must pass, and both sides of the fish could be seen easily. Identifying the tag color on both sides of a fish from towers was more difficult, however. An observer in a tower does not sit directly over the fish as they move upstream, and at times when tagged fish were observed at some distance from shore it was possible to identify the color of the tag on only one side of the fish. Therefore, rivers with weirs probably had a higher proportion of tagged fish in the spawning escapement positively identified than rivers covered by towers. Because of such things as the magnitude of the run and turbidity of the water, the ability to identify tagged fish from towers also varied from day to day, between river systems, and from year to year. The numbers of fish bearing each tag color combination observed in the spawning escapement to each river system have not been adjusted for possible differences in the ability of observers to identify the color of both tags. When viewing the recovery distribution in the discussion of the tagging results the reader should keep this point in mind. The actual number of tags in the spawning escapement of rivers having observation towers was probably higher than is shown in the results.

One additional method was used to show the distribution of Naknek, Kvichak, and Egegik river sockeye salmon stocks in upper Bristol Bay. In 1955 a scale sample was taken from each fish tagged. From the scales, the age group (6_3, 5_2, 4_2, etc.)[7] to which each fish

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[7]This method used to designate the age of Pacific salmon was first introduced by Gilbert and Rich (1927). The first number denotes the total age of the fish (figured from time of egg deposition), and the subscript represents the year of life that it migrated from fresh water to the sea. Thus, a 4_2 salmon, called a "four-two," refers to a fish that migrated to sea in its second year and returned as an adult in its fourth year of life.

belonged was determined. The percentage age group composition of all fish tagged at each tagging site was compiled. Two age groups (6_3 and 5_2) were found to change significantly at the tagging sites between Egegik Bay and the Naknek River mouth. The percentage of these two age groups in total numbers of fish tagged at each site is illustrated in a histogram to show this change. The percentage of these two age groups in the Naknek, Kvichak, and Egegik escapements is also shown in the same illustration for comparison with the results obtained for the fish tagged at each site. This illustration was then used as an aid in explaining the distribution of Naknek, Kvichak, and Egegik River sockeye salmon stocks in upper Bristol Bay.

VI. DISTRIBUTION OF RIVER WATERS AND CIRCULATION PATTERN IN UPPER BRISTOL BAY

Vertical and Horizontal Salinity Distribution

Vertical and horizontal salinity profiles prepared from measurements in July and August 1966 are shown in Figures 24-28. The vertical salinity gradient between the surface and the bottom of all transects was 3‰ or less, except near the Naknek River mouth (Figure 24--A). This type of salinity distribution is generally characteristic of vertically homogeneous estuaries where mixing is nearly complete from surface to bottom. In Bristol Bay, vertical mixing is facilitated by the extreme tidal fluctuations, shallow depth, and large cross-sectional area (exposure to winds).

In upper Bristol Bay there is considerable lateral variation in salinity (Figures 25-28); water on the northwest side of the bay has low salinity and that on the east side has high. Dodimead *et al.* (1963) showed that this condition persists farther offshore in the Bering Sea. Runoff water of low salinity moves seaward on the right side of the bay (looking seaward), and a counter current of high-salinity water is present on the left side. This current appears as a wedge of high-salinity water, which separates the river waters entering on each side of the bay and extends up the bay almost to Middle Bluff.

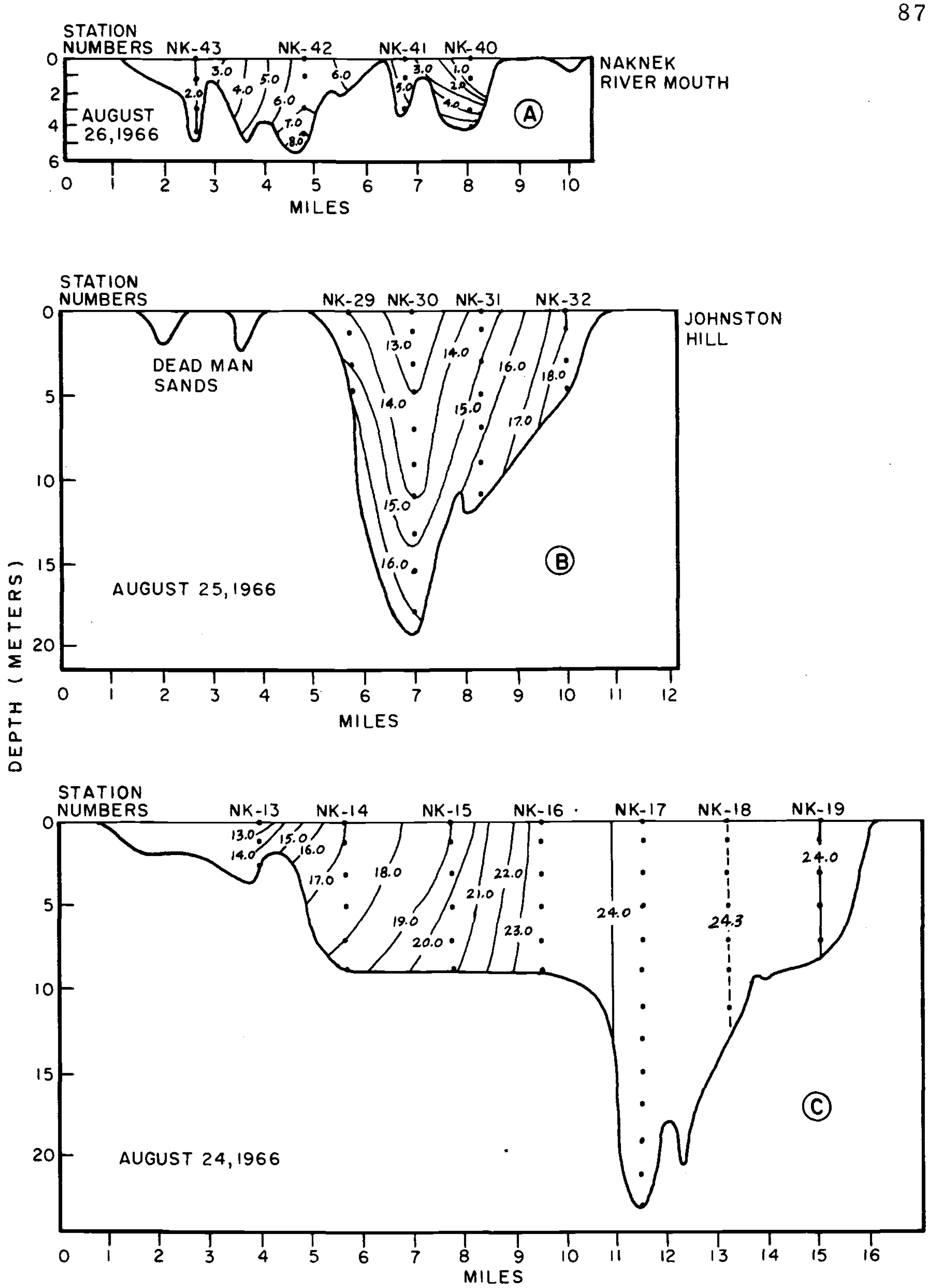

Figure 24. Vertical profiles of salinity (‰) at 10-mile intervals across upper Bristol Bay, August 1966.

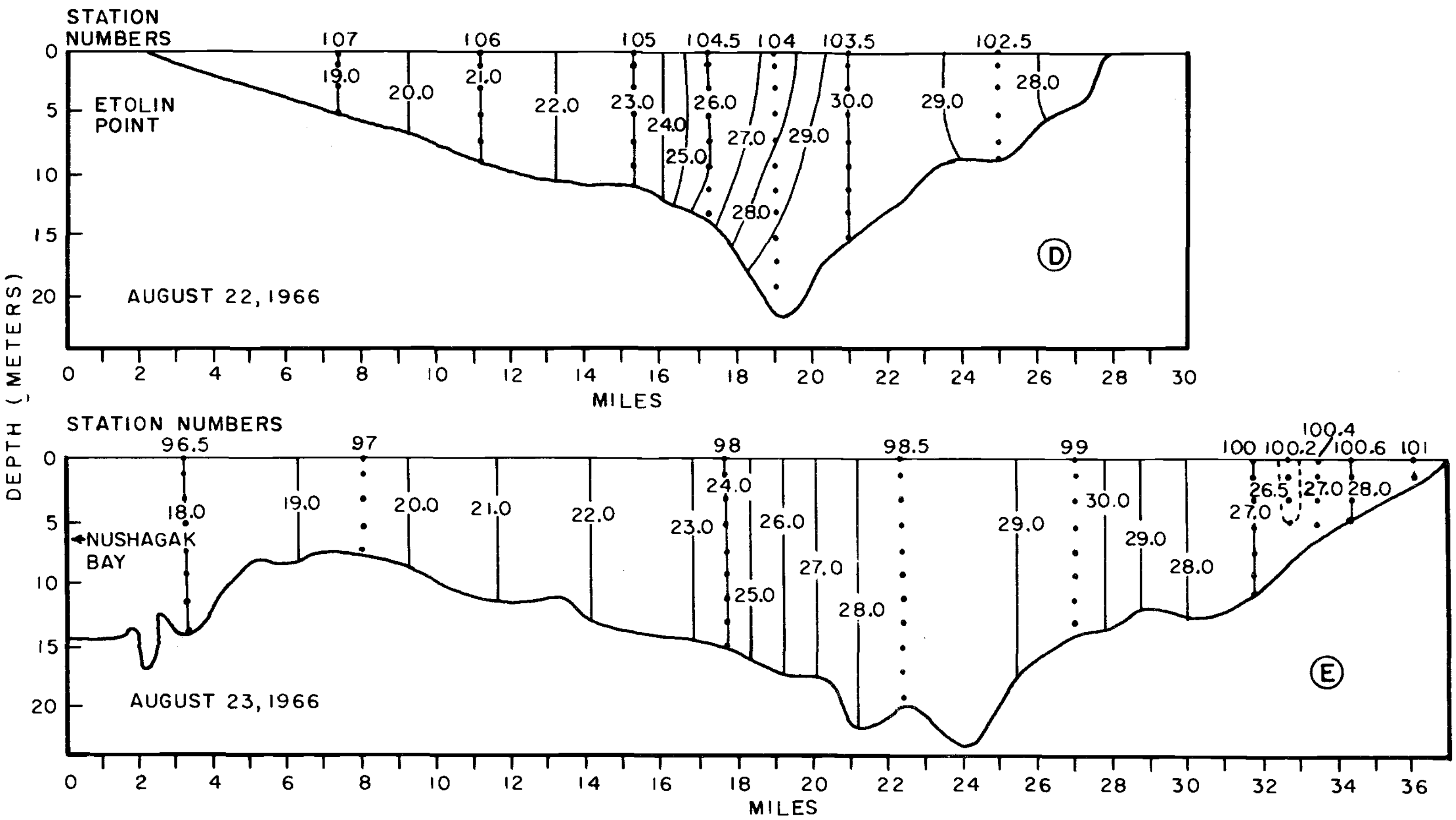

Figure 24 (continued). Vertical profiles of salinity (‰) at 10-mile intervals across upper Bristol Bay, August 1966.

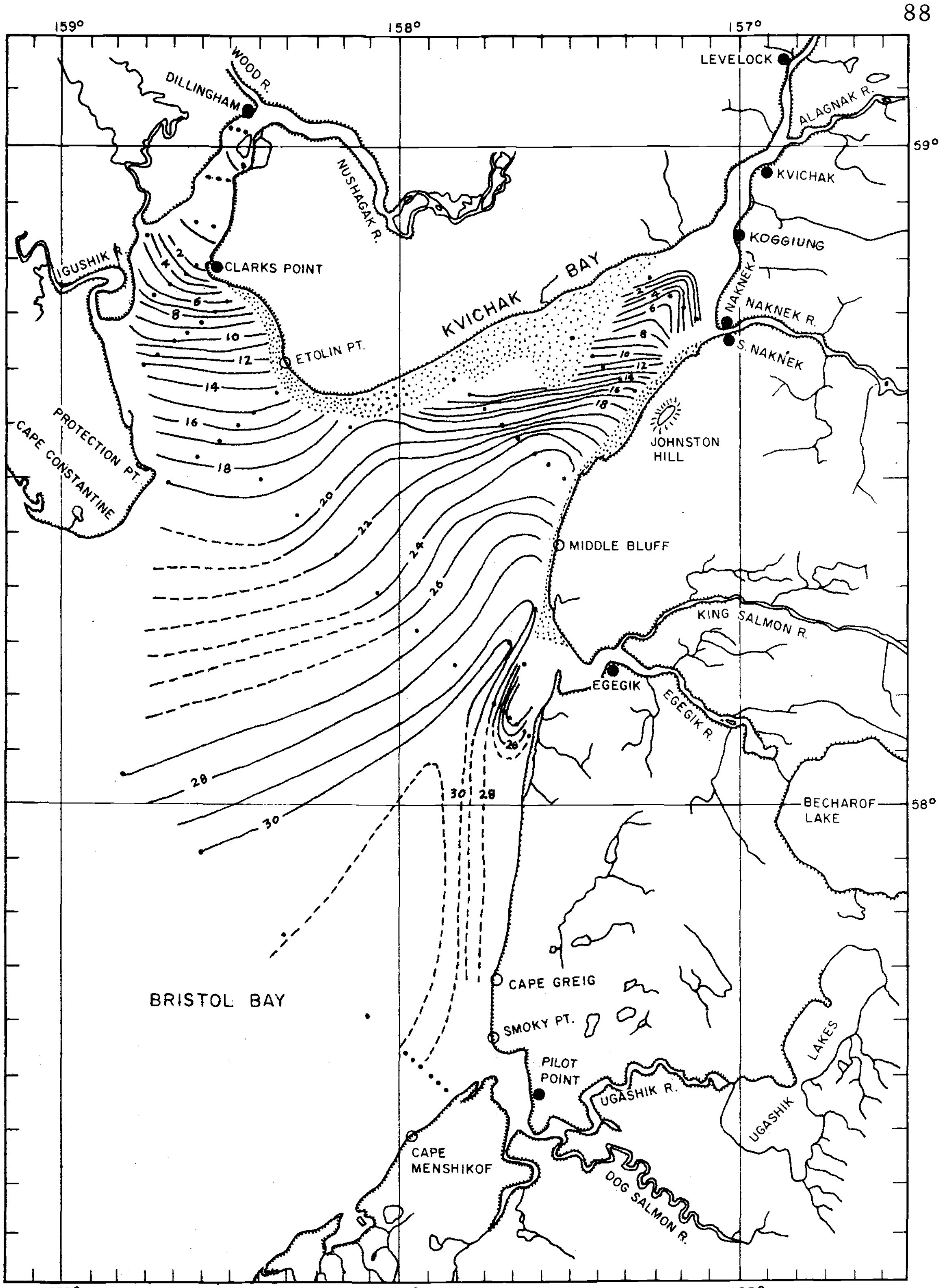

Figure 25. Surface salinity (‰) at low tide, Bristol Bay, July and August 1966.

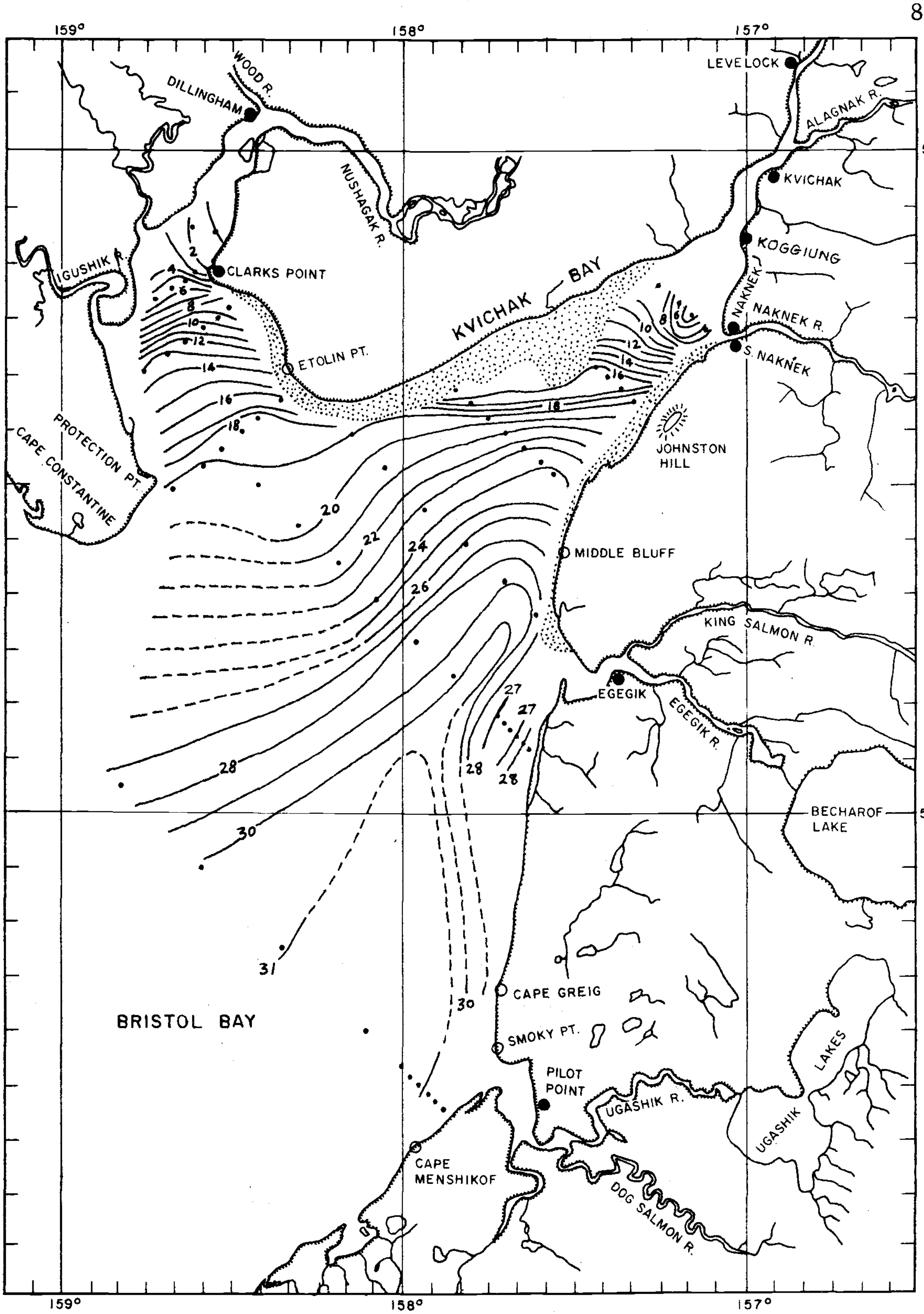

Figure 26. Bottom salinity (‰) at low tide, Bristol Bay, July and August 1966.

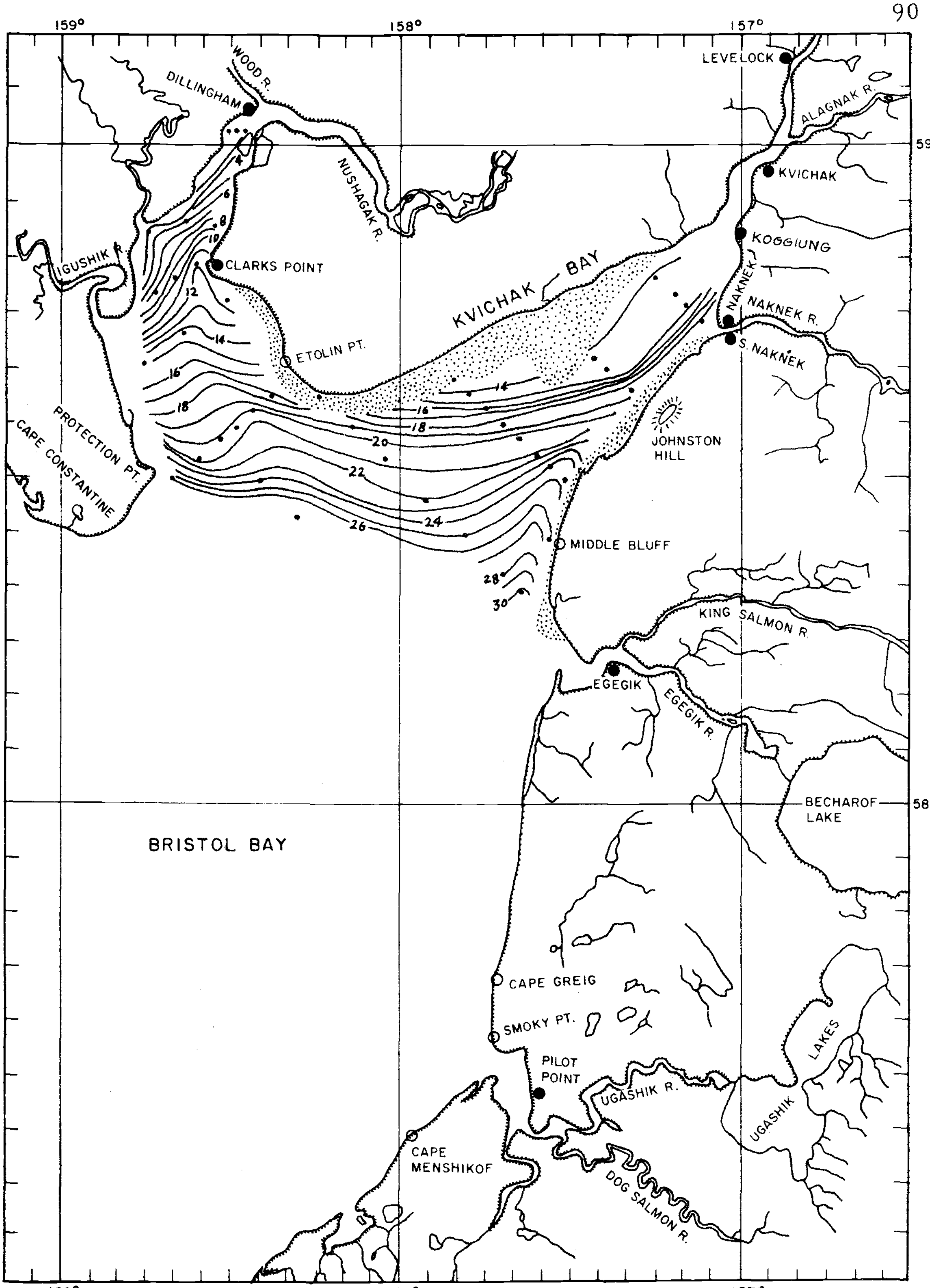

Figure 27. Surface salinity (‰) at high tide, Bristol Bay, July and August 1966.

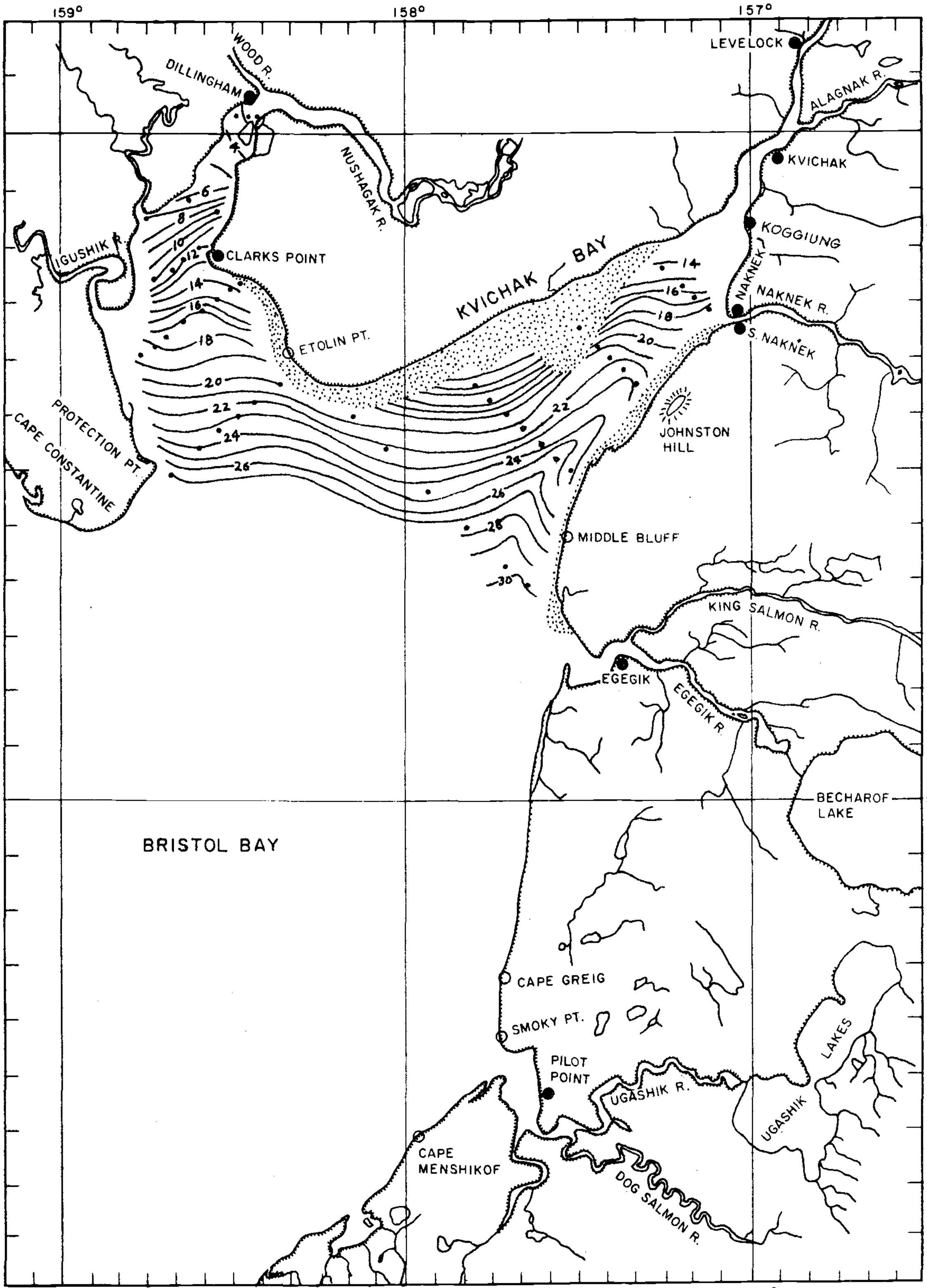

Figure 28. Bottom salinity (‰) at high tide, Bristol Bay, July and August 1966.

Results of Tracer Studies

The results of tracking individual dye releases in the Naknek, Egegik, and Ugashik rivers during the ebb and flood tide in 1965 and 1966 are illustrated by the position of the dye patch at successive times after release in Appendix Figures 1-11. The individual experiments are combined in Figures 29 and 30 to show the general course of these rivers in the bay during ebb and flood tides.

Under the low wind conditions (less than 15 knots) in which the tracking studies were carried out, the rivers followed rather discrete and similar courses in the upper bay during both the ebb and flood tides. Subsequent tracking of dye released near the river mouths (Naknek, Egegik, and Ugashik) about the end of the ebb tidal current showed that a portion of the river water was carried north of the mouths on the succeeding flood tidal current (Figure 30). This water has the lowest salinity and contains the greatest fraction of river water of any water that enters the bay during a tidal cycle. Unmixed Naknek River water reaches a mile or so beyond the river mouth out into Kvichak Bay. Waters from the Egegik and Ugashik rivers, however, are well mixed with higher salinity water in Egegik and Ugashik bays. Waters from these rivers entering Bristol Bay at the end of the ebb low tide were not less than 23 to 24‰. Unmixed Kvichak River water reaches as far as the village of Koggiung at the head of

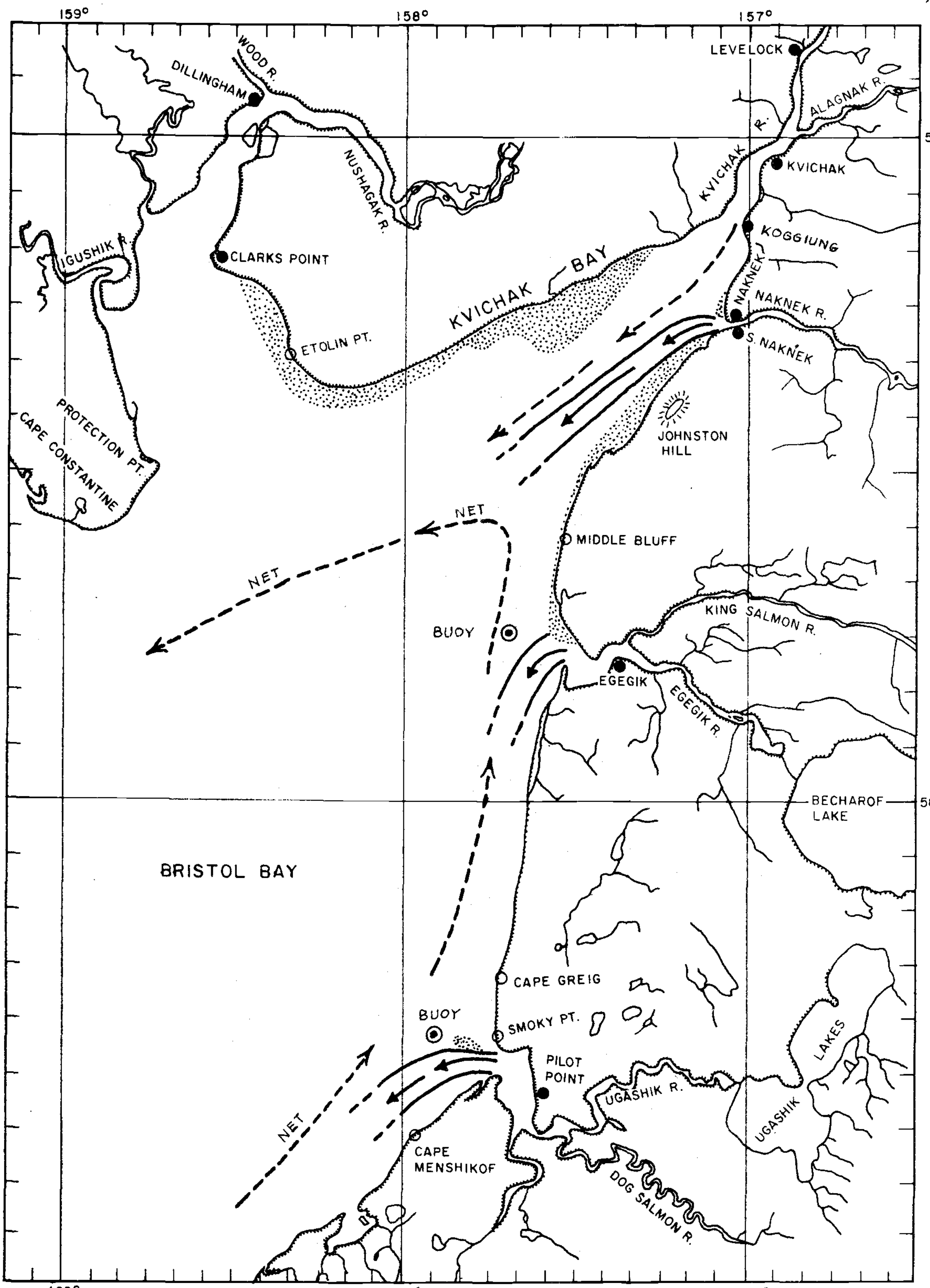

Figure 29. General course of river waters in Bristol Bay during ebb tide as determined from dye tracking.

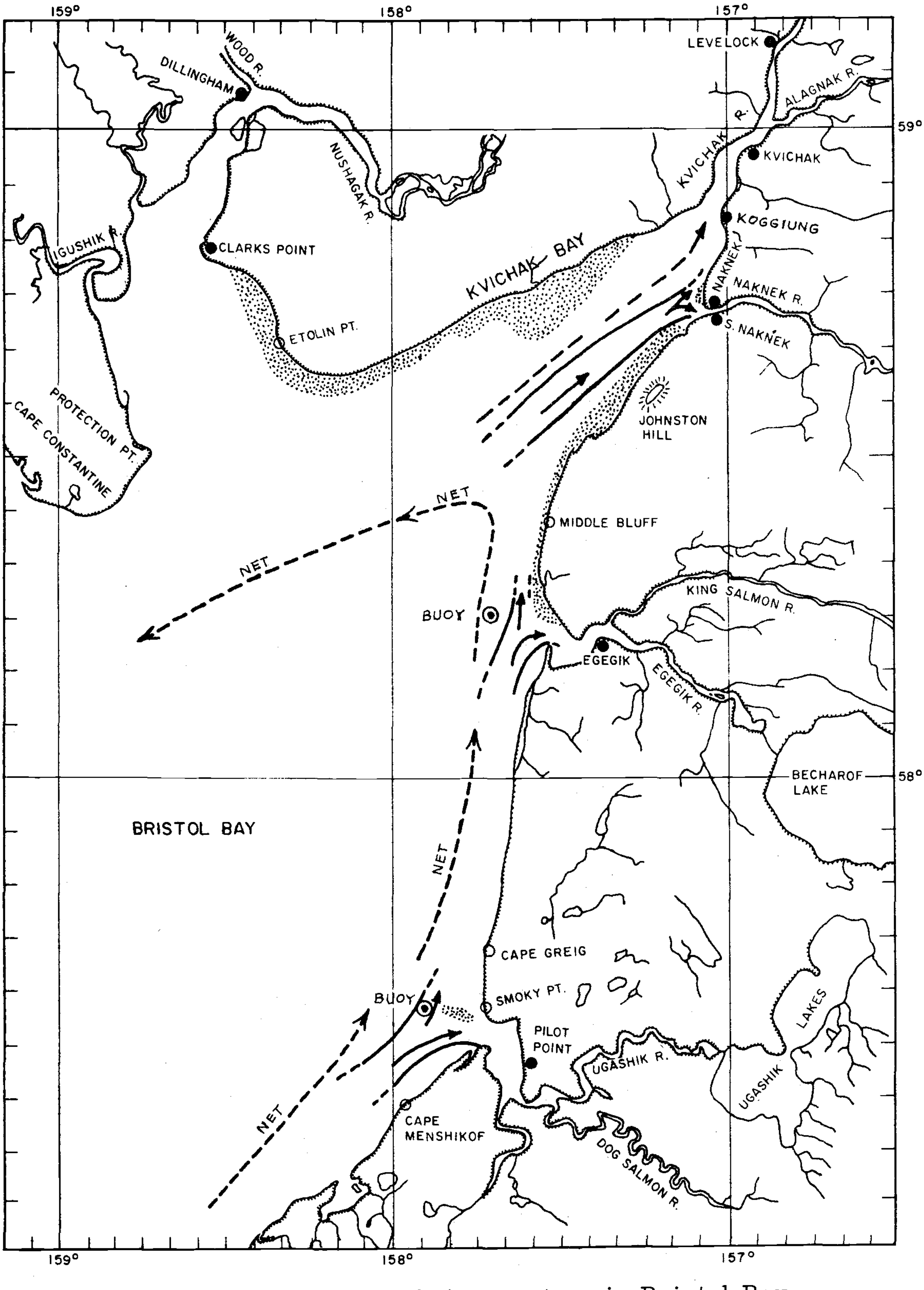

Figure 30. General course of river waters in Bristol Bay during flood tide as determined from dye tracking

Kvichak Bay. In most cases dye was tracked at least three miles north of the river mouth on the flood tide. This water moved toward shore and covered tideflats exposed at low tide.

The presence of shear lines, caused by adjoining currents having different speeds or directions, affected the distribution of dye. These shear lines are always discernible during relatively calm weather and are a characteristic feature of the upper bay. They are generally in specific regions during the middle phases of the ebb tide. For example, shear lines are formed during the ebb tide off the Naknek River mouth and at the entrances to Egegik and Ugashik bays. They disappear during the flood tide and reappear, usually with some lateral variation of the axis, during the following ebb tide. Shear lines marked the boundaries between the waters of the Naknek and Kvichak rivers and between the offshore waters flowing down the coast and the waters of the Egegik and Ugashik rivers. Depending on the surface turbulence, shear lines could be observed four miles offshore from the entrance to Egegik and Ugashik bays and eight miles from the mouth of the Naknek River. Dye released into Naknek, Egegik, and Ugashik rivers never crossed well-developed shear lines. Farther offshore the shear lines lost their identity, no doubt because of decreased velocities and differences in the direction of the separate currents, and the dye dispersed laterally to some extent. In Figure 29, the upper four to eight miles of the outer boundary denoting the course of the rivers corresponds to the location of the shear lines. The course followed by individual river waters during flood tide were not associated with shear lines.

The area of Kvichak Bay that is not occupied by Naknek River water must be occupied by water from the Kvichak River (Figures 29 and 30). Undoubtedly mixing takes place between these two rivers along their interface, particularly farther seaward on the ebb tide where the current velocities of the individual water masses are reduced. Mixing between water masses would also take place during the flood, but Kvichak River water should always be preponderant along the northwest shore and Naknek River water along the southeast shore of Kvichak Bay.

Naknek and Kvichak river water masses move toward the northwest side of upper Bristol Bay (Figures 29 and 30). By the time these waters have moved south as far as the Middle Bluff area, they are more than five miles offshore. This movement of less saline water toward the northwest side of the bay may be inferred also from the closer spacing of the isohalines to the west of the Middle Bluff area and above (Figures 25-28).

The course and distribution of Egegik River water is also clearly seen in the salinity distribution off the entrance to Egegik Bay (Figures 24--E, 25, and 26). The results of the dye studies and those shown by the distribution of salinity are consistent and serve to complement one another. Salinity data were not obtained from the entrance of Ugashik Bay, but the results of dye studies show that the salinity pattern there should be similar to the one observed off Egegik.

Results of Drift Card Studies

Of the 1,007 drift cards released at various locations, 141 were eventually recovered (Table 1). Eighty-nine (8.8 percent) were recovered from beaches; parts of an additional 31 cards were also found on the beaches but were unusable because the parts salvaged did not contain identifying serial numbers. The brittleness of the plastic from which the cards were constructed apparently caused them to break apart in the surf.

Table 1. Summary of drift card recoveries by site of release, Bristol Bay, 1967

Location of release (Figures 31-38)	Number released	Number recovered	Percent recovered
Kvichak River mouth	102	33	32.4
Naknek River mouth	100	44	44.0
Cape Chichagof	150	11	7.3
Egegik Bay entrance	101	5	4.9
58° parallel of latitude	152	14	9.2
Cape Greig	151	21	13.9
Ugashik Bay entrance	101	4	4.0
Cape Menshikof	150	9	6.0
Total	1,007	141	14.0

The location of recoveries by site of release are illustrated in Figures 31 through 38 and listed individually in Appendix Table 21. In the figures, the lines drawn from the site of release to the point of recovery show the direction of drift.

The direction of drift for cards released across the mouth of the Kvichak and Naknek rivers (Figures 31 and 32) was seaward in a southwesterly direction. Most of the cards recovered from these two releases came from the area between the Naknek River mouth and Johnston Hill. The recovery in this area was probably due to several factors. The bottom topography at the Naknek River mouth (Figure 39) is such that water leaving Naknek River during the first several hours after high slack water moves seaward along the southeast side to Kvichak Bay. This movement must also occur for the water above the Naknek River mouth along the east side of the Kvichak River. Once the water has dropped far enough, the influence of a gravel bar off the entrance to the Naknek River (Figure 39) causes the main stream of Naknek River water to be directed farther offshore. The water moving seaward along the east side of the Kvichak River is also directed farther offshore. At this stage of the tide, the meeting of the waters leaving the Kvichak and Naknek rivers causes the formation of the shear line in the Naknek River mouth mentioned earlier. The emergence of the gravel bar during ebb tide also causes an eddy, or dead-water area, seaward of the bar which seems to extend as far as

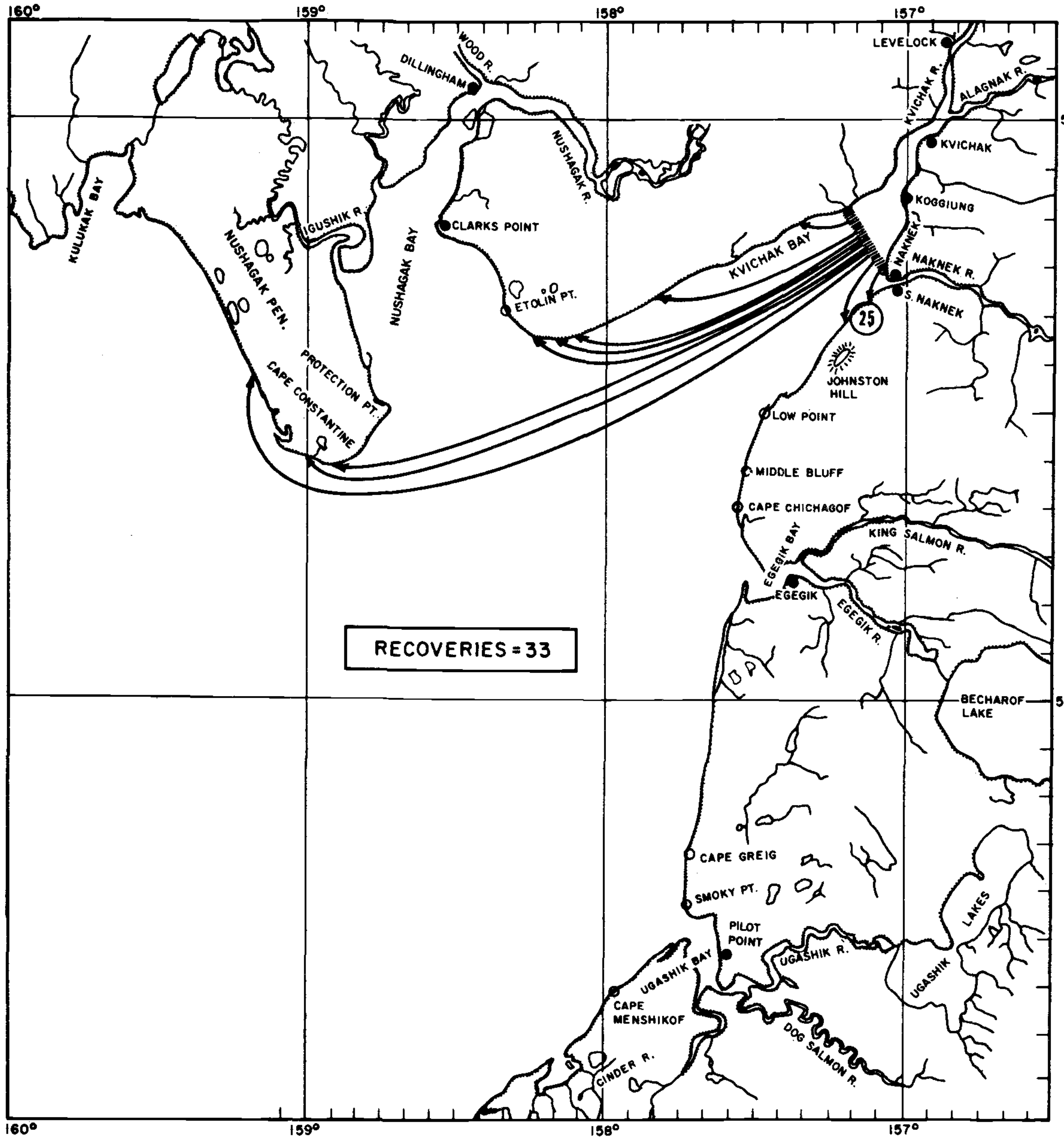

Figure 31. Recovery locations of drift cards released across the Naknek River mouth, Bristol Bay, June 2, 1967

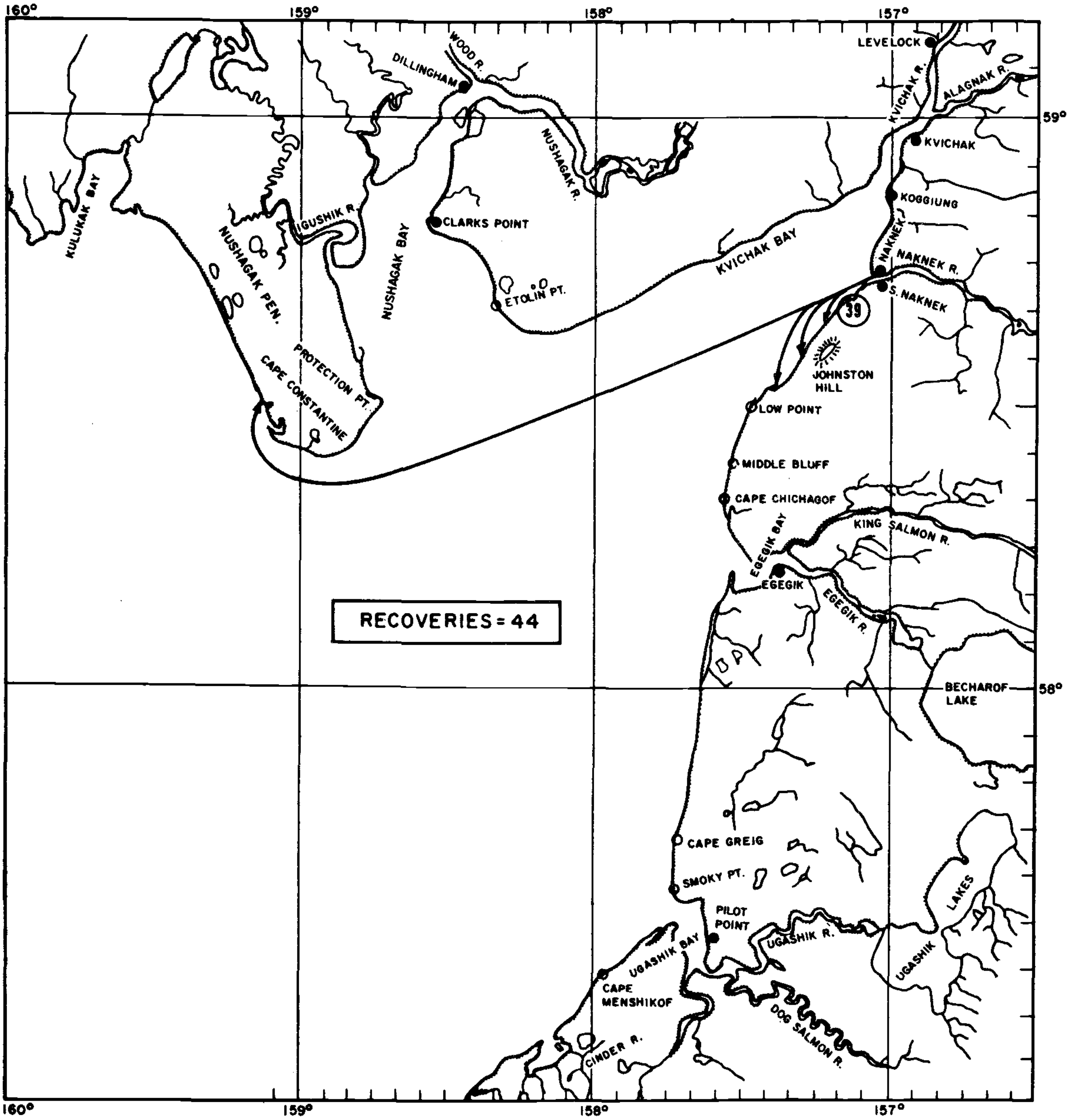

Figure 32. Recovery locations of drift cards released across the Kvichak River mouth, Bristol Bay, June 2, 1967.

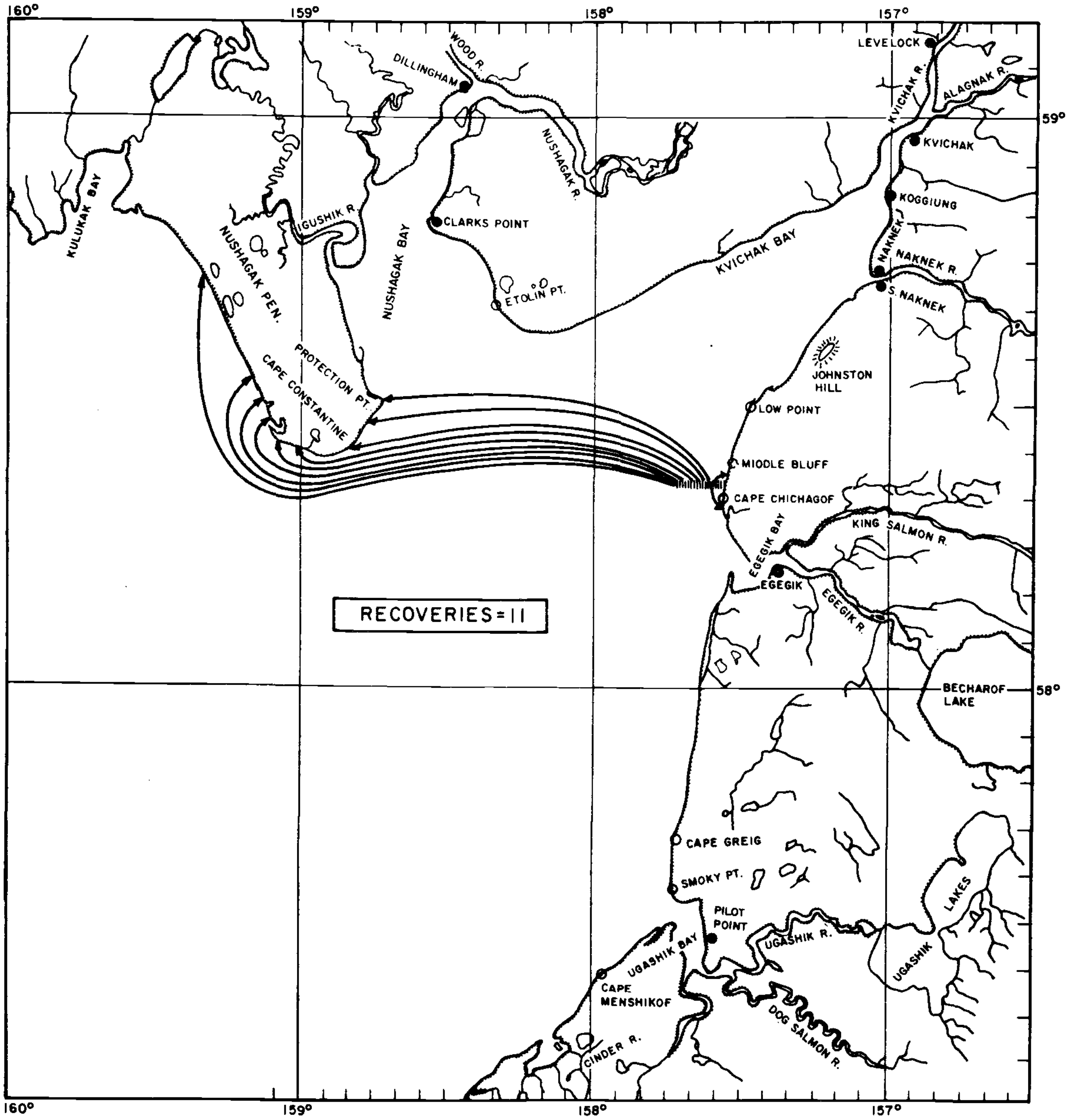

Figure 33. Recovery locations of drift cards released off Cape Chichagof, Bristol Bay, June 2, 1967.

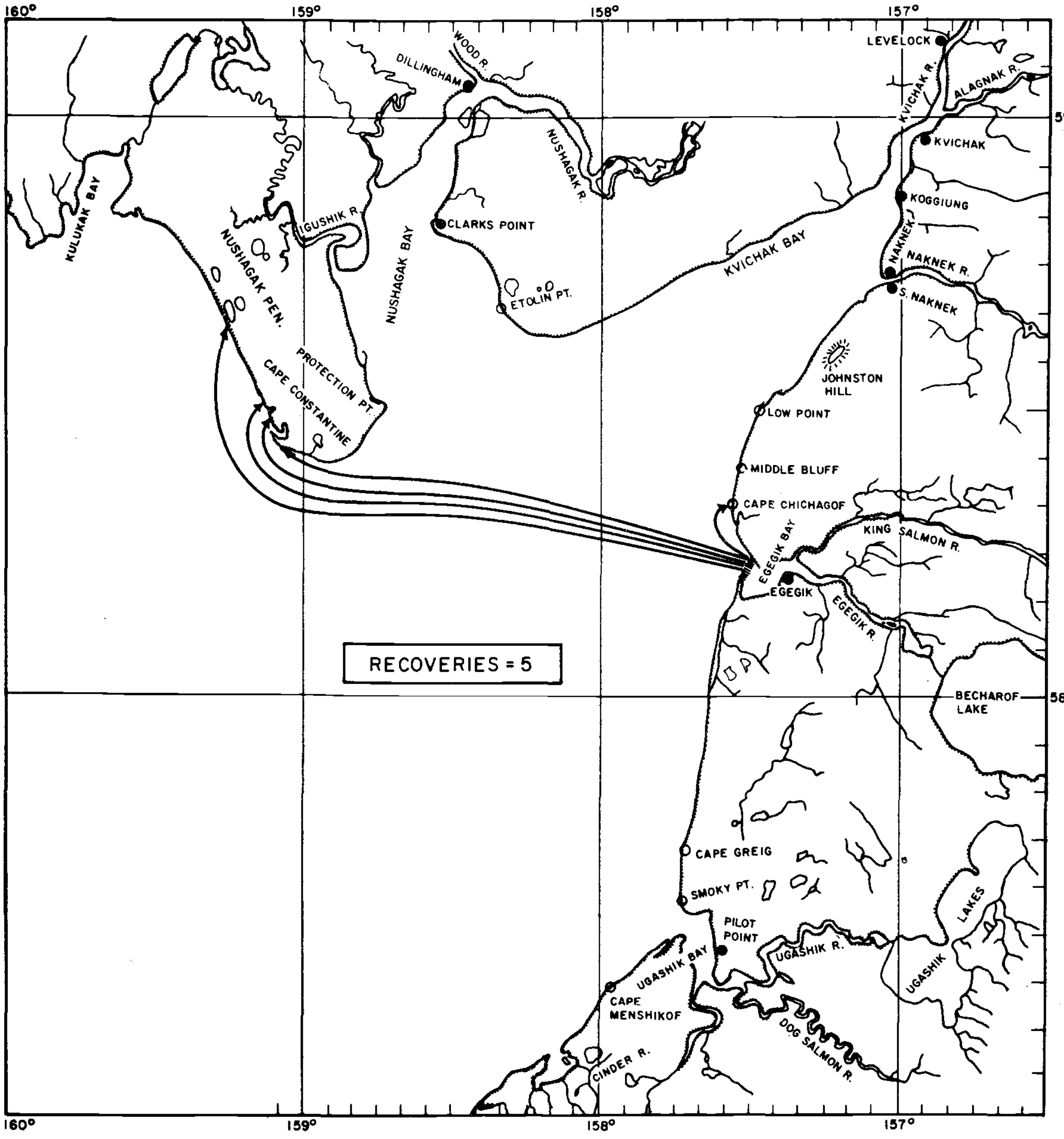

Figure 34. Recovery locations of drift cards released across the entrance to Egegik Bay, Bristol Bay, June 2, 1967.

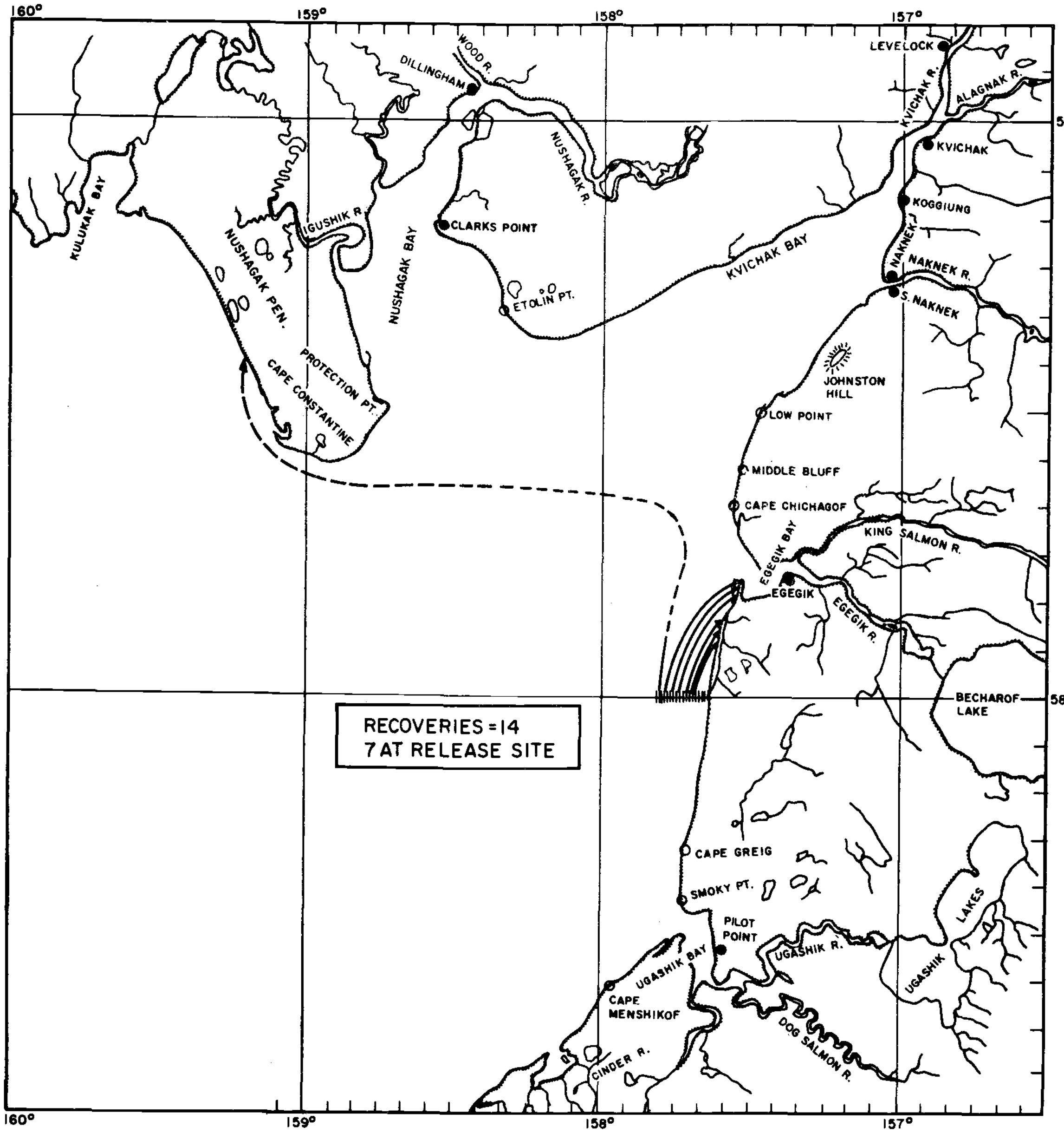

Figure 35. Recovery locations of drift cards released along the 58^{o} parallel of latitude, Bristol Bay, June 2, 1967.

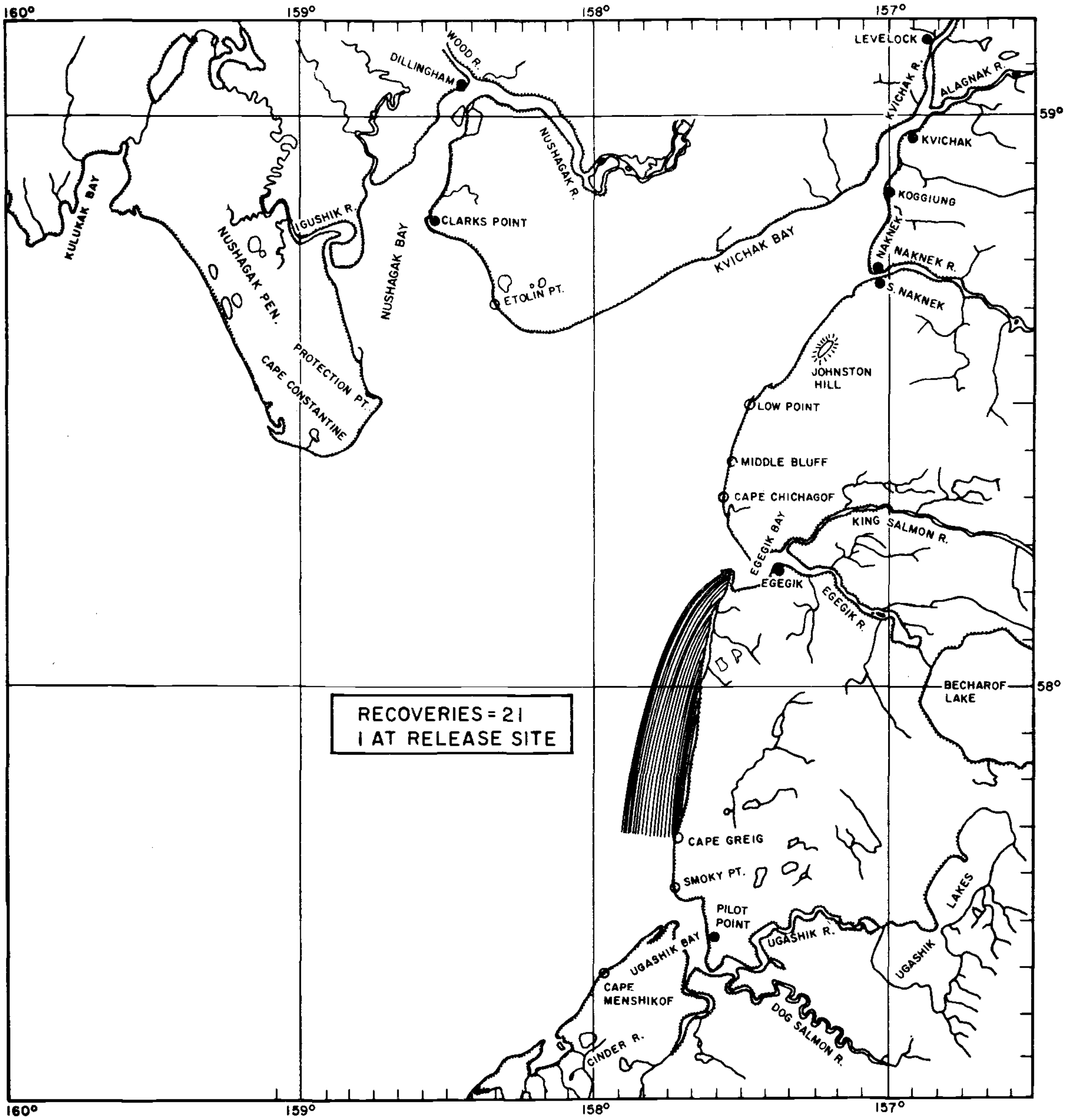

Figure 36. Recovery locations of drift cards released off Cape Greig, Bristol Bay, June 2, 1967.

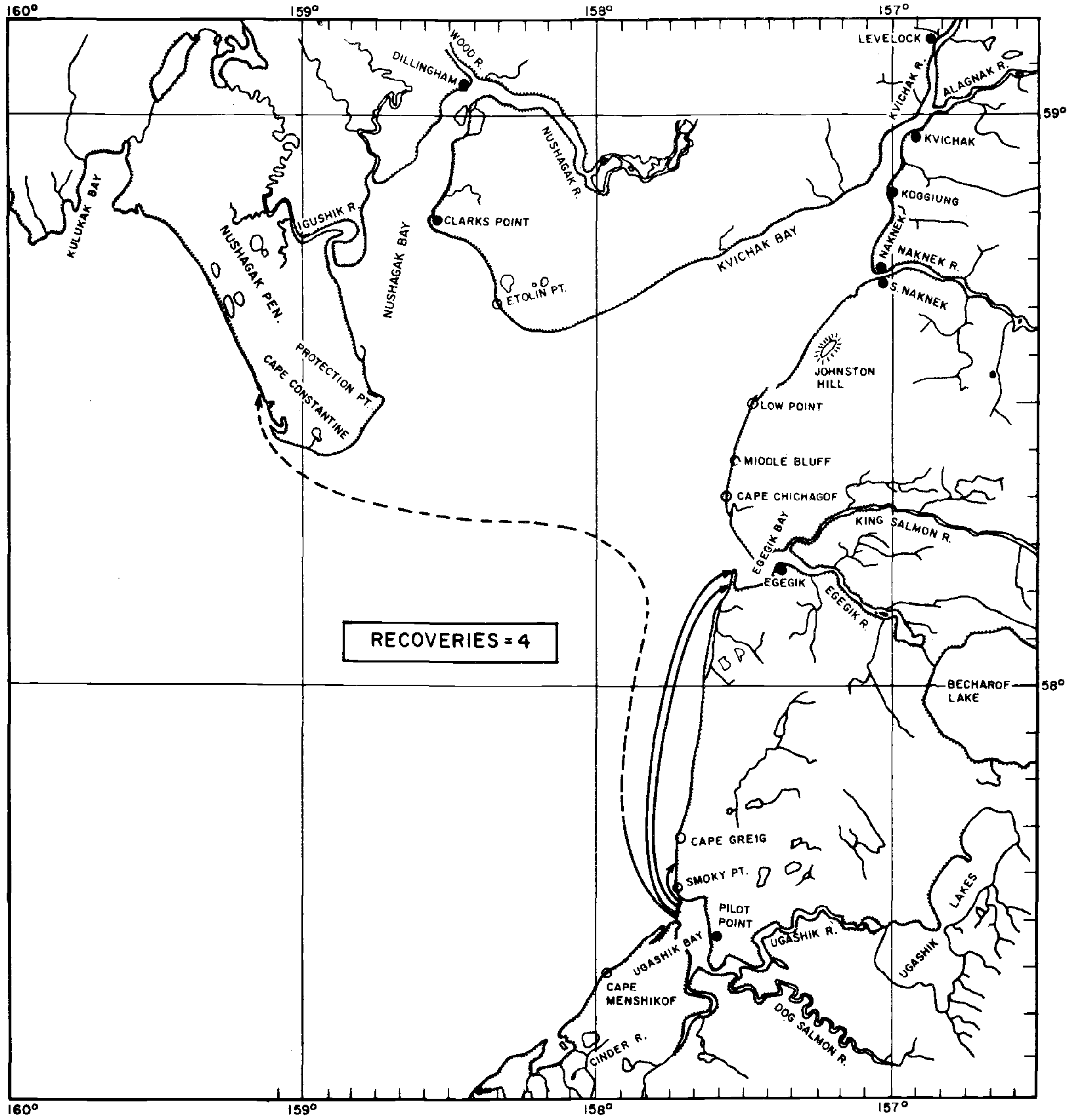

Figure 37. Recovery locations of drift cards released across the entrance to Ugashik Bay, Bristol Bay, June 2, 1967.

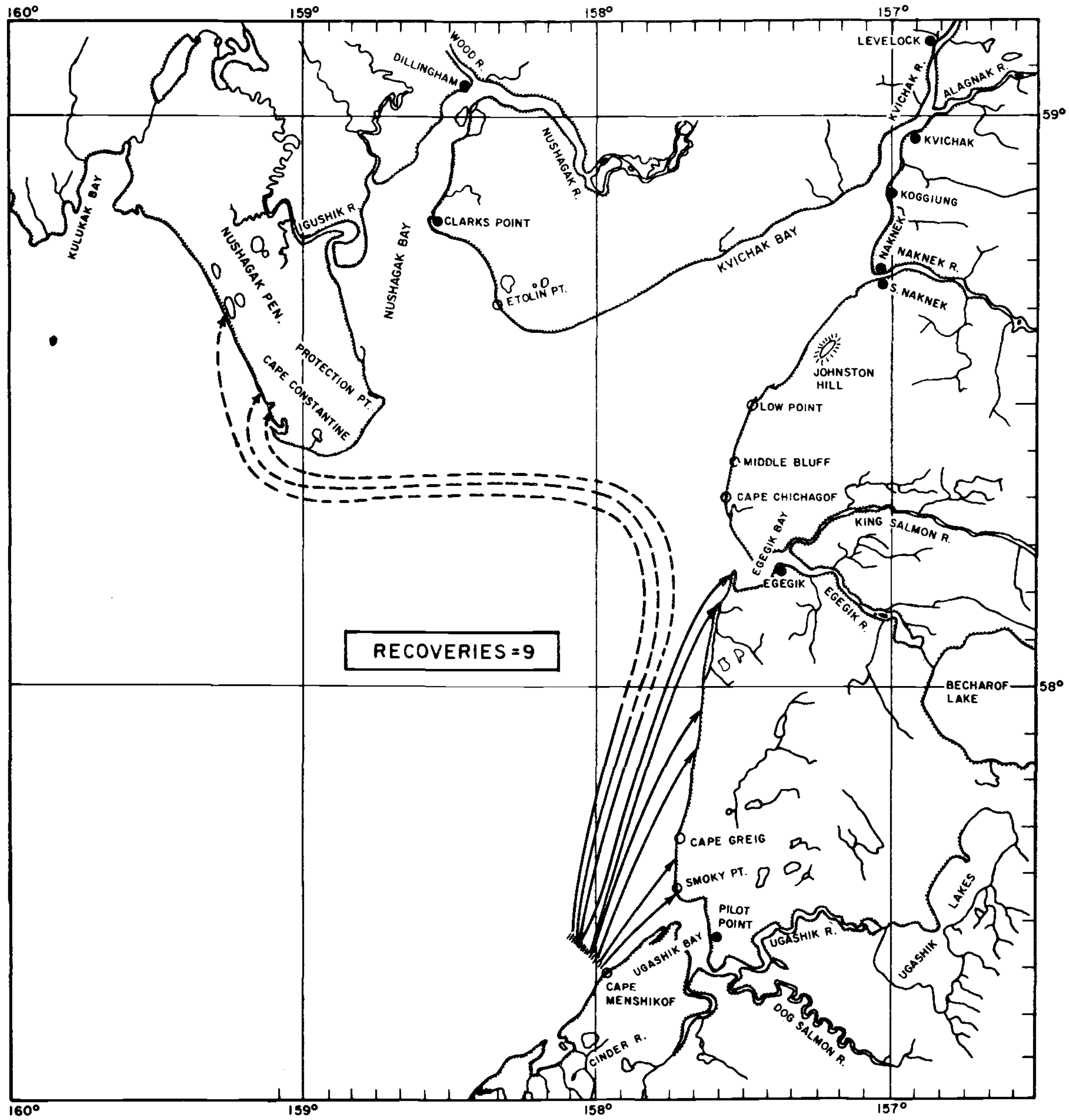

Figure 38. Recovery locations of drift cards released off Cape Menshikof, June 2, 1967.

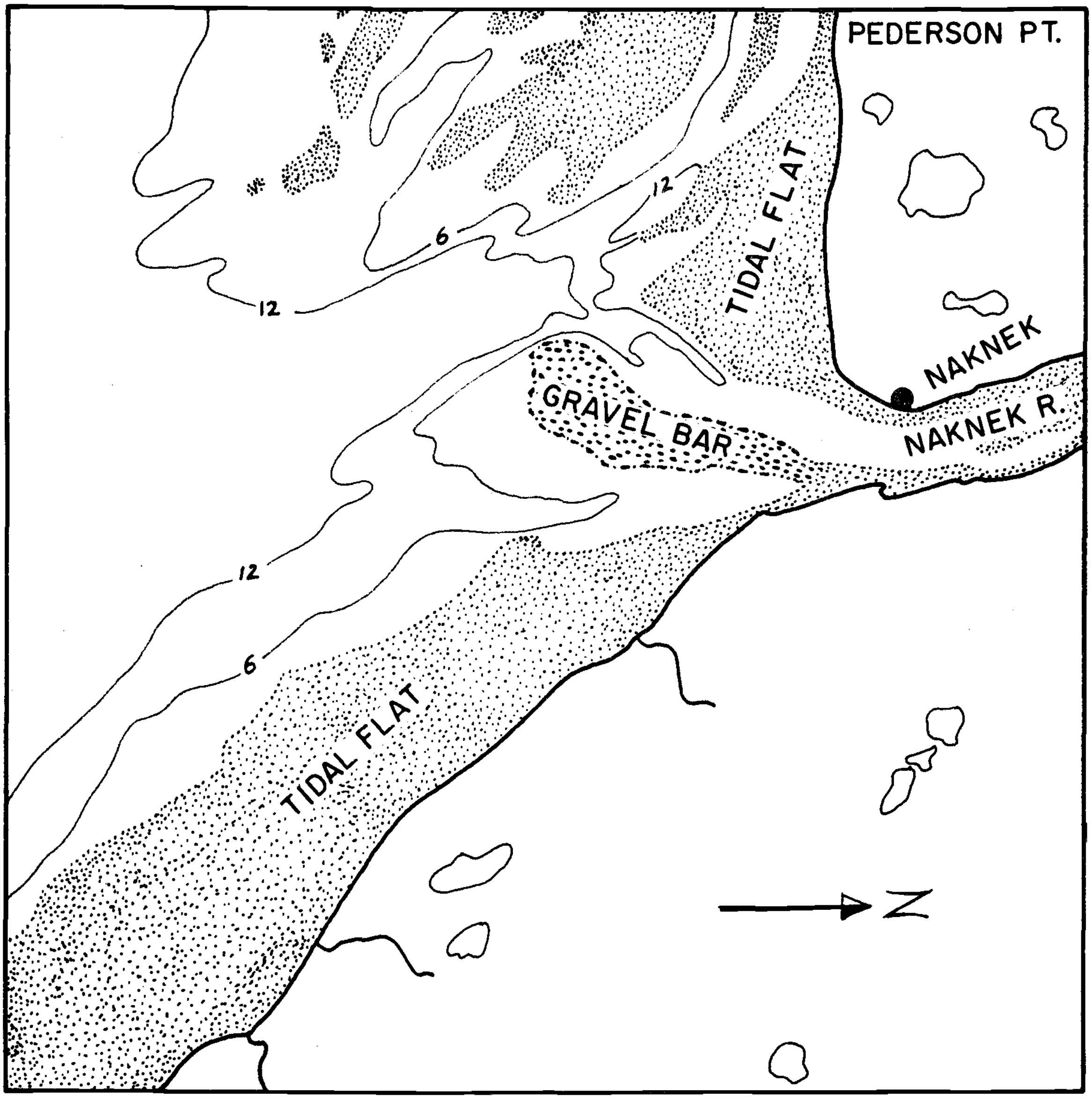

Figure 39. Bottom topography of Naknek River mouth, showing position of gravel bar.

the northern end of Johnston Hill.

Drift cards floating into this dead-water area at a certain stage of the tide would be prevented from farther seaward movement. More than half the cards recovered in the area were taken in the stationary salmon gill nets located there (Appendix Table 21). Most were recovered between 2 and 17 days after release, indicating some had been confined in the area for many tidal cycles. To obtain better offshore dispersal, cards should have been released in the Naknek and Kvichak rivers three or more hours after high slack water so that they would have had less chance of being retained in the area seaward of the gravel bar. A similar eddy or dead-water area probably exists south of Egegik also. A significant number of cards released between the Egegik and Ugashik rivers were eventually recovered on the beaches south of Egegik River.

Recoveries of drift cards not confined in the area south of the Naknek River mouth show that the seaward flow of Kvichak River water is along the northwest side of Kvichak Bay. Other than in the limited area mentioned, no Kvichak River cards were recovered on the southeast side of the bay (Figure 31). Naknek River cards occurred along the southeast side of Kvichak Bay, at least as far as Low Point, but no Naknek River cards were found seaward of this Point on this side of the bay. One was recovered, however, on the west side of the Nushagak Peninsula, indicating the route of Naknek

River water is offshore and toward the northwest side of upper Bristol Bay.

Drift cards released off Cape Chichagof and the entrance to Egegik Bay (Figures 33 and 34) show that movement of these waters is across and toward the northwest side of upper Bristol Bay; one card from each of the releases was recovered north of the release site.

Recoveries of cards from releases off the 58° parallel of latitude (Figure 35), off Cape Greig (Figure 36), at the entrance to Ugashik Bay (Figure 37), and off Cape Menshikof (Figure 38) all show the course of these waters to be north along the coast and ultimately toward the northwest side of Bristol Bay. No cards from any of these four releases were recovered to the south. The probable routes of cards released from these points and recovered on the northwest side of the bay (Nushagak Peninsula) are indicated by dashed lines in the figures.

The distribution of the drift cards has furnished direct evidence on the course followed by Kvichak, Naknek, Egegik, and Ugashik river waters and on the influence of the net or nontidal current on this pattern. This is consistent with the horizontal salinity distribution in the area and also with the results of the dye tracer studies.

Synopsis of the Course and Distribution of Waters of Major River Systems

On the basis of the foregoing results, it is possible to present a reasonable picture of the course and distribution of waters of the major sockeye salmon-producing river systems in upper Bristol Bay.

The vertical distribution of salinity shows that upper Bristol Bay and the lower reaches of the rivers are essentially vertically homogeneous. As a result, the circulation pattern in this region does not show any variation in water movement with depth. The distribution of salinity in this area is consistent with that in the offshore area, i.e. the net seaward flow of the lighter and less saline river runoff water is (as it should be in the Northern Hemisphere, assuming the action of Coriolis force) along the right side of the bay (looking seaward); and the net motion directed toward the head of the bay is on the left side. This motion toward the head of the bay, as pointed out earlier, extends to and perhaps somewhat above the Middle Bluff area in Kvichak Bay. This has been shown by the results presented thus far and indirectly by the distribution of glass fishing floats along the beaches of upper Bristol Bay. At high tide on beaches near Middle Bluff, there is always a large number of Japanese and Russian glass fishing floats. The floats came from the nets used in the king crab fishery several hundred miles farther out in Bristol Bay. Very few are found on beaches above Middle Bluff, but they become increasingly abundant on beaches seaward of Middle Bluff. They are also abundant on beaches of Cape Constantine and all along the west side of the Nushagak Peninsula, but not on those of Etolin Point and the northwest side of Kvichak Bay, where they might also be expected to collect. Presumably these floats were carried to the beaches by the wind and the net current. Direct evidence from the drift card studies supports the conclusion that the net current is responsible for the distribution of these floats. The direction of the net or nontidal current is illustrated by dashed lines in Figures 29 and 30.

The net flow pattern determines the overall course of all the river water entering upper Bristol Bay. From the distribution of salinity (Figures 25-28) and the routes of drift cards (Figures 31-38) the waters of rivers draining Kvichak Bay appear to move directly seaward along the northeast side of upper Bristol Bay past Cape Constantine. The Egegik and Ugashik rivers and others entering on the east side of the bay are separated from the waters of rivers entering at the head and on the west side of the bay by the counterflow of high-salinity water. A laterally directed flow must carry some high-salinity water from the left side to the right side, resulting in some horizontal mixing between the counterflows on the two sides of the bay. At the same time, lateral turbulent diffusion will lead to a mixing of the river waters (Egegik and Ugashik) that enter the left side of the bay with the adjacent sea water, which has a net movement toward the head of the bay. Thus the waters of the Egegik and Ugashik rivers are carried above their mouths toward the head of the bay by this net flow pattern. Near Middle Bluff this water enters the flow of less saline water, which is transported seaward on the right side of the bay. The transverse flow plus lateral diffusion therefore provides for the ultimate transport of these river waters to the north side of Bristol Bay.

Toward the head of the bay, the water must be a mixture of Ugashik and Egegik river water rather than being largely Ugashik River water. Between the entrance of Egegik Bay and Middle Bluff, river water must be largely of Egegik origin. In the Middle Bluff area itself, Egegik River water should predominate, but some Naknek River water should be present. Kvichak River water must be well offshore in this area.

Although the distribution of the individual river waters entering Nushagak Bay were not studied in detail, their probable course offshore can be described from the foregoing results and the bottom topography of this bay (Figure 40). The main channels of the Snake and Igushik rivers extend offshore on the west side of Nushagak Bay (Figure 40). Therefore the waters from these rivers may be expected to move seaward on this side of the bay. The waters of the Wood and Nushagak rivers entering at the head of Nushagak Bay must therefore occupy the eastern half of Nushagak Bay. The volume of discharge of

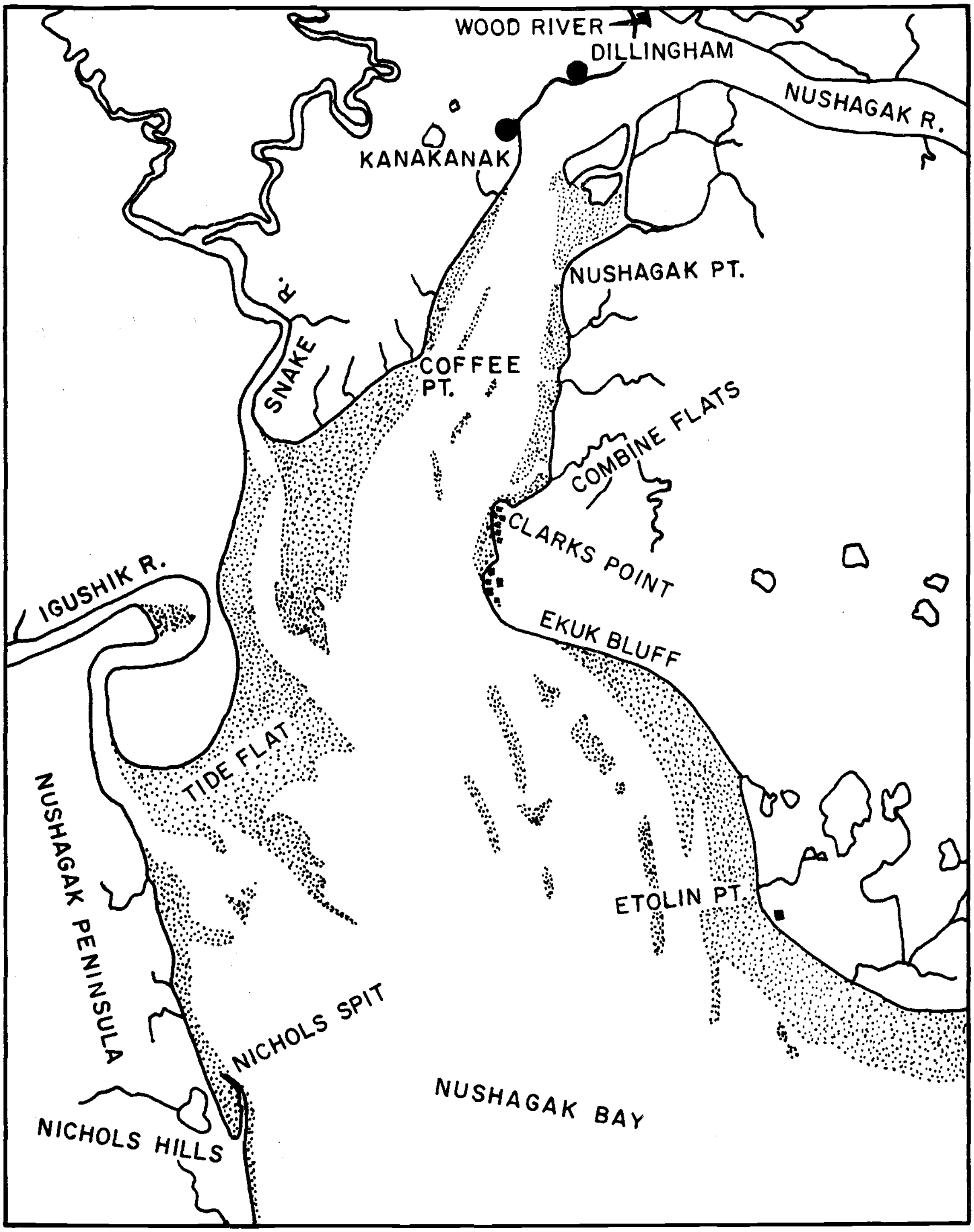

Figure 40. Bottom topography of Nushagak Bay.

the Wood and Nushagak rivers is much larger than that of the Snake and Igushik rivers. The seaward displacement of the isohalines on the east side of Nushagak Bay (Figures 25 and 26) indicate the route followed by this greater volume of fresh water. Upon leaving Nushagak Bay the waters of these four rivers must move seaward around Cape Constantine and north along the west side of the Nushagak Peninsula and the north side of Bristol Bay.

The waters of all the major sockeye salmon-producing river systems entering upper Bristol Bay are eventually transported to, and move seaward on, the right side of Bristol Bay. Depending on the extent of mixing, one would expect when proceeding south offshore from Cape Constantine to encounter first, waters of the Igushik and Snake rivers; then, those of the Wood and Nushagak rivers; and finally, those of the Kvichak, Naknek, Egegik, and Ugashik rivers.

Tidal Influence on the Distribution of River Water

Flood tidal currents carry some Naknek, Egegik, and Ugashik river waters above their respective outlets into Bristol Bay. This water moves toward shore and covers the tidal flats exposed at low tide.

Naknek River water transported above the Naknek River mouth by the flood current mixes with Kvichak River water. This mixture moves seaward on the succeeding ebb tide. It should occur just to the west of the boundary marking the interface between water leaving the Naknek and Kvichak rivers. Thus, regardless of the striking separation of these waters shown by shear lines, during the ebb tide the result should be a gradation from Naknek River water to Kvichak River water when proceeding from the left (southeast side) to the right (northwest side) of Kvichak Bay. In addition, there is also a change from Naknek to Kvichak River water along the coast directly above the Naknek River mouth during flood tide.

Egegik and Ugashik river waters transported above the entrances to Egegik and Ugashik bays respectively by the flood current mixes with the adjacent coastal waters. This mixture moves seaward on the succeeding ebb tide as part of the coastal water west of the shear line marking the separation of coastal water and waters leaving Egegik and Ugashik bays respectively. Proceeding from the left to the right side of Bristol Bay in these regions, there should be a change from coastal water of Egegik and Ugashik origin to almost pure sea water and then to water originating from nine of the ten major sockeye salmon-producing rivers entering Bristol Bay.

An additional effect of tidal action on the distribution of river water is apparent in the salinity distribution in the upper bay at low and high tide (Figures 25-28). The distribution of certain isohalines at low and high tide shows that a portion of the river runoff water moving seaward from Kvichak Bay may be actually transported into Nushagak Bay at high tide. This river water would be mainly of Kvichak and Naknek origin, but perhaps some would be of Egegik origin.

Effects of Wind on the Distribution of River Water

Dye studies were carried out and salinity measurements made during periods when wind velocities were generally less than 15 knots. The results presented here therefore represent conditions during relatively calm periods. The effects of prolonged strong winds on the distribution of river waters were not evaluated. Undoubtedly, strong winds increase horizontal mixing between individual river waters and between river and sea water. The circulation pattern, which determines the course followed by all river waters to the right side of upper Bristol Bay, does not change, however. Results of the drift card releases and recoveries support this conclusion. Recoveries of drift cards afloat for six or more weeks and during periods of strong winds followed the route indicated by the salinity distribution of the area.

Wind directions during the summer months are generally southerly (Appendix Table 22). Because the movement of water is to the right of the wind direction (Sverdrup, Johnson, and Fleming, 1942), southerly winds move water toward the head and right or left side of upper Bristol Bay, depending on the precise wind direction. Prolonged periods of strong winds may be expected then to expand or reduce the horizontal distribution of given river waters in the upper bay. For instance, strong southwest winds have been noted to increase the height of predicted tide levels by several feet on the Naknek River as far inland (18 miles) as King Salmon, Alaska. This indicates the movement of a large volume of water from the right to the left side of Kvichak Bay. Under such conditions, one would expect it is largely Kvichak River water (which occupies the northwestern side of Kvichak Bay) that is moved toward the eastern side of the bay. Also, considerable mixing would be expected to occur between Kvichak and Naknek river waters. The same situation holds true for the other rivers entering the bay. Although the horizontal distribution of individual river waters may be expected to expand or be reduced under prolonged strong winds, their seaward course and their positions relative to one another remain essentially the same.

VII. DISTRIBUTION AND MIGRATION PATTERN OF BRISTOL BAY SOCKEYE SALMON

Results of Offshore Fishing

The gill net catch of sockeye salmon at each location along six section lines across the approaches to Bristol Bay (Figure 17) are illustrated by distance offshore in Figures 41 to 48. The abundance of sockeye salmon increases and then decreases with increasing distance in a northerly direction offshore. With one exception (June 28 to July 3)--(Figure 44) this pattern is consistent for all years and along all section lines.

The area of heaviest sockeye salmon abundance along the long. 170° W. section line was between 100 and 200 miles offshore in 1958, 1959, and 1961 (Figures 41-43). Catches were smaller in the vicinity of the Pribilof Islands. In 1959 and 1961 large catches were made north of the Pribilof Islands (Figures 42 and 43), but they decreased in size with increasing distance to the north of these islands. A comparison of the abundance of fish along this section line at approximately the same locations but a week or more apart shows that the pattern of distribution remained essentially the same (Figure 43). This two-week period is sufficient time for passage through this area of a significant portion of the total sockeye salmon run. These results, plus the fact that the distributions of sockeye salmon in three

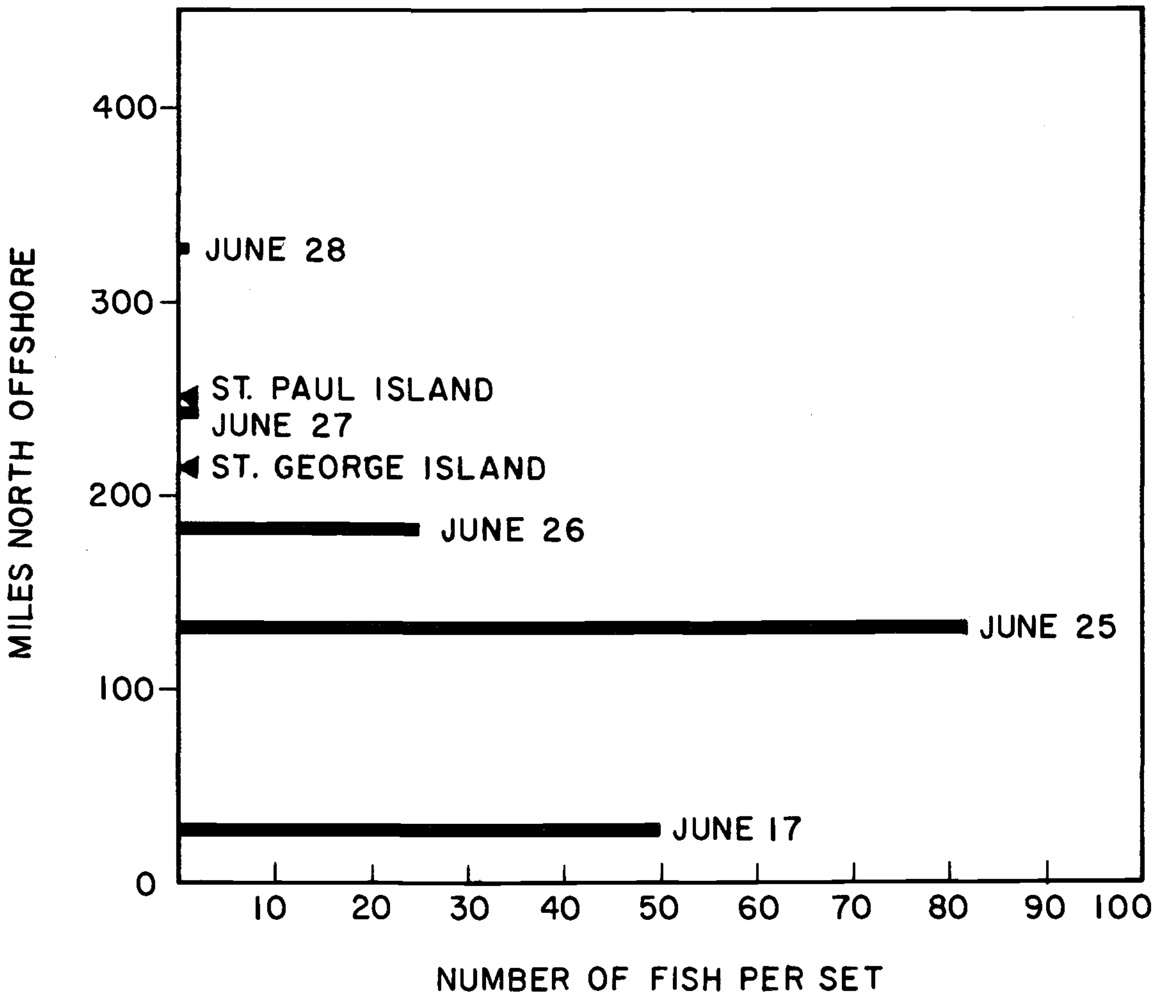

Figure 41. Gill net catches of sockeye salmon in the Bering Sea along approximately long. 170° W., June 17-18, 1958.

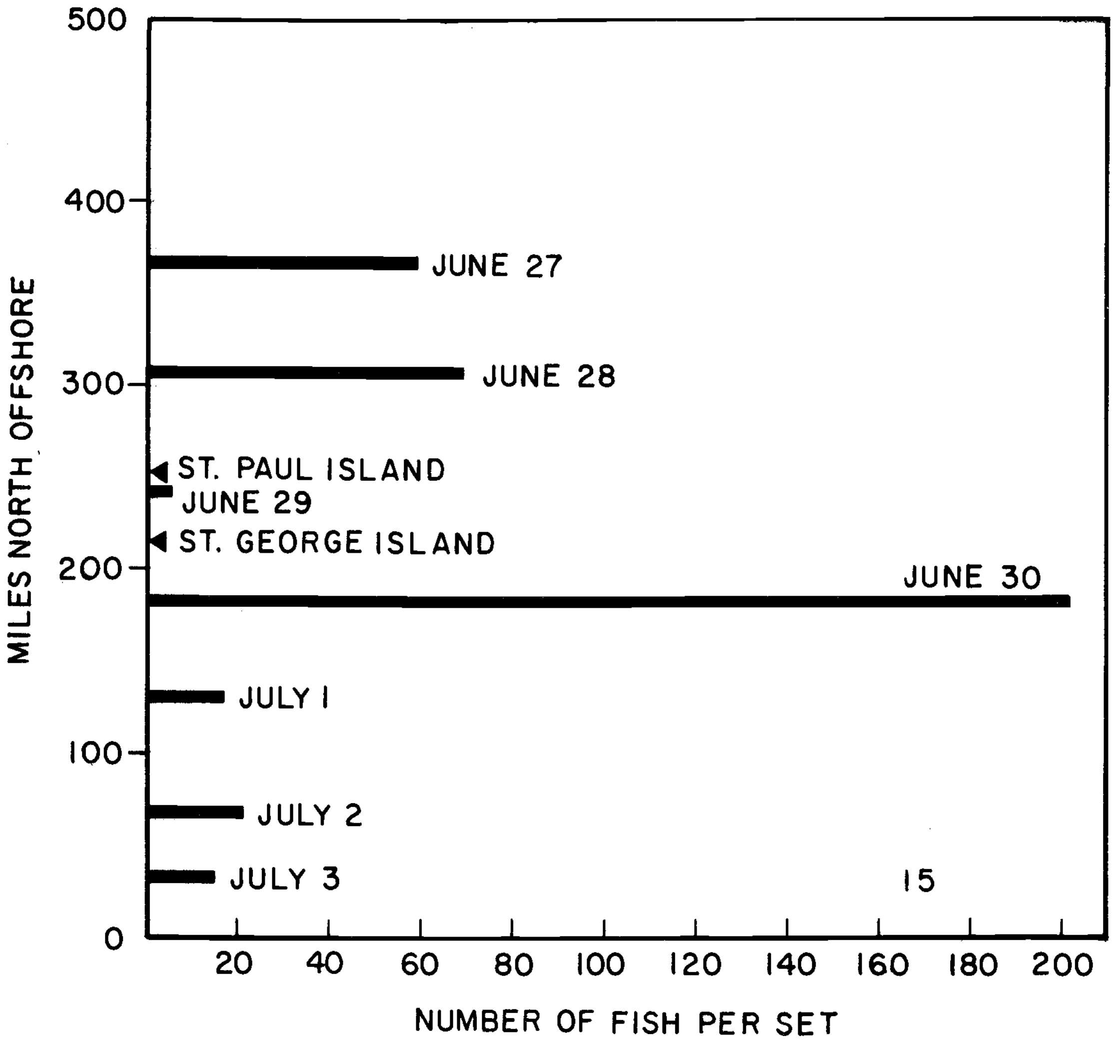

Figure 42. Gill net catches of sockeye salmon in the Bering Sea along approximately long. 170° W., June 27-July 3, 1959.

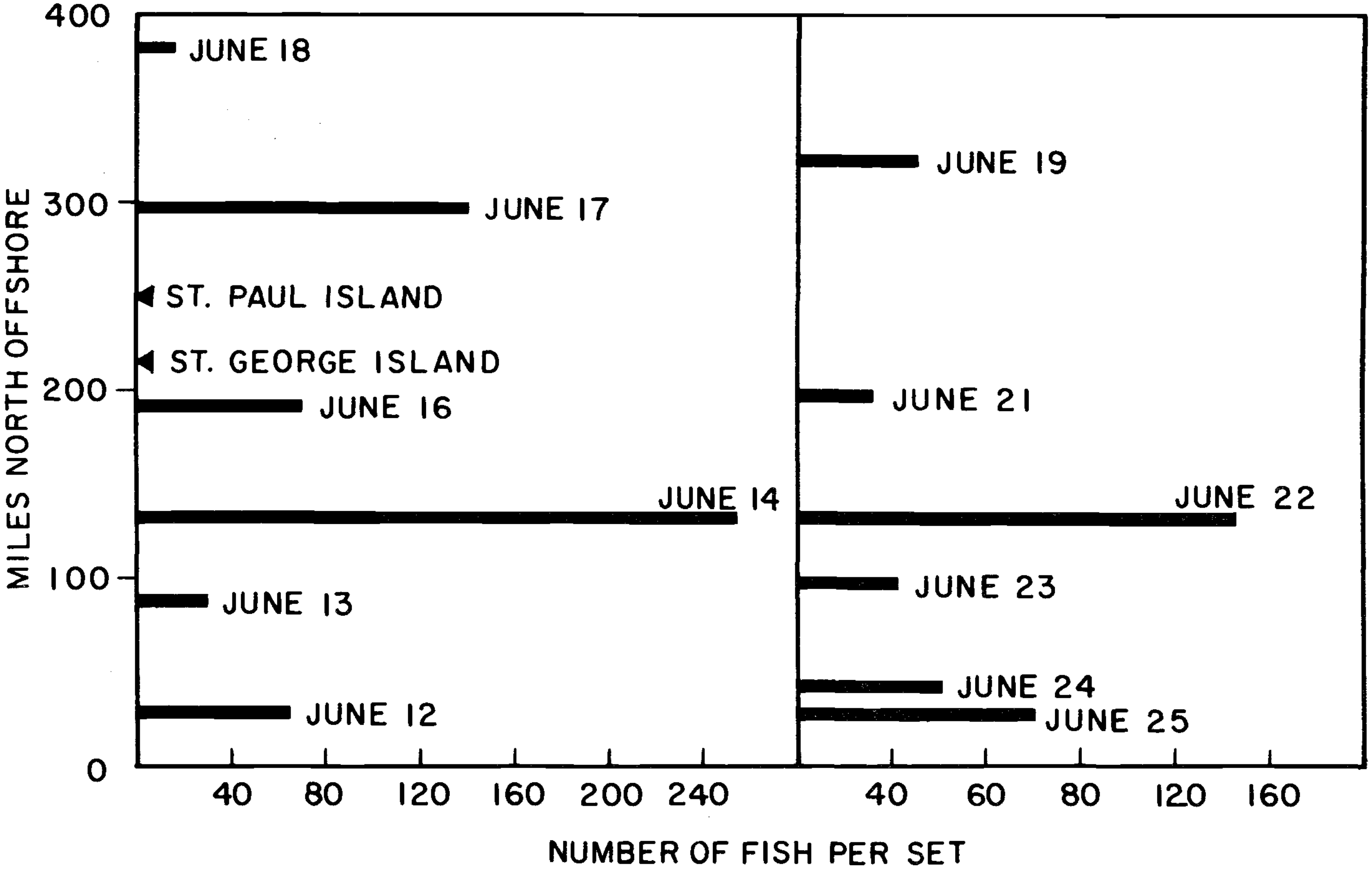

Figure 43. Gill net catches of sockeye salmon in the Bering Sea along approximately long. 170° W., June 12-25, 1961.

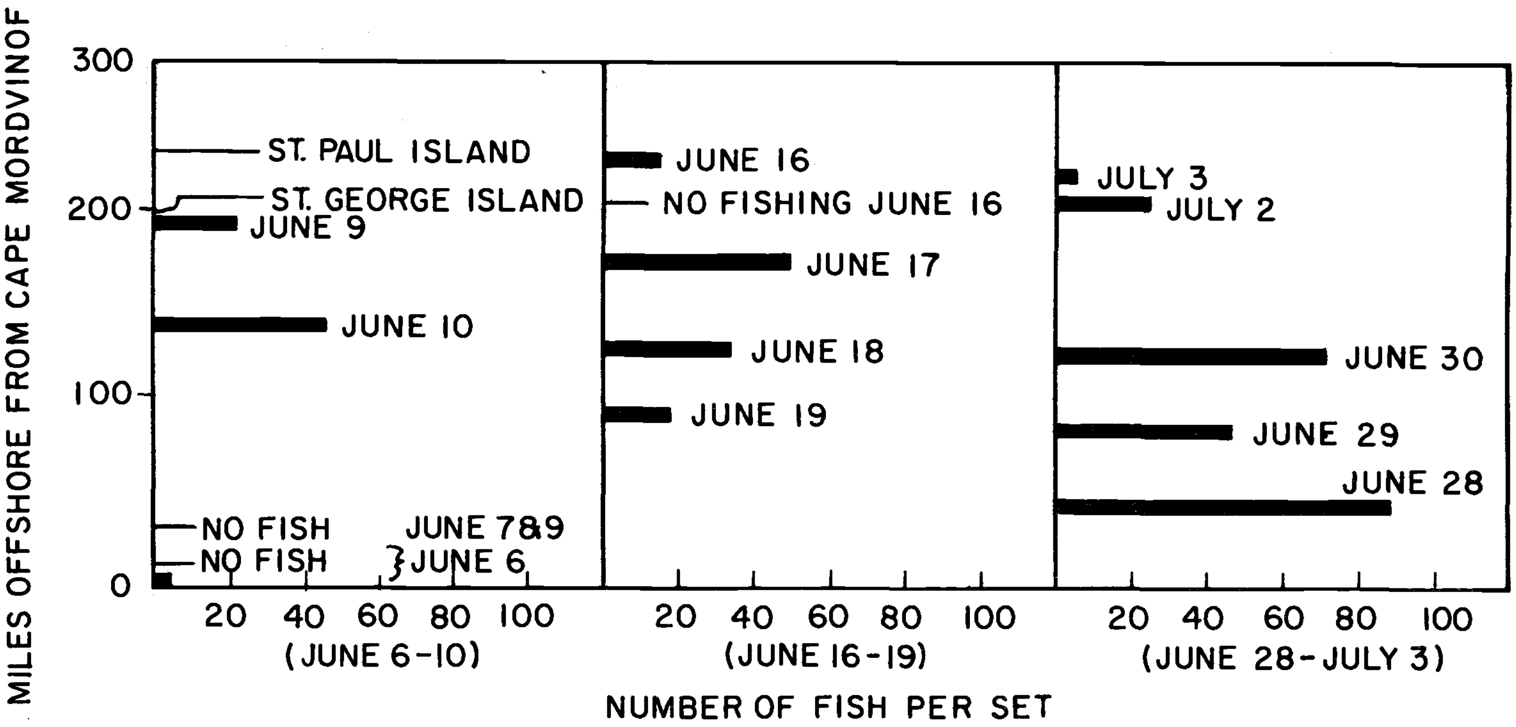

Figure 44. Gill net catches of sockeye salmon in the Bering Sea between Cape Mordvinof and Pribilof Islands, 1940.

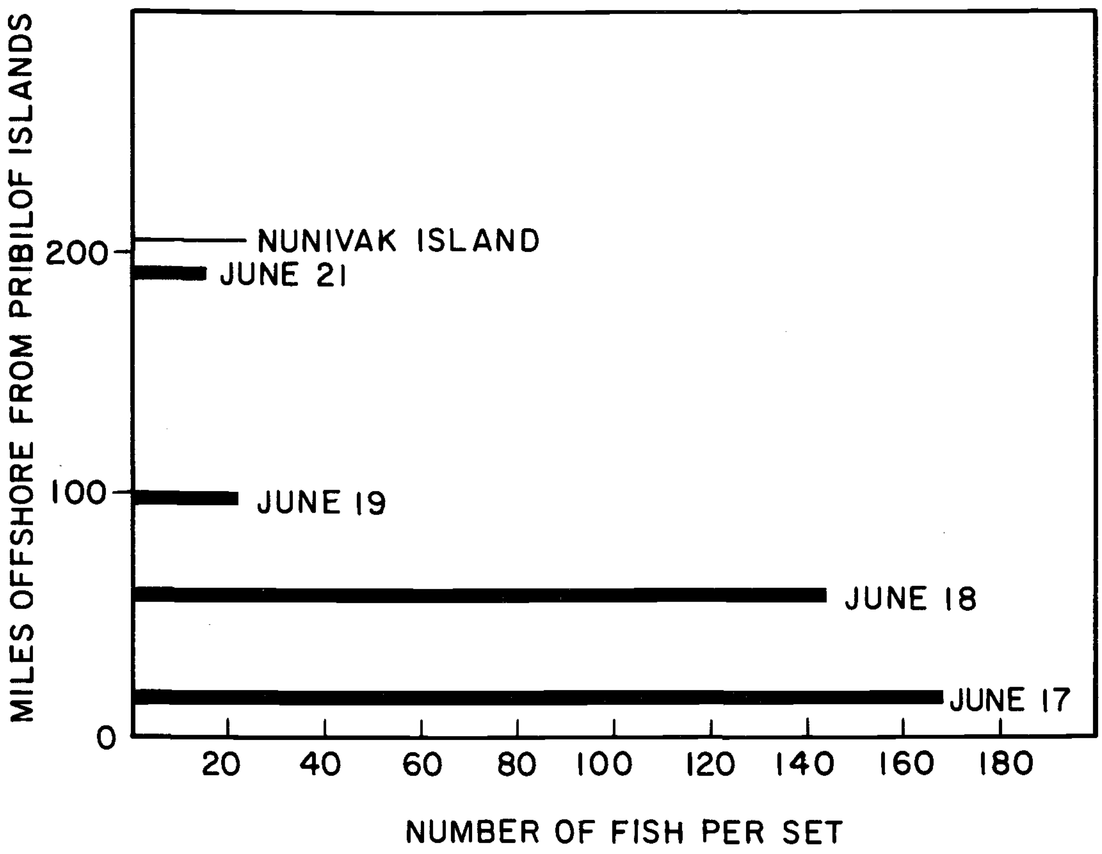

Figure 45. Gill net catches of sockeye salmon between Pribilof Islands and Nunivak Island, 1940.

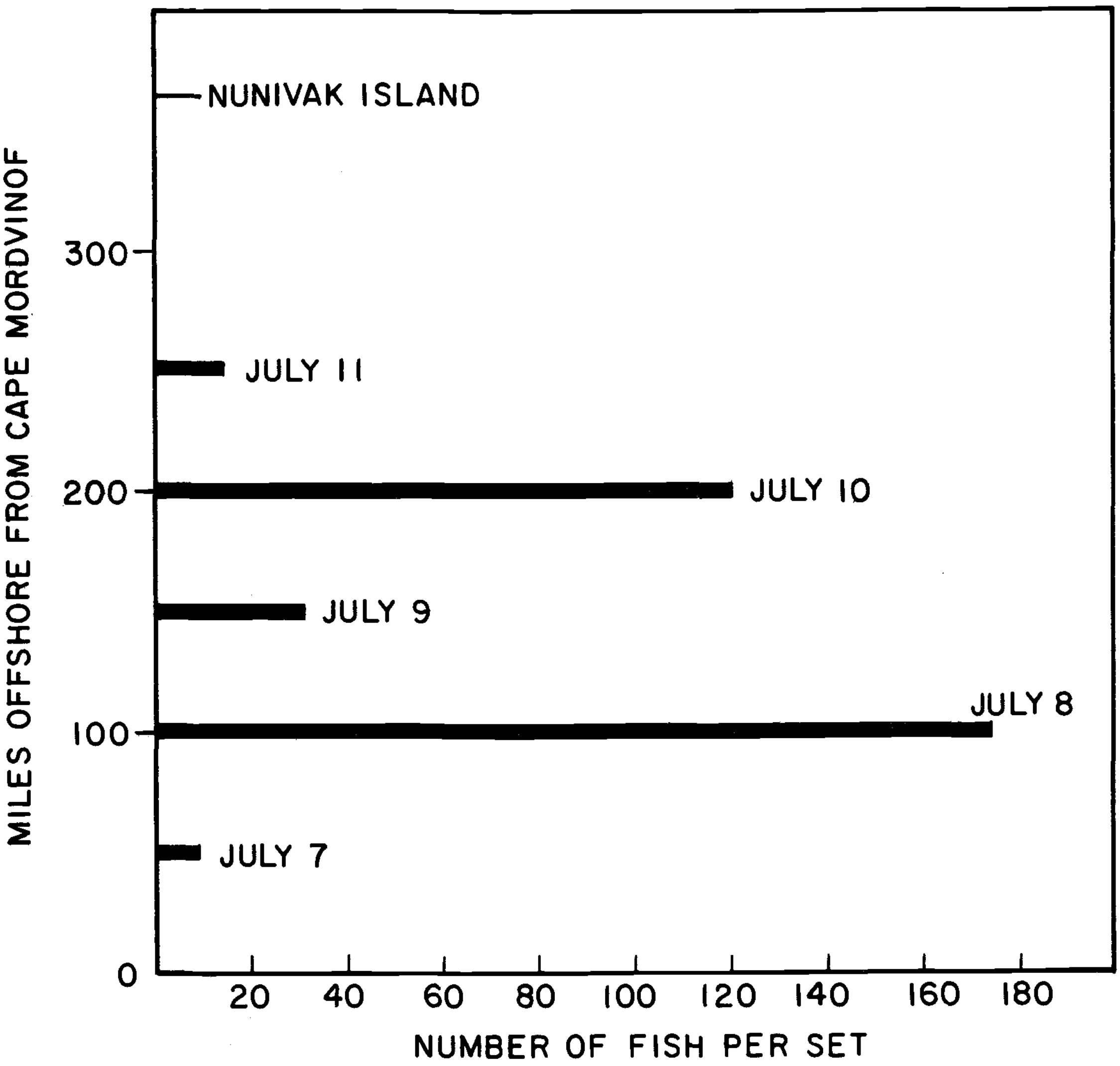

Figure 46. Gill net catches of sockeye salmon in the Bering Sea between Cape Mordvinof and Nunivak Island, 1941.

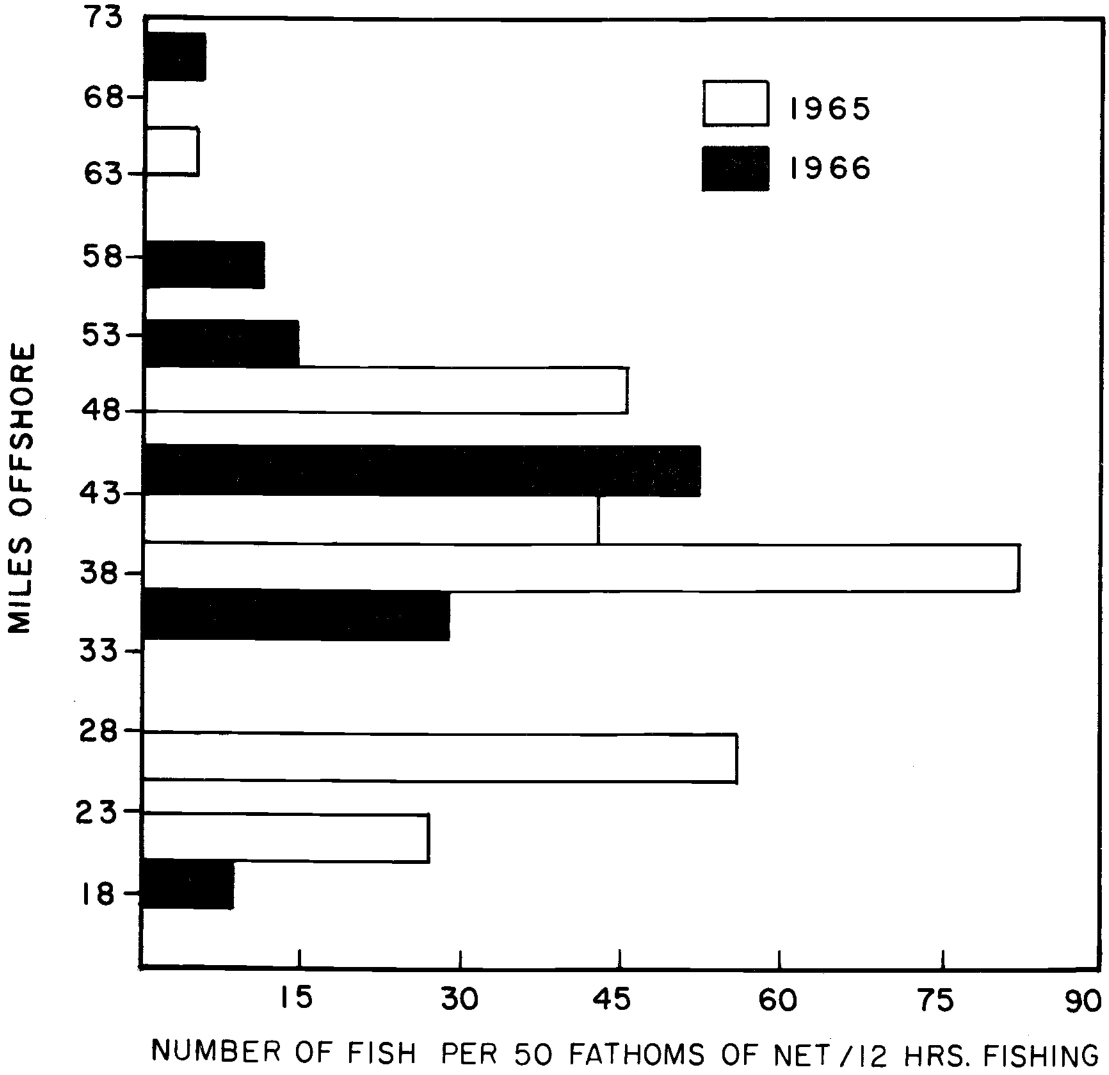

Figure 47. Gill net catches of sockeye salmon in the Bering Sea along approximately long. 161°30' W., June 24-July 6, 1965 and 1966.

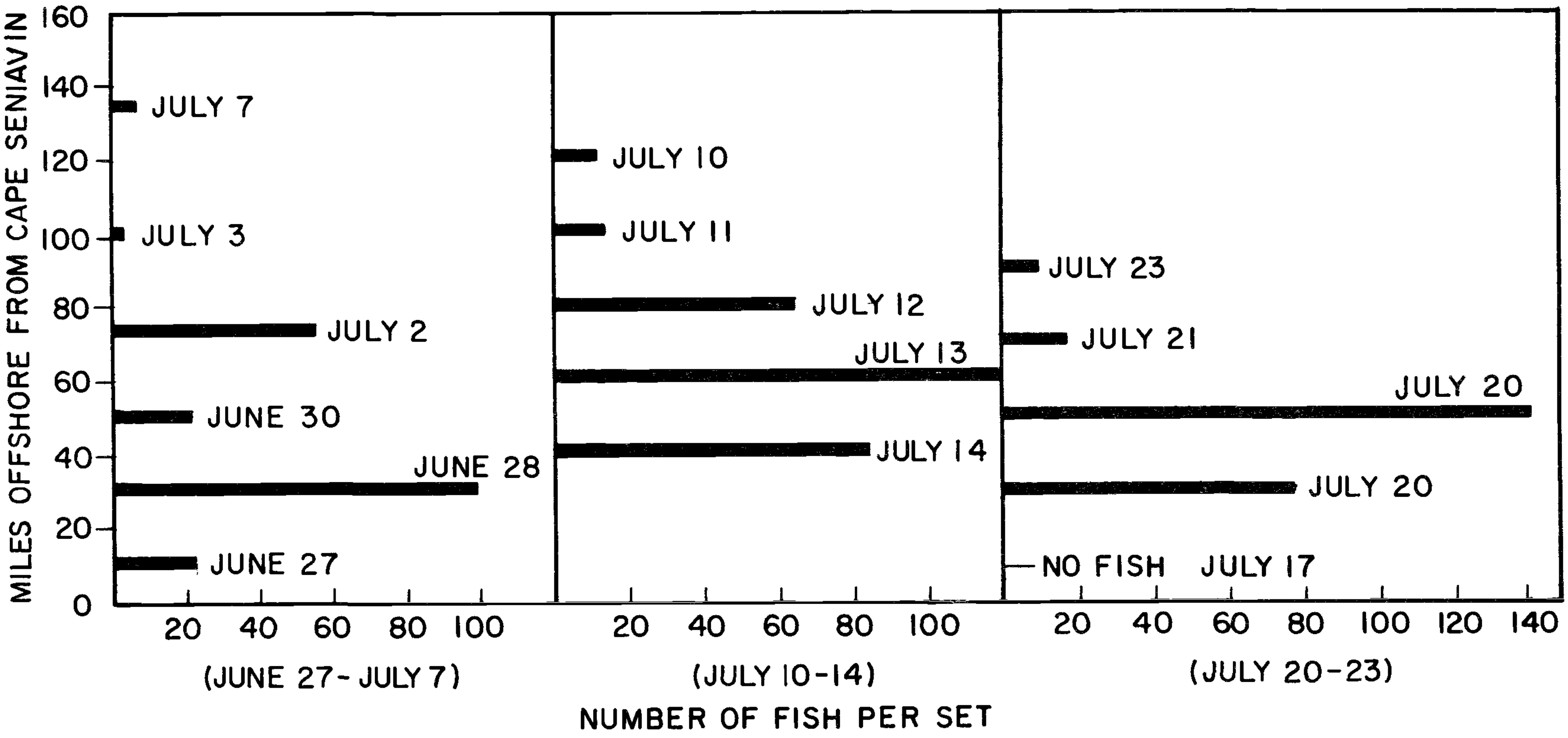

Figure 48. Gill net and lead catches of sockeye salmon between Cape Seniavin and Cape Newenham, Bristol Bay, 1939.

different years were similar, suggest that this pattern may not vary greatly during passage of the entire run through this area or from year to year.

Along the transect between Cape Mordvinof and the Pribilof Islands (Figure 44) the size of the catches increased, and then decreased with increasing distance offshore. This is consistent with the pattern of distribution along the long. 170° W. transect. Catches in the vicinity of the Pribilof Islands were again small. North of the Pribilof Islands, however, catches were large but decreased in size at locations farther offshore toward Nunivak Island (Figure 45).

From the results presented thus far, it is apparent that large numbers of sockeye salmon occur in two regions across the entrance to Bristol Bay: the offshore waters between the Aleutian and Pribilof Islands and the waters north of the Pribilof Islands.

Catches made along the section line between Cape Mordvinof and Nunivak Island in 1941 (Figure 46) also show two regions of heavy abundance. This pattern of distribution is consistent with that shown along long. 170° W. If the section line is moved seaward so as to intersect the Pribilof Islands, the two areas where large catches were made coincide with the regions of high abundance along the long. 170° W. section line.

Gill net catches of sockeye salmon at each location along long. 161°30' W. in 1965 and 1966 (Figure 47) show that the abundance again increases and then decreases with increasing distance offshore to the north. Along this section line there is a single offshore region of high abundance instead of the two found along the section lines farther westward. This distribution is consistent with that shown by catches along the section line between Cape Seniavin and Cape Newenham in 1939 (Figure 48). Here, the distribution remains essentially the same from early to late July. The greatest abundance of sockeye salmon along both section lines was offshore but in the southern half of Bristol Bay.

The abundance along all section lines was greatest offshore and in the southern half of the entrance to Bristol Bay and in the bay itself.

Offshore Migration Pattern of Bristol Bay Sockeye Salmon

From the foregoing results it is clear that sockeye salmon bound for Bristol Bay do not follow a route close inshore, at least not westward of Cape Seniavin. After entering the Bering Sea via the Aleutian Islands passes, they apparently move north for a considerable distance before moving east into Bristol Bay.

This northward movement into the offshore waters of the Bering Sea was reported by Hartt (1966). He stated:

> It is also interesting that salmon were not found in abundance close to the north side of the islands. As discussed in the report for 1956-58 (Hartt, 1962a), very few salmon were taken in sets close to the north side even at times when numbers along the south side were at a maximum.

> This suggests that salmon proceed offshore after traversing the passes.

Tagging experiments in the vicinity of Cape Seniavin (Gilbert, 1923) showed that even here Bristol Bay sockeye salmon are not present in the coastal waters. Gilbert stated:

> The red salmon bound in 1922 for Bristol Bay assuredly did not school close inshore until after they had passed the Sandy River and were perhaps approaching the mouth of the Ugashik.

These results were confirmed through additional tagging studies carried out in the same area in 1925 (Rich, 1926). Rich stated:

> . . . in 1925 as in 1922, the fish found in Bering Sea in the vicinity of the Bear and Sandy Rivers were predominately fish of local origin and were not natives of the important salmon streams of Bristol Bay.

From the data presented here a synoptic picture of the distribution pattern of sockeye salmon during migration through the area of study and into Bristol Bay was prepared (Figure 49). The main migration route of Bristol Bay sockeye salmon is apparent from the figure--the offshore waters of the southern half of the entrance to Bristol Bay and in the bay itself.

Results of Offshore Tagging

Recoveries from each year of tagging in the Eastern Bering Sea and outer Bristol Bay will be discussed separately. The actual and expected number of tag recoveries in Bristol Bay fishing districts

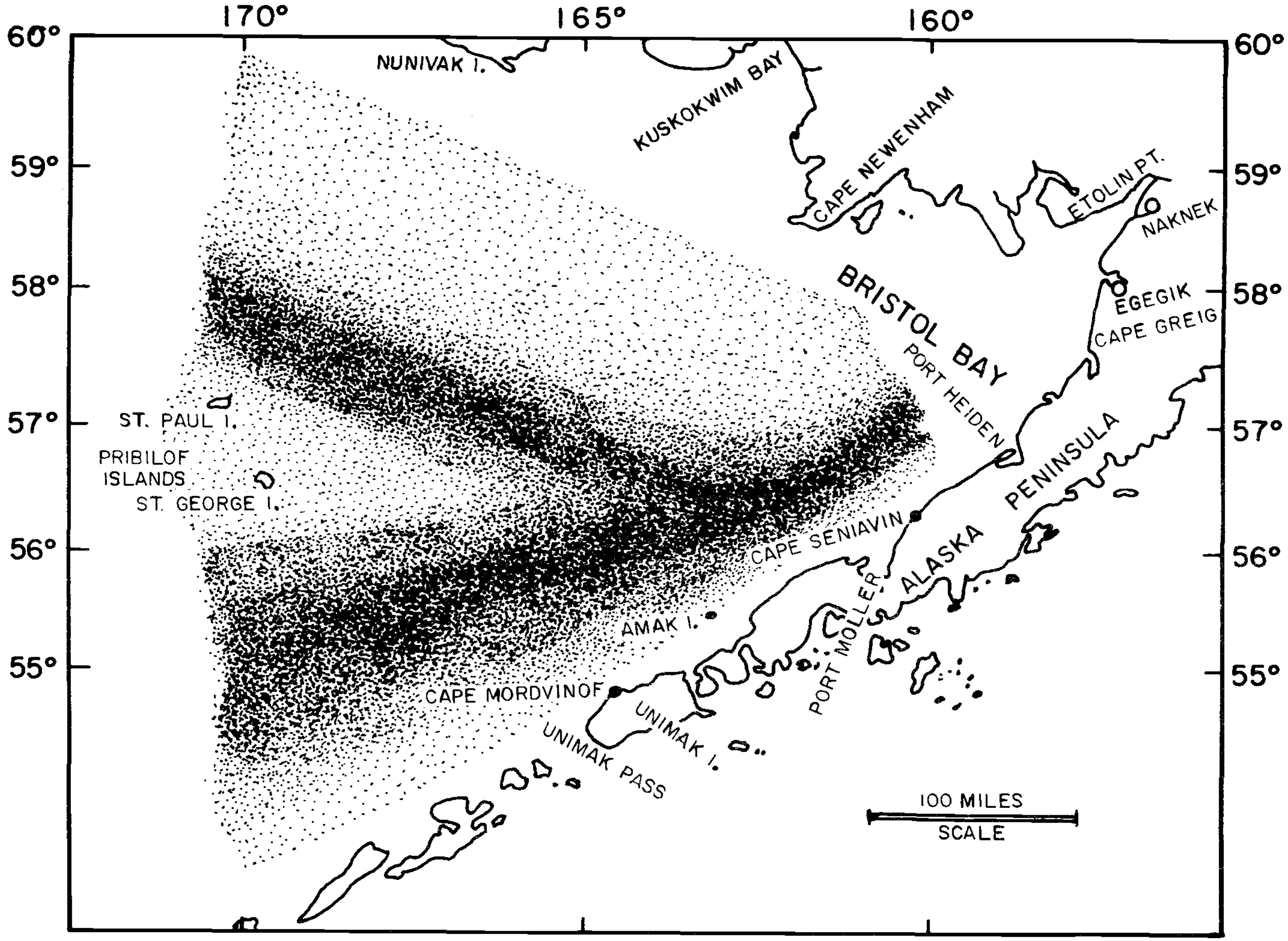

Figure 49. Distribution of sockeye salmon in outer Bristol Bay during spawning migration, showing areas of relative abundance.

are listed in Tables 2-8. The results of the chi-square analysis of these data testing the hypothesis of like offshore distributions for all sockeye salmon stocks of Bristol Bay origin are summarized in Table 9.

Table 2. Actual numbers and expected numbers (in parentheses)* of Bristol Bay recoveries of sockeye salmon tagged in the Bering Sea by the United States, 1957. (Data from: Hartt (1962), Table A-21, Pages 148 and 149)

		Recoveries by Bristol Bay fishing districts			
		West side		East side	
Location of tagging	Date of tagging	Nushagak	Naknek-Kvichak	Egegik	Ugashik
Midway between Unalaska and Pribilof Islands	June 17	0	1	0	0
55°37' N., 168°33' W.	June 19	0	3	0	0
56°00' N., 170°00' W.	June 20	0	3	1	0
56°12' N., 169°54' W.	June 21	0	0	1	1
56°50' N., 170°13' W.	June 22	0	3	0	0
56°10' N., 171°08' W.	June 23	0	4	3	0
54°21' N., 166°55' W.	June 29	0	1	0	0
Total		0 (1.65)	15 (15.42)	5 (2.74)	1 (1.18)

*See method of computing expected numbers on Page 66.

Table 3. Actual numbers and expected numbers (in parentheses)* of Bristol Bay recoveries of sockeye salmon tagged in the Bering Sea by the United States, 1958. (Data from: Hartt (1962), Table A 22, Pages 152-154)

		Recoveries by Bristol Bay fishing districts			
		West side		East side	
Location of tagging	Date of tagging	Nushagak	Naknek-Kvichak	Egegik	Ugashik
95 miles west of St. George Island	June 16	0	1	0	0
25 miles south of St. Paul Island	June 22	0	0	1	0
6 miles north of St. George Island	June 24-27	0	3	7	5
5 miles north of St. George Island	June 25-27	2	6	2	1
Total		2 (10.36)	10 (8.76)	10 (4.75)	6 (4.12)

*See method of computing expected numbers on Page 66.

Table 4. Actual numbers and expected numbers (in parentheses)* of Bristol Bay recoveries of sockeye salmon tagged in the Bering Sea by the United States, 1960. (Data from: Hartt (1966), Table A-15, Page 128)

		Recoveries by Bristol Bay fishing districts			
		West side		East side	
Location of tagging	Date of tagging	Nushagak	Naknek-Kvichak	Egegik	Ugashik
53°25' N., 168°51' W.	June 20	0 (1.11)	7 (7.26)	1 (1.07)	2 (0.55)

*See method of computing expected numbers on page 66.

Table 5. Actual numbers and expected numbers (in parentheses)* of Bristol Bay recoveries of sockeye salmon tagged in the Bering Sea by Japan, 1960. (Data from: Kondo *et al.* (1965), Appendix Table H, Page 200)

		Recoveries by Bristol Bay fishing districts			
		West side		East side	
Location of tagging	Date of tagging	Nushagak	Naknek-Kvichak	Egegik	Ugashik
54°16' N., 169°36' W.	June 28	0	9	0	1
54°38' N., 168°49' W.	June 29	0	3	3	1
54°22' N., 169°38' W.	June 30	0	2	0	1
Total		0 (2.24)	14 (14.52)	3 (2.13)	3 (1.11)

*See method of computing expected numbers on page 66.

Table 6. Actual numbers and expected numbers (in parentheses)* of Bristol Bay recoveries of sockeye salmon tagged in the Bering Sea by Japan, 1961. (Data from Kondo *et al.* (1965), Appendix Table H, Pages 205 and 206)

		Recoveries by Bristol Bay fishing districts			
		West side		East side	
Location of tagging	Date of tagging	Nushagak	Naknek-Kvichak	Egegik	Ugashik
55°00' N., 170°10' W.	June 20	0	6	2	1
55°11' N., 169°50' W.	June 21	0	8	5	0
55°00' N., 169°55' W.	June 22	0	7	6	0
54°49' N., 169°40' W.	June 23	1	7	3	0
Total		1 (1.99)	28 (32.06)	16 (10.54)	1 (1.40)

*See method of computing expected numbers on Page 66.

Table 7. Actual numbers and expected numbers (in parentheses)* of Bristol Bay recoveries of sockeye salmon tagged in the Bering Sea and Bristol Bay by the United States, 1964. (Data from: Lander *et al.* (1966), Table 14, Pages 106 and 107)

			Recoveries by Bristol Bay fishing districts			
			West side		East side	
Location of tagging	Station number**	Date of tagging	Nushagak	Naknek-Kvichak	Egegik	Ugashik
56°29' N., 170°12' W.	8	June 19	0	1	1	0
56°41' N., 169°55' W.	9	June 20	1	2	1	0
Total			1	3	2	0
			(1.60)	(2.52)	(1.24)	(0.65)
55°17' N., 166°54' W.	10	June 21	0	1	2	1
			(1.07)	(1.68)	(0.83)	(0.43)
56°30' N., 160°20' W.	12	June 24	2	1	1	2
			(1.60)	(2.52)	(1.24)	(0.65)
57°06' N., 158°54' W.	15	June 27	2	2	4	3
			(2.92)	(4.62)	(2.27)	(1.19)
Total			4	3	5	5
			(4.52)	(7.14)	(3.50)	(1.84)
57°30' N., 161°07' W.	13	June 25	2	2	0	0
			(1.07)	(1.68)	(0.83)	(0.43)
57°44' N., 159°24' W.	16	June 28	2	3	1	0
			(1.60)	(2.52)	(1.24)	(0.65)
Total			4	5	1	0
			(2.66)	(4.20)	(2.06)	(1.08)

* See method of computing expected numbers on Page 66.

** See Figure 18, Page 63.

Table 8. Actual numbers and expected numbers (in parentheses)* of Bristol Bay recoveries of sockeye salmon tagged in Bristol Bay by the United States, 1965. (Data from: Lander *et al.* (1967), Table 8, Page 100)

		Recoveries by Bristol Bay fishing districts			
		West side		East side	
Location of tagging	Date of tagging	Nushagak	Naknek-Kvichak	Egegik	Ugashik
57°00' N., 160°00' W.	June 24	4 (6.97)	172 (168.73)	30 (27.99)	6 (8.27)
57°48' N., 158°30' W.	June 27	20 (1.28)	18 (31.04)	1 (5.15)	0 (1.52)
57°25' N., 159°12' W.	June 26	1	57	13	2
57°32' N., 159°15' W.	June 30	0	48	8	4
57°28' N., 159°11' W.	June 30	1	47	6	2
57°27' N., 159°03' W.	July 1	3	48	17	5
57°30' N., 159°00' W.	July 1	3	60	10	4
57°32' N., 159°00' W.	July 2	0	81	17	2
57°34' N., 159°04' W.	July 2	4	59	9	1
Total		12 (16.84)	400 (407.51)	80 (67.61)	20 (19.98)

*See method of computing expected numbers on Page 66.

Table 9. Summary of chi-square analysis of Eastern Bering Sea and outer Bristol Bay tag recovery data by United States and Japan

Year of tagging and country	Locations of tag recoveries treated	Results of chi-square tests: Between fishing districts (d.f. = 3)		Between east and west side districts (d.f. = 1)	
		Chi square	Probability	Chi square	Probability
1957--United States	All release sites grouped	3.56	0.331	0.87	0.380
1958--United States	All release sites grouped	13.58	<0.005	9.48	<0.005
1960--United States	Single release location	4.89	0.195	0.39	0.543
1960--Japan	All release sites grouped	5.83	0.129	1.52	0.228
1961--Japan	All release sites grouped	3.95	0.273	0.13	0.729
1964--United States	Stations 8 and 9 grouped	1.43	0.703	0.08	0.788
	Station 10	3.75	0.302	0.41	0.529
	Station 12	3.88	0.283	0.70	0.428
	Station 13	2.14	0.550	0.24	0.600
	Station 15	5.85	0.128	0.08	0.788
	Station 16	0.89	0.826	0.70	0.428
	Stations 12 and 15 grouped	8.53	0.038	0.0001	>0.900
	Stations 13 and 16 grouped	2.46	0.487	0.36	0.564
1965--United States	Release location 57°00' N., 160°00' W.	2.07	0.565	0.91	0.368
	Release location 57°48' N. 158°30' W.	240.54	<0.005	267.48	<0.005
	Remaining release locations grouped	3.88	0.283	1.16	0.296

Bering Sea Tagging by the United States, 1957

Because of the small number of tag recoveries in Bristol Bay resulting from the 1957 Bering Sea taggings, all have been grouped for analysis (Table 2). The most apparent feature in the recovery data is the lack of recoveries in the Nushagak Bay fishing district. The number of tag recoveries in the Egegik fishing district was somewhat higher than expected. These differences, however, were not large enough to result in significant chi-squares[8] and cause rejection of the hypothesis of like offshore distributions for individual stocks (Table 9).

Bering Sea Tagging by the United States, 1958

Tag recoveries from releases made in the vicinity of the Pribilof Islands in 1958 (Figure 18) were grouped for analysis (Table 3) because all of the tagging stations were in the same general area and the number of recoveries was small. The lack of Nushagak recoveries and the greater than expected number of Egegik recoveries were sufficient to result in significant chi-squares in tests of recoveries between individual fishing districts and east and west side districts (Table 9). The recovery distribution indicates that

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[8] $P \leq 0.05$.

stocks of sockeye salmon destined for the rivers draining into Nushagak Bay were not present at the time and place of tagging in the numbers to be expected. Egegik River sockeye salmon were more abundant than expected at the time of tagging. It is possible that this situation actually existed or that these results suffered from the vagaries of sampling, either at the time of tagging or at recovery. Because only a limited amount of tagging had been carried out in any one year in the Bering Sea, it is necessary to look for consistencies in the recovery distributions resulting from all years before arriving at conclusions on the offshore distribution of individual sockeye stocks.

Bering Sea Tagging by the United States and Japan, 1960

The results are similar in 1960 for both the single near-shore tagging by the United States and the grouped taggings farther offshore by Japan. Again there is a lack of recoveries in Nushagak Bay (Tables 4 and 5). Also, in both cases the number of recoveries are somewhat less than expected. These differences were not sufficient, however, to result in significant chi-squares (Table 9) in the tests between individual fishing districts or districts on the east and west side of Bristol Bay.

Bering Sea Tagging by Japan, 1961

Because the four taggings by Japan were carried out in the same general area (Figure 18) their recoveries were grouped for analysis (Table 6). The differences between the number of actual and expected recoveries were not sufficient to result in significant chi-squares (Table 9) in tests performed on the recovery data. Therefore the hypothesis of like distribution for all stocks is accepted. Tag recoveries in the Nushagak fishing district, however, were again lower than expected.

Bering Sea and Bristol Bay Tagging by the United States, 1964

The few Bristol Bay tag recoveries from release stations 8 and 9 near the Pribilof Islands (Figure 18) were grouped for analysis (Table 7). The results of chi-square tests performed on these data (Table 9) did not result in significant chi-squares and rejection of the hypothesis of like distributions for all stocks. This is in contrast to the results of the 1958 tagging in the same general area which was discussed above. The number of Nushagak recoveries continued to be less than expected.

The recovery distribution resulting from tagging at station 10 (Figure 18 and Table 7) was not significantly different than expected (Table 9), causing acceptance of the stated hypothesis. Nushagak district recoveries were again less than expected.

Taggings at stations 12, 13, 15, and 16 (Figure 18) were well inside Bristol Bay closer to the mouths of major Bristol Bay river systems. In this region one might expect a greater likelihood for segregation of individual stocks of sockeye salmon. In addition the tagging stations were widely separated, i. e. they occurred both near shore (stations 12 and 15) and well offshore (stations 13 and 16). For these reasons tag recoveries from each of the four stations were treated individually and then combined as near-shore and offshore tagging (Table 7).

In all tests the differences between the actual and the expected number of tag recoveries were not sufficient to result in significant values of chi-square (Table 9). Again the hypothesis of like distributions for all sockeye salmon stocks should not be rejected. Although the number of tag recoveries from these stations is admittedly small, their distribution suggests that segregation of individual stocks is beginning to occur in this region of the bay.

Consider first, recoveries from inshore station 12 and offshore station 13 (Table 7). Note that Egegik and Ugashik recoveries are about equal to or greater than the expected number from the tagging at station 12 inshore. They are lacking, however, in the recoveries from the offshore tagging at station 13. Note also that Naknek-Kvichak district recoveries are less than expected at station 12 but are about as expected at station 13. Nushagak recoveries are about as expected from station 12 tagging and greater than expected from station 13 tagging.

Because of the small number of recoveries from these taggings the differences we are dealing with are small, i.e. fractions of tags. The data, although weak, suggest the beginning of a pattern of stock distribution in this area, which might be expected and which seems to be borne out by, and is consistent with, the results of tagging nearer the head of Bristol Bay.

My interpretation of this pattern is as follows: Ugashik and Egegik fish are present at station 12 near shore but not at station 13 offshore. This indicates that these stocks are beginning to leave the offshore waters and move toward their home-river systems on the southeast side of Bristol Bay. This would decrease the proportion of Naknek-Kvichak stocks at station 12 inshore. The number of Naknek-Kvichak recoveries from station 12 tagging was, in fact, less than expected (Table 7). The actual number of Naknek-Kvichak recoveries at station 13 is about as expected and indicates that stocks of sockeye salmon bound for these river systems are still abundant in the offshore waters. Although the differences are slight, the recovery data indicate that Nushagak Bay stocks are more abundant offshore at station 13, as might be expected.

Consider now the recovery distribution resulting from taggings at stations 15 and 16 (Table 7) nearer the head of Bristol Bay.

Ugashik and Egegik recoveries from tagging at station 15, inshore, were substantially greater than expected. Recoveries in the Egegik and Ugashik districts of fish tagged at station 16, offshore, were almost lacking. This is consistent with the pattern indicated by the results of taggings at stations 12 and 13 farther seaward. The same pattern of distribution holds true for the Naknek-Kvichak and Nushagak stocks tagged at stations 15 and 16, as shown by the results of taggings at stations 12 and 13. These stocks are still more abundant in the offshore waters (station 16) and less abundant inshore (station 15). The same distribution pattern is shown when recoveries from inshore taggings (stations 12 and 15) and offshore taggings (stations 13 and 16) are grouped for analysis (Table 7).

Finally, consider the recovery distribution by fishing districts on the southeast side (Naknek-Kvichak, Egegik, and Ugashik combined) and the northwest side (Nushagak) of Bristol Bay from the inshore taggings (stations 12 and 15) and the offshore taggings (stations 13 and 16) (Table 7). Chi-square analysis of these data (Table 9) did not result in rejection of the hypothesis of like distributions in the area of tagging for stocks of sockeye salmon destined for fishing districts on each side of Bristol Bay. The recovery distribution by southeast and northwest side fishing districts is about as expected from the combined inshore taggings (stations 12 and 15). Stocks of sockeye salmon bound for the Nushagak or the northwest side district were more abundant offshore than expected, while stocks destined for southeast side districts were less abundant. This, of course, is what would be expected; and these results merely serve to further illustrate that segregation of stocks is taking place in the area under discussion.

Bristol Bay Tagging by the United States, 1965

Recovery data from tag releases in Bristol Bay in 1965 have been analyzed in three groups. These include recoveries from taggings at (1) lat. 57° N. and long. 160° W., the most seaward release site; (2) lat. 57°48' N. and long. 158°30' W., the release site nearest the head of the bay; and (3) a group of seven release sites opposite Port Heiden midway between locations one and two (Figure 18, Table 8).

The results of chi-square tests run on the recovery distributions from the taggings at lat. 57° N. and long. 160° W., and from the group of seven taggings opposite Port Heiden (Table 9), did not reject the hypothesis of like distributions for all stocks. Nushagak district recoveries were less than expected, whereas Naknek-Kvichak recoveries occurred in about the numbers expected. Egegik recoveries were present in about the numbers expected at station lat. 57° N. and long. 160° W. but were considerably more abundant from the seven grouped taggings. Differences from the expected in the number of Ugashik recoveries were not very great. When considered from the standpoint of southeast and northwest side fishing district recoveries, northwest side stocks (Nushagak Bay) were less abundant than might be expected, assuming like distributions for all stocks. Considering these results and those from the 1964 taggings farther offshore (stations 13 and 16), the indication is that Nushagak Bay (northwest side district) stocks were more abundant farther offshore and toward the northwest side of the bay, as might be expected.

The recovery distribution resulting from taggings at lat. 58° 48' N. and long. 158° 30' W., near the head of Bristol Bay, is in contrast to those resulting from the previous taggings (Table 8). Significant chi-squares were obtained for comparisons both between individual fishing districts and southeast and northwest side districts (Table 9), and is cause for rejection of the hypothesis of like distribution for all stocks in the area of tagging. The high chi-square values are due to the much greater than expected number of Nushagak Bay recoveries and the substantially smaller than expected number of Naknek-Kvichak recoveries. This recovery distribution suggests a pattern of continued stock segregation toward the head of the bay, which is consistent with the results farther offshore. Stocks of sockeye salmon destined for Nushagak Bay are now most abundant in the offshore waters. The proportion of Naknek-Kvichak stocks appear to be declining in these waters, and they are probably moving toward the coast on the southeast side of the bay. Egegik and Ugashiak fish have apparently left the offshore waters by the time they reach the area of tagging and have moved toward the coast and the mouths of their home-river systems.

Offshore Distribution of Fishing District Stocks of Bristol Bay Sockeye Salmon

The recovery distributions of sockeye salmon tagged at various locations between long. 165° and 170° W. and south of lat. 57° N. (Figure 18) were consistent in showing that fish bound for the four major fishing districts occurred in proportion to their abundance in the total run to Bristol Bay. In only one instance (1958) was the hypothesis of like offshore distributions for all stocks rejected. In most cases, the results also showed that stocks of sockeye salmon bound for the Nushagak fishing district occurred at tagging locations in numbers less than expected. Unfortunately only limited tagging has been carried out north of lat. 57° N. in this region, and too few tags were recovered to make an analysis. The exploratory fishing discussed earlier showed that substantial numbers of sockeye salmon were caught in this region. The recovery distributions resulting from tagging inside Bristol Bay between long. 158° and 161° W. (Figure 18) showed that Nushagak district stocks were present in expected or greater than expected numbers at the northernmost tagging sites. Sockeye salmon bound for the Nushagak district may also be more abundant than expected farther seaward in the more northerly portion of the area encompassing their migration route. Data to substantiate this point are lacking, however. On the basis of the available data, I concluded that there is little segregation of individual stocks of Bristol Bay sockeye salmon in the eastern Bering Sea region of tagging. For the present the stock composition of sockeye salmon in the northern portion of the approach to Bristol Bay remains open to question.

The recovery distribution of sockeye salmon tagged in outer Bristol Bay between long. 158° and 161° W. showed a progressive segregation of district stocks toward the head of the bay. Fish bound for the Nushagak and Naknek-Kvichak fishing districts remained abundant in the offshore waters toward the head of the bay. Those bound for Ugashik and Egegik, however, decreased in abundance at offshore locations and apparently moved toward the coast and the mouths of their home-river systems.

There has been little tagging in the eastern Bering Sea between long. 161° and 167° W. (Figure 18). The results of a tagging study carried out in this area would serve to answer some of the questions posed by the results of the present analysis. Such data are required for a more complete description of the offshore distribution and migration routes of individual sockeye salmon stocks.

Results of Inshore Tagging

The recoveries of fish tagged and released at inshore sites are listed by fishing district or river system in Appendix Tables 23-28. These data are illustrated graphically in Figures 50-56.

The relative size of the sockeye salmon run (catch plus escapement) to each fishing district (Table 10) must be taken into account when drawing inferences about the distribution of each stock from the distribution of tagged fish. This is necessary because the size of the runs to each district varies each year. Tag recoveries have not been weighted for size of run, because, as will become apparent in the discussion below, the recorded catch for each district was composed of stocks of sockeye salmon destined for the river systems of several fishing districts. The contribution of each stock to the commercial catch of a fishing district will vary from year to year depending on the relative size of the individual runs. Assignment of portions of the catch in each district to individual river systems was not done in 1955 and 1956. This has been done since 1957, but the calculations were based on the age composition of the spawning escapement of each river system. The age composition of the escapement, however, has been modified to a certain extent by the selective action of the gill nets (Pages 67 and 68). The mixing of stocks within fishing districts was not considered serious enough to prevent interpretation of the

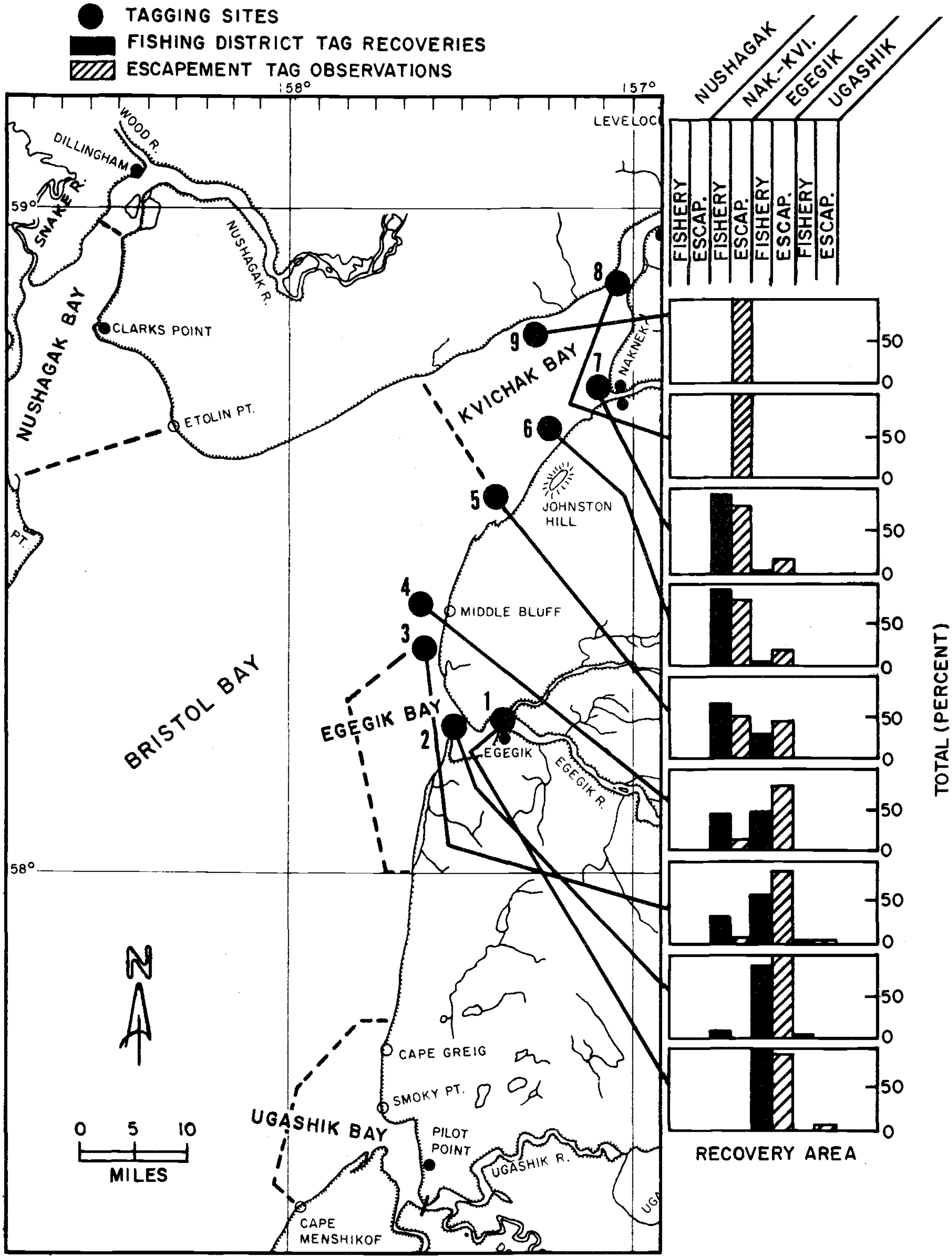

Figure 50. Distribution of fishery recoveries and escapement observations of tagged sockeye salmon, Bristol Bay, 1955.

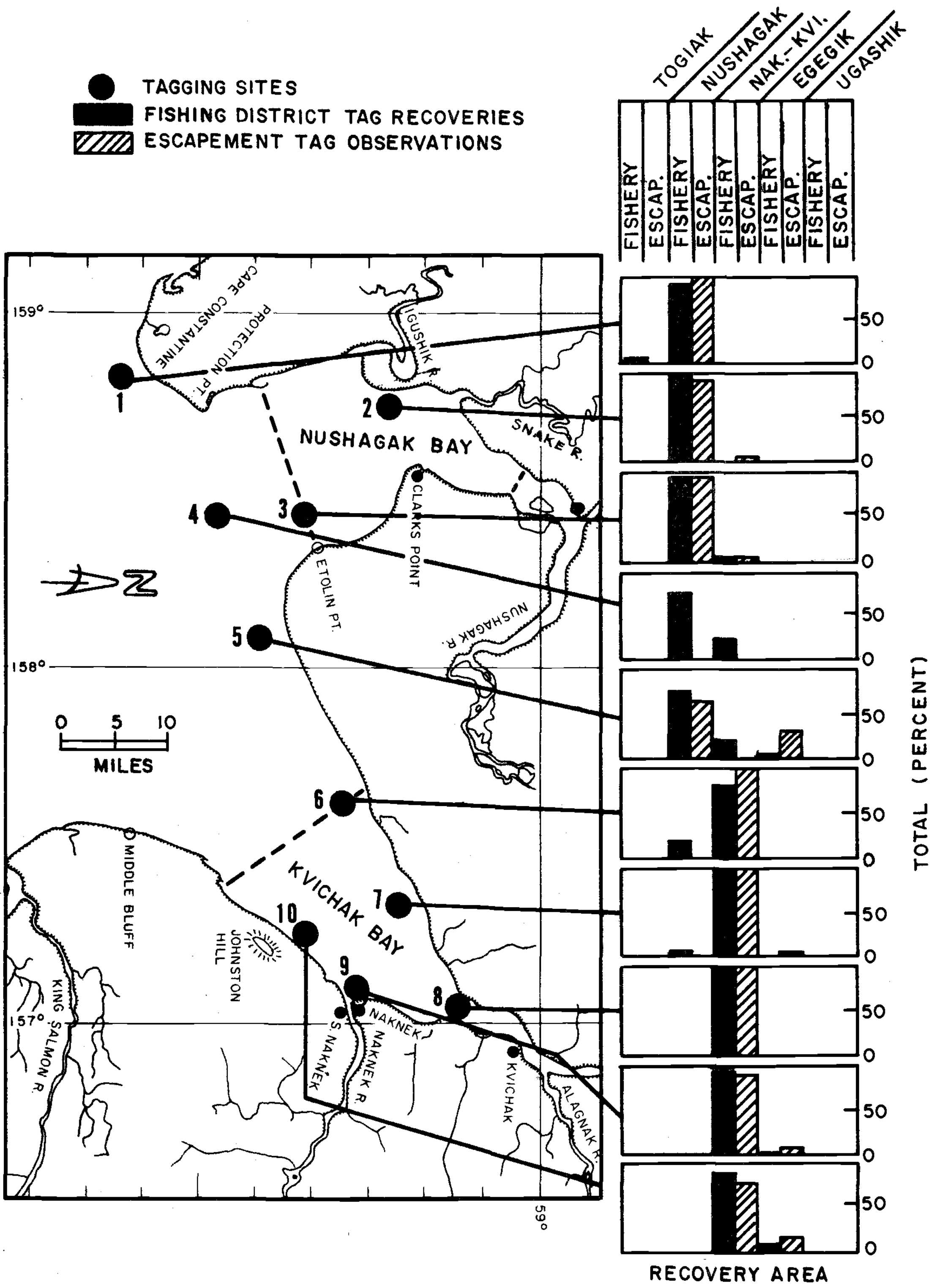

Figure 51. Distribution of fishery recoveries and escapement observations of tagged sockeye salmon (Nushagak and Kvichak Bays), Bristol Bay, 1956.

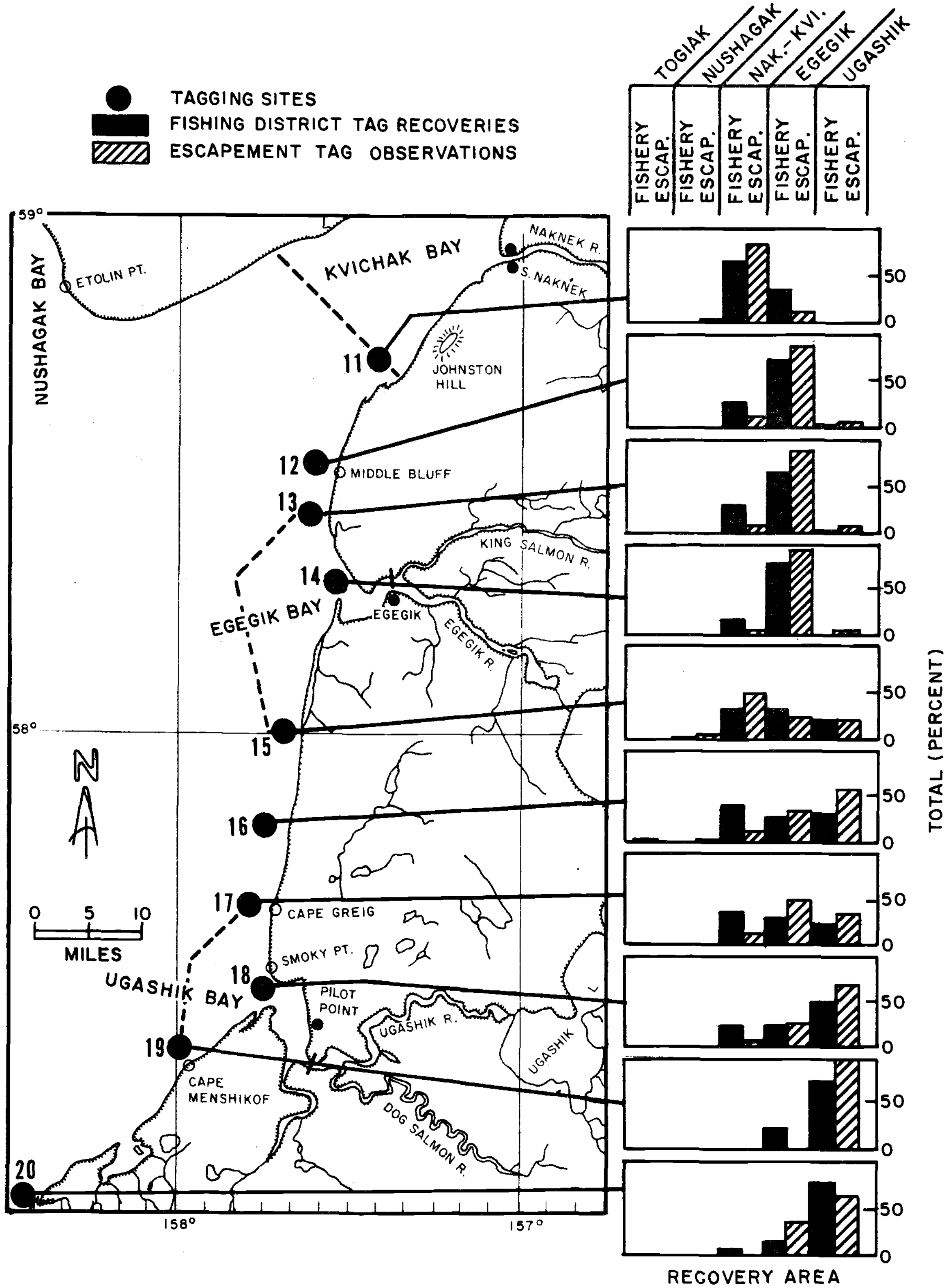

Figure 52. Distribution of fishery recoveries and escapement sightings of tagged sockeye salmon (Kvichak, Egegik, and Ugashik bays), Bristol Bay, 1956.

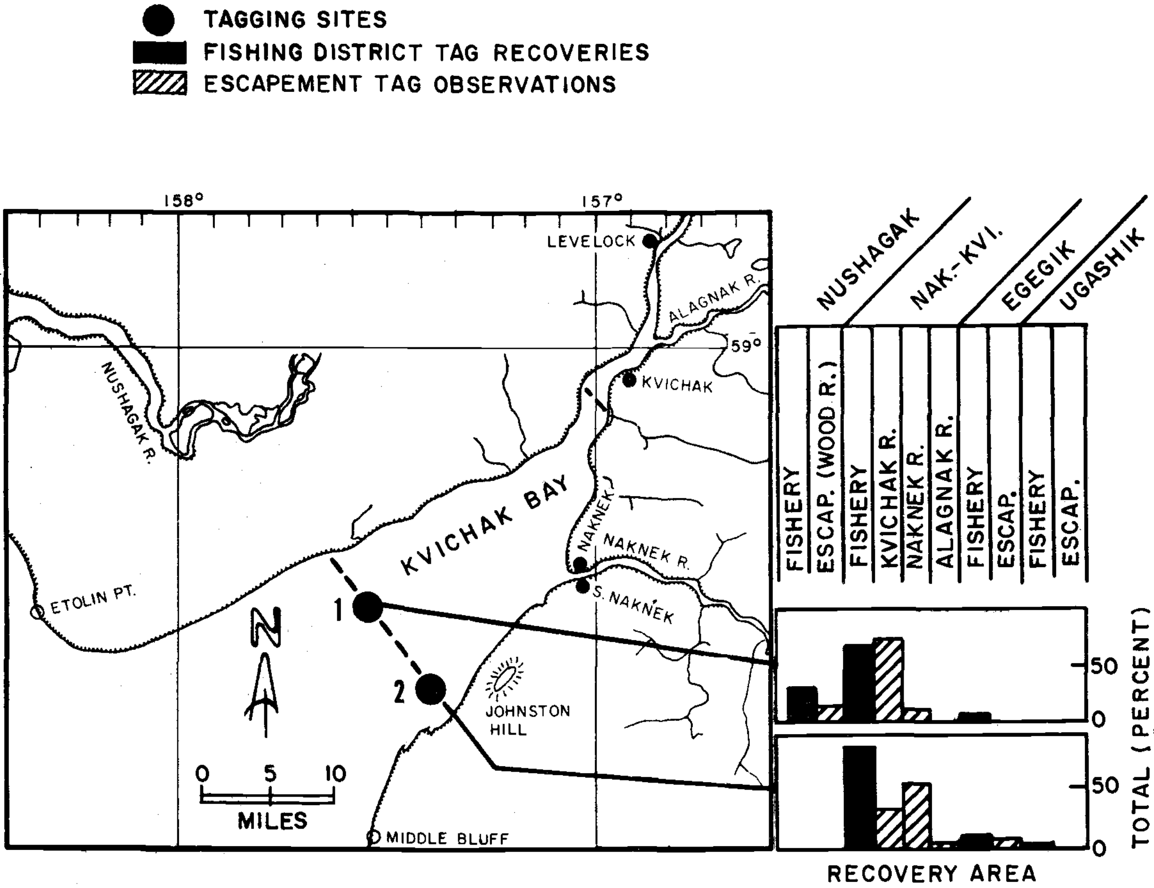

Figure 53. Distribution of fishery recoveries and escapement observations of tagged sockeye salmon, Bristol Bay, 1957.

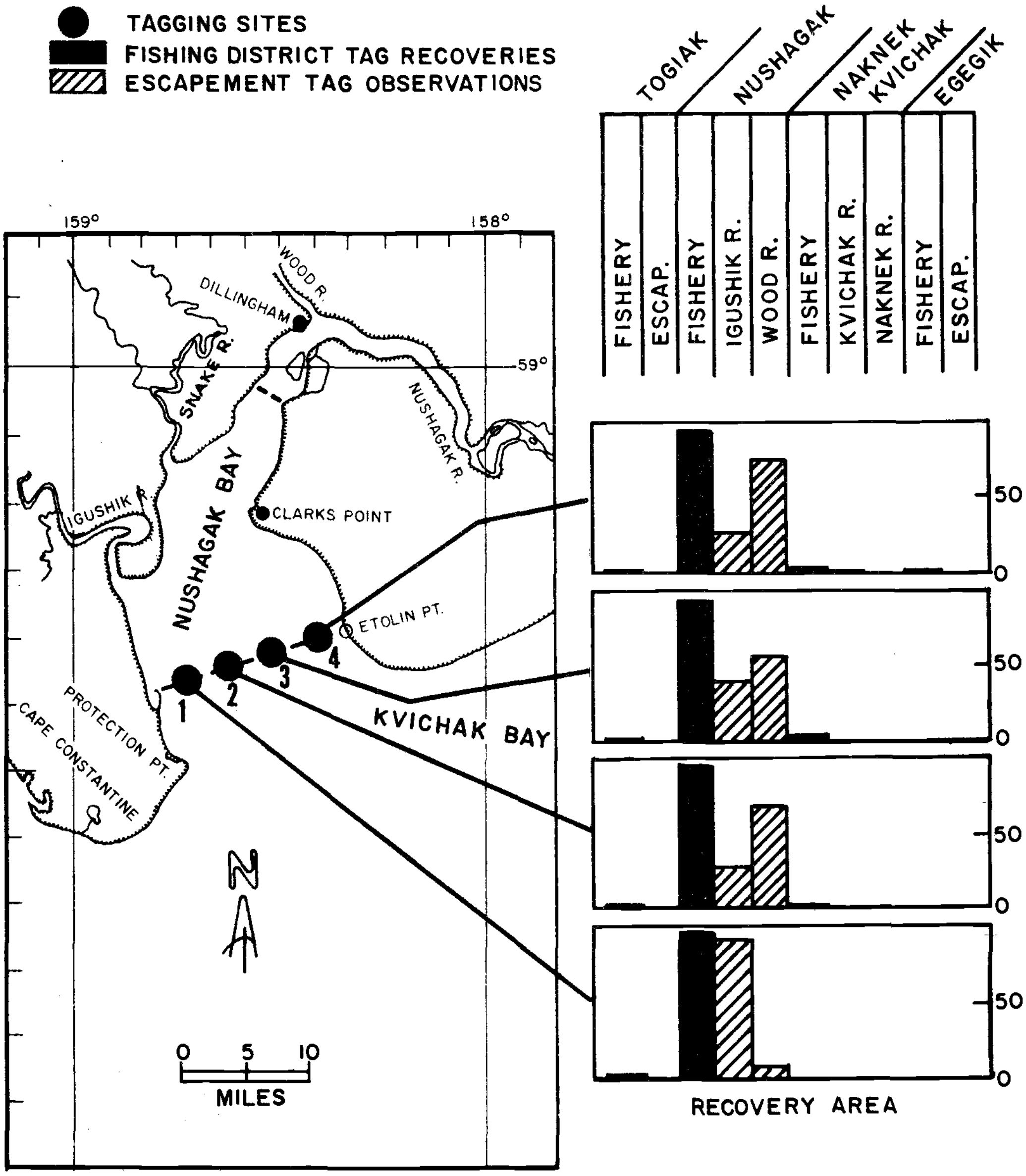

Figure 54. Distribution of fishery recoveries and escapement observations of tagged sockeye salmon, Bristol Bay, 1959.

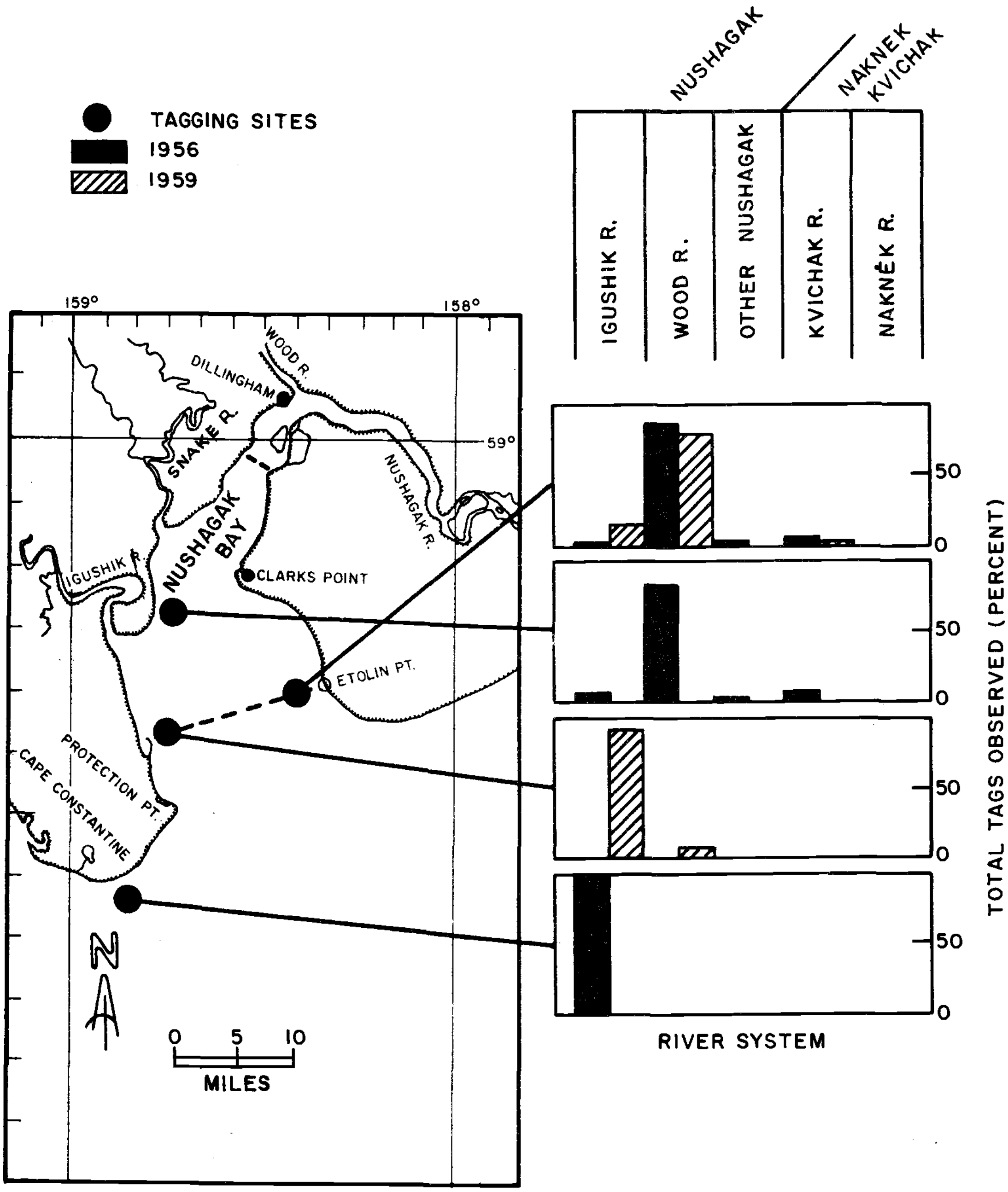

Figure 55. Distribution of tagged sockey salmon in the Igushik, Wood, Kvichak, Naknek, and other Nushagak Bay river escapements, Bristol Bay, 1956 and 1959.

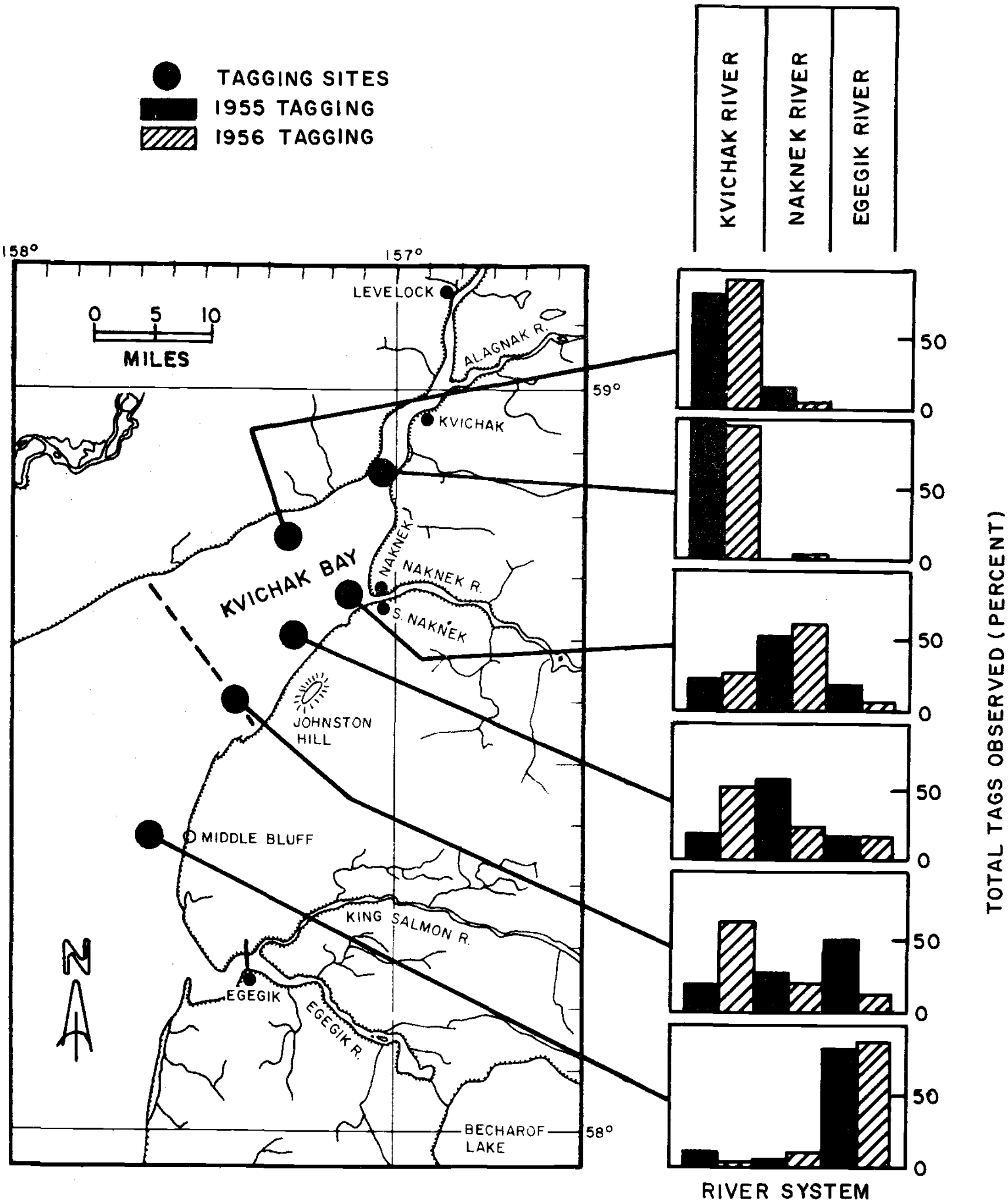

Figure 56. Distribution of tagged sockeye salmon in the Kvichak, Naknek, and Egegik river escapements, Bristol Bay, 1955 and 1956.

Table 10. Total run (commercial catch plus escapement) of sockeye salmon (thousands of fish) by fishing district, Bristol Bay, 1955-57 and 1959[a] and ratio of Naknek-Kvichak district stocks to other district stocks

Naknek-Kvichak District

Year	Catch	Escapement: Kvichak River	Escapement: Alagnak River	Escapement: Naknek River	Total run
1955	2, 564	250	170	280	3, 264
1956	5, 988	9, 440	780	1, 770	17, 978
1957	4, 579	2, 840	120	630	8, 169
1959	1, 689	680	820	2, 230	5, 419

Nushagak District

Year	Catch	Escapement: Wood River	Escapement: Igushik River	Escapement: Nushagak River	Escapement: Snake River	Total run	Ratio--Nushagak: Naknek-Kvichak
1955	1, 055	1, 380	(b)	550	(b)	2, 985	1:1. 09
1956	1, 263	720	(b)	440	(b)	2, 473	1:7. 27
1957	491	290	(b)	210	(b)	991	1:8. 24
1959	1, 720	2, 210	644[c]	49[c]	137[d]	4, 760	1:1. 14

Egegik District

Year	Catch	Escapement	Total run	Ratio--Egegik: Naknek-Kvichak
1955	622	270	892	1:3. 66
1956	1, 187	1, 100	2, 287	1:7. 86
1957	814	390	1, 204	1:6. 78
1959	662	1, 070	1, 732	1:3. 13

Ugashik District

Year	Catch	Escapement	Total run	Ratio--Ugashik: Naknek-Kvichak
1955	241	240	481	1:6. 79
1956	341	340	681	1:26. 40
1957	351	350	701	1:11. 65
1959	423	220	643	1:8. 43

[a] Source: Kasahara (1963).

[b] Data not available.

[c] Unpublished data on file at the Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska.

[d] This figure was determined by subtracting the sum of the Igushik and Nushagak River escapements from 830, the figure given by Kasahara (1963), Page 79, for the total escapement of all river systems in Nushagak Bay except the Wood River.

distributions and migration routes of these stocks. The recorded size of the spawning escapement (regarded as a pure or unmixed stock) of individual river systems may be used alone to indicate the magnitude of a run. In most years large escapements occurred when large catches were made within a fishing district (Table 10). Therefore, I have referred to total run size in my interpretation of the results for the four years of tagging.

Distribution of Southeast versus Northwest Side Fishing District Stocks of Sockeye Salmon

The distribution of tag recoveries in both the commercial fishery and the spawning escapement (Figures 50-54) showed that sockeye salmon stocks on the northwest side of upper Bristol Bay were not appreciably mixed with stocks on the southeast side of the bay. Very few fish tagged in the vicinity of Nushagak Bay (sites 1-5, 1956 (Figure 51) and sites 1-4, 1959 (Figure 54)) were captured in the fishing districts on the southeast side of the bay or were observed in the escapement of southeast side river systems. Few fish tagged on the southeast side of Bristol Bay were captured in the Nushagak Bay fishery or observed in the escapement to Nushagak Bay river systems (Figures 50-53, Appendix Tables 23-26). The distribution of tag recoveries showed that some mixing of Nushagak and Kvichak bay stocks occurs on the northwest side of Kvichak Bay between Etolin

Point and the outer boundary of the Naknek-Kvichak fishing district (Figures 51, 53, and 54). Observations of tagged fish in the escapement show this to be primarily a mixture of Wood and Kvichak river sockeye salmon (Figures 53-55 and Appendix Tables 24, 26, and 28).

Nushagak Bay sockeye salmon are well separated in the area of tagging from those bound for the other major river systems of Bristol Bay. The main migration route of non-Nushagak stocks must be well offshore and southeast of the entrance to Nushagak Bay. Sockeye salmon on the northwest side of upper Bristol Bay are bound primarily for the rivers entering Nushagak Bay. The area in the middle of upper Bristol Bay between Nushagak and Egegik bays must be the main migration route of sockeye salmon bound for the Kvichak and Naknek river systems. Few fish tagged on the northwest side of Kvichak Bay were taken in the Egegik or Ugashik fishing districts or observed in the spawning escapements of these river systems (Figures 50, 51, and 53, Appendix Tables 23-26). Ugashik and, to a lesser extent, Egegik sockeye salmon tagged in outer Bristol Bay between long. 158° and 161° W. in 1964 and 1965 (page 146) were shown to be leaving the offshore waters for the coast on the southeast side of Bristol Bay and the mouths of their home-river systems.

Distribution of Ugashik River Sockeye Salmon

The most extensive tagging of sockeye salmon in the vicinity of the Ugashik River was carried out in 1956. Ugashik fish were dominant in the region between sites 20 and 15 (Figure 52, Appendix Table 24). Most recoveries of sockeye salmon tagged and released south of the entrance to Ugashik Bay were made in the Ugashik fishery and escapement. Some sockeye salmon tagged as far north as the outer boundary of the Naknek-Kvichak fishing district were also recovered in the Ugashik fishery in 1955 (Figure 50, Appendix Table 23) and 1957 (Figure 53, Appendix Table 25). A small number of sockeye salmon tagged off Middle Bluff in 1955 (Figure 50, Appendix Table 23) and 1956 (Figure 52, Appendix Table 24) were recovered in the Ugashik fishery and observed in the Ugashik River escapement.

Although significant numbers of fish tagged at sites 18 through 16 were recovered in the Naknek-Kvichak fishery, relatively few were observed in the escapement of the Naknek and Kvichak river systems. This suggests that only a small number of fish were actually Naknek and Kvichak river stocks. A large number of these tagged fish were observed in the Egegik and Ugashik river escapements (Figure 52, Appendix Table 24), however, which indicates that these fish were predominantly Egegik and Ugashik sockeye salmon. The proportion of Ugashik fish increased toward the entrance to Ugashik Bay. The Naknek-Kvichak sockeye salmon run in 1956 was more than 26 times the size of the Ugashik run and almost eight times that of the Egegik run (Table 10). When the relative size of the sockeye salmon runs to the Naknek-Kvichak, Egegik, and Ugashik fishing districts (Table 10) are considered in viewing the tag recovery distribution, then Ugashik River sockeye must have been the most abundant stock in the near-shore area between sites 15 and 20.

In spite of the dominance of Naknek-Kvichak sockeye salmon in 1956, only a small number of fish tagged at sites 20 through 16 were observed in the escapements of the Naknek and Kvichak rivers (Figure 52, Appendix Table 24). This indicates that the main migration route of these stocks is offshore outside the area within, and adjacent to, the Ugashik fishing district.

Distribution of Egegik River Sockeye Salmon

The escapement distribution of sockeye salmon tagged in 1956 (Figures 51 and 52) showed that the Egegik River stock was present in the area between the entrance to Ugashik Bay and the mouth of the Naknek River. The distribution of fish tagged in 1955 (Figure 50) also showed that fish bound for the Egegik River occurred off the mouth of the Naknek River. With the exception of tagging site 5 in 1956, few fish tagged on the northwest side of upper Bristol Bay (Figure 51 and Appendix Table 24) were captured in the Egegik fishing district or observed in the spawning escapement of the Egegik River system. The greatest abundance of Egegik River sockeye salmon occurred between Middle Bluff and the entrance to Ugashik Bay on the southeast side of Bristol Bay (Figure 52).

In the area between the outer southeast side boundary of the Naknek-Kvichak fishing district and Middle Bluff there was a marked increase in the proportion of tagged fish recovered in the Egegik fishery and observed in the Egegik River escapement (Figures 50 and 52). This was particularly apparent in the escapement distribution of fish tagged off Middle Bluff and at the outer southeast side boundary of the Naknek-Kvichak fishing district in both 1955 and 1956 (Figure 56). In 1956 the sockeye salmon run to the Naknek-Kvichak district was almost eight times the size of the Egegik run (Table 10). In 1955 it was less than four times as large. In both years, however, the distribution of tagged fish observed in the escapement to the Egegik and combined Naknek and Kvichak river systems was similar (Figures 50 and 52). In both years significant numbers of fish tagged off Middle Bluff were captured in the Naknek-Kvichak fishing district, but few were observed in the escapement to these two rivers. Many of these tagged fish, however, were observed in the Egegik River escapement. This indicates that most fish tagged off Middle Bluff and captured in the Naknek-Kvichak fishing district were actually Egegik fish.

Significantly more tagged fish were observed in the Naknek and Kvichak river escapements than in the Egegik River escapement from the tagging carried out at the outer southeast side boundary of the Naknek-Kvichak fishing district in 1956 and 1957 (Figures 53 and 56, Appendix Tables 24 and 26). The number of tagged fish observed in the Naknek and Kvichak river escapements from the 1955 tagging at the same location was only slightly higher than the number observed in the Egegik River escapement. This was probably due to the lower abundance of Naknek and Kvichak river sockeye salmon in 1955 compared with 1956 and 1957 (Table 10). As a result a greater proportion of tagged fish of Egegik origin were taken in the Naknek-Kvichak fishing district in 1955 than in either 1956 or 1957.

The distribution of fishery recaptures and escapement sightings of fish tagged between Middle Bluff and the entrance to Egegik Bay (Figures 50 and 52) showed that Egegik River sockeye salmon were the most abundant stock in this area. Naknek and Kvichak river fish, which outnumbered Egegik fish in all years of tagging, must still have been offshore and outside this area of tagging. The distribution of sockeye salmon tagged at the outer southeast side boundary of the Naknek-Kvichak fishing district, however, showed that Naknek and Kvichak river fish became the most abundant stocks in the near-shore area north of Middle Bluff. Most Egegik River fish apparently left the offshore waters to the south of the outer boundary of the Naknek-Kvichak fishing district for the coast and their home-river system.

The distribution of sockeye salmon tagged south of the entrance to Egegik Bay in 1956 (Figure 52) showed that Egegik fish were abundant in the coastal areas as far south as the entrance to Ugashik Bay. Ugashik River fish, as pointed out above, were the most abundant stock present in the area between tagging sites 18 and 16. Egegik River sockeye salmon were probably the most abundant stock north of site 15. Most fish bound for the Naknek, Kvichak, and Alagnak rivers must have been farther offshore outside the area of tagging.

Distribution of Naknek and Kvichak River Sockeye Salmon

Sockeye salmon tagged as far south as the entrance to Ugashik Bay on the southeast side of upper Bristol Bay were recaptured in the Naknek-Kvichak fishing district and observed in the Kvichak River escapement (Figure 52, Appendix Table 24). Sockeye salmon tagged on the northwest side of Kvichak Bay and in outer Nushagak Bay off Etolin Point were recovered in the Naknek-Kvichak fishing district and observed in the Kvichak River escapement (Figures 51 and 53, Appendix Tables 24-26). The results of the taggings discussed thus far, however, have shown that the main migration route of sockeye salmon bound for the Naknek and Kvichak river systems was offshore outside the area of tagging on both the southeast and northwest sides of upper Bristol Bay. Naknek and Kvichak river sockeye salmon stocks only became abundant in the coastal waters north of Middle Bluff on the southeast side and northeast of Etolin Point on the northwest side of Kvichak Bay. In this region Kvichak Bay is only about 20 miles wide and Naknek, Kvichak, and Alagnak river stocks probably occupy the entire area during the migration to their home-river systems.

The escapement distribution of sockeye salmon tagged at the same locations on the southeast and northwest sides of Kvichak Bay in 1955 and 1956 (Figure 56) indicate that the sockeye salmon on the northwest side of the bay were largely Kvichak River stocks. Most of the escapement observations of fish tagged on the northwest side of the bay were made in the Kvichak River. Few were observed in the Naknek River escapement (Appendix Tables 23 and 24). The results were similar for sockeye salmon tagged at site 1 on the northwest side of Kvichak Bay in 1957 (Figure 53, Appendix Table 26).

The escapement distribution of fish tagged on the southeast side of Kvichak Bay between the Naknek River mouth and the outer boundary of the Naknek-Kvichak fishing district indicated that a mixture of Naknek, Kvichak, and Egegik stocks occurred here (Figures 50-52). More fish from these taggings were observed in the Naknek River escapement than in the Kvichak River escapement in 1955 (Figure 50, Appendix Table 23), indicating a greater abundance of Naknek fish in the area of tagging.

This dominance of Naknek River sockeye salmon in the area of tagging is also reflected in the age composition of fish tagged at sites 1 through 7 in 1955 (Appendix Table 29). The age composition of the escapements of the Naknek, Kvichak, and Egegik rivers in 1955 differed significantly from one another (Appendix Table 30). The 6_3 age group was the most abundant group in the Egegik River escapement, whereas the 5_2 age group was dominant in the Naknek River escapement. The dominant age group in the Kvichak River escapement was the 4_2. The proportion of the 6_3 and 5_2 age groups at each tagging site changed between the mouth of the Egegik and Naknek rivers (Figure 57). The 6_3 age group decreased in abundance north of the Egegik River mouth, and the 5_2 age increased in abundance. This showed a change from Egegik River stocks to predominantly Naknek River stocks, which was consistent with the results of tagging discussed above.

With the exception of the tagging off the Naknek River mouth, more fish from the 1956 taggings along the southeast side of Kvichak Bay were observed in the Kvichak River escapement than in the Naknek River escapement (Figure 56, Appendix Table 24). The escapement to the Kvichak River system in 1956 was more than five times that to the Naknek River system (Table 10). This much greater abundance of Kvichak River sockeye salmon in 1956 probably accounted for more Kvichak River fish being tagged on the southeast side of Kvichak Bay than Naknek River fish. Naknek stocks, however, were still more abundant on the southeast side than on the northwest side of Kvichak Bay in 1956 (Figure 56, Appendix Table 24).

The escapement distribution of sockeye salmon tagged at site 2

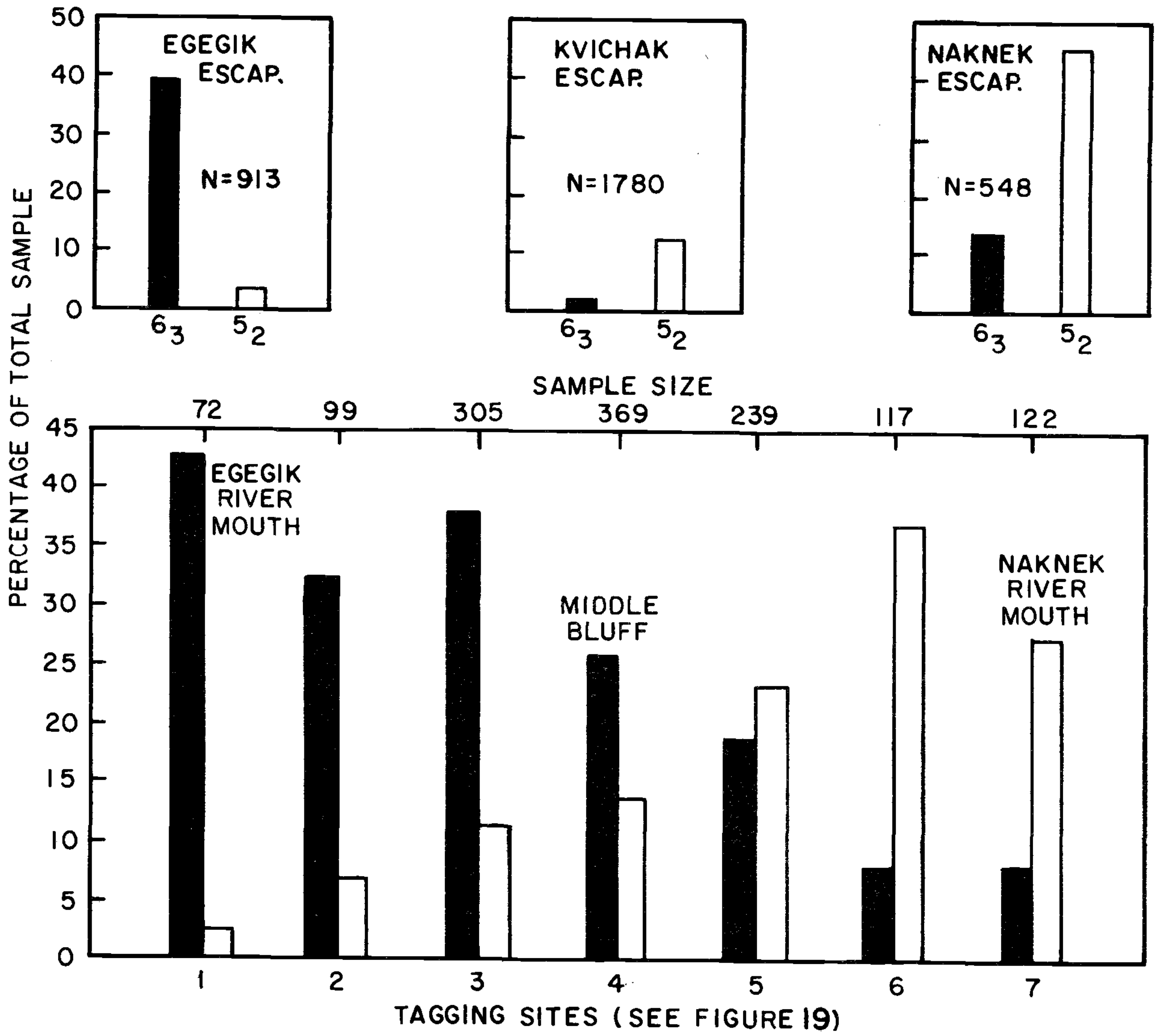

Figure 57. Distribution of the 6_3 and 5_2 age groups of sockeye salmon by tagging site and in the Egegik, Kvichak, and Naknek river spawning escapements, Bristol Bay, 1955.

on the southeast side of Kvichak Bay in 1957 (Figure 53) also showed that Naknek River fish were more abundant in this area than were Kvichak River fish. Although they were not as large as in 1956, the relative sizes of the Naknek and Kvichak river escapements (Table 10) indicated that Kvichak River stocks again dominated the run to the Naknek-Kvichak fishing district in 1957. The total run to the Naknek-Kvichak fishing district in 1957 was about half the size of the 1956 run (Table 10). Kvichak River fish probably did not occur in the near-shore waters on the southeast side of Kvichak Bay in as great numbers as in 1956. Most Kvichak River sockeye salmon must have been farther offshore in the middle and on the northwest side of Kvichak Bay.

The foregoing results illustrate the distribution of Naknek and Kvichak river sockeye salmon stocks in Kvichak Bay. There was a change from principally Naknek River sockeye on the southeast side of the bay to mainly Kvichak River sockeye salmon on the northwest side. A mixture of primarily Naknek and Egegik river stocks occurred along the southeast coast of Kvichak Bay. Kvichak and Wood river stocks occurred together along the northwest side of Kvichak Bay between Etolin Point and the outer boundary of the Naknek-Kvichak fishing district.

Distribution of Nushagak Bay (Wood, Igushik, and Snake Rivers) Stocks of Sockeye Salmon

Sockeye salmon migrating to the rivers on the southeast side of Bristol Bay do not enter Nushagak Bay. Within Nushagak Bay, there appeared to be segregation of the individual stocks of sockeye salmon in the run to this bay. The results of the tagging studies carried out in the vicinity of Nushagak Bay in 1956 and 1959 showed that this was particularly true for the Wood and Igushik river stocks. The tag recovery data suggested this may also be true for Snake River fish.

The recovery distribution of sockeye salmon tagged at sites 1 through 4 in 1959 (Figure 54, Appendix Table 28) showed Igushik River fish were most abundant on the west side of Nushagak Bay. Wood River fish appeared to be the most abundant stock on the east side of the bay. A greater number of fish tagged at site 1 on the west side of Nushagak Bay were observed in the Igushik River escapement than in the Wood River escapement. The opposite was true for the fish tagged at site 4. More fish tagged at site 4 were observed in the Wood River escapement than in the Igushik River escapement. Fish tagged at sites 2 and 3 were also more abundant in the Wood River escapement. Between sites 1 and 4 there was a decrease in the proportion of Igushik fish and an increase in the proportion of Wood River fish at the tagging sites.

Although sockeye salmon tagged at all sites were recaptured by the fishery in all parts of Nushagak Bay, the distribution of these recaptures also showed that sockeye salmon tagged at site 1 were bound for the Igushik River system. A high proportion of the fish tagged at sites 1 and 2 were taken by the fishery operating in the sub-district encompassing the Igushik River mouth (Figure 58). Most of these tagged fish were taken in the set and drift gill nets operated within, or close to, the Igushik River mouth. Most of the recaptures of sockeye salmon tagged at sites 3 and 4 were made in the sub-districts on the east side of Nushagak Bay. Sockeye salmon from these taggings, as shown above, were most abundant in the Wood River escapement, indicating that movement of this stock through Nushagak Bay was principally on the east side.

Wood River stocks generally make up the greater portion of the total run to Nushagak Bay. In 1959 the Wood River escapement was more than three times that of the Igushik escapement (Table 10), indicating dominance of the Wood River stock. In addition, over 75 percent of the fishing effort (estimated from aerial surveys of the fishery) was concentrated in the eastern half of Nushagak Bay in 1959, which is the area of greatest fishing success. Regardless of the dominance of Wood River stocks in 1959 and the smaller amount of fishing effort on the west side of Nushagak Bay, most of the fishery recaptures of site 1 tagged fish were on the west side of Nushagak Bay. The proportion of site 1 tagged fish in the spawning escapement

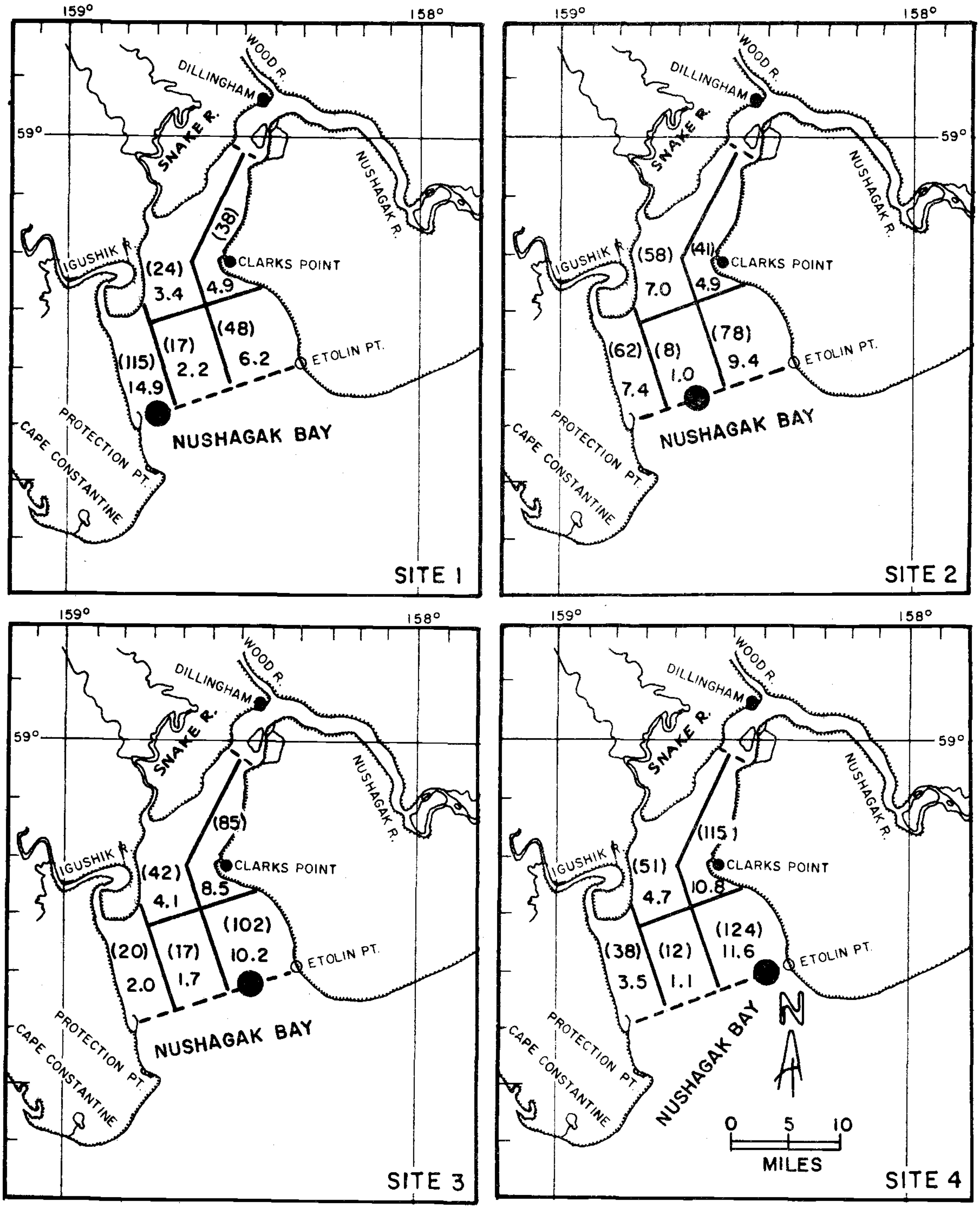

Figure 58. Percentage of distribution of tagged sockeye salmon captured in the Nushagak fishing district by site of tagging and subdistrict of capture, Bristol Bay, 1959.

was significantly higher than for the other three sites (Appendix Table 28), and probably reflects the smaller amount of fishing effort on the west side of Nushagak Bay.

The escapement distribution of sockeye salmon tagged off Etolin Point in 1956 was similar to that resulting from the 1959 tagging at this location (Figure 55), i. e. sockeye salmon on the east side of Nushagak Bay were primarily Wood River stocks. No fish tagged at site 1 off Cape Constantine in 1956 were observed in the Wood River escapement (Figure 55, Appendix Table 24). The only escapement recoveries came from set gill nets near the mouth of the Igushik River. Few tagged fish from 1956 tagging site 2 (Figure 55), located just above the Igushik River mouth, were recaptured in the Igushik River set nets. Most of the escapement observations of these fish were made in the Wood River, indicating Igushik River fish were not present in abundance at this location. This indicates the Igushik River sockeye probably go directly up the Igushik River after entering Nushagak Bay.

My interpretation of the distribution of the individual stocks in the sockeye salmon run to Nushagak Bay is as follows: (1) Igushik River fish have already become segregated, to a certain extent, from Wood River stocks before entering Nushagak Bay; (2) the main migration route of Igushik River fish appears to be in the near-shore area route around Cape Constantine, along the west side of Nushagak Bay and up the Igushik River; and (3) Wood River fish and most probably those of the Snake and Nushagak rivers must occur farther offshore in the Cape Constantine area. Therefore, these three stocks must enter Nushagak Bay in the middle and on the east side of the bay during migration to their home-river systems.

The results of the 1959 tagging in Nushagak Bay suggest that a substantial number of fish tagged at site 2 (Figure 54) (near the middle of the bay) may have been bound for the Snake River system. The proportion of fish observed in the escapement of the Wood and Igushik rivers was significantly lower for fish tagged at site 2 than for those tagged at sites 1, 3, and 4 (Appendix Table 28). The proportion of site 2 tagged fish recaptured in the Nushagak fishery was not significantly different from that of the other three sites (Appendix Table 27). Therefore, the fishery recaptures were not regarded as the cause of the lower proportion of site 2 tagged fish in the escapement. Fishery recaptures of site 2 tagged fish were equally abundant on the east and west side of Nushagak Bay (Figure 58). The effort on the west side of Nushagak Bay, as pointed out, was considerably less than that on the east side of the bay. This indicated that a greater number of site 2 tagged fish were present on the west side than on the east side of Nushagak Bay. This should have permitted a larger number of site 2 ragged fish to escape the fishery and be observed in the spawning escapement. A plausible explanation for the lower proportion of site 2 tagged fish in the escapement is that they escaped to some river system not adequately canvassed for tagged fish.

No reliable observations of tagged sockeye salmon were made in the Nushagak River escapement. Five tags, however, were recovered in the personal-use gill nets on the main Nushagak River, which is well above the fishery and below the escapement enumeration towers. These fish were from taggings at sites 2, 3, and 4 (Appendix Table 28) in the middle and on the east side of Nushagak Bay.

The Snake River system was not checked for tags until late August, when it was discovered it had received an unusually large escapement (Table 10). Most of the sockeye salmon in the Snake River escapement spawn on the beaches of Nunavaugaluk Lake (Figure 1). High winds and rough water during a three-day survey of this lake hampered observations of the spawning fish. Only three tags were positively identified during this survey (Appendix Table 28). Two fish were tagged at site 2 and one at site 3. These tag observations are too few to make conclusive statements about the distribution of Snake River fish in Nushagak Bay. However, they suggest a distribution which is consistent with that indicated by the results previously discussed, i. e. Snake River fish are most abundant on the west side and in the middle of Nushagak Bay.

Synopsis of the Distribution and Migration Route of Bristol Bay Sockeye Salmon

When the foregoing results are considered in their entirety a reasonable picture of the distribution and migration routes of the major stocks of adult sockeye salmon bound for Bristol Bay can be described.

Exploratory fishing in the eastern Bering Sea east of long. 170° W. showed that the main migration route of sockeye salmon returning to Bristol Bay river systems to spawn was in the offshore waters but in the southern half of the approaches to Bristol Bay. Exploratory fishing and the offshore and inshore tagging studies showed that Bristol Bay stocks remained in the offshore waters until they were within 20 to 50 miles of the mouths of their home-river systems.

There was no statistically significant difference in the distribution of the major fishing districts stocks of Bristol Bay sockeye salmon in the area between about long. 167° and 171° W. Stocks bound for Nushagak Bay may have been more abundant in the more northerly approaches to Bristol Bay. The results were inconclusive, however, because of insufficient tagging in this area.

Tagging of sockeye salmon in the eastern Bering Sea between long. 167° and 161° W. (Figure 18) was also insufficient, and the distribution of Bristol Bay sockeye salmon stocks in this area remains open to question. In the area between Port Moller and Cape Newenham, however, segregation of stocks destined for rivers entering on the northwest and southeast sides of Bristol Bay is apparent. Stocks bound for Nushagak Bay are more abundant in the offshore waters. Sockeye salmon migrating to Kvichak Bay remain abundant in the offshore waters in the southern half of Bristol Bay. Ugashik and Egegik river sockeye salmon stocks appear to decline in abundance in the offshore waters and to increase in abundance nearer to shore on the southeast side of Bristol Bay. The tagging carried out in outer Bristol Bay between long. 161° and 158°30' W. showed a continuation of this pattern of stock segregation toward the head of Bristol Bay.

The results of the tagging studies carried out in the near-shore areas on the northwest and southeast side of upper Bristol Bay were consistent with those carried out in outer Bristol Bay, i. e. they showed a continuation of stock segregation. Nushagak Bay sockeye salmon became the most abundant stocks on the northwest side of the upper Bristol Bay. Ugashik and Egegik river fish became most abundant in the near-shore areas on the southeast side of the upper bay. From this distribution, I concluded that Naknek, Kvichak, and Alagnak river fish remained most abundant in the offshore waters until reaching Kvichak Bay in the area northeast of Middle Bluff.

The stocks in the run to Nushagak Bay were shown to have become segregated to a certain extent before entering that bay. The

Igushik River stock was most abundant in the near-shore area off Cape Constantine and along the west side of Nushagak Bay to the Igushik River mouth. The data, although weak, suggest that Snake River fish were also most abundant on the west side and in the middle of Nushagak Bay. I conclude that Wood River and probably Nushagak River sockeye salmon enter Nushagak Bay en masse in the middle on the east side. The Wood River stock was shown to be most abundant on the east side of Nushagak Bay.

Naknek and Kvichak river sockeye salmon were also shown to have become segregated by the time they entered Kvichak Bay. Fish bound for the Kvichak River were most abundant on the northwest side and in the middle of Kvichak Bay. Naknek River fish were most abundant in the near-shore waters on the southeast side of Kvichak Bay northeast of Middle Bluff.

Sockeye salmon bound for the Egegik River system were shown to be declining in abundance in the offshore waters of outer Bristol Bay as far seaward as long. 159° W. They apparently reach the coastal area in greatest abundance between Middle Bluff and lat. 58° N.

Ugashik sockeye salmon were also shown to be declining in abundance in the offshore waters of outer Bristol Bay and increasing in abundance nearer to shore on the southeast side of upper Bristol Bay. South of lat. 58° N. Ugashik River fish were shown to increase in abundance, becoming most abundant in the near-shore area south of the entrance to Ugashik Bay.

In Figure 59 I show the general distribution of the major stocks of sockeye salmon in Bristol Bay as interpreted from the available tagging data presented above. The area shown in the figure is that in which the segregation of sockeye salmon stocks was found to occur. To complete the picture of stock distribution additional tagging is needed in the near-shore waters on the southeast side and in both the near-shore and offshore waters on the north side of Bristol Bay.

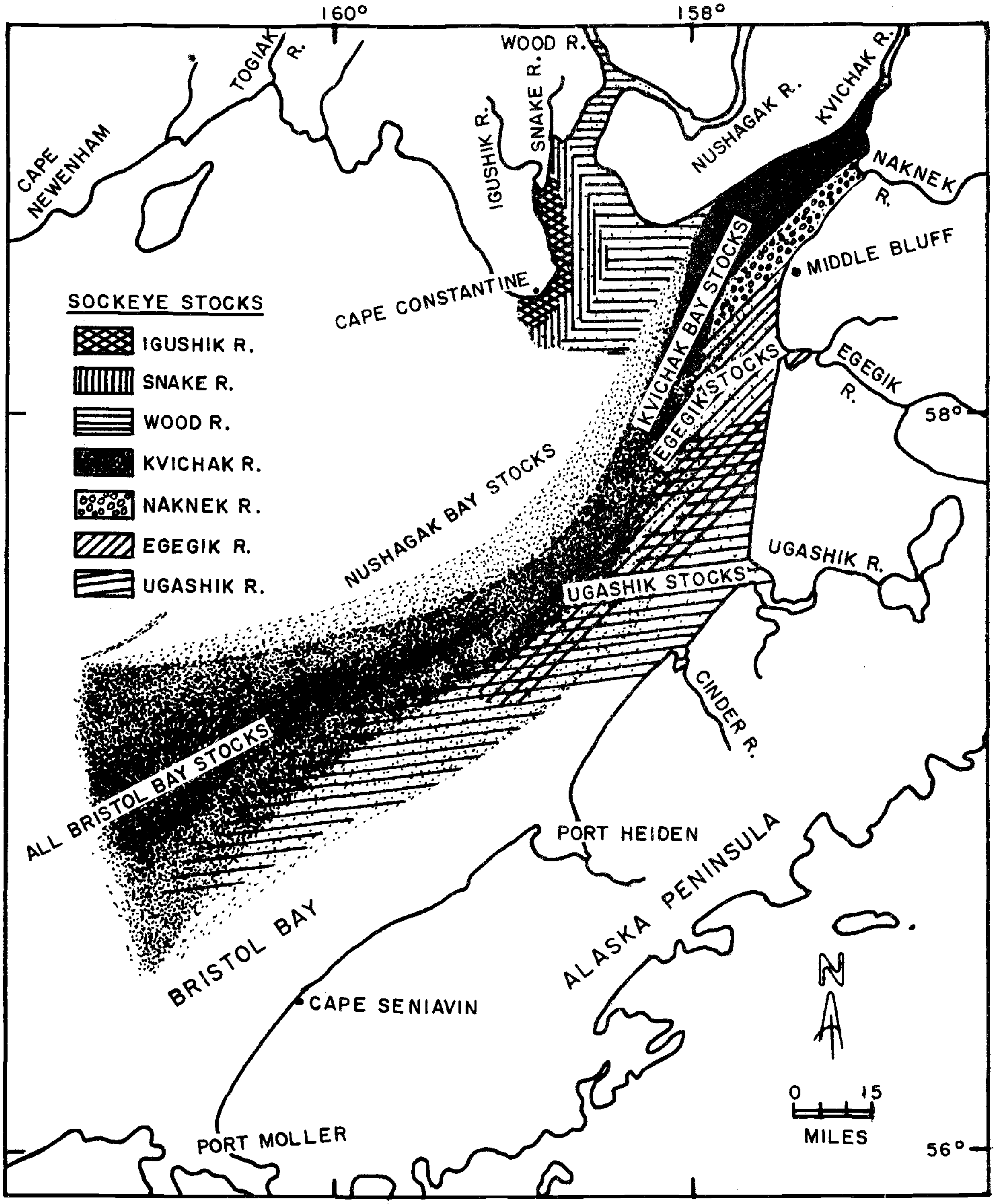

Figure 59. General distribution of Bristol Bay stocks of sockeye salmon, showing areas of greatest stock abundance.

VIII. RELATION BETWEEN DISTRIBUTION OF MAJOR STOCKS OF BRISTOL BAY SOCKEYE SALMON AND THAT OF THEIR HOME-RIVER SYSTEM WATERS

The salinity distribution in upper Bristol Bay was shown to be consistent with that in the offshore waters of the bay in that the seaward flow of the lighter less saline river runoff is on the northwest side of the bay. The results of the dye tracer and drift card studies showed that water from all the major sockeye salmon-producing river systems in Bristol Bay ultimately is transported to this side of the bay. The net movement of the heavier high-salinity water is toward the head of the bay on the left or southeast side and extends as far as Middle Bluff in Kvichak Bay.

The results of exploratory fishing showed that the main migration route of all stocks of sockeye salmon into Bristol Bay was in the off-shore waters of the southern half of the entrance to the bay and in the bay itself. Thus, the migration route in the eastern Bering Sea and outer Bristol Bay is in the region of highest salinity and is not associated with the distribution of river water which occurs on the north and northwest side of the Bay. Therefore, even though river water may be present in the northern part of outer Bristol Bay, it is apparently not used as a cue by salmon to guide them to their home-river systems. The more direct route in the southern half of the bay is followed. For the eastern Bering Sea and outer Bristol

Bay, at least, the hypothesis that the distribution of individual sockeye salmon stocks is related to the distribution of their home-river system waters must be rejected. The homing migration of sockeye salmon in this area must be true open-sea migration, for neither bottom nor land references are available to serve as orienting signals. Other guidance mechanisms which have been hypothesized to explain open-water migrations, such as celestial cues (Hasler et al., 1958; Groot, 1965), electrical voltages generated by ocean currents as the fish swim through the earth's magnetic field (Smith, 1967), or as yet some unknown means, must be used by the sockeye salmon in this area to guide them to the vicinity of their home-river systems.

The results of exploratory fishing and the tagging carried out within and outside Bristol Bay showed that all stocks remained in the offshore waters until they were within 20 to 50 miles of the mouths of their home-river systems. Seaward of a line between Port Moller and Cape Newenham there was little segregation of the individual sockeye salmon stocks in the run to Bristol Bay. Toward the head of the bay from this line, however, there is a progressive segregation of the stocks according to their river system of origin. This segregation was already beginning to occur while the fish were still in the offshore waters of high salinity in the southern half of Bristol Bay and well away from the influence of home-river system waters. Therefore, even toward the head of the Bay the distribution of river water seems to have no influence on the distribution of sockeye salmon stocks. Sockeye salmon must be using cues other than those offered by river waters to guide them toward their home-river systems. Whatever these guidance mechanisms may be, each stock appears to make the appropriate directional changes which will bring it to the vicinity of its respective bays and home-river systems. For example, Ugashik and Egegik stocks were shown to be leaving the offshore waters for the southeast coastal areas of the bay, whereas Nushagak Bay stocks became increasingly more abundant in the offshore waters toward the northwest side of the bay. Naknek and Kvichak river stocks remained abundant offshore until within Kvichak Bay. This segregation was occurring while most stocks were still in the offshore waters more than 150 miles from their home-river systems.

Once within the coastal waters and Nushagak and Kvichak bays, the individual sockeye salmon stocks bound for each river system appear to assume a distribution which closely approximates that of the upper bay distribution of their home-river system waters. Ugashik and Egegik river sockeye salmon leave the clearer high-salinity offshore waters, arriving in the more turbid coastal waters in greatest abundance between 20 miles to the north and south of the entrance to Ugashik and Egegik bays respectively. Thus, those fish arriving to the north of the entrance to these bays must reverse their previous course by almost 180° to reach the bay entrance and ultimately their home-river system. Whatever factor is used by the fish to guide them from the offshore waters into the coastal water near their home-river systems, it is apparently not precise enough for them to arrive en masse at the entrance to their respective bays. Tidal currents may play an important role in the distribution of these stocks. Some fish may be transported by these currents to the north or south of the bay entrances during their migration to the coast. The results of tagging show, however, that once these stocks are in the turbid coastal waters, they move from both north and south of the bay entrances to reach their home-river systems.

The question may be raised as to what mechanisms are being used by the sockeye salmon to guide them to their home-river systems once they have reached the coastal areas of Bristol Bay. The turbidity of the coastal waters combined with the changing direction and velocity of the tidal currents would seem to preclude the use of celestial cues as a precise enough guidance mechanism for this purpose. Here the odor hypothesis proposed by Hasler and Wisby (1951) to explain home-stream selection could account for such movement. The results of the hydrographic studies carried out in upper Bristol Bay have shown that the waters from the Egegik and Ugashik rivers occur both to the north and south of Egegik and Ugashik bays respectively. Once they are within the coastal region, the sockeye salmon bound for these river systems, regardless of their position with respect to the bay entrances, could perceive and recognize the olfactory features of their home-river system waters and use these as a cue to guide them to its source. The distribution of sockeye salmon from these two river systems was shown to be similar to the coastal distribution of their home-river system waters in upper Bristol Bay.

A comparison of Figures 29 and 59 shows that the distribution of Kvichak and Naknek river sockeye salmon also approximates that of the distribution of their home-river system waters in Kvichak Bay. Kvichak river fish were shown to be most abundant on the northwest side of Kvichak Bay, while Naknek River fish were most abundant on the southeast side. The drift card and dye tracer studies showed that the waters from these two river systems followed seaward courses through the area occupied in greatest abundance by their respective stocks. Naknek and Kvichak river stocks entering Kvichak Bay in the offshore high-salinity water, as they do, would meet "head on" the water of these two river systems. By olfactory perception of the characteristic features of these waters each stock could track them through the turbid upper bay area to their source.

Although not studied in as great detail as the other river system stocks of sockeye salmon, the distribution within and adjacent to Nushagak Bay of sockeye salmon bound for the rivers entering this bay also conforms to the distribution of their home-river system waters. Igushik, Snake, Wood, and probably Nushagak river sockeye salmon stocks occurred in greatest abundance where hydrographic studies indicated their home-river system waters occurred in greatest abundance (see Figure 59, Page 177). This evidence also suggests that the distribution of home-river system waters may be responsible for the guidance and therefore the distribution of sockeye salmon stocks in the upper turbid water region of Bristol Bay.

Hasler (1966) has suggested that since salmon smolts have been shown to linger in the estuarine waters at the ocean-river junction for several weeks (Manzer, 1956; Manzer and Shepard, 1962; McInerney, 1964) there is ample time for them to be conditioned to the odor of the river mouth region. An even more likely possibility is that sockeye salmon smolts may have become conditioned to the particular olfactory feature or perhaps other physicochemical features of the lake waters in which they spend most of their freshwater life. These waters via the home-river systems have been shown in this study to follow a rather definite course through upper Bristol Bay. They mix in the river mouth areas and smaller bays with high-salinity water from offshore, resulting in rather steep salinity, and therefore odor, gradients. McInerney (1964) has reported that salmon smolts prefer increasingly saline waters as their age increases. Recent findings (unpublished) by the Bureau of Commercial Fisheries indicate that sockeye salmon smolts from the major river systems follow a route seaward on the southeast side of Bristol Bay which is in the region of high salinity. This route for all stocks is through the area having the steepest salinity gradient and therefore odor or other physicochemical gradients (see Figure 25). As adults returning to spawn, these fish must again pass through this same area but in the opposite direction. During the homing migration, all stocks after leaving the offshore high-salinity waters, encounter rapidly increasing amounts of their home-river system waters upon arrival near the coast. Since adult sockeye salmon are again becoming physiologically adapted to life in fresh water, the decreasing salinity combined with an increase in the recognizable olfactory or physicochemical features of their home-river system waters would seem more than adequate to guide them to the proper river mouth. Once near the river mouth-bay junction, perhaps as Hasler (1966) has suggested, the tactile and sound vibrations arising from the movement of shallow water through the unique topography of this area may provide an additional signal by which a fish recognizes the mouth of its home-river system.

The means by which a salmon might actually follow river water to its source have not been studied in detail. Several possibilities discussed by Hasler (1966) have been suggested to explain the means by which a salmon traces its home-stream water to its source. These include tracing the water by continuously reacting to increases in the gradient or to concentration of a recognizable chemical attractant which it contains and by passing in and out of odor-carrying currents in a manner similar to the way in which a dog follows the tracks of another animal. Salinity and therefore odor gradients and odor-carrying currents have been shown by this study to be present in upper Bristol Bay and would be available for use by adult sockeye salmon seeking the mouth of their home-river system.

Whatever the mechanisms used by sockeye salmon in upper Bristol Bay to locate their river system of origin the results of this study indicate they are somehow associated with the characteristics of their home-river system waters. The migration of adult sockeye salmon into Bristol Bay and from the offshore waters to the coastal areas where their home-river system waters are encountered is true open-water migration. Although the beginning of the segregation of stocks was shown to occur in this area, this portion of their migration route did not conform to the distribution of home-river system waters. In conclusion then, the distribution of river water in outer Bristol Bay has no influence on the distribution of individual sockeye salmon stocks here, but in the upper bay these stocks assume a distribution which is very similar to that of their home-river system waters.

IX. SUMMARY

1. The individual stocks of sockeye salmon that make up the annual run to Bristol Bay are produced in the lakes and streams of ten major river systems which discharge into the bay over a shoreline distance of 120 miles. The hypothesis adopted in this study was that bay distribution of the water from these river systems and controlling factors such as tide, wind, and bottom topography determine the distribution of the individual stocks of sockeye salmon in Bristol Bay. This hypothesis is based on the premise that when mature, sockeye salmon return to their river system of origin to spawn and in doing so utilize recognizable characteristics of their home-river waters to guide them to its source.

2. Hydrographic studies were carried out in upper Bristol Bay to determine the seaward course and distribution of the waters of major sockeye salmon-producing river systems draining into Bristol Bay. These studies included: (a) determination of the vertical and horizontal salinity distribution in the upper bay; (b) tracking and plotting the distribution and course of Naknek, Egegik, and Ugashik river waters during flood and ebb tide, using Rhodamine B dye as a tracer; and (c) plotting the seaward course of plastic drift cards released at various strategic locations in upper Bristol Bay.

3. The results of the hydrographic studies showed that the net

seaward flow of the lighter and less saline river runoff water is along the right or northwest side of upper Bristol Bay. The net motion of high-salinity water directed toward the head of the bay is on the left or southeast side and extends to and perhaps somewhat above Middle Bluff in Kvichak Bay. This movement of high-salinity water toward the head of Bristol Bay was shown to be responsible for transporting with it the waters of the Ugashik and Egegik rivers, which enter the bay on the southeast side. Near Egegik Bay to Middle Bluff these waters joined the seaward flow of river waters (Kvichak and Naknek) entering at the head of Bristol Bay. These river waters along with the water from the rivers entering Nushagak Bay were all shown eventually to be transported to, and move seaward on, the right or northwest side of Bristol Bay. The results of the dye tracer studies showed that the Naknek, Egegik, and Ugashik rivers followed similar courses during both ebb and flood tides. Flood tide currents, along with the net or nontidal current, were responsible for transporting water from the Egegik and Ugashik rivers above or north of the entrance to Egegik and Ugashik bays respectively. On the basis of these results the course and distribution of the waters of each of the major sockeye salmon-producing river systems was described for upper Bristol Bay.

4. The distribution and migration routes of the individual stocks of sockeye salmon which make up the run to Bristol Bay were

determined from analysis of the results of exploratory fishing operations by research vessels of the United States and from adult sockeye salmon tagging studies conducted offshore and inshore by the United States and Japan.

5. The results of the analysis of the exploratory fishing operations in the eastern Bering Sea and outer Bristol Bay showed that the main migration route of Bristol Bay sockeye salmon is in the offshore waters of the southern half of the entrance to the bay and in the bay itself. From the analysis of the offshore tagging, the conclusion was reached that there was little segregation of the individual stocks of Bristol Bay sockeye salmon in the eastern Bering Sea and into Bristol Bay as far as a line between Port Moller and Cape Newenham. Toward the head of the bay from this line, tagging results showed a progressive segregation of sockeye salmon stocks according to their river system of origin. This segregation was already beginning while these fish were in the clear offshore waters and as much as 150 miles from the mouths of their home-river systems. On the basis of these results the general distribution of all major stocks of Bristol Bay sockeye salmon is described, and illustrated on a chart of the area.

6. The distribution of the major river system waters draining into Bristol Bay is compared with the distribution of their respective sockeye salmon stocks. The conclusions reached in this study are: (a) the distribution of river water in outer Bristol Bay does not

conform to the distribution of sockeye salmon and therefore has no influence on their distribution in this area; and (b) sockeye salmon in the turbid waters of upper Bristol Bay assume a distribution which is very similar to that of their home-river system waters; therefore, this distribution must somehow be related to the distribution of these waters and the recognizable characteristics which they contain. Possible mechanisms by which sockeye salmon might utilize their home-river system waters to guide them to its source are discussed.

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APPENDIX

Appendix Table 1. Date, location, time, and tidal stage and height for hydrographic surveys in Bristol Bay, 1966

Date	Station numbers	Time of survey	Stage of tide	Time and height of tide[1]		Reference station
				Time[2]	Height (feet)[3]	
July 26	NB 30-32	0900-0927	High	0931	19.2	Snag Point
July 26	NB 30-32	1735-1815	Low	1631(1735)	-2.9	Snag Point
July 27	NB 25-26	0810-0830	High	0936	18.1	Clarks Point
July 27	NB 25-26	1737-1835	Low	1612(1737)	-3.1	Clarks Point
July 27	NB 24-21	0910-1015	High	0936	18.1	Clarks Point
July 27	NB 21-24	1605-1635	Low	1612(1730)	-3.1	Clarks Point
July 29	NB 14-20	1020-1240	High	1124	16.2	Clarks Point
July 29	NB 14-20	1645-1850	Low	1800	-2.5	Clarks Point
July 30	NB 1- 6	1653-1915	Low	1826	-1.8	Protection Point
July 31	NB 1- 6	1143-1347	High	1254	14.6	Protection Point
Aug. 17	58-63	1712-0015	Low	1929	-1.8	Egegik Bay entrance
Aug. 22	107-102	1125-1530	Low	1159	-2.1	Egegik Bay entrance
Aug. 23	101-96.5	1117-1718	Low	1247	-2.7	Egegik Bay entrance
Aug. 24	107-102	0606-1107	High	0654	17.9	Egegik Bay entrance
Aug. 24	NK 19-13	1338-1535	Low	1404	-2.7	Middle Bluff
Aug. 25	NK 18-13	0754-0925	High	0828	17.1	Middle Bluff
Aug. 25	NK 32-29	1514-1558	Low	1614	-2.4	Naknek River entrance
Aug. 26	NK 32-29	0857-0951	High	0953	16.4	Naknek River entrance
Aug. 26	NK 43-40	1613-1717	Low	1708	-1.8	Naknek River entrance
Aug. 27	MK 43-40	0947-1038	High	1047	15.7	Naknek River entrance

[1] Tidal data from: U.S. Coast and Geodetic Survey (1965).

[2] Time of high and low water is that of the reference sations nearest a given transect line (see Figure 10). The times in parentheses are the actual times the tide was observed and are different from the predicted times given by U.S. Coast and Geodetic Survey (1965).

[3] Since the height of the tide on any given day varies with location, the heights given here are those for Clarks Point, Nushagak Bay, the primary reference station for Bristol Bay.

Appendix Table 2. Date and location of tracer studies and water conditions at time of dye release, Bristol Bay, 1965-66

Date and location of study	Time of release	Wind velocity (knots)	Tide	Background fluorescence level* (dial reading)	Rhodamine B dye used (gallons)	Water temperature at 1 m. (°C)	Salinity at 1 m. ($^o/oo$)
Naknek River studies							
July 26, 1965--6 miles above Naknek River mouth (Appendix Figure 1)	1130	NW 0-5	Ebb	6	13.0	13.2	11.08
August 7, 1965--Naknek River mouth (Appendix Figure 2)	1200	SSE 5-10	Ebb	6.5	15.0	14.8	14.70
August 17, 1965--off Johnston Hill fishery marker (Appendix Figure 3)	0820	ESE 0-3	Ebb	5	13.5	13.6	18.21
August 18, 1965--Low Point (Appendix Figure 4)	1000	SW 4	Ebb	4	13.0	13.1	18.13
Egegik River studies							
August 3, 1966--main channel between outer southern bar and northern mudflat (Appendix Figure 5)	0545	ESE 12	Ebb	3	17.5	12.1	27.61
August 3, 1966--along course at seaward limit of previous dye release (Appendix Figure 6)	0830	ESE 12	Flood	3	13.0	12.0	29.32
August 4, 1966--main channel between outer southern bar and northern mudflat (Appendix Figure 7)	0850	E&S 5	Ebb, 1 hour before low slack	3	7.0	12.1	27.35
August 4, 1966--along course at seaward limit of previous dye release (Appendix Figure 8)	0955	E&S 10-15	Low slack	3	7.0	12.1	29.10
Ugashik River studies							
August 10, 1966--main channel between northern tideflat and coast (Appendix Figure 9)	0735	W 5	Ebb	2	10	10.6	30.45
August 11, 1966--main channel between northern tideflat and coast (Appendix Figure 10)	1012	E 5-10	One hour before low slack	2	10	11.5	29.91
August 12, 1966--along course at seaward limit of August 10 release (Appendix Figure 11)	0648	E 12	Ebb	2	10	9.8	30.7

* Fluorometer dial readings obtained during the tracking of Rhodamine B dye which were one dial unit or more above these minimum values were considered to indicate the presence of dye.

Appendix Table 3. Calibration data for fluorometer used in Rhodamine B dye tracer studies in Bristol Bay, 1965-66*

Standard concentration of Rhodamine B (p.p.b.)	Fluorometer dial reading	Operating range**
0.00	0.5	30X
0.10	3.0	30X
0.25	7.5	30X
0.50	15.2	30X
1.00	33.0	30X
5.00	42.0	10X
10.00	85.5	10X
20.00	58.0	3X
30.00	84.0	3X
40.00	36.2	1X
50.00	45.5	1X
100.00	91.0	1X

* In calibrating the fluorometer, I followed method II, as outlined in the "Operating and Service Manual" (Page 8) provided by the manufacturer.

** The numbers 3X, 10X, and 30X indicate the approximate increase in sensitivity that is obtained over the least sensitive, or 1X, position. The operating range used sets the amount of ultraviolet light falling on the sample. The 1X range gives the least light, 3X about three times as much, and so forth.

Appendix Table 4. Location and serial numbers of drift cards released in Bristol Bay, June 2, 1967

Location of release (Figure 16)	Number released	Serial numbers
Kvichak River mouth 58°48' N., 157°08' W.	102	1501-1603
Naknek River mouth 58°43' N., 157°04' W.	100	1401-1500
Cape Chichagof 58°22' N., 157°30' W.	150	1301-1400 797- 846
Egegik Bay entrance 58°13' N., 157°28' W.	101	746- 796 1100-1149
58° Parallel of latitude 58°00' N., 157°36' W.	152	847- 998
Cape Greig 57°44' N., 157°42' W.	151	1150-1300
Ugashik Bay entrance 57°36' N., 157°42' W.	101	999-1099
Cape Menshikof 57°29' N., 157°55' W.	150	596- 745
Total	1,007	---

Appendix Table 5. Year, location, and dates of fishing and source of data for gill net catches used to determine the distribution of sockeye salmon east of long. 170° W.

Year	Location of fishing	Inclusive dates of fishing	Source of data
1939	Between Cape Seniavin and Cape Newenham	June 28-July 23	Barnaby (1952), Table 4, Page 12
1940	Between Cape Mordvinof and Pribilof Islands	June 6-July 3	Barnaby (1952), Table 7, Page 16
1940	Between Pribilof Islands and Nunivak Island	June 17-21	Barnaby (1952), Table 9, Page 17
1941	Between Cape Mordvinof and Nunivak Island	July 7-11	Barnaby (1952), Table 16, Page 20
1958	Between lat. 53°30' N. and 57°59' N. along approximately long. 170°00' W.	June 17-28	International North Pacific Fisheries Commission (1959), Table 2, Page 75
1959	Between lat. 53°18' N. and 59°00' N. along approximately long. 170°00' W.	June 27-July 3	International North Pacific Fisheries Commission (1960), Table 2, Page 82
1961	Between lat. 53°25' N. and 59°14' N. along approximately long. 170°00' W.	June 12-25	French (1963), Table 9, Page 100
1965-66	Between lat. 56°10' N. and 57°15' N. along approximately long. 161°30' W.	June 24-July 6	French *et al.* (1967), Figure 8, Page 79

Appendix Table 6. Year, country, and inclusive dates of tagging, type of fishing gear and tags used, and source of recovery data used to study the offshore distribution of sockeye salmon stocks

Year	Country	Inclusive dates of tagging	Type of fishing gear used	Type of tag	Source of recovery data
1922	U.S.	June 26-27	Trap, purse seine	Aluminum (cattle type) on tail	Gilbert (1923)
1925	U.S.	July 1-5	Purse seine	Aluminum (cattle type) on tail	Rich (1926)
1957	U.S.	June 17-29	Purse seine	1/16-inch diameter vinyl tube, 1/2-inch diameter plastic disc	Hartt (1962)
1958	U.S.	June 16-27	Purse seine	1/16-inch diameter vinyl tube, 1/2-inch diameter plastic disc	Hartt (1962)
1960	U.S.	June 20	Purse seine	3/4-inch diameter plastic disc, 1/2-inch diameter plastic disc, 1/16-inch diameter vinyl tube	Hartt (1966)
1960	Japan	June 28-30	Long lines	14-mm. diameter celluloid disc, 1/16-inch diameter vinyl tube	Kondo _et al_. (1965)
1961	Japan	June 20-23	Long lines	16-mm. diameter celluloid disc	Kondo _et al_. (1965)
1964	U.S.	June 19-28	Long lines	3/4-inch diameter plastic disc	Lander _et al_. (1966)
1965	U.S.	June 24-July 2	Purse seine	3/4-inch diameter plastic disc 1/16-inch diameter vinyl tube	Lander _et al_. (1967)

Appendix Table 7. Size of run and commercial catch of sockeye salmon by fishing districts, Bristol Bay, 1957. (Data from: U.S. Bureau of Commercial Fisheries, Alaska (1957), Page 46)

Fishing district	Size of run[1] (thousands of fish)	Catch--percent of total run	Percent of Bristol Bay run
Northwest side			
Nushagak	980[2]	50.102	8.864
Southeast side			
Naknek-Kvichak	8,305[3]	55.135	75.118
Egegik	1,205	67.552	10.899
Ugashik	566	62.014	5.119
Total	10,076	57.007	91.136
Grand total	11,056	56.39	--

[1] Commercial catch plus spawning escapement.

[2] Includes the commercial catch in Nushagak Bay plus the spawning escapement to the Igushik, Snake, Wood, and Nushagak river systems.

[3] Includes the commercial catch in Kvichak Bay plus escapement to the Kvichak, Alagnak, and Naknek river systems.

Appendix Table 8. Size of run and commercial catch of sockeye salmon by fishing districts, Bristol Bay, 1958. (Data from: U.S. Bureau of Commercial Fisheries (1958), Page 51)

Fishing district	Size of run[1] (thousands of fish)	Catch--percent of total run	Percent of Bristol Bay run
Northwest side			
Nushagak	2,365[2]	46.17	41.81
Southeast side			
Naknek-Kvichak	1,831[3]	50.41	32.37
Egegik	747	67.07	13.20
Ugashik	714	60.78	12.62
Total	3,292	56.44	58.19
Grand total	5,657	52.15	--

[1] Commercial catch plus spawning escapement.

[2] Includes the commercial catch in Nushagak Bay plus the spawning escapement to the Igushik, Snake, Wood, and Nushagak river systems.

[3] Includes the commercial catch in Kvichak Bay plus escapement to the Kvichak, Alagnak, and Naknek river systems.

Appendix Table 9. Size of run and commercial catch of sockeye salmon by fishing districts, Bristol Bay, 1960. (Unpublished data on file U.S. Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska)

Fishing district	Size of run[1] (thousands of fish)	Catch--percent of total run	Percent of Bristol Bay run
Northwest side			
Nushagak	3,192[2]	47.56	8.86
Southeast side			
Naknek-Kvichak	26,547[3]	37.10	73.66
Egegik	3,246	44.58	9.01
Ugashik	3,057	24.63	8.48
Total	32,850	36.68	91.14
Grand total	36,042	37.64	--

[1] Commercial catch plus spawning escapement.

[2] Includes the commercial catch in Nushagak Bay plus the spawning escapements in the Igushik, Snake, Wood, and Nushagak river systems.

[3] Includes commercial catch in Kvichak Bay (Naknek-Kvichak district) plus spawning escapements in the Kvichak, Alagnak, and Naknek river systems.

Appendix Table 10. Size of run and commercial catch of sockeye salmon by fishing districts, Bristol Bay, 1961. (Unpublished data on file U.S. Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska)

Fishing district	Size of run[1] (thousands of fish)	Catch--percent of total run	Percent of Bristol Bay run
Northwest side			
Nushagak	1,347[2]	37.64	7.59
Southeast side			
Naknek-Kvichak	12,314[3]	66.32	69.35
Egegik	3,388	79.28	19.08
Ugashik	706	50.57	3.98
Total	16,408	68.32	92.41
Grand total	17,755	65.99	--

[1] Commercial catch plus spawning escapement.

[2] Includes the commercial catch in Nushagak Bay plus the spawning escapements in the Igushik, Snake, Wood, and Nushagak river systems.

[3] Includes the commercial catch in Kvichak Bay plus escapement in the Kvichak, Alagnak, and Naknek river systems.

Appendix Table 11. Size of run and commercial catch of sockeye salmon by fishing districts, Bristol Bay, 1964. (Pennoyer and Seibel, 1964)

Fishing district	Size of run[1] (thousands of fish)	Catch--percent of total run	Percent of Bristol Bay run
Northwest side			
Nushagak	2,741[2]	51.84	26.00
Southeast side			
Naknek-Kvichak	4,799[3]	46.75	45.51
Egegik	1,954	56.51	18.53
Ugashik	1,050	54.95	9.96
Total	7,803	50.29	74.00
Grand total	10,544	50.69	--

[1]Commercial catch plus spawning escapement.

[2]Includes the commercial catch in Nushagak Bay plus the spawning escapement in the Igushik, Snake, Wood, and Nushagak river systems.

[3]Includes the commercial catch in Kvichak Bay plus escapement in the Kvichak, Alagnak, and Naknek river systems.

Appendix Table 12. Size of run and commercial catch of sockeye salmon by fishing districts, Bristol Bay, 1965. (Pennoyer and Seibel, 1965)

Fishing districts	Size of run[1] (thousands of fish)	Catch--percent of total run	Percent of Bristol Bay run
Northwest side			
Nushagak	1,893[2]	41.92	3.58
Southeast side			
Naknek-Kvichak	44,358[3]	43.15	84.02
Egegik	4,624	68.76	8.76
Ugashik	1,922	48.16	3.64
Total	50,904	45.66	96.42
Grand total	52,297	45.53	--

[1]Commercial catch plus spawning escapement.

[2]Includes the commercial catch in Nushagak Bay plus the spawning escapements in the Igushik, Snake, Wood, and Nushagak river systems.

[3]Includes the commercial catch in Kvichak Bay plus escapement in the Kvichak, Alagnak, and Naknek river systems.

Appendix Table 13. Color combinations* of tags on sockeye salmon released in upper Bristol Bay, 1955

Site and date	Number tagged	Tag colors
Site 1		
July 5	12	W-G
July 13	65	Y-W
Total	77	--
Site 2		
July 4	31	W-Y
July 6	31	W-B
July 9	3	R-W
July 14	41	Y-R
July 16	19	Y-Y
July 17	3	Y-G
Total	104	--
Site 3		
July 8	71	R-R
July 10	90	R-Y
July 12	165	R-B
Total	326	--
Site 4		
July 6	112	B-W
July 9	45	B-R
July 11	229	R-G
Total	386	--
Site 5		
July 4	103	G-R
July 10	143	G-G
Total	246	--
Site 6		
June 30	7	W-R
July 5	32	G-Y
July 17	54	B-B
July 18	28	B-Y
Total	121	--
Site 7		
June 28	35	W-W
July 3	96	G-W
Total	131	--
Site 8		
July 21	14	Y-B
Site 9		
July 19	8	B-G
July 20	12	B-G
Total	20	--

*Colors used were blue (B), green (G), red (R), white (W), and yellow (Y). The first letter of the color combination designates the color of the left tag, which bears the serial number.

Appendix Table 14. Color combinations* of tags on sockeye salmon released in upper Bristol Bay, 1956

	Site-- 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Date	Tag colors-- W-B	W-B	W-Y	W-G	R-B	R-B	R-R	Y-Y	Y-G	Y-B	Y-R	G-G	G-B	G-R	G-W	B-B	B-Y	B-R	B-W	B-G
June 18	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	48	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	6	-	11	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-
23	35	-	-	-	-	-	-	-	-	-	15	-	-	-	-	-	-	-	1	-
24	-	-	1	2	-	12	-	-	-	-	-	-	-	-	5	-	-	-	-	-
25	-	4	-	-	-	-	-	-	-	-	-	-	-	15	-	-	-	-	-	30
26	-	-	-	-	51	-	-	-	-	-	44	-	43	-	-	36	-	-	-	-
27	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	-	8	-	-	-	-	-	-	-	24	-	-	-	-	47	29	-	-	-	-
29	-	7	-	-	-	1	-	-	-	-	6	3	7	-	-	-	-	-	-	-
30	-	-	15	1	-	12	-	-	-	-	-	-	20	2	-	-	12	-	-	-
July 1	-	-	2	-	-	-	-	-	-	-	-	-	-	40	-	-	-	-	-	-
2	13	3	-	-	-	-	-	-	-	-	-	-	-	-	64	-	-	-	-	9
3	-	-	-	-	-	-	-	-	-	-	10	-	6	-	-	-	-	-	27	-
4	-	-	-	-	-	-	-	-	23	131	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	67	-	152	-	-	-	67	-	-
6	-	-	-	-	-	-	-	-	-	-	300	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	11	-	-	-	-	-	108	-	-	-	254	-	-
8	287	-	-	-	-	4	114	132	-	-	-	-	-	-	96	-	-	-	-	85
9	-	-	-	-	5	-	-	-	229	-	-	-	-	-	107	-	188	-	-	-
10	-	95	-	-	-	-	166	-	-	-	-	-	100	-	-	-	-	139	-	-
11	-	53	-	-	-	-	-	163	-	256	-	378	-	-	-	160	-	-	-	-
12	-	-	191	-	-	-	9	-	-	-	-	-	-	-	208	-	-	-	-	-
13	-	-	155	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	42	4
14	82	-	-	-	-	-	-	-	-	78	35	-	85	-	-	105	-	-	-	-
15	-	33	-	-	-	-	58	-	56	-	-	-	-	149	-	-	-	165	-	-
16	-	-	138	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	13	43	-	-	-	-	-	-	-	26	-
18	-	-	-	-	-	-	-	-	-	-	-	8	-	-	-	-	3	-	-	-
20	-	-	2	-	-	-	-	17	-	-	-	-	-	-	21	-	-	-	1	-
21	-	-	-	-	8	-	1	-	-	-	-	-	-	7	-	49	-	-	-	-
22	-	1	-	-	-	-	-	9	-	-	-	-	-	13	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-
Total	418	205	504	9	64	29	348	332	361	511	461	467	251	497	549	380	203	729	97	128

* Colors used were blue (B), green (G), red (R), white (W), and yellow (Y). The first letter of a color combination designates the color of the left tag, which bears the serial number.

Appendix Table 15. Color combinations[1] on tags of sockeye salmon released in Kvichak Bay, 1957

Date	Site 1		Site 2	
	Number tagged	Tag colors	Number tagged	Tag colors
June 21	0	-	312	G-B
22	0	-	0[2]	-
23	0	R-Y	12	B-W
24	4	R-Y	77	B-B
25	0[2]	-	273	G-Y
26	15	R-R	306	W-G
27	16	R-G	395	W-Y
28	0[2]	-	0[2]	-
29	4	Y-B	277	B-G
30	9	R-W	267	W-B
July 1	0[2]	-	283	G-R
2	13	Y-R	74	B-Y
3	9	R-B	166	W-R
4	40	Y-Y	346	B-R
5	45	G-G	433	G-B
6	8	Y-G	39	B-W
7	26	Y-W	778	B-B
8	85	G-W	1,156	G-Y
9	20	R-Y	426	W-G
10	0[2]	-	0[2]	-
11	0[2]	-	0[2]	-
12	3	R-R	263	W-Y
13	0[3]	-	471	B-G
14	0[3]	-	356	W-B
15	0[3]	-	423	B-Y
16	6	R-G	538	W-R
17	0[3]	-	300	B-R
18	0[3]	-	452	B-W
19	6	Y-B	56	R-Y
20	0[3]	-	550	R-R
21	0[2]	-	0[2]	-
22	0[3]	-	17	R-W
23	0[3]	-	95	Y-R
24	0[3]	-	222	Y-Y
Total	309	-	9,363	-

[1] Colors used were blue (B), green (G), red (R), white (W), and yellow (W). The first letter of a color combination designates the color of the left tag, which bears the serial number.

[2] Rough water prevented tagging.

[3] Due to the continued poor catches at Site 1, efforts were concentrated at Site 2.

Appendix Table 16. Color combinations* of tags on sockeye salmon released in Nushagak Bay, 1959

Date	Site 1		Site 2		Site 3		Site 4	
	Number tagged	Tag colors	Number tagged	Tag colors	Number tagged	Tag colors	Number tagged	Tag colors
June 19	-	-	-	-	-	-	5	G-W
20	13	R-W	11	B-W	-	-	-	-
21	-	-	-	-	17	Y-B	5	G-B
22	-	-	-	-	-	-	-	-
23	18	R-B	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-
25	-	-	-	-	266	Y-G	12	G-G
26	61	R-G	110	B-G	-	-	-	-
27	-	-	-	-	73	Y-R	19	G-R
28	82	R-R	31	B-R	-	-	-	-
29	-	-	-	-	118	Y-Y	18	G-Y
30	86	R-Y	330	B-Y	-	-	-	-
July 1	-	-	-	-	310	W-B	343	W-R
2	122	R-W	223	B-W	-	-	-	-
3	-	-	-	-	140	W-G	-	-
4	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-
6	185	R-B	-	-	-	-	-	-
7	27	R-G	19	B-G	-	-	-	-
8	-	-	-	-	15	Y-W	11	G-W
9	33	R-R	66	B-R	-	-	-	-
10	-	-	-	-	37	Y-B	413	G-B
11	60	R-Y	15	R-Y	-	-	-	-
12	-	-	-	-	17	Y-G	206	G-G
13	72	R-W	20	B-W	-	-	-	-
14	-	-	-	-	12	Y-R	39	G-R
15	12	R-B	8	B-R	-	-	-	-
16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
Total	771	-	833	-	1,005	-	1,071	-

* Colors used were blue (B), green (G), red (R), white (W), and yellow (Y). The first letter of a color combination designates the color of the left tag, which bears the serial number.

Appendix Table 17. Bristol Bay sockeye salmon catch by district and fishing period, 1955*

Fishing period	Nushagak	Naknek-Kvichak	Egegik	Ugashik
June 25	--	22,892	17,973	2,569
June 27-28	74,853	181,574	--	--
June 27-29	--	--	111,010	29,581
June 30-July 1	22,126	--	--	--
June 30-July 2	--	415,149	146,050	43,893
July 4-5	324,884	614,141	87,506	33,254
July 7-8	266,573	--	--	--
July 7-9	--	792,562	120,994	105,718
July 11-12	227,388	201,549	83,500	40,952
July 14-15	77,725	287,224	62,397	36,910
July 18-23	71,178	--	--	--
July 18-19	--	55,315	19,153	Season closed
Total	1,064,727	2,570,406	648,583	292,877

*Source: Unpublished data on file, U.S. Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska.

Appendix Table 18. Bristol Bay sockeye salmon catch by district and fishing period, 1956*

Fishing period	Dates	Nushagak	Naknek-Kvichak	Egegik	Ugashik
1	June 25-26	27,256	67,631	46,542	10,387
2	June 28-29	66,035	238,923	44,557	10,097
3	July 2-3	112,812	298,894	67,208	25,123
4	July 5-6	125,822	1,078,784	178,398	46,875
5	July 9-10	313,884	1,737,771	333,809	77,194
6	July 12-13	396,821	1,752,819	393,990	108,000
7	July 16-17	168,570	638,680	88,011	46,480
8	July 19-20	27,081	94,479	18,007	12,640
9	July 23-24	24,713	65,409	6,589	4,703
Total	--	1,262,994	5,973,390	1,177,111	341,499

*Source: Unpublished data on file, U.S. Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska.

Appendix Table 19. Bristol Bay sockeye salmon catch by district and fishing period, 1957*

Fishing period	Dates	Nushagak	Naknek-Kvichak	Egegik	Ugashik
1	June 24-25	19,994	83,660	28,355	14,179
2	June 27-28	68,770	441,850	89,017	19,147
3	July 1-2	102,177	491,663	58,881	23,260
4	July 4-5	91,286	777,299	166,725	35,639
5	July 8-9	155,563	--	247,368	85,728
6	July 8-9	--	1,868,823	--	--
6	July 11-12	--	--	96,831	75,092
7	July 10-11	28,914	505,044	--	--
7	July 15-16	24,537	--	56,240	57,427
8	July 12-13	--	177,232	--	--
8	July 18-19	20,856	--	29,576	33,058
9	July 15	--	116,209	--	--
9	July 22-23	8,678	--	13,213	11,597
10	July 18	--	109,259	--	--
10	July 25-26	18,617	--	3,669	7,018
11	July 22-23	--	44,367	--	--
12	July 25-27	--	33,267	--	--
Total	--	539,392	4,648,673	789,875	362,145

*Source: U.S. Bureau of Commercial Fisheries (1957).

Appendix Table 20. Bristol Bay sockeye salmon catch by district and fishing period, 1959*

Fishing period	Dates	Nushagak	Naknek-Kvichak	Egegik	Ugashik
1	June 22-23	5,243	20,492	22,351	9,221
2	June 25-26	9,294	50,155	29,710	13,809
3	June 29-30	36,342	59,097	47,650	27,231
4	July 2-3	457,905	438,787	137,696	66,495
5	July 4	127,591	--	--	--
6	July 6-7	190,434	204,574	102,931	84,573
7	July 8	130,644	--	--	--
8	July 9-10	286,397	225,155	83,080	68,374
9	July 11	--	--	92,541	27,369
10	July 13-15	242,374	364,915	87,018	60,718
11	July 16-18	127,524	174,747	42,804	30,446
12	July 20-22	28,636	55,712	12,458	17,277
13	July 23-25	32,802	43,374	3,055	9,029
Total	--	1,675,186	1,637,008	661,294	414,542

*Source: Unpublished data on file, U.S. Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska.

Appendix Table 21. Location and recovery date of drift cards released in upper Bristol Bay, June 2, 1967. (All recoveries were in 1967)

Release location and card number	Recovery location	Recovery date
Kvichak River mouth		
1507	Afloat between 58°36' N., 157°16' W. and 58°42' N., 157°06' W.	June 13
1511	ditto	June 19
1514	ditto	June 13
1531	ditto	July 4
1532	ditto	July 4
1535	ditto	June 13
1548	ditto	July 4
1557	ditto	June 13
1564	ditto	June 13
1565	ditto	July 7
1566	ditto	June 17
1567	ditto	June 13
1568	ditto	June 13
1590	ditto	June 21
1594	ditto	June 13
1595	ditto	June 13
1596	ditto	June 13
1598	ditto	June 13
1600	ditto	June 13
1509	On beach between 58°36' N., 157°16' W. and 58°42' N., 157°06' W.	July 4
1527	ditto	July 4
1536	ditto	June 4
1540	58°50' N., 157°17' W.	July 19
1563	ditto	June 4
1571	ditto	July 4
1575	ditto	July 4
1516	58°31' N., 159°09' W.	July 26
1537	58°23' N., 158°53' W.	Aug. 9
1538	58°37' N., 158°09' W.	Aug. 9
1543	58°42' N., 157°50' W.	July 26
1549	58°24' N., 158°59' W.	Aug. 9
1560	58°39' N., 158°00' W.	July 26
1584	58°38' N., 158°04' W.	July 26
Naknek River mouth		
1402	Afloat between 58°36' N., 157°16' W. and 58°42' N., 157°06' W.	June 10
1409	ditto	June 10
1416	ditto	June 4
1417	ditto	June 12
1420	ditto	June 10
1422	ditto	June 13
1423	ditto	June 13
1424	ditto	June 13
1426	ditto	June 13

Appendix Table 21. Location and recovery date of drift cards released in upper Bristol Bay, June 2, 1967. (All recoveries were in 1967)--Continued

Release location and card number	Recovery location	Recovery date
Naknek River mouth--Continued		
1432	Afloat between 58° 36' N., 157°16' W. and 58°42' N., 157°06' W.	June 13
1433	ditto	June 13
1438	ditto	June 13
1440	ditto	June 13
1442	ditto	June 21
1452	ditto	June 13
1456	ditto	June 19
1458	ditto	July 17
1460	ditto	June 13
1461	ditto	June 13
1462	ditto	June 13
1468	ditto	June 13
1477	ditto	June 13
1478	ditto	June 13
1481	ditto	June 13
1489	ditto	June 13
1421	On beach between 58°36' N., 157°16' W. and 58°42' N., 157°06' W.	June 19
1425	ditto	July 4
1427	ditto	July 4
1435	ditto	June 19
1443	ditto	July 4
1446	ditto	June 21
1449	ditto	June 19
1450	ditto	June 27
1466	ditto	July 7
1475	ditto	July 4
1479	ditto	July 8
1480	ditto	June 23
1488	ditto	June 19
1490	ditto	July 4
1493	ditto	June 22
1494	ditto	June 19
1495	ditto	July 4
1498	ditto	June 15
1500	ditto	July 4
Cape Chichagof		
806	58°24' N., 158°58' W.	Aug. 9
819	58°28' N., 158°44' W.	July 26
820	58°23' N., 158°53' W.	Aug. 9
825	58°29' N., 158°38' W.	Aug. 9
830	58°28' N., 159°06' W.	Aug. 9
1328	58°26' N., 158°42' W.	July 17
1341	58°53' N., 159°25' W.	Aug. 9

Appendix Table 21. Location and recovery date of drift cards released in upper Bristol Bay, June 2, 1967. (All recoveries were in 1967)--Continued

Release location and card number	Recovery location	Recovery date
Cape Chichagof--Continued		
1343	58°19' N., 157°32' W.	July 26
1367	58°05' N., 157°33' W.	July 27
1371	58°28' N., 159°05' W.	July 26
1393	58°27' N., 159°04' W.	July 26
Egegik Bay entrance		
752	58°44' N., 159°24' W.	Aug. 9
758	58°22' N., 157°29' W.	July 12
781	58°26' N., 159°04' W.	Aug. 9
792	58°28' N., 159°05' W.	July 26
1119	58°29' N., 159°07' W.	July 26
58° line		
850	58°05' N., 157°33' W.	July 27
882	58°03' N., 157°36' W.	July 27
889	58°09' N., 157°32' W.	Oct. 8
946	58°34' N., 159°14' W.	July 17
955	57°58' N., 157°37' W.	July 9
963	57°58' N., 157°36' W.	July 17
978	58°05' N., 157°33' W.	July 27
860	Between 58°08' N., 157°30' W. and 58°12' N., 157°35' W.	July 17
894	ditto	July 17
902	ditto	July 17
904	ditto	July 17
905	ditto	July 17
908	ditto	July 17
974	ditto	July 17
Cape Greig		
1153	Between 58°08' N., 157°30' W. and 58°12' N., 157°35' W.	July 17
1173	ditto	July 17
1175	ditto	July 17
1180	ditto	July 17
1181	ditto	July 17
1188	ditto	July 6
1217	ditto	July 17
1227	ditto	July 17
1241	ditto	July 17
1279	ditto	July 17
1162	57°58' N., 157°36' W.	July 17
1165	58°06' N., 157°35' W.	July 27
1209	58°04' N., 157°35' W.	July 27
1226	57°54' N., 157°36' W.	July 17
1235	58°05' N., 157°33' W.	July 27
1246	ditto	July 27
1266	ditto	July 27

Appendix Table 21. Location and recovery date of drift cards released in upper Bristol Bay, June 2, 1967. (All recoveries were in 1967)--Continued

Release location and card number	Recovery location	Recovery date
Cape Greig--Continued		
1269	58°05' N., 157°33' W.	July 27
1282	ditto	July 27
1284	58°10' N., 157°32' W.	Aug. 16
Ugashik Bay entrance		
1053	57°39' N., 157°41' W.	July 17
1086	58°30' N., 159°09' W.	Aug. 9
1043	Between 58°08' N., 157°30' W. and 58°12' N., 157°35' W.	July 17
1052	ditto	July 17
Cape Menshikof		
648	Between 58°08' N., 157°30' W. and 58°12' N., 157°35' W.	July 17
609	57°41' N., 157°41' W.	July 19
673	58°28' N., 159°05' W.	July 26
680	57°37' N., 157°37' W.	July 13
682	58°39' N., 159°16' W.	July 26
694	57°54' N., 157°36' W.	July 17
701	58°05' N., 157°33' W.	July 27
719	57°56' N., 157°36' W.	July 17
725	58°29' N., 159°07' W.	July 26

Appendix Table 22. Resultant wind direction[1] at King Salmon Airport, Bristol Bay, Alaska, June, July, and August, 1965-67

Month	1965[2]	1966[3]	1967[4]
June	15	13	18
July	18	18	22
August	19	Missing	14

[1] Resultant wind is the vector sum of wind directions divided by the numbers of observations. Direction figures in tens of degrees.

[2] Data from: U.S. Weather Bureau (1965).

[3] Data from: U.S. Environmental Science Services Administration (1966).

[4] Data from: U.S. Environmental Science Services Administration (1967).

Appendix Table 23. Commercial fishery recoveries and escapement sightings of tagged sockeye salmon by site of release and area of recapture, Bristol Bay, 1955

Tagging			Recoveries and Sightings									
			Nushagak		Naknek-Kvichak[1]			Egegik		Ugashik		Unknown
Site	No. Tagged		Catch	Escapement Wood R. Tower	Catch	Escapement Kvichak[2] Tower	Escapement Naknek Weir	Catch	Escapement Weir	Catch	Escapement Weir	Catch
1	77	No.	0	0	0	0	0	30	15	0	1	0
		%[3]	-	-	-	-	-	39.0	19.5	-	1.3	-
2	104	No.	0	0	4	0	0	34	32	1	0	1
		%	-	-	38	-	-	32.7	30.8	0.9	-	0.9
3	326	No.	0	0	44	3	3	87	75	4	2	0
		%	-	-	13.5	0.9	0.9	26.7	23.0	1.2	0.6	-
4	386	No.	1	0	79	6	3	84	56	2	1	1
		%	0.3	-	20.5	1.6	0.8	21.8	14.5	0.5	0.3	0.3
5	246	No.	0	0	79	6	8	38	14	1	0	1
		%	-	-	32.1	2.4	3.3	15.4	5.7	0.4	-	0.4
6	121	No.	0	0	38	3	9	2	3	0	0	0
		%	-	-	31.4	2.5	7.4	1.6	2.5	-	-	-
7	131	No.	0	0	56	5	11	3	4	0	0	0
		%	-	-	42.7	3.8	8.4	2.3	3.1	-	-	-
8	14[4]	No.	0	0	-	1	0	-	0	-	0	-
		%	-	-	-	7.1	-	-	-	-	-	-
9	20[5]	No.	0	0	-	5	1	-	0	-	0	-
		%	-	-	-	25.0	5.0	-	-	-	-	-

1 Alagnak River not covered by a tower or weir.
2 Includes 4 tags positively identified at tower, 16 recovered from spawning grounds, and 9 recovered in
3 Kvichak River above fishery.
4 Percent of total number tagged.
5 Tagging conducted after close of commercial fishing season.

Appendix Table 24. Commercial fishery recoveries and escapement sightings of tagged sockeye salmon by site of release and area of recapture, Bristol Bay, 1956

Tagging: Site	Tagging: No. tagged		Togiak[1]: Catch	Togiak[1]: Escapement survey	Nushagak[2]: Nushagak catch	Nushagak[2]: Escapement Wood R. tower[4]	Nushagak[2]: Escapement Nushagak River survey	Nushagak[2]: Escapement Igushik River survey	Naknek-Kvichak[3]: Catch Naknek-Kvichak	Naknek-Kvichak[3]: Escapement Kvichak tower[4]	Naknek-Kvichak[3]: Escapement Naknek weir[4]	Egegik: Catch	Egegik: Escapement weir[4]	Ugashik: Catch	Ugashik: Escapement weir[5]
		No.	11	0	114	0	0	18	0	0	0	0	0	0	0
1	418	%[6]	2.6	-	27.3	-	-	4.3	-	-	-	-	-	-	-
		No.	0	0	81	46	1	4	0	4	0	0	1	0	1
2	205	%	-	-	39.5	22.4	0.5	1.9	-	1.9	-	-	0.5	-	0.5
		No.	0	0	153	110	4	3	5	8	0	0	0	0	1
3	504	%	-	-	30.4	21.8	0.8	0.6	1.0	1.6	-	-	-	-	0.2
		No.	0	0	3	0	0	0	1	0	0	0	0	0	2
4	9	%	-	-	33.3	-	-	-	11.1	-	-	-	-	-	22.2
		No.	0	0	17	13	0	0	5	0	0	1	9	0	0
5	94	%	-	-	26.6	20.3	-	-	7.8	-	-	1.5	14.1	-	-
		No.	0	0	3	0	0	0	13	0	3	0	0	0	0
6	29	%	-	-	10.3	-	-	-	44.8	-	10.3	-	-	-	-
		No.	0	0	2	0	0	0	83	121	6	0	2	0	0
7	348	%	-	-	0.6	-	-	-	23.8	34.8	1.7	-	0.6	-	-
		No.	0	0	0	0	0	0	71	65	1	0	0	0	0
8	332	%	-	-	-	-	-	-	21.4	19.6	0.3	-	-	-	-
		No.	0	0	0	0	0	0	159	22[7]	48	1	6	0	0
9	361	%	-	-	-	-	-	-	44.1	6.1	13.3	0.2	1.7	-	-
		No.	0	0	0	0	1	0	153	60[8]	28	19	21	0	0
10	511	%	-	-	-	-	0.2	-	29.9	11.7	6.1	3.7	4.1	-	-
		No.	0	0	0	2	0	0	112	70	21	60	14	0	0
11	461	%	-	-	-	0.4	-	-	24.3	15.2	4.6	13.0	3.0	-	-

Appendix Table 24. Commercial fishery recoveries and escapement sightings of tagged sockeye salmon by site of release and area of recapture, Bristol Bay, 1956 (Continued)

Tagging			Recoveries													
			Togiak[1]		Nushagak[2]				Naknek-Kvichak[3]			Egegik		Ugashik	
Site	No. tagged		Catch	Escapement survey	Nushagak catch	Escapement Wood R. tower[4]	Escapement Nushagak River survey	Escapement Igushik River survey	Catch Naknek-Kvichak	Escapement Kvichak tower[4]	Escapement Naknek weir[4]	Catch	Escapement weir[4]	Catch	Escapement weir[5]
12	467	No.	0	0	0	0	0	0	47	4	15	128	144	1	5
		%	-	-	-	-	-	-	10.1	0.9	3.2	27.8	30.2	0.2	1.1
13	251	No.	0	0	0	0	0	0	27	5	0	59	54	3	3
		%	-	-	-	-	-	-	10.8	2.0	-	23.5	21.5	1.2	1.2
14	486	No.	0	0	0	0	0	0	24	5	0	106	168	1	4
		%	-	-	-	-	-	-	4.9	1.0	-	21.8	33.9	0.2	0.8
15	548	No.	0	0	1	2	0	0	69	37	21	67	28	43	28
		%	-	-	0.2	0.4	-	-	12.6	6.8	2.7	12.2	5.1	7.8	5.1
16	379	No.	1	0	0	0	1	0	53	7	3	36	24	39	47
		%	0.3	-	-	-	0.3	-	14.0	1.8	0.8	9.5	5.5	10.3	12.4
17	203	No.	0	0	0	0	0	0	34	0	9	24	30	21	21
		%	-	-	-	-	-	-	16.7	-	4.4	11.8	16.3	10.4	10.3
18	628	No.	0	0	0	0	0	0	48	6	0	49	31	94	80
		%	-	-	-	-	-	-	7.6	0.9	-	7.8	4.9	15.0	12.7
19	97	No.	0	0	0	0	0	0	0	0	0	5	0	15	24
		%	-	-	-	-	-	-	-	-	-	5.1	-	15.5	24.7
20	128	No.	0	0	0	0	0	0	3	0	0	7	10	35	19
		%	-	-	-	-	-	-	2.3	-	-	5.5	7.8	27.3	14.8

Appendix Table 24. Commercial fishery recoveries and escapement sightings of tagged sockeye salmon by site of release and area of recapture, Bristol Bay, 1956 (Continued)

[1] Limited foot survey of Togiak system.

[2] Igushik and Nushagak partly covered by foot surveys.

[3] Alagnak system not covered by tower, weir, or foot surveys.

[4] Weighted count.

[5] Includes 16 caught in personal-use nets in river 12 miles above fishery.

[6] Percent of total number tagged.

[7] Includes one tag recovered 18 miles above fishery but below tower site.

[8] One returned from Alagnak system (0.2%).

Appendix Table 25.--Commercial fishery recoveries of tagged sockeye salmon, Bristol Bay, 1957

Date and site	Number tagged	Fishing district					Total
		Nushagak	Naknek-Kvichak	Egegik	Ugashik	Unknown	
Site 1							
June 24	4	1	2	-	-	-	3
26	15	1	7	-	-	-	8
27	16	-	1	1	-	-	2
29	4	-	1	-	-	-	1
30	9	-	6	-	-	-	6
July 2	13	2	2	-	-	-	4
3	9	-	2	-	-	-	2
4	40	1	9	-	-	-	10
5	45	-	9	1	-	1	11
6	8	-	2	-	-	-	2
7	26	3	7	-	-	-	10
8	85	13	6	-	-	-	19
9	20	3	5	-	-	-	8
12	3	1	-	-	-	-	1
16	6	-	1	-	-	-	1
19	6	-	-	-	-	-	-
Total	309	25	60	2	-	1	88
Percent*	-	8.1	19.4	0.6	-	0.3	28.5
Site 2							
June 21	312	-	131	10	-	9	150
23	12	-	6	1	-	1	8
24	77	-	24	6	-	3	33
25	273	-	120	7	-	3	130
26	306	-	138	15	-	6	159
27	305	-	127	4	-	7	138
29	288	-	113	29	-	14	156
30	278	-	123	12	-	5	140
July 1	293	-	101	13	-	6	120
2	84	-	28	10	-	2	40
3	166	-	70	-	-	4	74
4	346	-	152	3	-	10	165
5	433	-	152	5	-	10	167
6	39	-	17	1	-	-	18
7	778	2	310	14	-	17	343
8	1,156	2	394	8	-	30	434
9	426	-	202	4	-	11	217
12	263	-	71	5	-	6	82
13	471	-	105	34	-	4	143
14	356	1	103	22	-	10	136
15	423	1	73	18	1	3	96
16	538	1	120	39	-	6	166
17	300	-	85	4	-	1	90
18	452	-	81	5	-	3	89
19	56	-	5	1	-	-	6
20	550	-	92	13	1	1	107
22	17	-	5	-	-	-	5
23	95	-	17	2	-	-	19
24	222	-	60	2	-	3	65
Total	9,363	7	3,025	287	2	175	3,496
Percent*	-	0.07	32.3	3.1	0.02	1.9	37.3

* Percent of total number tagged.

Appendix Table 26. Escapement observations of tagged sockeye salmon, Bristol Bay, 1957

Location	Sightings (weighted counts)			
	Site 1	Percent*	Site 2	Percent*
Wood River tower	21	6.8	5	0.1
Kvichak River tower	111	35.9	306	3.2
Alagnak River tower	0	--	54	0.6
Naknek River weir	16	5.2	653	7.0
Egegik River tower	0	--	96	1.0

* Percent of total number tagged.

Appendix Table 27. Commercial fishery recoveries of tagged sockeye salmon, Bristol Bay, 1959

Date and site	Number tagged	Fishing district					Total
		Togiak	Nushagak	Naknek-Kvichak	Egegik	Ugashik	
Site 1							
June 20	13	1	2	-	-	-	3
23	18	-	2	-	-	-	2
26	61	-	4	-	-	-	4
28	82	-	22	-	-	-	22
30	86	-	27	-	-	-	27
July 2	122	-	36	-	-	-	36
6	185	-	75	-	-	-	75
7	27	-	17	-	-	-	17
9	33	-	6	-	-	-	6
11	60	2	24	-	-	-	26
13	72	2	28	-	-	-	30
15	12	-	2	-	-	-	2
Total	771	5	245	-	-	-	250
Percent*	-	0.7	31.8	-	-	-	32.4
Site 2							
June 20	11	-	2	-	-	-	2
26	110	-	11	-	-	-	11
28	31	-	12	-	-	-	12
30	330	-	110	3	-	-	113
July 2	223	-	82	-	-	-	82
7	19	-	6	-	-	-	6
9	66	-	18	-	-	-	18
11	15	1	10	-	-	-	11
13	20	-	11	-	-	-	11
15	8	-	3	-	-	-	3
Total	833	1	265	3	-	-	269
Percent*	-	0.1	31.8	0.4	-	-	32.13
Site 3							
June 21	17	-	1	-	-	-	1
25	266	1	38	1	-	-	40
27	73	-	16	4	-	-	20
29	118	2	30	1	-	-	33
July 1	310	-	117	4	-	-	121
3	140	-	58	-	-	-	58
8	15	-	5	1	-	-	6
10	37	-	3	-	-	-	3
12	17	-	8	-	-	-	8
14	12	-	5	-	-	-	5
Total	1,005	3	281	11	-	-	295
Percent*	-	0.3	28.0	1.1	-	-	29.4
Site 4							
June 19	5	-	-	-	-	-	0
21	5	-	-	-	-	-	0
25	12	-	2	-	-	-	2
27	19	-	4	1	-	-	5
29	18	-	7	-	-	-	7
July 1	343	-	141	4	1	-	146
8	11	-	3	1	-	-	4
10	413	1	88	5	-	-	94
12	206	-	99	1	-	-	100
14	39	-	20	-	-	-	20
Total	1,071	1	364	12	1	-	378
Percent*	-	0.09	34.0	1.1	0.09	-	35.3

* Percent of total number tagged.

Appendix Table 28. Escapement observations of tagged sockeye salmon, Bristol Bay, 1959

Location	Sightings							
	Site 1	Percent[1]	Site 2	Percent[1]	Site 3	Percent[1]	Site 4	Percent[1]
Igushik River tower[2]	328	42.5	54	6.5	121	12.0	48	4.5
Wood River tower[2]	28	3.6	133	16.0	171	17.0	236	22.0
Kvichak River	--	--	--	--	--	--	3[3]	0.3
Snake River	--	--	2[4]	0.2	1[4]	0.1	--	--
Nushagak River	--	--	1[5]	0.1	3[5]	0.3	1[5]	0.1
Kuskokwim River	1[6]	0.1	--	--	--	--	--	--

[1] Percent of total number tagged.
[2] Weighted counts.
[3] Spawning ground recaptures by Fisheries Research Institute personnel.
[4] Spawning ground recaptures by U.S. Fish and Wildlife Service personnel.
[5] Tagged fish recaptured in "personal-use gill nets" located upstream from the commercial fishing district and downstream from the escapement enumeration towers.
[6] Recovered in gill net near mouth of river.

Appendix Table 29. Percentage age composition of tagged sockeye salmon by tagging site, Bristol Bay, 1955

Tagging site	Sample size	Age group 4_2 Number	4_2 Percent	5_2 Number	5_2 Percent	5_3 Number	5_3 Percent	6_2 Number	6_2 Percent	6_3 Number	6_3 Percent	6_4 Number	6_4 Percent	7_3 Number	7_3 Percent	7_4 Number	7_4 Percent
1	72	18	25.0	2	2.8	10	22.2	0	--	31	43.1	2	2.8	1	1.4	2	2.8
2	99	16	16.2	7	7.1	34	34.3	0	--	32	32.3	8	8.1	1	1.0	1	1.0
3	305	46	15.1	35	11.5	97	31.8	0	--	115	37.7	2	0.7	4	1.3	6	1.9
4	369	85	23.0	51	13.8	128	34.7	1	0.3	94	25.5	4	1.1	2	0.5	4	1.1
5	239	62	25.9	55	23.0	73	30.5	1	0.4	45	18.8	2	0.8	0	--	1	0.4
6	117	37	31.6	43	36.8	28	23.9	0	--	9	7.7	0	--	0	--	0	--
7	122	37	30.3	33	27.1	42	34.4	0	--	10	8.2	0	--	0	--	0	--

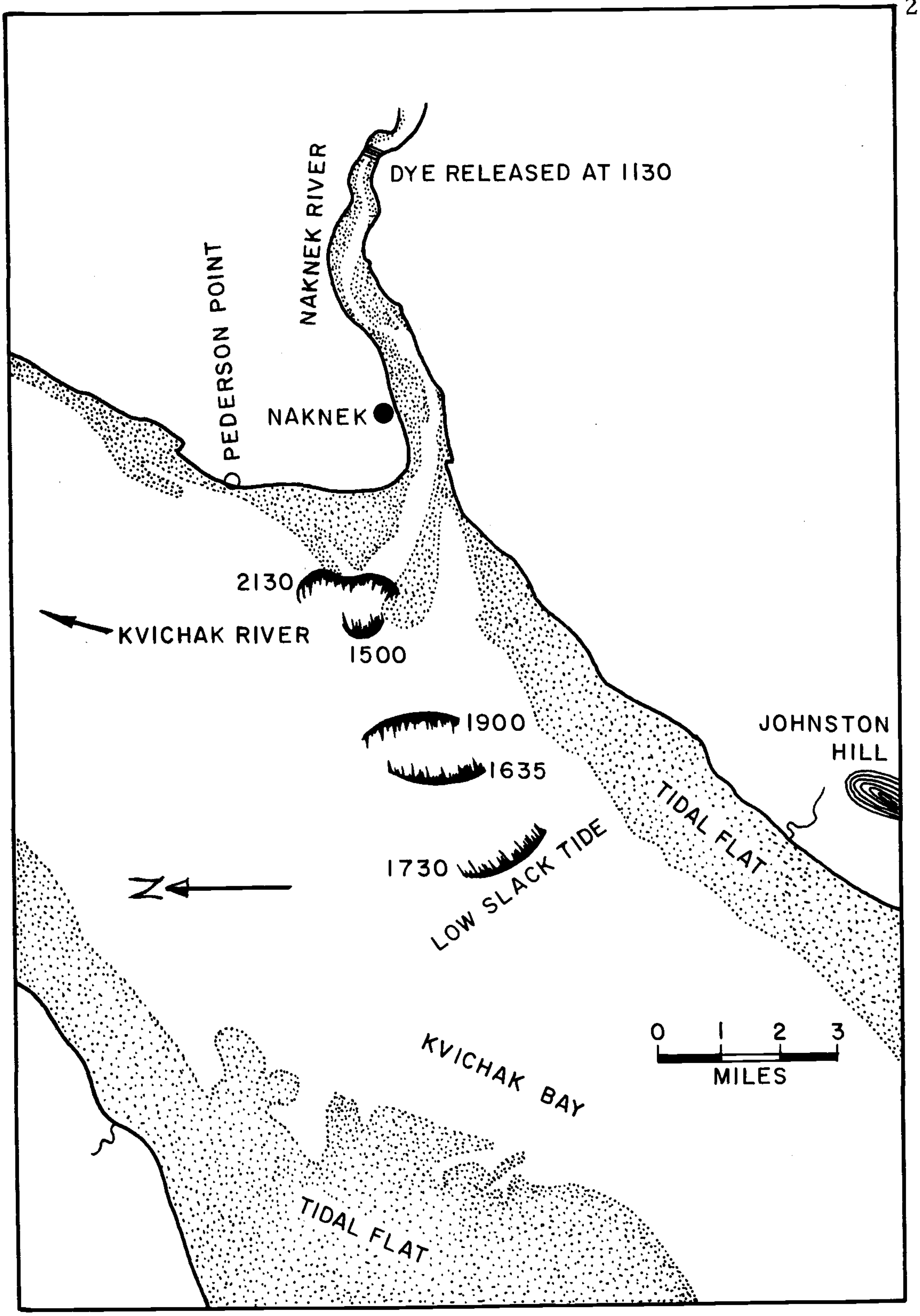
Appendix Table 30. Percentage age composition of sockeye salmon escapements in Egegik, Kvichak, and Naknek river systems, Bristol Bay, 1955

River system	Sample size	Age groups										
		3_2	4_1	4_2	4_3	5_2	5_3	6_2	6_3	6_4	7_3	7_4
Egegik[1]	913	--	--	9.7	0.2	2.1	38.8	0.1	39.4	7.8	1.0	0.9
Kvichak[2]	1,780	1.2	0.5	47.9	10.8	12.5	25.3	--	1.5	--	0.1	--
Naknek[3]	548	--	--	21.21	--	45.68	19.27	0.36	13.37	0.04	0.07	--

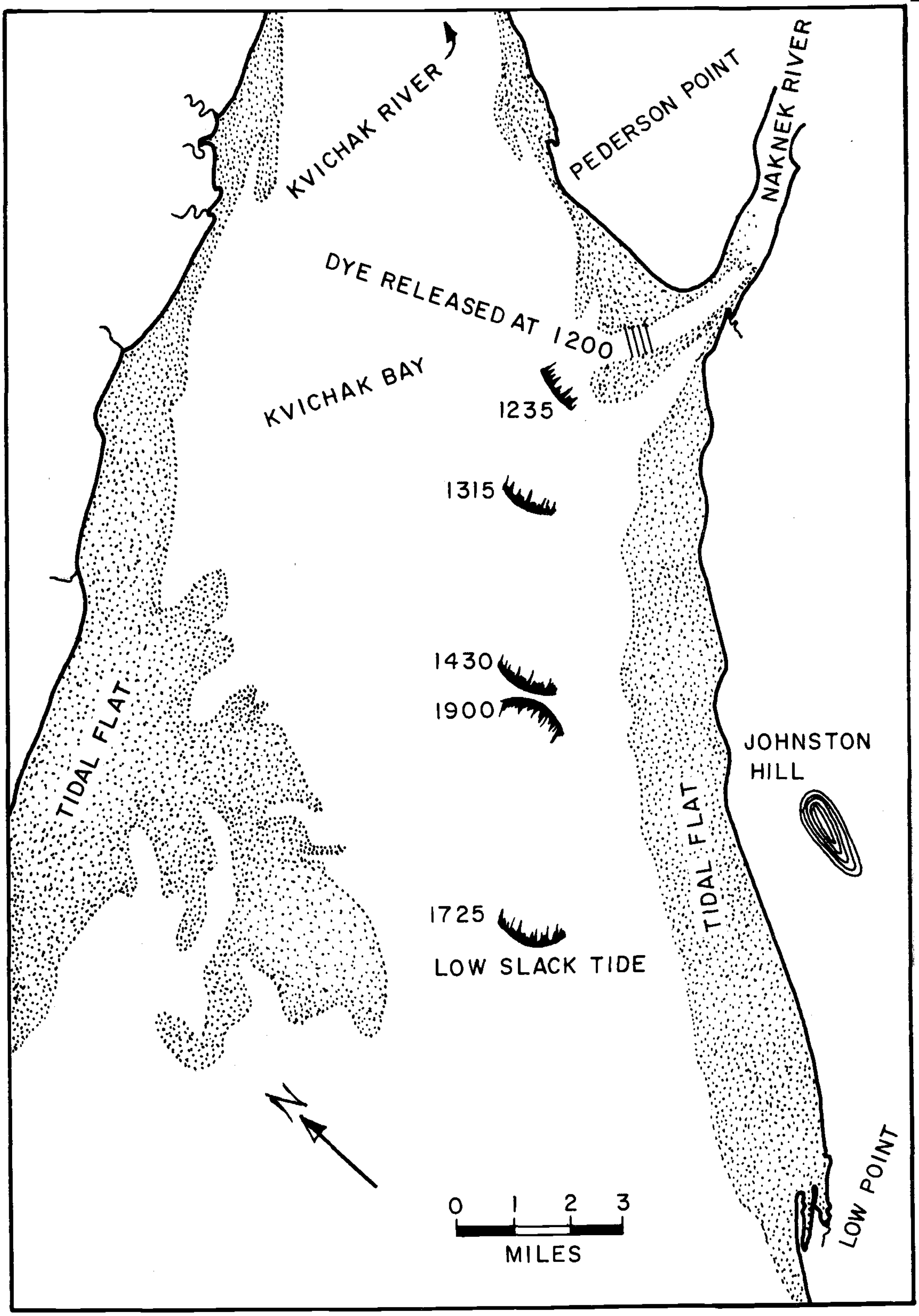
[1] Source: International North Pacific Fisheries Commission Bulletin (1962), Page 56.

[2] Source: Age analysis of red salmon in the Kvichak-Naknek and Egegik areas, 1955 by S. Y. Koo. Unpublished data provided by the Fisheries Research Institute, University of Washington, Seattle.

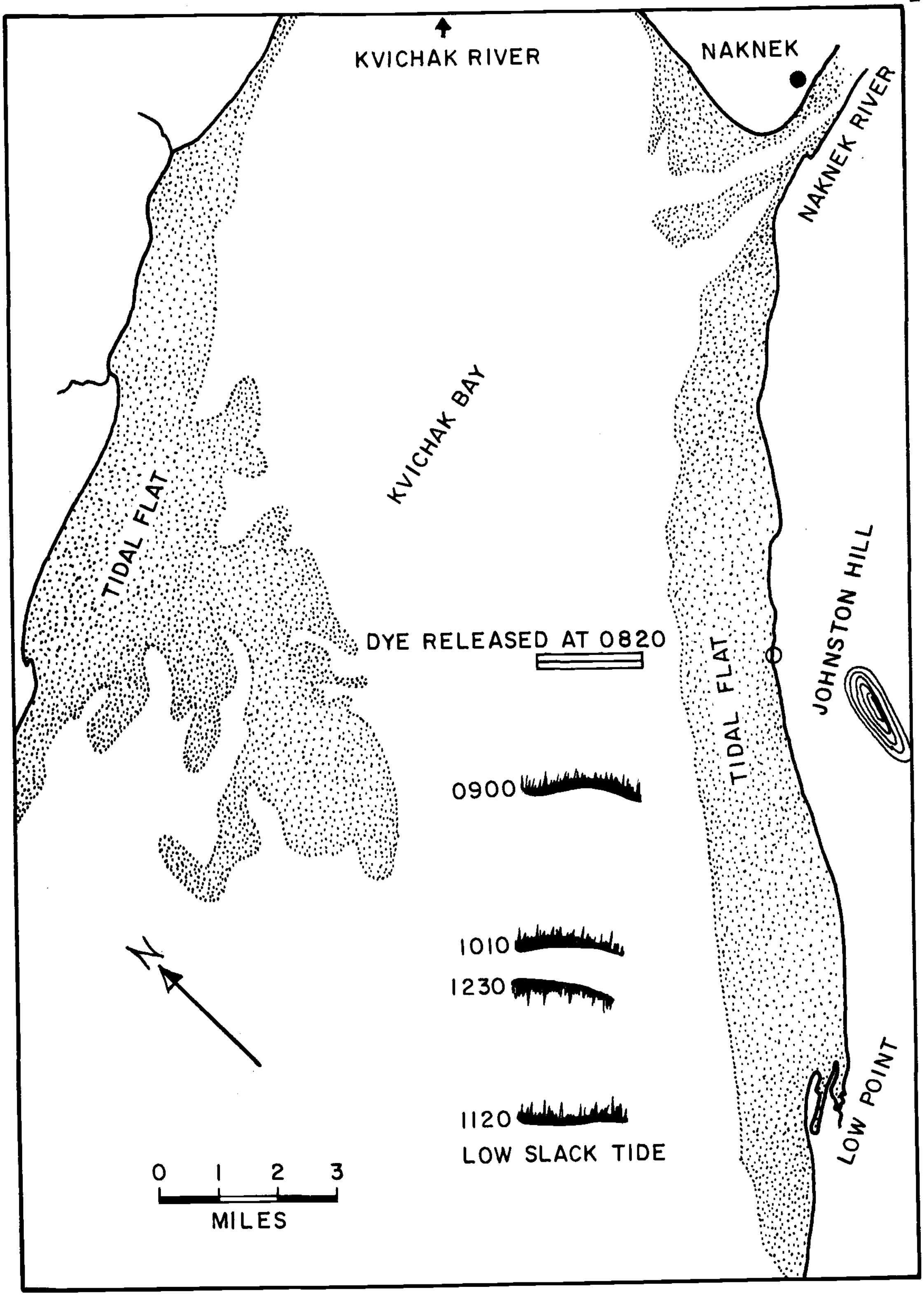
[3] Source: Unpublished data on file at the U.S. Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska.



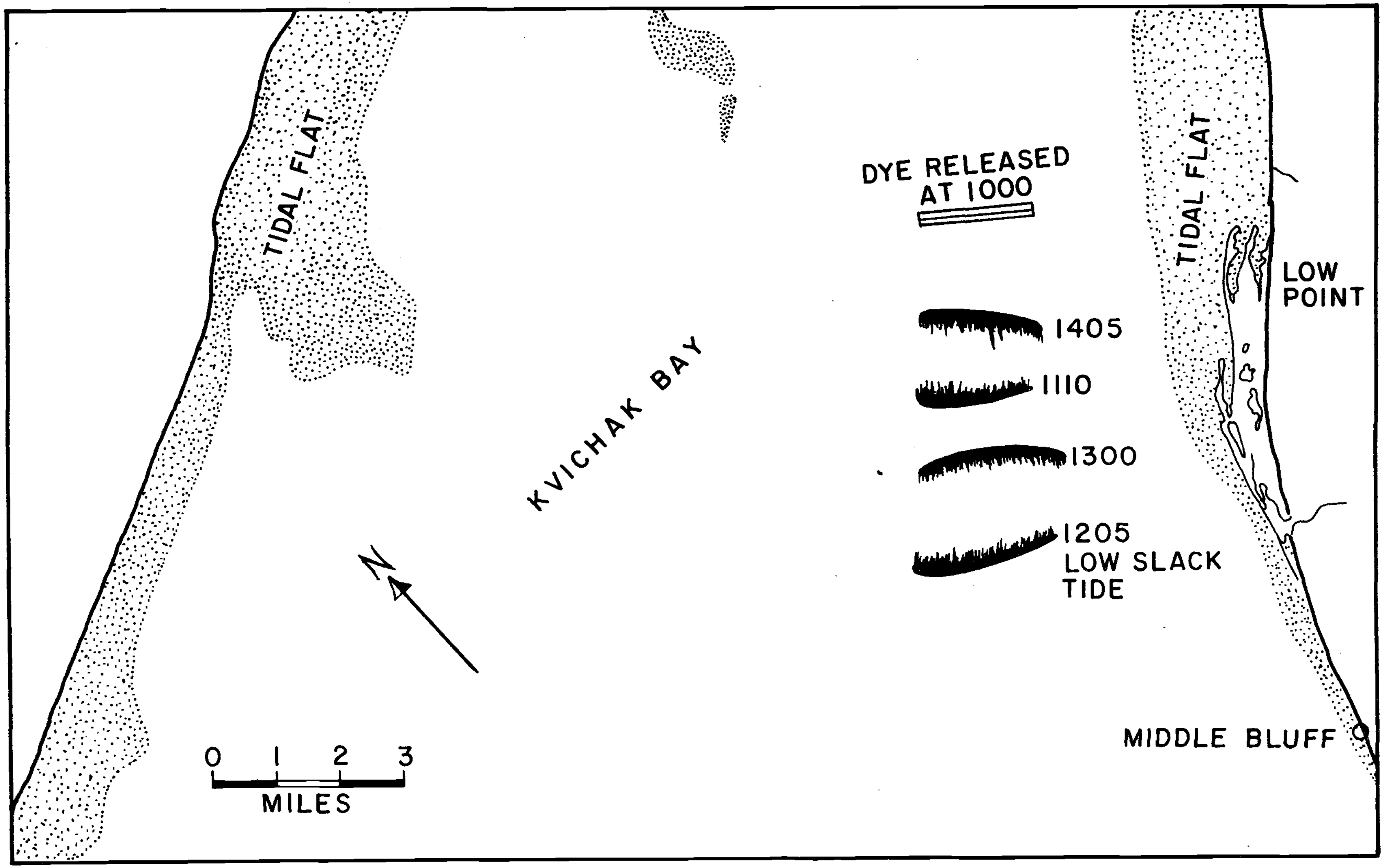
Appendix Figure 1. Position of dye patch during ebb and flood tide by time after release, July 26, 1965.



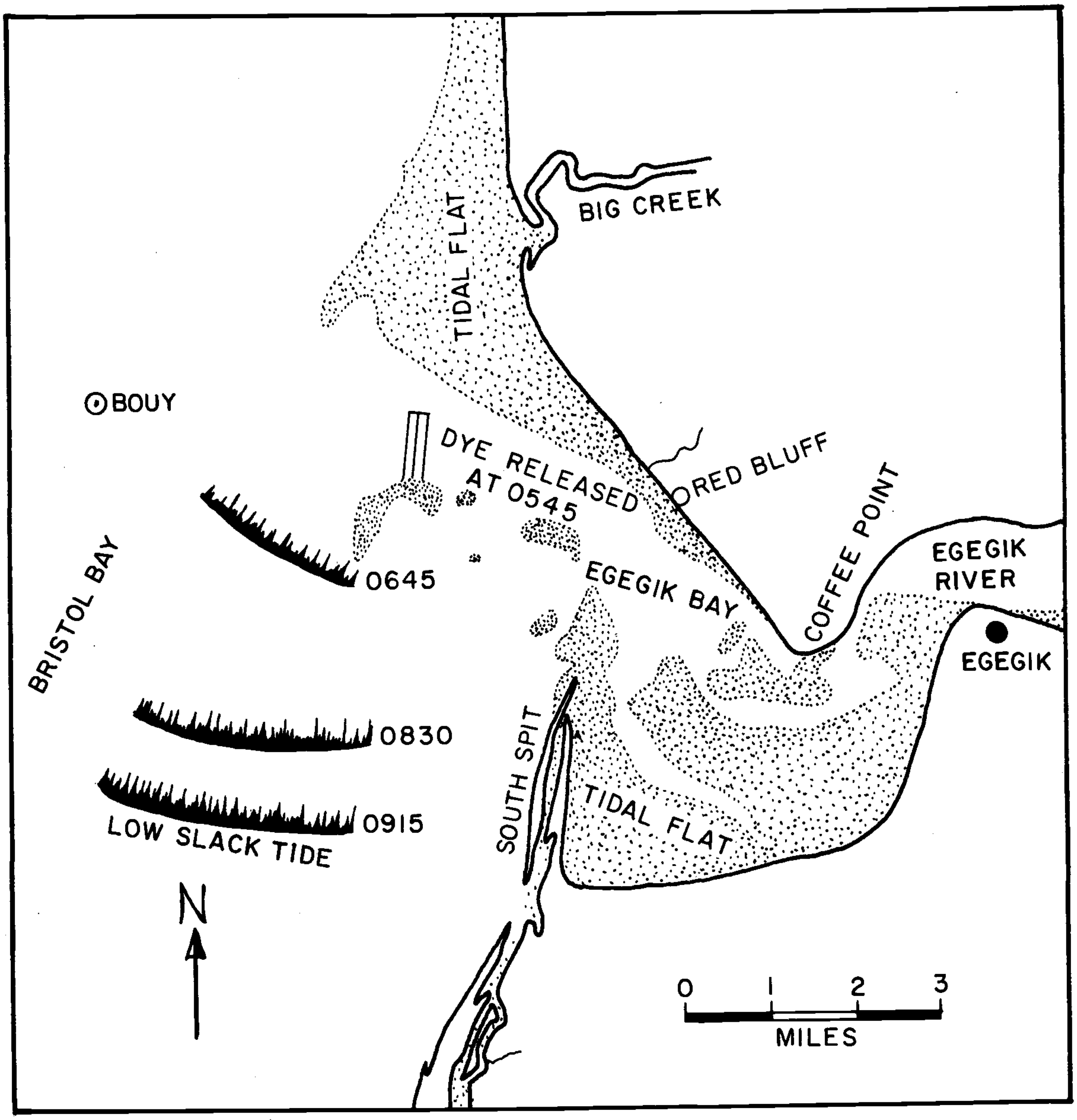
Appendix Figure 2. Position of dye patch during ebb and flood tide by time after release, August 7, 1965.



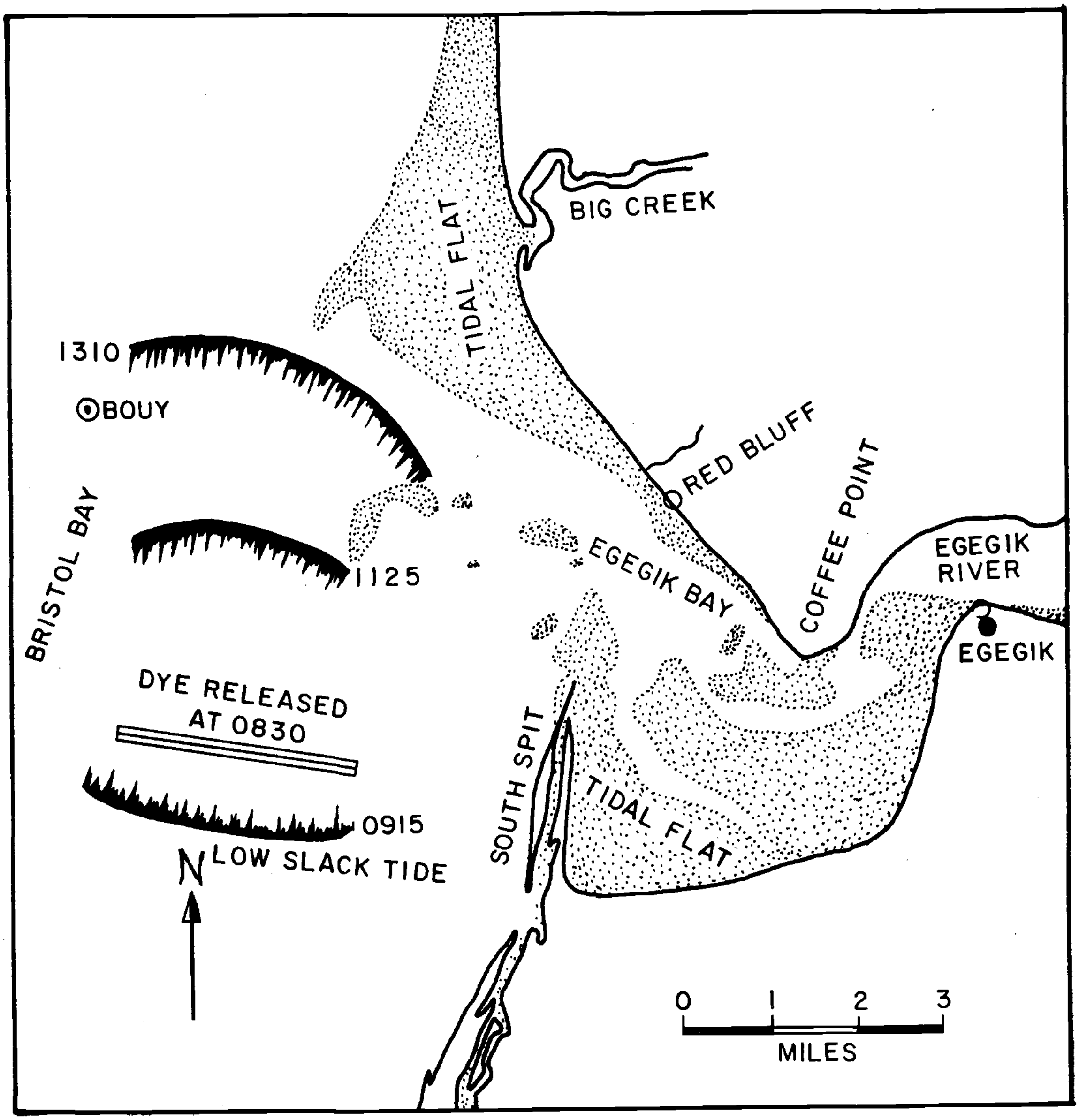
Appendix Figure 3. Position of dye patch during ebb and flood tide by time after release, August 17, 1965.



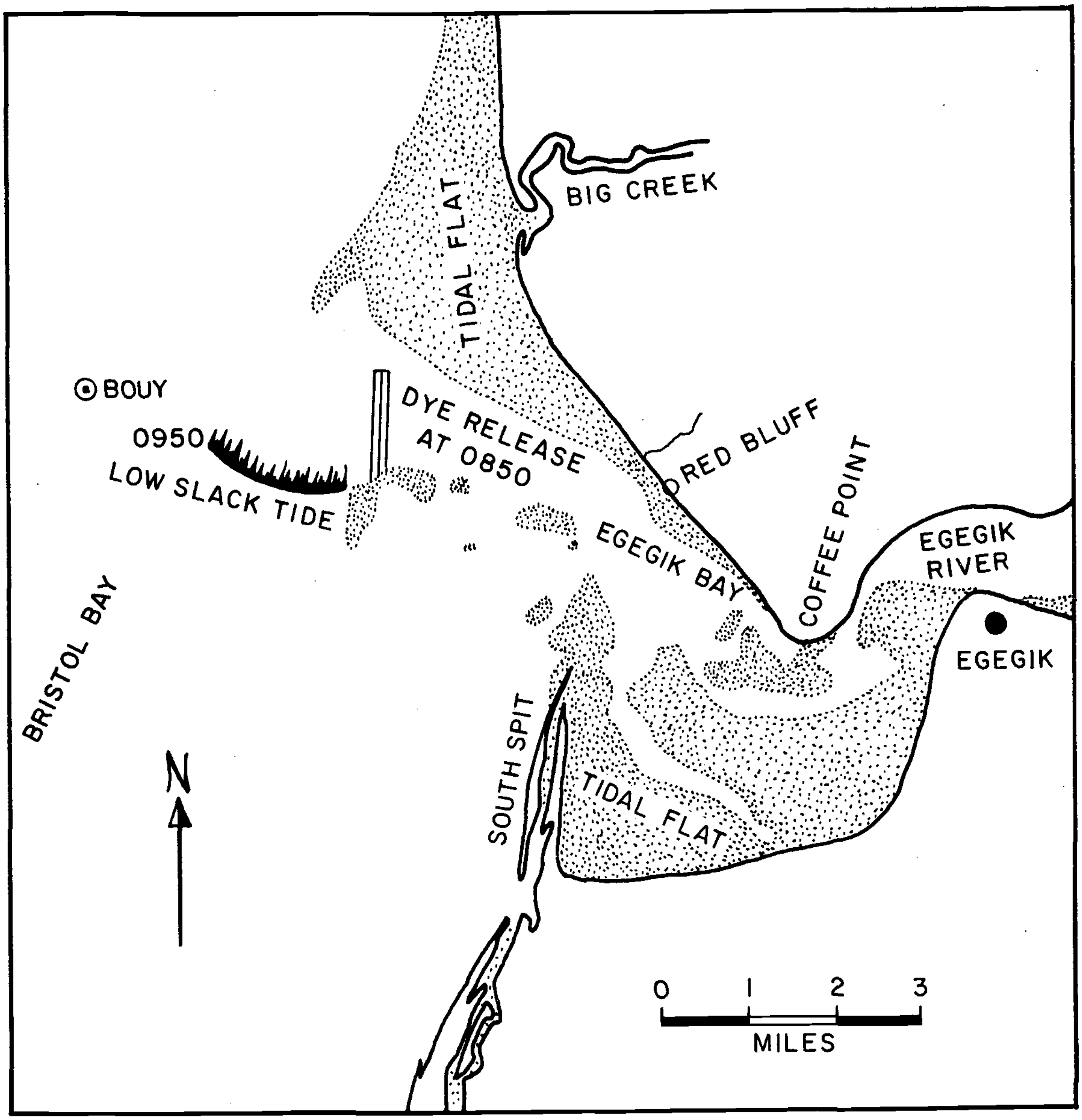
Appendix Figure 4. Position of dye patch during ebb and flood tide by time after release, August 18, 1965.



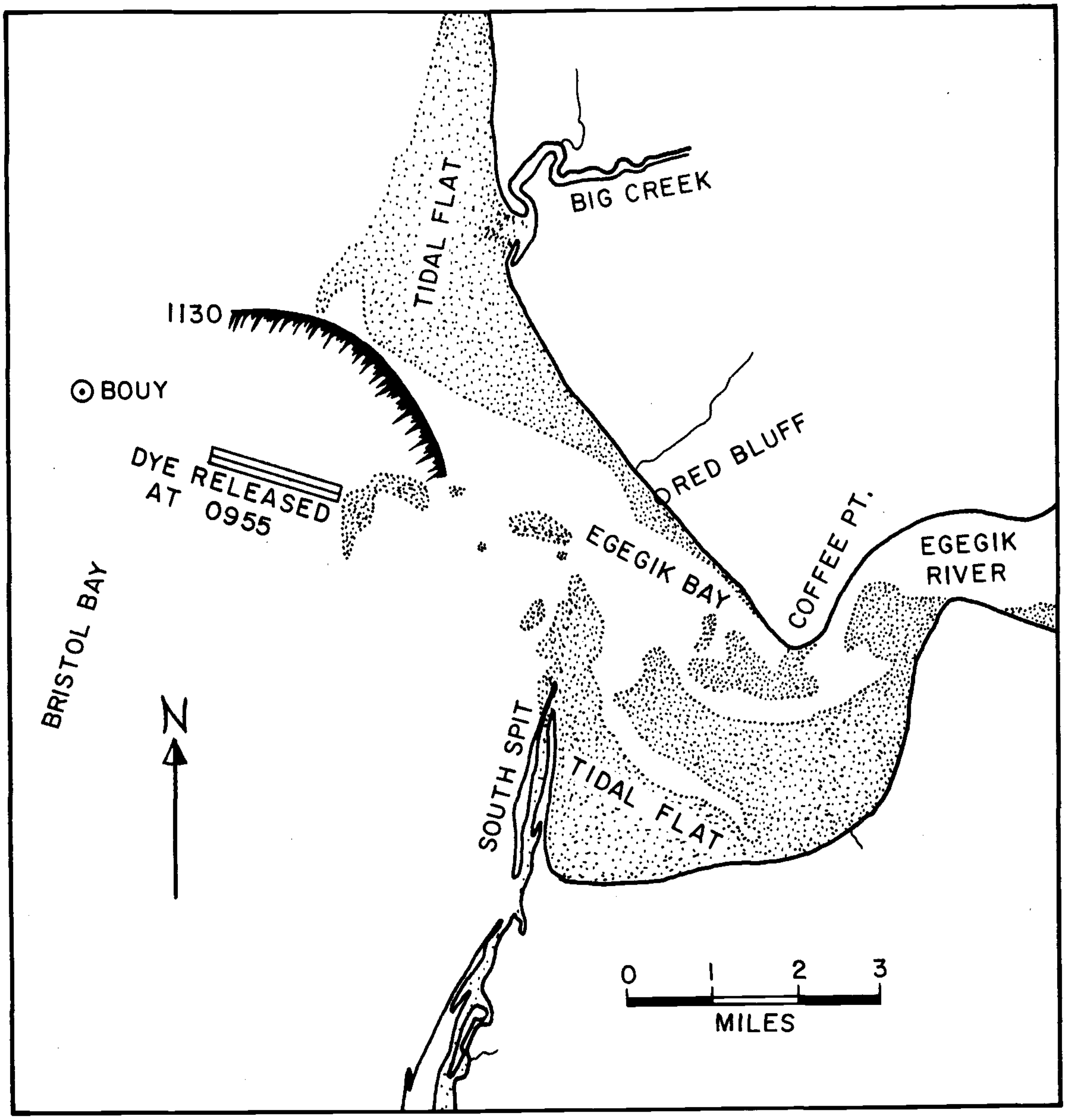
Appendix Figure 5. Position of dye patch during ebb tide by time after release, August 3, 1966.



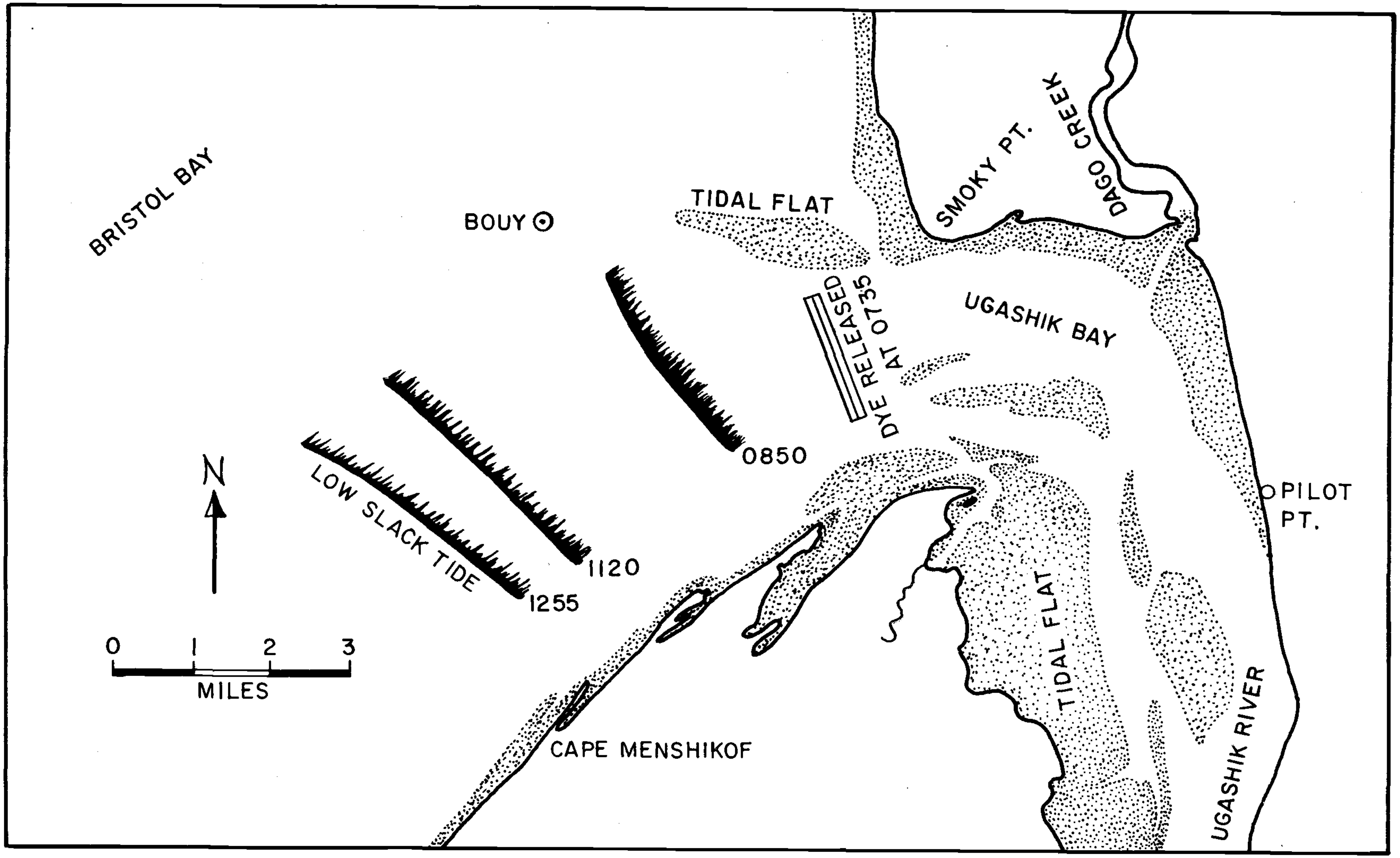
Appendix Figure 6. Position of dye patch during ebb and flood tide by time after release, August 3, 1966.



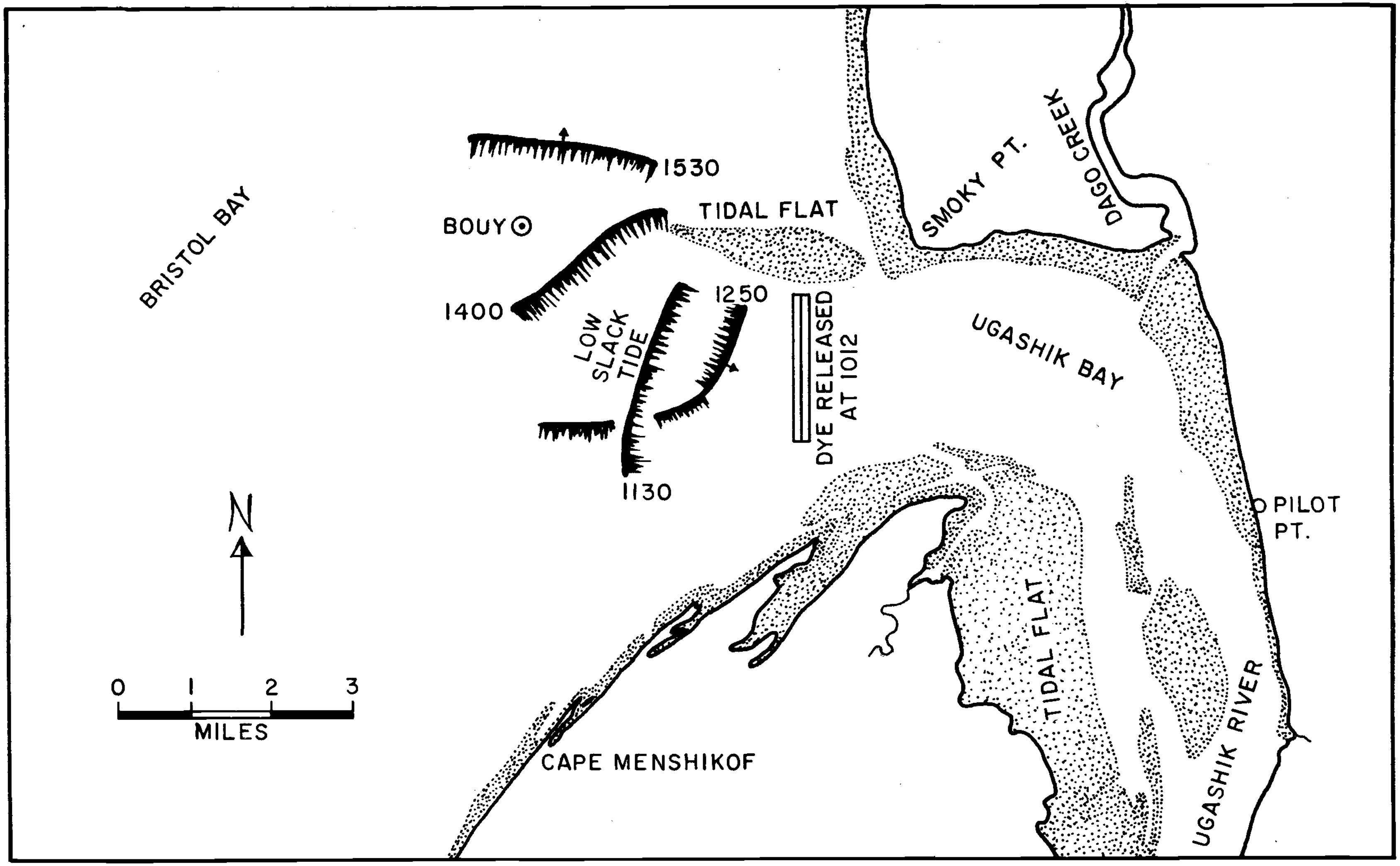
Appendix Figure 7. Position of dye patch during ebb tide by time after release, August 4, 1966.



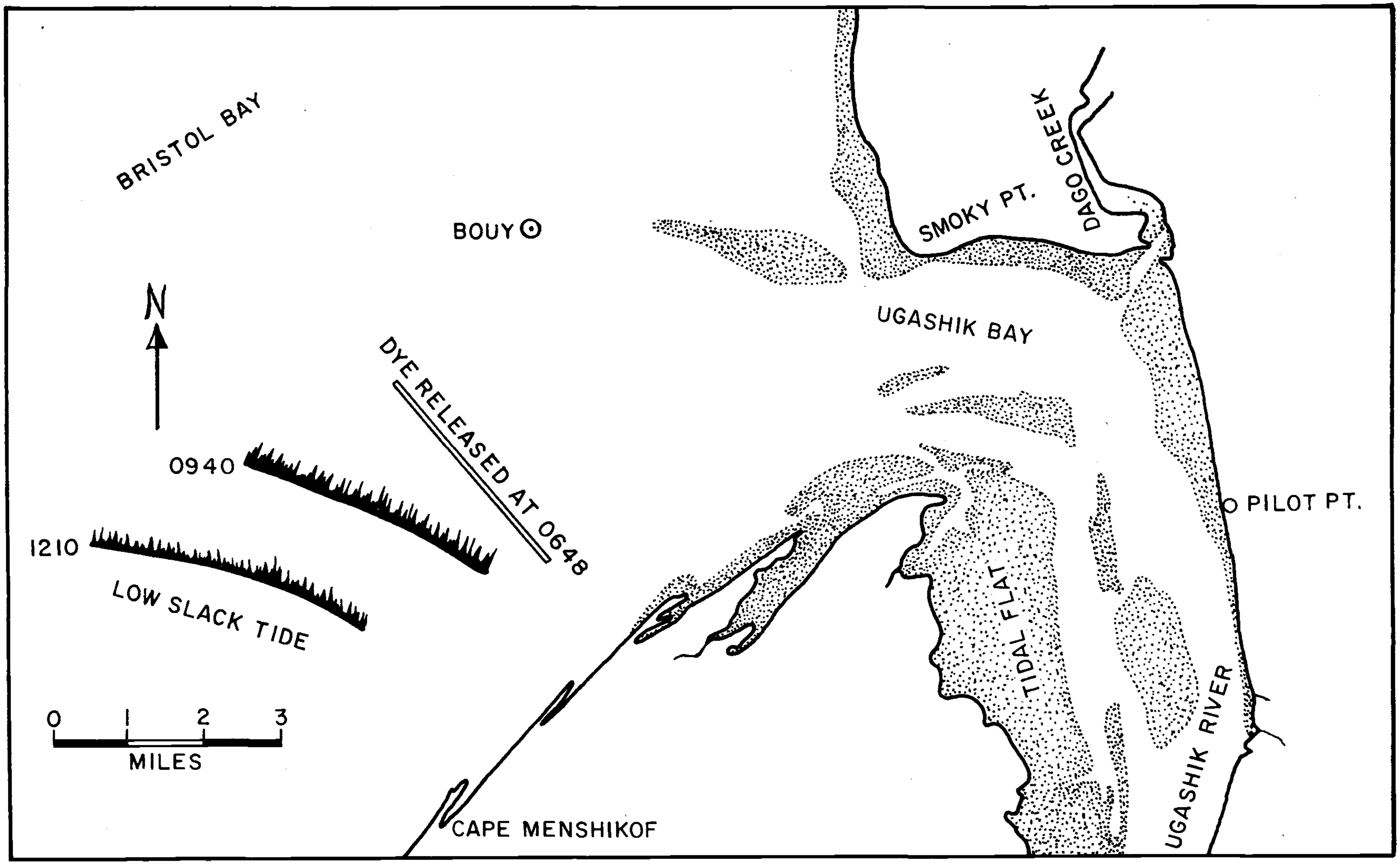
Appendix Figure 8. Position of dye patch during flood tide by time after release, August 4, 1966.



Appendix Figure 9. Position of dye patch during ebb tide by time after release, August 10, 1966.



Appendix Figure 10. Position of dye patch during last of ebb tide and first half of flood tide by time after release, August 11, 1966.



Appendix Figure 11. Position of dye patch during ebb tide by time after release, August 12, 1966.