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Vertical Sections of Semimonthly Mean Temperature on the San Francisco-Honolulu Route: From Expendable Bathythermograph Observations, June 1966-December 1974

J. F. T. Saur, L. E. Eber, D. R. McLain,
and C. E. Dorman

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U.S. DEPARTMENT OF COMMERCE
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National Marine Fisheries Service

NOAA TECHNICAL REPORTS

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NOAA Technical Report NMFS SSRF- 728

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CONTENTS

Table

Figures

Vertical Sections of Semimonthly Mean Temperature on the San Francisco-Honolulu Route: From Expendable Bathythermograph Observations, June 1966-December 1974

J. F. T. SAUR,[1] L. E. EBER,[2] D. R. McLAIN,[3] and C. E. DORMAN[4]

ABSTRACT

Frequently repeated sections of expendable bathythermograph observations between San Francisco and Honolulu, taken by merchant vessels during the period June 1966 through December 1974, were analyzed to obtain mean seasonal cycles. Results are depicted in a set of semimonthly vertical sections of mean temperatures to 500 m and in a set of corresponding sections of 30-day mean temperature changes to 200 m. In addition, seasonal cycles at selected depths are included along with mean monthly vertical profiles for seven typical locations along the route.

The analyses reveal geographic and temporal facets of the mean thermal structure, including: 1) depth of the surface mixed layers in winter, 2) growth and decay of the seasonal thermocline, 3) decrease in depth of the permanent thermocline from Oahu to the California coast, 4) a region of temperature inversions or very weak vertical temperature gradients that develops between 50 and 100 m during the spring in the Transition Zone, and 5) the location and movement of warming and cooling regions during the year.

Vertical mixing appears to be the dominant process along most of the route for transmitting the annual surface warming and cooling cycle downwards to depths of 100 to 150 m. However, advective processes are active in the California Current.

Tables of semimonthly mean temperatures are given in an Appendix.

INTRODUCTION

Vertical sections of mean subsurface temperatures from the surface to 500 m, presented here, were derived from a time-series of sections of expendable bathythermograph (XBT) observations made from June 1966 through December 1974 by merchant ships between San Francisco, Calif., and Honolulu, Hawaii (Fig. 1). The observational program was developed by Saur and the data collected under the direction of the National Marine Fisheries Service (NMFS). With technical assistance from the Fleet Numerical Weather Central (FNWC), XBT systems were placed on merchant ships and observations were made routinely by the ship's mates. Saur and Stevens (1972) described the XBT system, observational procedures, and early projects for obtaining observations from cooperating ships.

Collection of subsurface temperature observations on the San Francisco-Honolulu route began when the first production models of the XBT system became available. The work started as a 1- to 2-yr feasibility and development project on the use of the system aboard merchant vessels. It was then continued as an ocean monitoring project, and is now a part of a coordinated program among FNWC, NMFS, and NORPAX (North Pacific Experiment) programs to obtain XBT observations in the Pacific. The data are now routinely collected

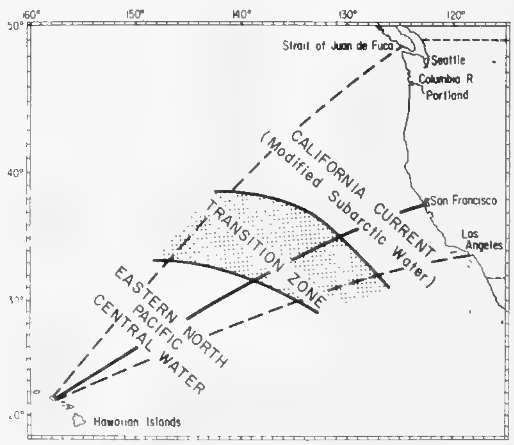

Figure 1.—Three great circle routes between Honolulu and U.S. west coast ports, on which frequent XBT observations have been made by cooperating merchant ships, and a schematic representation of the three upper ocean regimes in the area. Mean subsurface temperatures reported here are for the San Francisco-Honolulu route for which the longest time series—starting in June 1966—exists.

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and selected vertical sections of the temperature distribution, with individual XBT profiles, have been published regularly in *Fishing Information*[5] since March 1972.

The ship routes between Honolulu and U.S. west coast ports cross the eastern limb of the major anticyclonic gyre of the North Pacific Ocean. If we confine our attention to the upper ocean, from the surface to a few hundred meters, we can identify three oceanic regimes: the California Current and the Eastern North Pacific Central waters separated by a Transition Zone (Fig. 1).

The waters in the California Current are mainly cooler, lower salinity waters of subarctic origin that are modified in their slow southeastward movement along the California coast. The Eastern North Pacific Central waters are warmer, higher salinity waters that occupy about the southwestern one-half of the route.

The Transition Zone is a complex region, not yet fully understood. In our region of interest it is bounded on the south and southwest by the subtropical front (Roden 1971, 1975). On the north and northeast it is bounded, respectively, by the subarctic front (Dodimead et al. 1963) and some type of southeastward extension of this feature, which LaFond and LaFond (1971) called the California Front. Saur (1974) described criteria for identifying these regimes from the XBT profiles, changes in slopes of isotherms in the vertical sections, and accompanying surface salinity observations. Laurs and Lynn (1977) discussed features of the Transition Zone from oceanographic observations made in June of several different years by fishery research vessels.

Mean temperatures presented here provide a base for study of temperature anomalies (Dorman and Saur 1977, 1978) and for further research on the relation of temperature variability to air-sea interaction and the changing environment of marine organisms.

METHODS

Observations

The time-distance distribution of XBT observations for the period June 1966 through December 1974 is shown in Fig. 2. The great circle distance from a reference point near Oahu was used for location. About 90% of the observations were made by ships on the great circle route. Some departures from the great circle track resulted from storms and the fact that tankers of Chevron Shipping Company generally followed a rhumb line (constant heading) course. For these observations taken at locations displaced from the usual route by 100 to 150 km, the use of great circle distance from Oahu tends to minimize temperature errors, because the general orientation of isotherms in the upper layers is northwest-

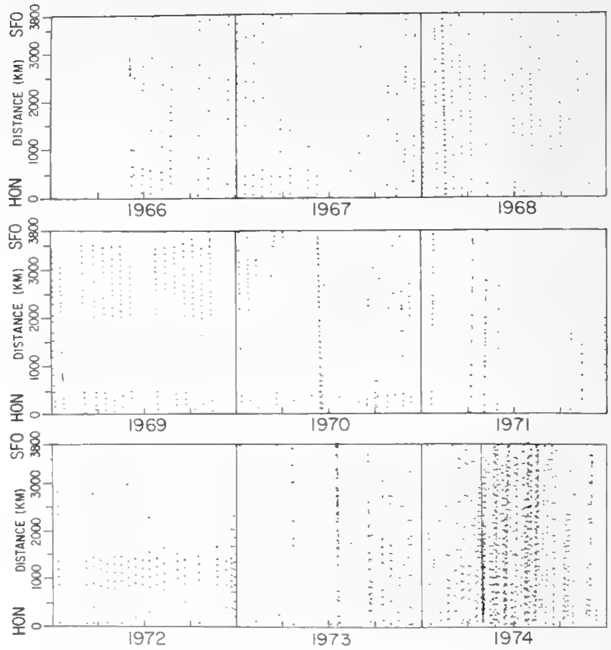

Figure 2.—The time-distance distribution of XBT observations on or near the San Francisco-Honolulu route from June 1966 through December 1974. Location of an observation is measured by its great circle distance from an offshore reference point (lat. 21°12′N, long. 157°42′W) near Honolulu.

southeast. The San Francisco end of our section is a point on the edge of the continental shelf a short distance south-southwest of the Farallon Islands and 3,800 km (2,050 n.mi.) from the reference point.

With the exception of the first year and one-half when only four observations per day were scheduled, the XBT observations were taken on a 4-h schedule related to the ship's watch, rather than at prespecified "stations." Thus the location of observations along the route differs from one section to another. Also, the distance between observations depended upon the ship's speed. Of those ships cooperating in the program, normal speeds were either about 16 to 17 kn or about 22 kn, so that the distance between observations was about 120 km (65 n.mi.) or 165 km (90 n.mi.), respectively. The slower ships would generally get 27 to 30 observations per transit and the faster ships about 17 to 20 observations. A few sections with more closely spaced observations for special studies were made when scientific personnel were aboard.

The frequency of sections reflects the growth and change in character of the project. With the exception of six sections made by oil tankers in the summer of 1970, all of the observations from the beginning of the project in June 1966 through January 1971 were made from one vessel, *Californian,* a bulk-cargo and container vessel of Matson Navigation Company. This 17-kn ship made a round trip about every 18 to 21 days, generally making observations on one 5-day leg only. During this period several gaps of 4 to 8 wk duration occurred because of ship repair schedules, short labor strikes, and equipment failures.

[5]*Fishing Information* is a National Marine Fisheries Service monthly publication, containing fishery advisory information and environmental charts for the equatorial and North Pacific Ocean. It is compiled and distributed by the Southwest Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 271, La Jolla, CA 92038.

A prolonged maritime strike in 1971 interrupted the series for two periods of nearly 3 and 5 mo each. A faster (22 kn) ship, *Hawaiian Enterprise,* made most of the sections in 1971 and 1972, resulting in more frequent sections but with greater spacing between observations. As a part of the International Decade of Ocean Exploration (IDOE) programs, we began instrumenting other ships in late 1972 for other routes, but which also would make sections irregularly on the San Francisco route. Using these ships, the frequency of sections on the San Francisco route was increased in 1973 and intense coverage was obtained in 1974.

For the entire period from June 1966 through December 1974 there was a total of 4,913 observations (Table 1). A number of the sections did not have complete coverage, with the coverage generally being poorest near either end of the route. This should be considered when interpreting the computer analyses which will be presented.

Instrumentation

The basic sensing and recording system used throughout the period was the Sippican XBT system. Progressive improvements were made in the recorder by the manufacturer—some partially due to the field experiences from this project—during the first few years, 1966-68. Since then, the recorder, with pressure sensitive paper and an option switch for 460 m (1,500 ft) or 760 m (2,500 ft) depth recording, has remained essentially unchanged.

The XBT system initially installed aboard the *Californian* included an experimental digitizer (developed by FNWC) with analog signal input from a retransmitting slidewire in the XBT recorder and digital output onto a 5-level punched paper tape at depth intervals of slightly less than 3 m (Saur and Stewart 1967). This was a dual purpose output for testing radio transmission of data to FNWC and for subsequent computer conversion, ashore, onto magnetic tape for permanent archives. The digitizer system became unstable after April 1969 which made the output unsuitable for archiving data. Although commercial digitizing systems were tried with some of the new recorders installed on other ships in 1971 and 1972, all of the data used herein from May 1969 onward were derived from the analog traces.

Sippican model T-4 XBT probes (460 m) were used during the first 1.5 yr of the project. We switched to use of model T-7 probes (760 m) in November 1967, to try to minimize probe-to-probe temperature errors by correcting deep temperatures to a smoothed deep level temperature (e.g., 600 or 700 m). This plan proved to be unworkable because the deep level temperatures could be offset to warmer temperatures by insulation failures on the wire and such a bias could not always be recognized with certainty by examination of the analog traces or vertical sections. At a later date mesoscale eddies were discovered and appeared to have deep

Table 1.—Number of expendable bathythermograph (XBT) sections by cooperating ship and total observations by year on the San Francisco-Honolulu route.

	Year									Total
	1966	1967	1968	1969	1970	1971	1972	1973	1974	sections
Matson Navigation Co.										
Californian	10	15	18	15	15	5			6	84
Hawaiian Enterprise						4	[1]18	19	[2]26	67
Hawaiian Citizen									1	1
Hawaiian Queen									10	10
Chevron Shipping Co.										
Idaho Standard					3					3
Washington Standard					2					2
McGarragill					1					1
Chevron Californian							1	2	1	4
Chevron Mississippi							1	4		5
States Lines										
Michigan						1				1
Idaho						1				1
American President Line										
President Cleveland						1				1
Pacific Far East Line										
Monterey								2	1	3
Mariposa									9	9
U.S. Coast Guard										
USCGC *Midgett*								2		2
Total sections	10	15	18	15	21	12	20	29	54	194
Total observations	204	329	550	435	592	229	453	635	1,486	4,913

[1]11-16 February 1968 section had two XBT drops at each 4-h interval.

[2]Includes one special section, 27 April-1 May 1974, with hourly observations by R. L. Bernstein and C. A. Collins.

temperature changes equal to or greater than temperature error of the probes manufactured in 1968 and later.

As the cost of probes rose in the early 1970's we returned to using T-4 probes. With the merchant ships the amount of wire on the probe was the limiting factor on depth of the XBT observation. We found that the manufacturer's safety margin of excess wire on the probe usually permitted a reliable determination of temperature to 500 m.

Initial Processing

The procedures for initial processing of the observations into digital form on magnetic tape evolved as the project developed.

As noted earlier, the XBT system used during 1966-69 aboard the *Californian* included an experimental digitizer with a punched paper tape output. Most of the observations through April 1969 were computer translated from this output, which was regularly calibrated with the manufacturer's test canister on the visit to the ships before and after each voyage. In cases of digitizer failure significant points were read by eye from the analog traces, as were all observations for May-December 1969. Some sets of observations from 1967 to 1968 were semiautomatically digitized by FNWC in the early stages of development of its XBT digitizing system for computer determination of temperature-depth inflection points.

When the NMFS Pacific Environmental Group (PEG) was established in Monterey, the 1970 and later observations were digitized on an analog-digital table, under the supervision of McLain and using the facilities and computers of FNWC. The digitizing procedures generally followed those used at FNWC, described by Dale and Stevens (1970), except as modified by McLain at PEG to handle the NMFS data separately from FNWC data, to digitize analogs from T-4 probes to 500 m, and to plot vertical sections.

Quality Control

Preliminary vertical sections of the distribution of temperature were constructed, at first by hand and later by computer, for quality control. Saur reviewed each data set for possible errors utilizing the preliminary sections, analog traces, and continuity from section to section. Locations of observations were plotted to help check positions and an independent check of time and distance between observations was made against the ship's speed. For observations through 1970, copies of marine weather logs on which positions of 6-h weather observations were logged independently of XBT logs were also used to correct time and position errors.

The data checks were made to eliminate large errors due to instrument failure not detected before digitizing. These were of several types: 1) erroneously high temperatures throughout a trace due to defective thermistors or insulation failure from the start, 2) insulation failure during the probe descent which would introduce bias toward higher temperatures in the remainder of an analog record, and 3) slippage of the friction clutch on the chart drive, which occurred mainly in early years before we became more experienced with the XBT system. Corrections were made at a later time when temperature values were interpolated at 5-m intervals between the surface and 300 m and at 10-m intervals between 300 and 500 m depth, for the computer analysis of temperature fields.

Computational Procedures

The determination of the vertical sections of mean subsurface temperature presented herein involved three steps: 1) Conversion of observed temperatures from each section to temperatures on a standard grid; 2) computation of a seasonally varying mean at each grid point by least squares fit of 12-, 6-, and 4-mo harmonics; and 3) reconstruction of gridded temperature fields from the harmonics, spatial smoothing, and contouring of vertical sections. The computer programs used for this were adaptations by Eber of those he prepared at SWFC to map environmental variables in marine weather observations for presentation in *Fishing Information.*

1. Conversion to a standard grid.—It was previously mentioned that observations were not taken at the same predetermined location from section to section. The first step was to analyze observed values from each section to a standard rectangular grid, using a procedure from Eber's EDMAP[6] (Environmental Data Manipulation, Analysis, and Plotting) program.

The grid was selected with a distance interval of 92.5 km (50 n.mi.) and a depth interval of 10 m. This resulted in a grid of 42 by 51 points representing a vertical section 3,800 km (2,050 n.mi.) by 500 m. Distance and depth were converted to grid coordinate units for the temperature analysis.

The procedure scanned the data list and fitted temperature values to the grid. Each observation contributed to the values at its nearest grid points according to an inverse weighting scheme based on distance from the observation to each of the grid points. The weighting factor decreased to zero at one grid length. If no observation was found within one grid length of a grid point, it was flagged as a "no data" point in that section.

The procedure can be viewed as a refinement of centering the observational data within 185-km (100 n.mi.) by 20-m blocks that have a 50% overlap between adjacent (both vertically and horizontally) blocks. However, if there is more than one observation within a block, each is weighted according to the distance to the center of the block and the number of grid points it will affect. (The

[6]Unpublished documentation of the EDMAP program is on file at the Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92038.

procedure gives somewhat greater weight to an observation near a grid point than would a weighting of $1\text{-}R^2$, where R is the distance in fractions of a grid length.) If there is only one observation within a unit grid area and there are no observations in any of the surrounding grid areas, the observed value would be assigned to each of the four nearest grid points.

The middate of the observations in a given section was assigned to its corresponding grid field for later use in determining harmonic coefficients. Thus the maximum time error for data at either end of the section would be about 2.0 to 2.5 days.

2. Least squares harmonic fit.—In order to establish a smooth mean seasonal cycle for each gridpoint, a least squares fit was made for the harmonic function

$$T_{i,j} = (A_o)_{i,j} + \sum_{n=1}^{3} (A_n \cos n\omega t + B_n \sin n\omega t)_{i,j}$$

where $\omega = 2\pi/365$, t is the day of the year, and i and j are gridpoint indices. Robinson (1976) also used the first three harmonics of the Fourier function for time smoothing of monthly mean values of mechanical bathythermograph data (to 400 ft) for the North Pacific Ocean. Since our initial gridded fields were not distributed at equal intervals in time, the terms which normally disappear in harmonic analysis of evenly spaced data (due to orthogonality) are not zero when applying the least squares fit. Seven simultaneous equations for least squares fit were solved to determine the seven unknown constants to represent the mean temperature and the12-, 6-, and 4-mo cycles.

To avoid overweighting certain years because of greater sampling frequency, a set of harmonic constants was determined for each of three time periods: June 1966-December 1970, 1971-73, and 1974. The first period was selected because of the consistency of the sampling mentioned earlier. The year 1974 was analyzed separately because of the unusually high-density sampling. The observations from 1971 and 1972 were considered as 1 yr and combined with 1973.

Constants from the three periods were weighted and combined by Dorman to provide the mean constants representative of the 1966-74 period. Weights assigned to the periods were as follows:

Period	*Weight*
June 1966-December 1970	4.5
1971-1973	2.0
1974	1.0

3. Vertical sections of mean temperature and mean temperature change.—Appendix 1 contains vertical sections of the mean temperature structure along the Honolulu-San Francisco route, to depths of 500 m, for 24 equally spaced times throughout a year. (For convenience of identification these are labeled as 01 January, mid-January, 01 February, etc., to mid-December.)

The data field for each of the 24 mean vertical sections was reconstructed from the harmonic functions at each grid point. Because the time smoothing by the least squares fit was independent from point to point, a spatial smoothing was applied to the grid field before contouring.

The spatial smoothing was done with one pass of a 5 × 5 point (370 km by 40 m) smoother in the EDMAP program. The smoother was a two-step numerical filter, after Shapiro (1970), which was mostly effective for reducing amplitudes of perturbations with wave lengths of less than about four grid lengths. Its response was zero at a wave length of two grid lengths, 0.45 at three grid lengths, and 0.75 at four grid lengths. The response was 0.96, or greater, at wave lengths of seven grid lengths or more.

The contouring part of the EDMAP program divided each grid square into 25 subsquares, whose corner values were determined by Bessel's central difference formula for double quadratic interpolation. The intersection of each contour with the boundary of a subsquare it transects was determined by linear interpolation. The isotherms were computer plotted and are reproduced herein, with drafting touch-up only for clarity of presentation. The isotherms were not changed subjectively.

The major changes in the seasonally varying mean temperature were found to occur in the upper 200 m of the water column. The figures of Appendix 1 also show the distribution of the "30-day" temperature changes for the upper 200 m. The changes were computed from the spatially smoothed data (described on page 7) and are centered on the date of the vertical section in the upper panel. Note that there is a 50% overlap between two consecutive temperature change charts.

4. Tables of mean temperature.—Mean temperature values, in °C, for selected depths and alternating grid points (intervals of 185 km) are presented in Appendix 2. The values are those reconstructed from the fitted harmonics for the given grid point (distance and depth) and extracted before the grid was spatially smoothed for contouring. The tables are identified as 01 January, mid-January, etc., to mid-December, as were the vertical sections of Appendix 1.

RESULTS

This section discusses some of the general features of the mean temperature distributions in Appendix 1. Further, we have selected seven locations, each of which has vertical temperature structure and cycles characteristic of a part of the route. For each of these, Figure 3a-g shows the seasonally varying mean temperature for eight depths from the surface to 500 m, and Figure 4a-g shows the mean monthly vertical profiles of temperature for the warming and cooling periods.

Annual Cycles

At the surface the annual period is predominant at all locations (Fig. 3a-g). The annual range was smallest (about 4°C) near Oahu, largest (about 7°C) in the Transition Zone, and again smaller near the California coast (about 5°C). From near Oahu to the California front, the cycles at 50 m diminished in amplitude and the summer maximum lagged that at the surface by 1 to 2 mo. At the low salinity core of the California Current (Fig. 3f) the summer maximum penetrated almost simultaneously from the surface to 200 m. In the inshore area, California Current (Fig. 3g), the temperature range at 50 m was small (about 1°C). Here the minimum and the maximum temperatures lagged those at the surface by about 4 mo, and appear to be related to the occurrence of upwelling and the subsurface countercurrent, respectively.

Mixed Layers and Thermoclines

The surface mixed layers reach their maximum depth in winter, mid-February through early April, Appendix 1. Depths of the mixed layers were generally at least 100 m, except they decreased to 75 m near California. They were deepest, about 150 m, in the central part of the section (2,000 to 2,200 km) in the neighborhood of the subtropical front.

We consider the permanent thermocline to be the region of the maximum vertical temperature gradient in winter (January through March); vertical sections of Appendix 1 and profiles of Figure 4. In the western half of the section it was deeper (200 to 250 m) and warmer (15° to 17°C) than in the California Current region where it lay at depths of 100 to 120 m and had temperatures of 11° to 13°C. The seasonal thermoclines are formed by warming in spring and summer (May through September) and are generally confined to the upper 50 to 100 m which are vertically mixed in winter. In the California Current region the seasonal thermocline merged with the permanent thermocline into a single feature, whereas in the Transition Zone the two thermoclines were separated in the spring by temperature inversions (next section) and later by a near thermostad (vertically isothermal) layer, Figure 4d. The latter was particularly evident in the summer (July through August) sections by the steeper slope of the 15°-19°C isotherms at depths from 50 to 150 m at distances of 2,000 to 3,000 km from Honolulu. In the Eastern North Pacific Central waters from Honolulu to near 1,800 to 2,000 km along the route, a layer of weak vertical temperature gradient occurred between the seasonal and permanent thermoclines.

Temperature Inversions

A characteristic feature found by Saur (1974) in the individual profiles in the Transition Zone (between 2,000 and 3,000 km from Honolulu) was the occurrence of complex vertical thermal structure, especially in the spring months. The thermocline would often be interrupted by isothermal layers and temperature inversions appeared in some profiles. These were attributed to interleaving, by horizontal mixing, of layers of cool, low-salinity water with warmer, higher salinity water of nearly the same density. These features usually are relatively small scale and transient, so that during our computation of means, they were generally smoothed out. However, some

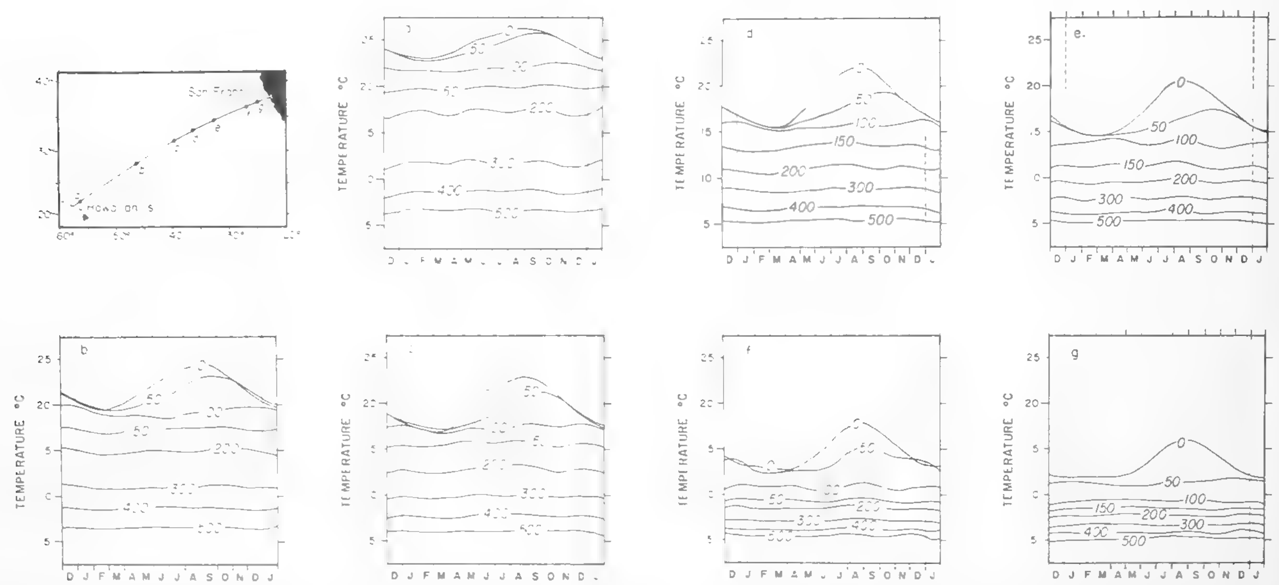

Figure 3.—Station position chart and mean temperature cycles at selected depths (meters) for seven typical locations, great circle distances from offshore reference point (lat. 21°12'N, long. 157°42'W) near Honolulu, and geographic coordinates: a. Near Oahu: 185 km (100 n.mi.); lat. 22°10'N, long. 156°15'W. b. Eastern North Pacific Central Water: 1,390 km (750 n.mi.); lat. 28°17'N, long. 146°20'W. c. Subtropical front: 2,130 km (1,150 n.mi.); lat. 31°39'N, long. 139°42'W. d. Transition Zone: 2,500 km (1,350 n.mi); lat. 33°12'N, long. 136°12'W. e. California front: 2,870 km (1,550 n.mi.); lat. 34°39'N, long. 132°35'W. f. Low salinity core, California Current: 3,430 km (1,850 n.mi.); lat. 36°36'N, long. 126°55'W. g. Inshore region, California Current: 3,615 km (1,950 n.mi.); lat. 37°12'N, long. 124°59'W.

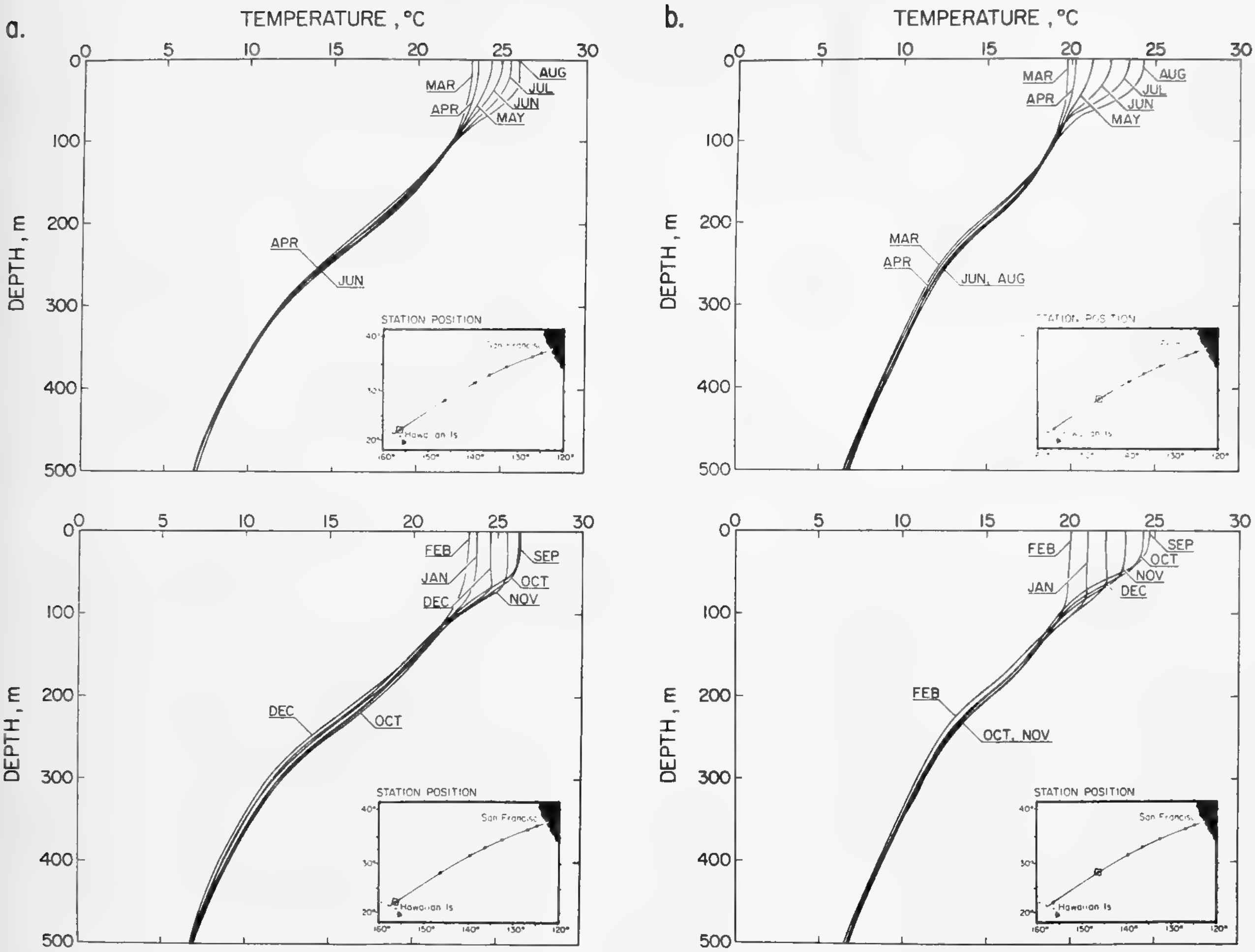

Figure 4.—Monthly profiles of mean temperature (°C), for warming and cooling periods at seven typical locations (shown by diamond on inset chart); distance from offshore reference point near Honolulu and geographic coordinates as in Figure 3. a. Near Oahu. b. Eastern North Pacific Central Water. c. Subtropical front. d. Transition Zone. e. California front. f. Low-salinity core of the California Current. g. Inshore region of California Current.

temperature inversions remained in the vertical sections of Appendix 1, e.g., the 15°C isotherm in the 01 April section, the 15°-17°C isotherms in the mid-April section, the 16°-17°C isotherms in the 01 May section, and the 16°C isotherm in the mid-May section. It appears that, on the average, when surface warming begins in the spring and vertical mixing is suppressed, the warmer, higher salinity Eastern North Pacific Central waters spread toward the California coast around 100 m, underrunning the low-salinity, modified subarctic waters which are still cool around 50 m.

In winter months, e.g., mid-January section of Appendix 1, there appeared to be a temperature maximum at the base of the mixed layer between 1,200 and 3,000 km along the section. From an examination of individual profiles it was found that these were not typical of usual conditions. There was almost always an isothermal layer to the top of the thermocline. The apparent maximum resulted from the tendency of the three harmonics to give near-surface temperatures for this area in winter which were slightly low, 0.1° to 0.2°C. The weak horizontal temperature gradients and vertical exaggeration of the section, amplified the effect in the computer contoured sections.

Structure Below the Permanent Thermocline

Below the permanent thermocline, the slopes of the isotherms can be used to separate the section into two regions. The 10°C isotherm is typical. In the western part of the section from Honolulu to about 1,800 km it generally changed depth by less than 50 m, i.e., the slope was less than 3 m/100 km. In the eastern part of the section, from a point at 2,200 km on the section to near San Francisco (3,800 km) the depth of the 10°C isotherm decreased by 150 to 200 m, or a slope of greater than 9 m/100 km. The smaller slopes are associated with the Eastern North Pacific Central waters, while the steeper slopes were associated with both the California Current and Transition Zone regions.

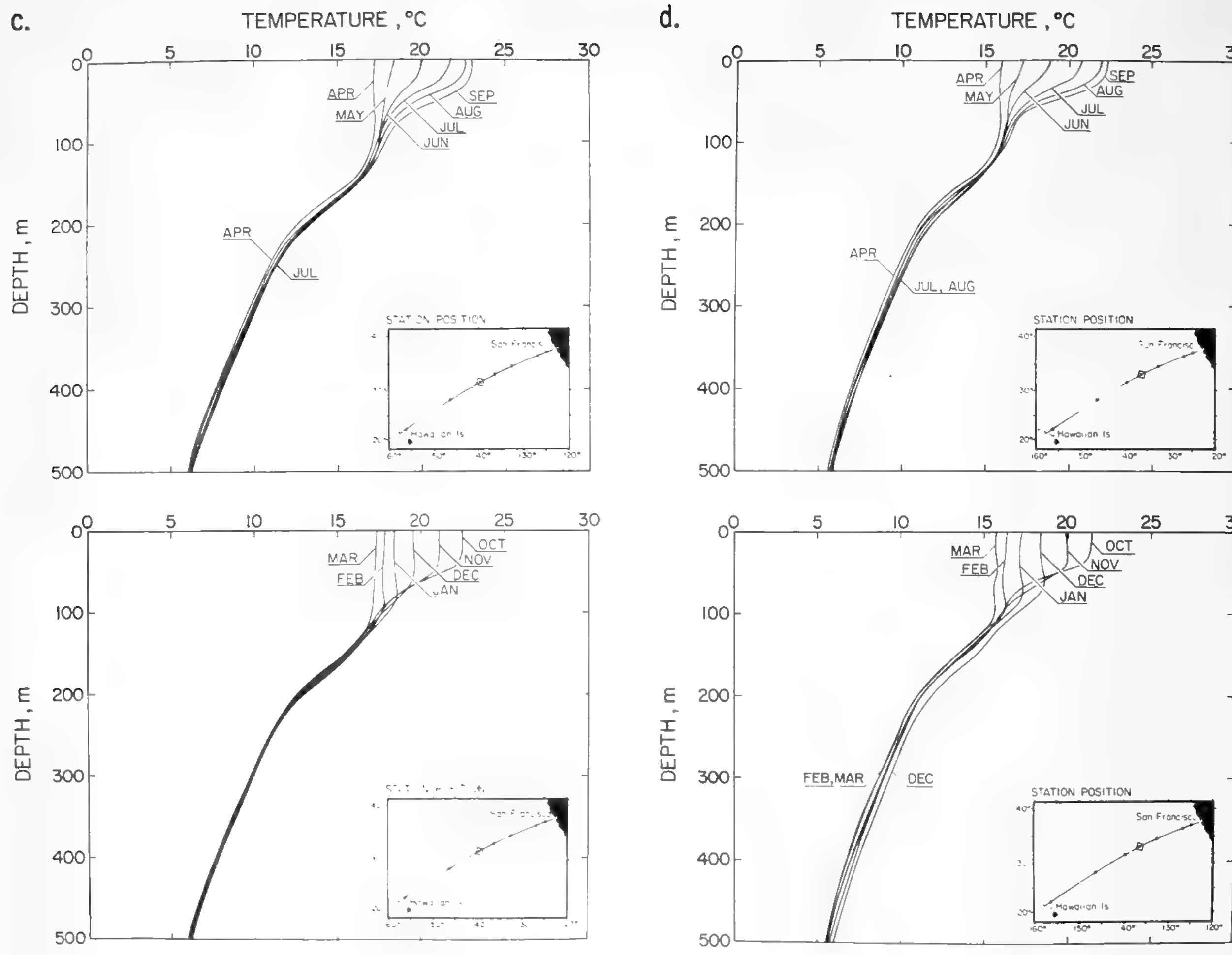

Figure 4.—Continued.

Coastal Upwelling

Reid et al. (1958) have described upwelling and the subsurface countercurrent along the California coast from repeated detailed oceanographic observations by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program. Some effects of upwelling also appear in XBT mean temperatures, although sampling was poor at the California end of the route. In January, Appendix 1, the 9°C isotherm was closest to the surface (about 130 m) some 200 km from the California coast, but bent downward to 150 m at the coast. About late March the 9°C isotherm began to rise and reached a depth of about 120 m at the coast by mid-June, so that it then had nearly a uniform upward trend approaching the coast. Starting in September it began to sink again at the coast and the "ridge" in the isotherm again moved gradually offshore and by mid-November had returned to the position 200 km offshore where it was in January.

Coastal upwelling causes a delay in the onset of summer warming and a reduced range of the seasonally varying mean temperature. In the inshore area of the California Current (Fig. 3g), after a nearly constant winter temperature of about 12°C, summer warming at the surface did not begin until late May or early June, as compared with April or May farther offshore (Fig. 3e, f). Also, in the inshore area the September temperature maximum reached only 16°C, for an annual range of only 4°C, whereas farther offshore (Fig. 3f) it reached 17.5°C for an annual range exceeding 5°C.

California Subsurface Countercurrent

In the vertical sections of Appendix 1 the downwarping of the 6°, 7°, and 8°C isotherms from 200 km at sea to the California coast shows warmer water against the coast (at depths of 200 to 500 m) than offshore. This agrees with observations of Reid et al. (1958) who reported the existence of a narrow northward moving undercurrent against the California coast and below 200 m. An exception occurred during April and May when the 8°C isotherm rose to about 200 m at the coast. This indicates that upwelling normally reached to that depth during these months. Another exception was the nearly level approach to the coast of the 8°C isotherm from mid-August to mid-September. This may reflect a brief late-summer upwelling period, but might just be the result of inadequate sampling immediately adjacent to the coast.

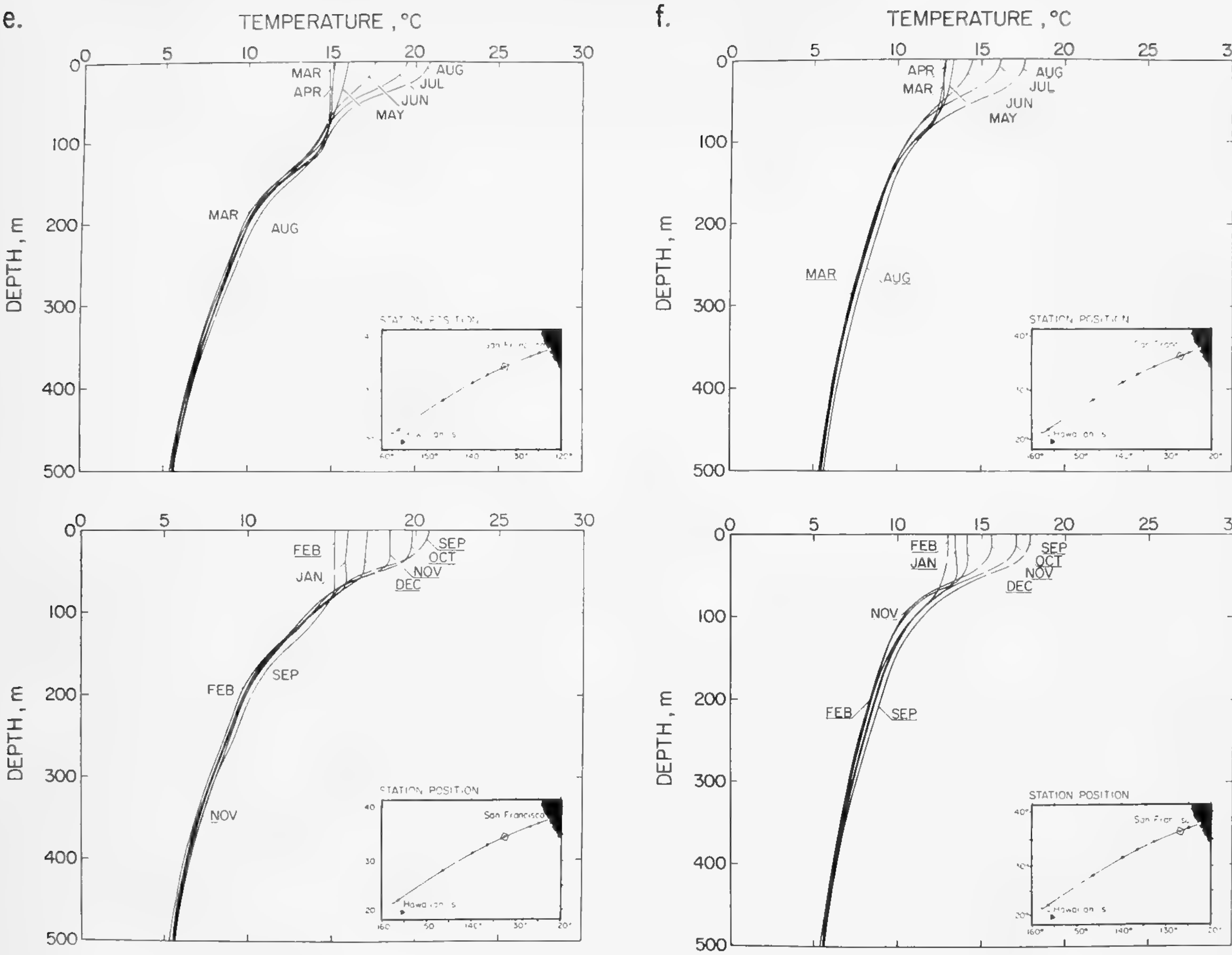

Figure 4.—Continued.

The 30-Day Temperature Changes

The lower panels of the figures in Appendix 1 show contours of temperature change in the upper 200 m during 30-day periods (of a 360-day yr). The maximum rate of warming was 2°C/mo in June at the surface near 2,600 km, which is in the Transition Zone. The maximum rate of cooling was just over 1.5°C/mo during November and December in the same area. The rate of cooling was smaller because the cooling takes place over a depth of at least 50 m whereas the warming is confined to a shallower layer of about 25 m. There was very little temperature change at any depth throughout the section from mid-March to mid-April, but there was no corresponding period in the fall.

In the fall period the downward mixing of heat into the upper thermocline as the surface cools is evident over most of the route in the temperature changes (Appendix 1) and in the vertical profiles (Fig. 4a-g). Beginning in August a subsurface maximum of warming appeared just above 50 m throughout most of the section. The level of maximum warming moved downward during the fall reaching 100 m in December. During this time the surface was cooling and a strong gradient of temperature change developed between the surface cooling and the subsurface warming. The maximum subsurface warming decreased as its depth increased with time, and subsurface warming essentially disappeared by February.

The patterns of temperature change in the California Current region differ from those over most of the section. For example, from September through November and at distances of 3,200 to 3,400 km along the route, cooling extended downward from the surface to 200 m, at least. This created a break in the pattern of the warming maximum at 50 m, which existed over the rest of the section. A secondary center of cooling below 100 m occurred at 2,700 to 2,900 km on the route. These changes were associated with the development of a wave pattern in the isotherms along the permanent thermocline. The centers of cooling were associated with a steepening of the slope of the isotherms in the corresponding vertical sections, whereas in between these centers the isotherms flatten out. The steepening and flattening indicate a splitting of the broad flow of the California Current into filaments of stronger and weaker flow, respectively. The cooling pattern propagated westward along the section at a speed of about 100 km/mo (3.8 cm/s).

There was a counterpart center of warming which appeared in mid-December in the California Current region (around 3,400 km and 90 m) and which could be followed g.

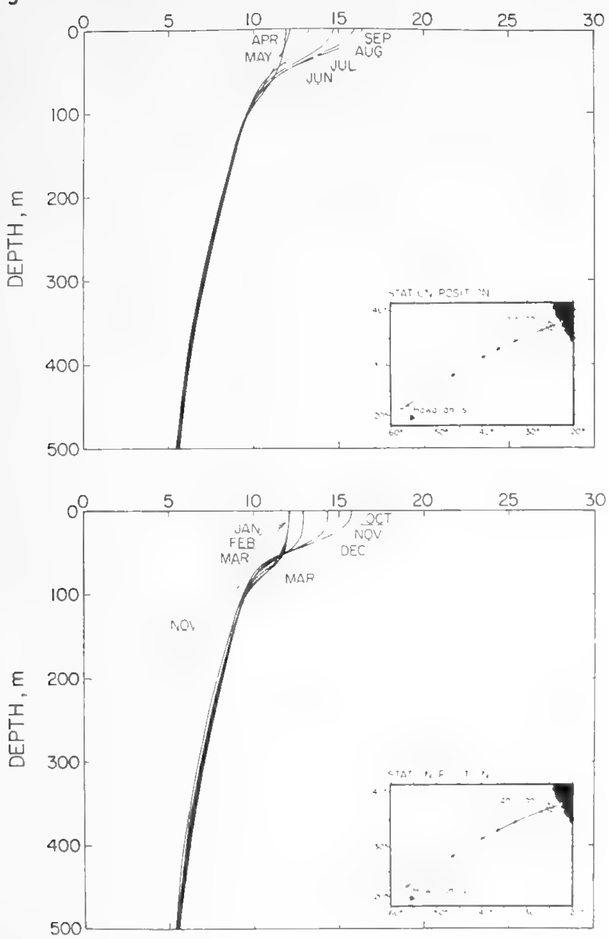

Figure 4.—Continued.

through early April propagating westward, also at the rate of 100 km/mo. This warming, however, was associated with the disappearance of the previously mentioned wave pattern along the thermocline.

From considerations of heat balance we may infer from the patterns of temperature changes that over most of the section vertical mixing dominates in transmitting the surface warming-cooling cycle downward to subsurface levels of 100 to 150 m. In contrast, horizontal advection of heat may be dominant in the California Current to depths of 200 to 300 m. The cause of the growth and decay of the wave pattern on the thermocline in the eastern part of the sections should be investigated.

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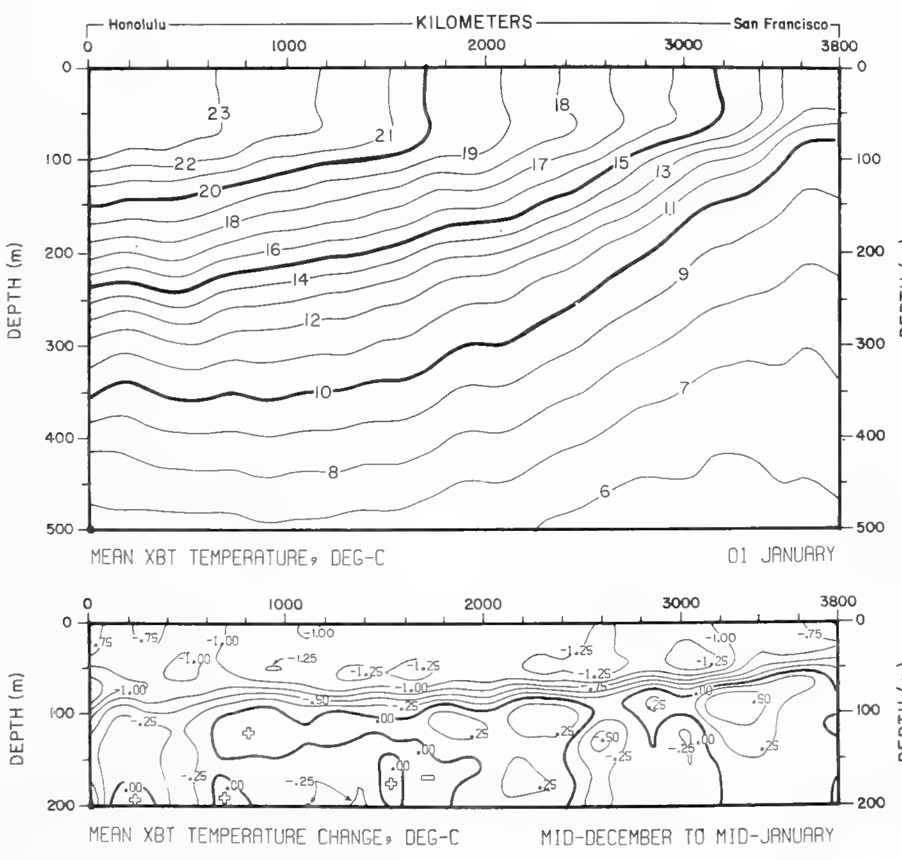
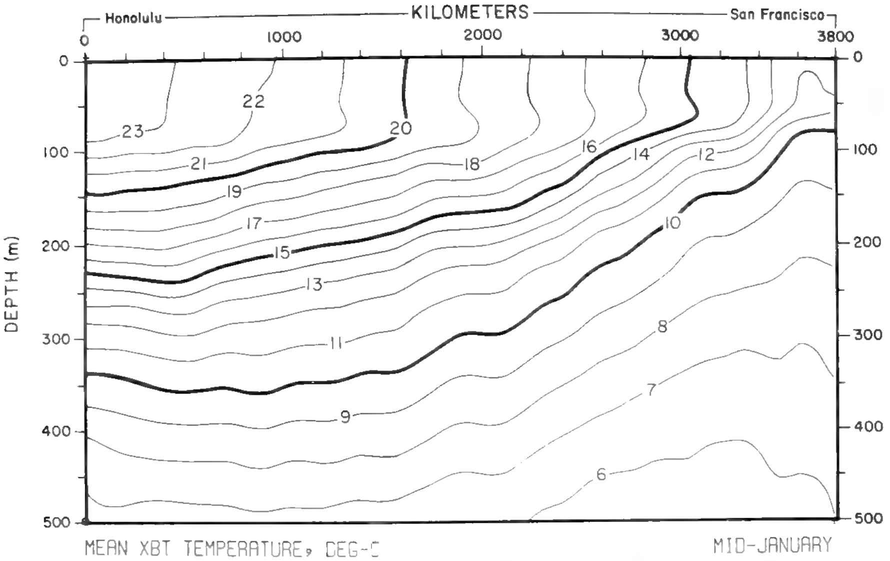
APPENDIX 1

Vertical Sections of Mean Temperature and Mean "30-day" Temperature Change

This Appendix contains 24 vertical sections of mean temperature (°C), from the surface to 500 m, between San Francisco and Honolulu (upper panel) and spaced at 15-day intervals of a 360-day yr. The lower panel is a vertical section to 200 m showing the 30-day changes in temperature and centered on the date of the temperature section above it. For convenience the sections are labeled as: 01 January, mid-January, 01 February, etc., through mid-December.

The grids of mean temperature were spatially smoothed, as explained in the text, before being contoured.





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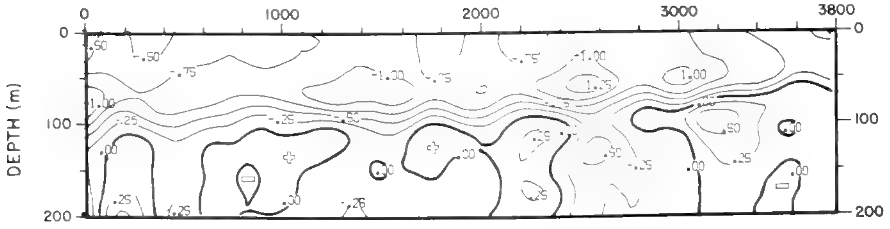

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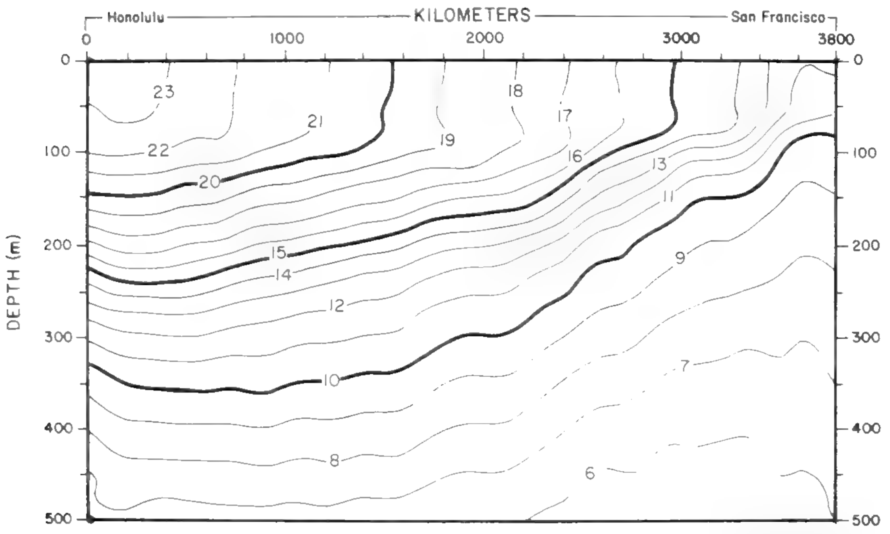

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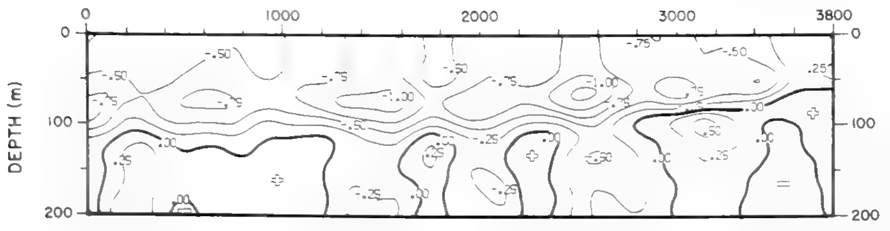

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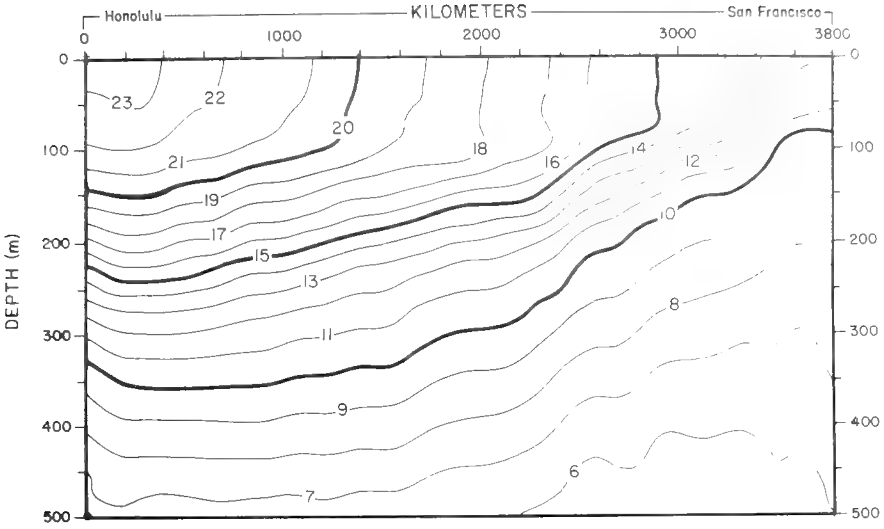

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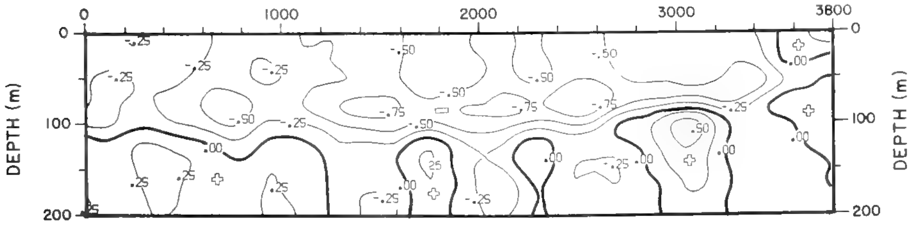

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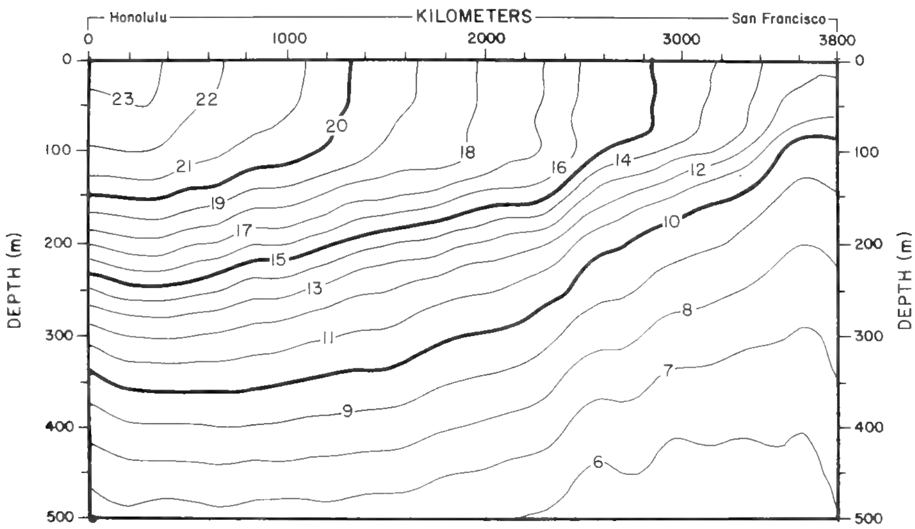

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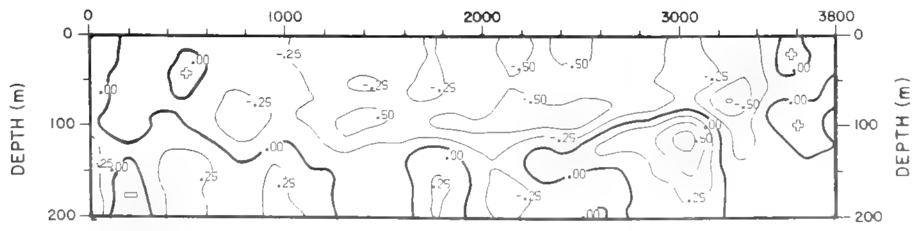

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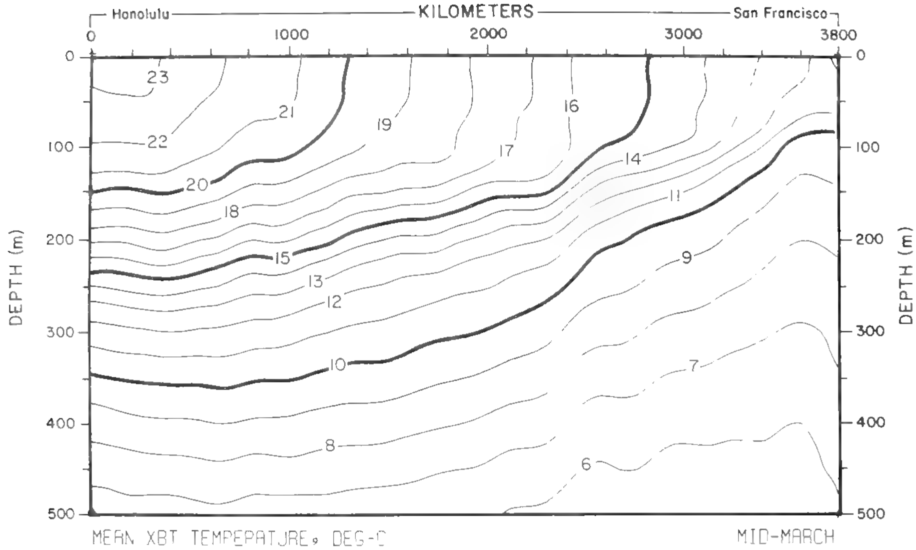
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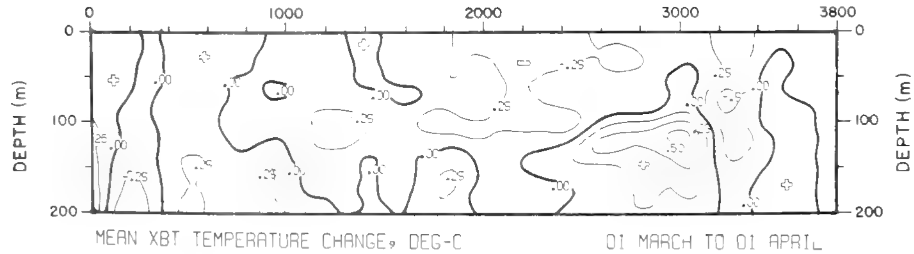
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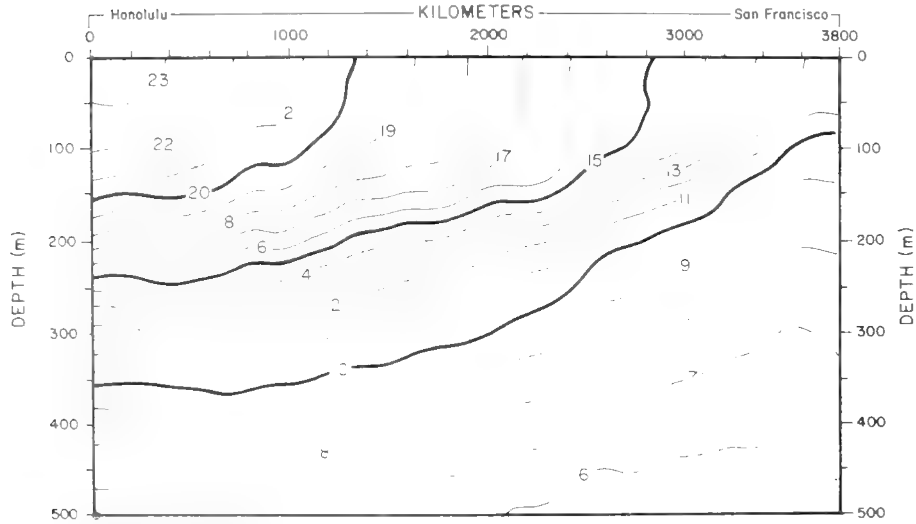
01 MARCH TO 01 APRIL


Honolulu
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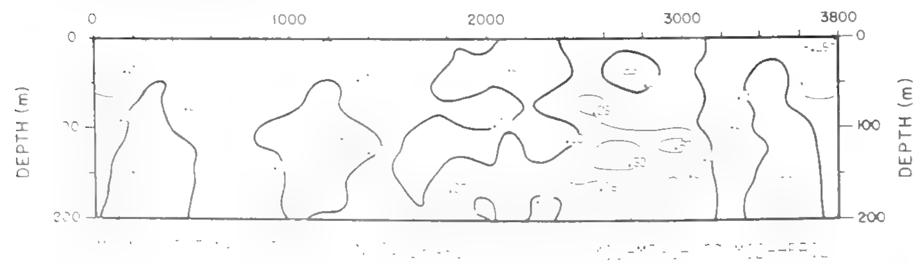
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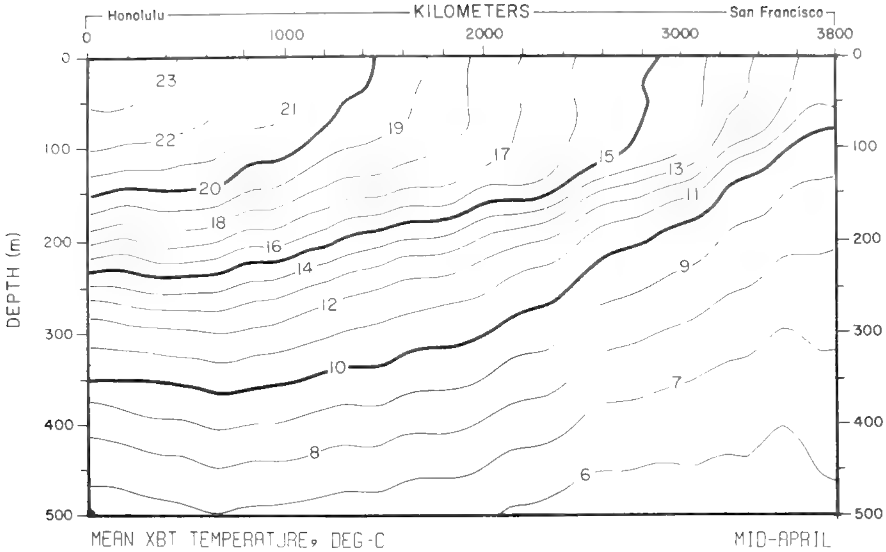
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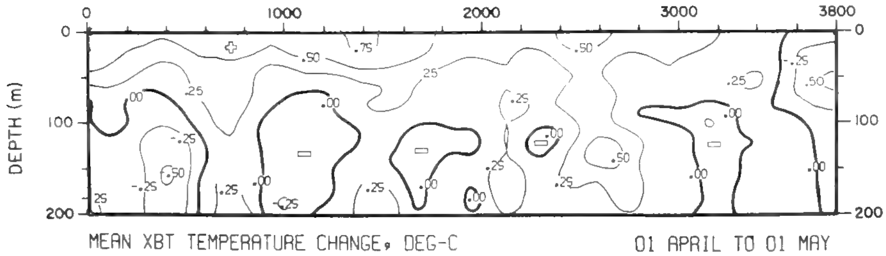
MID-APRIL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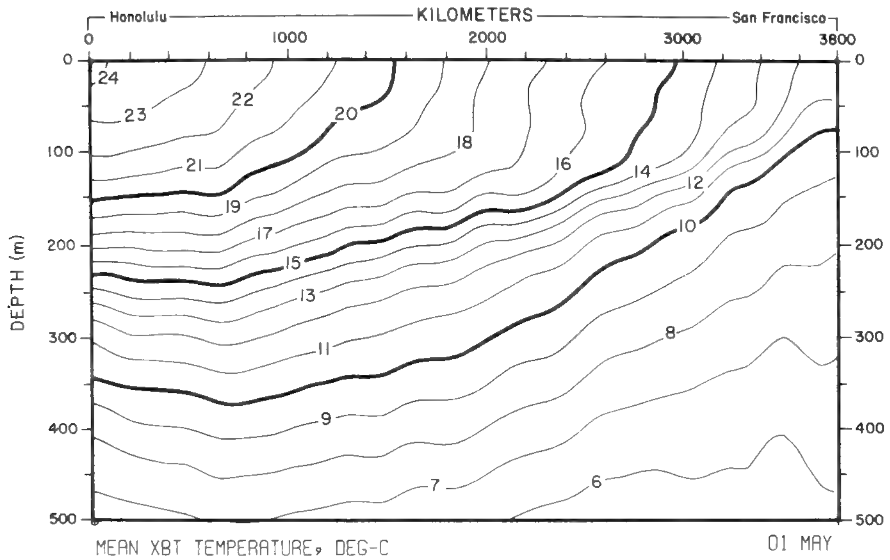
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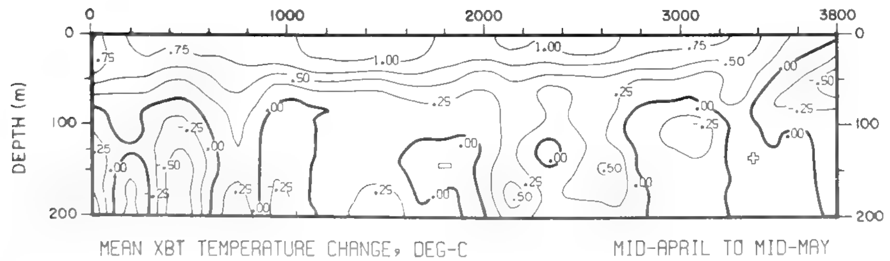
01 MAY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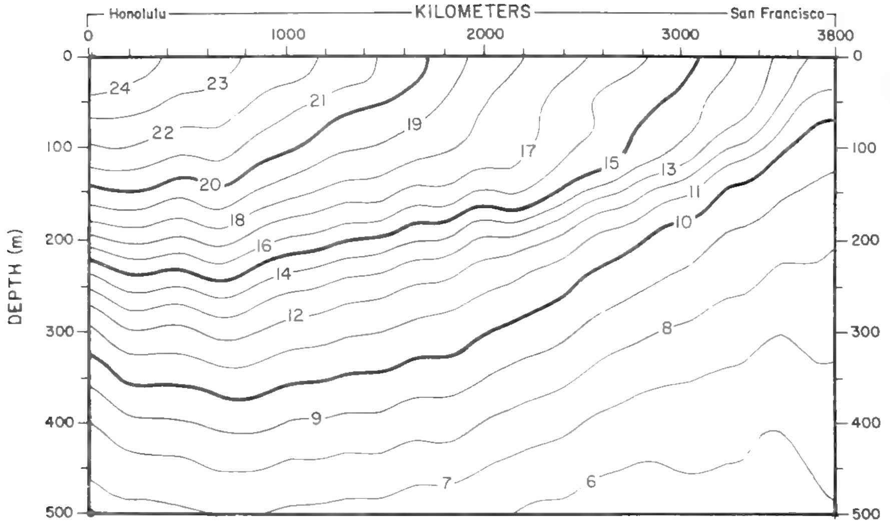

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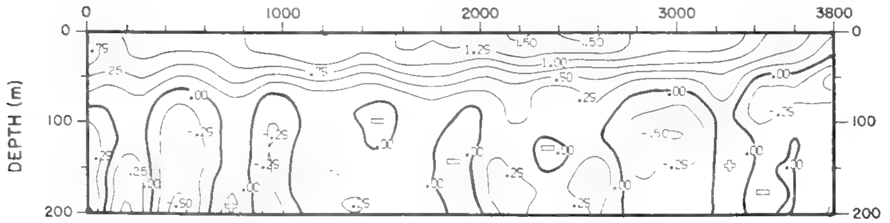

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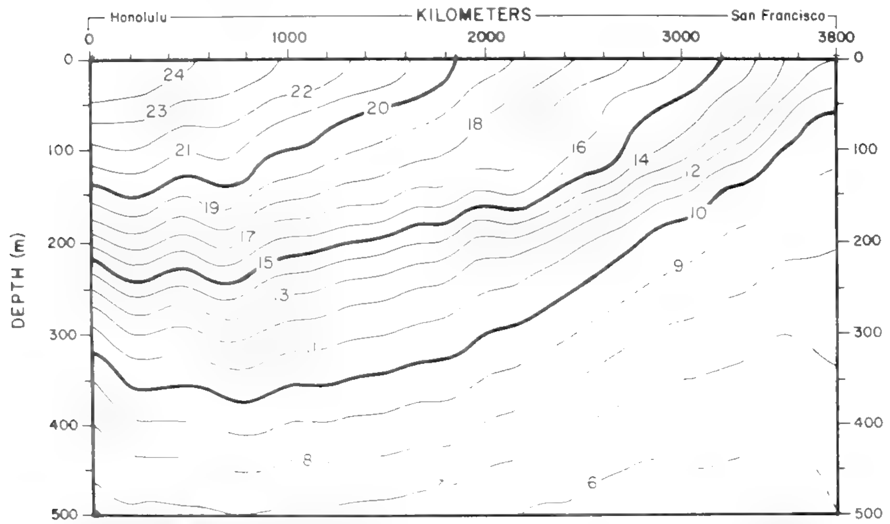

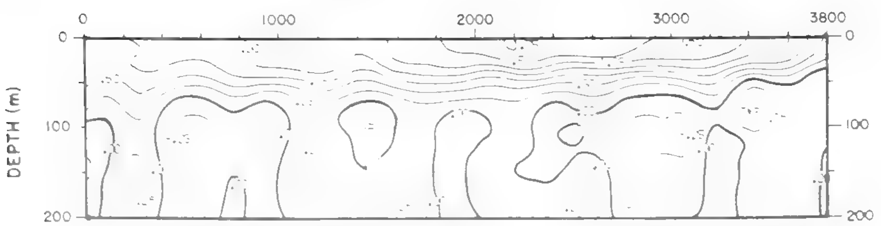

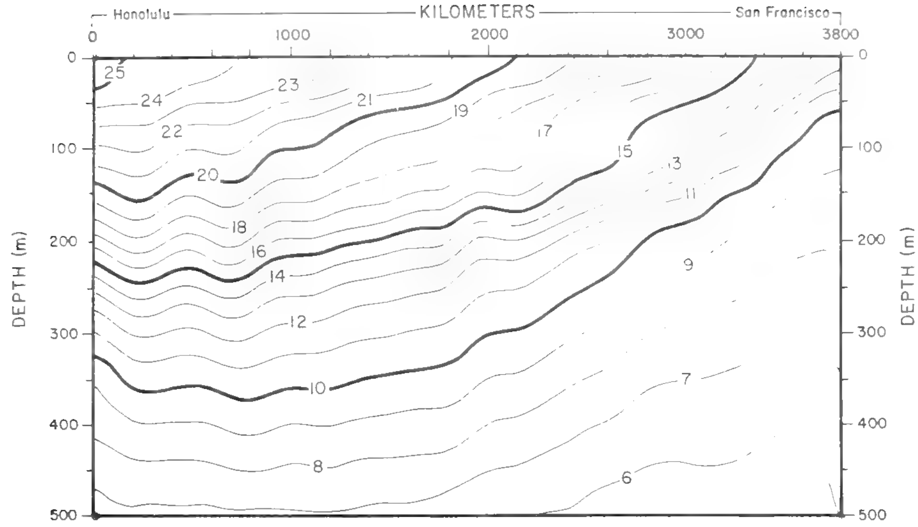

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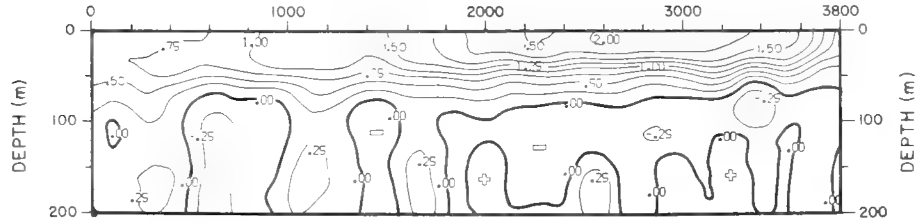

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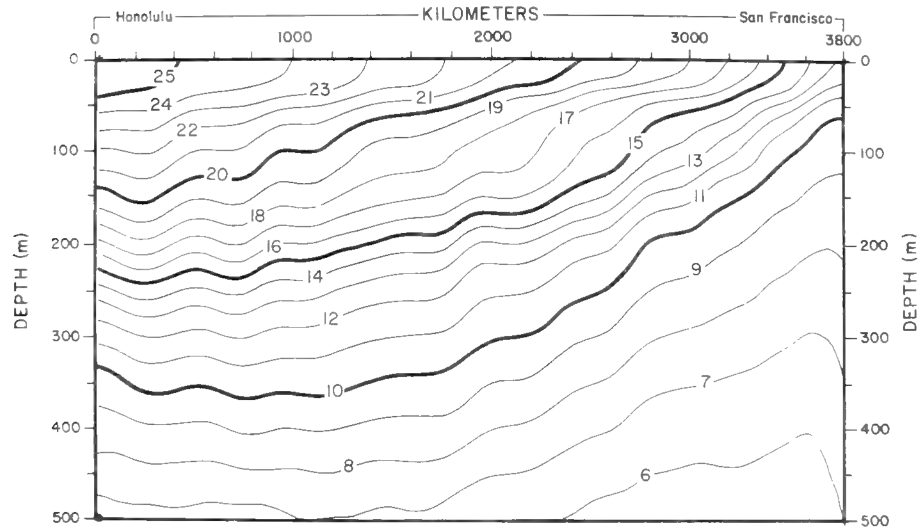

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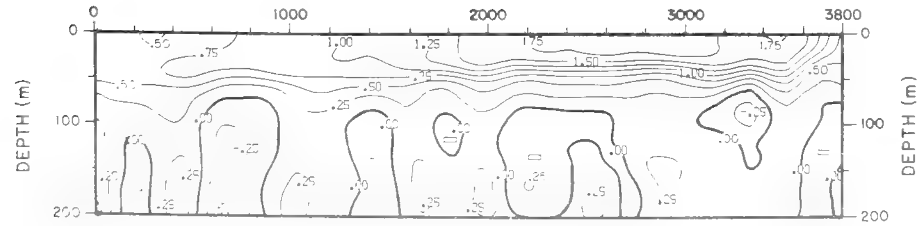

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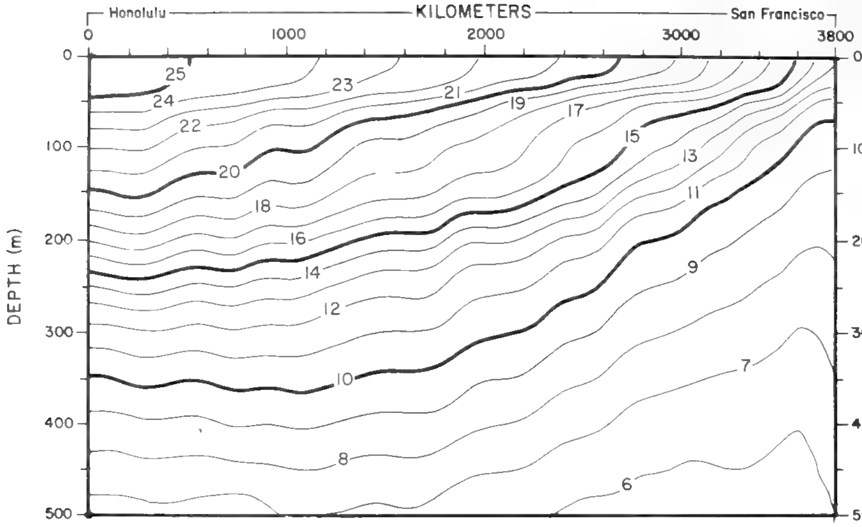

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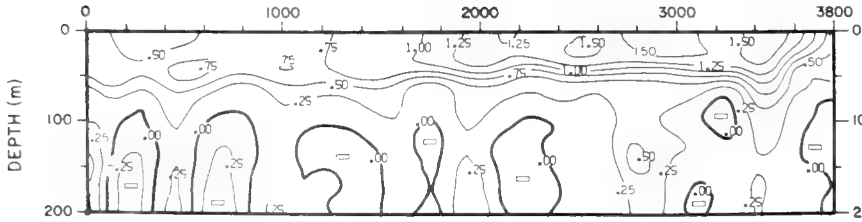
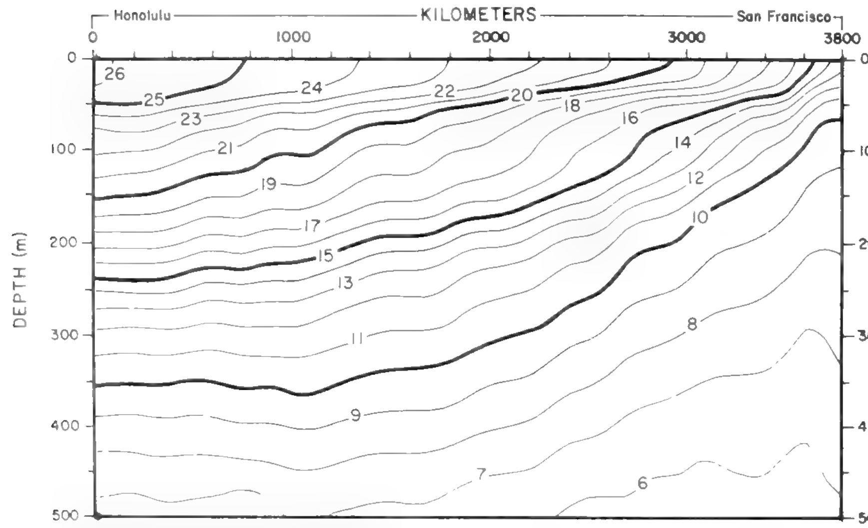
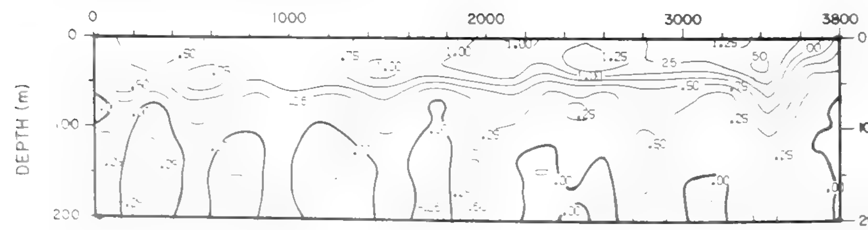


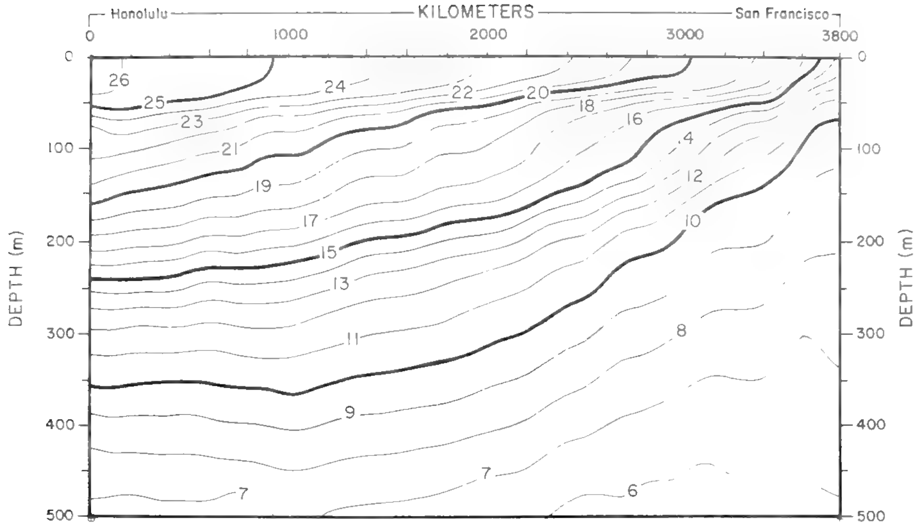
MEAN XBT TEMPERATURE CHANGE, DEG-C 01 JULY TO 01 AUGUST



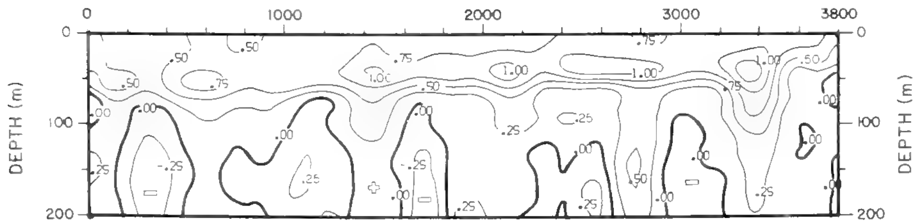
MEAN XBT TEMPERATURE, DEG-C 01 AUGUST



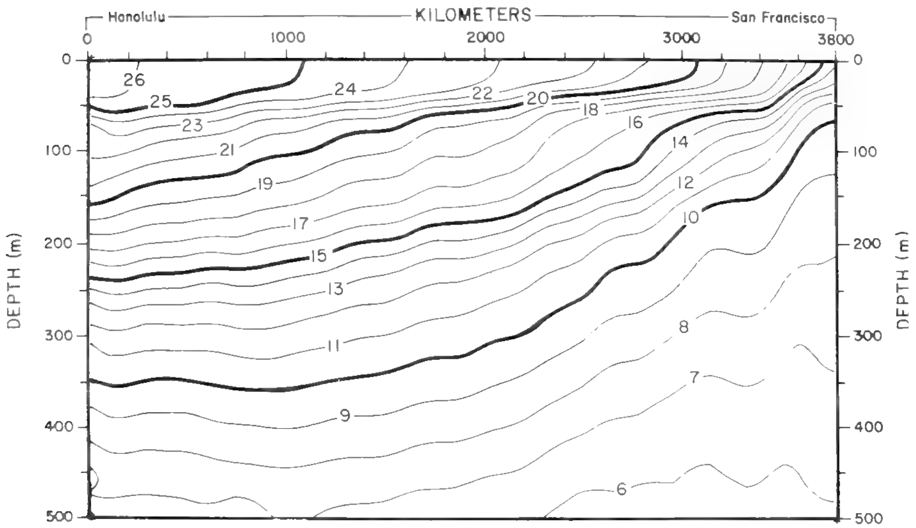
MEAN XBT TEMPERATURE CHANGE, DEG-C MID-JULY TO MID-AUGUST



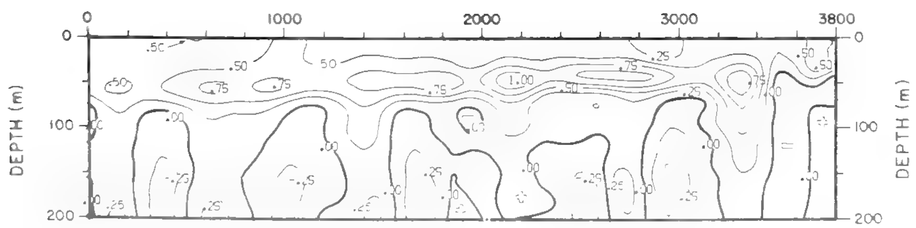
MEAN XBT TEMPERATURE, DEG-C MID-AUGUST



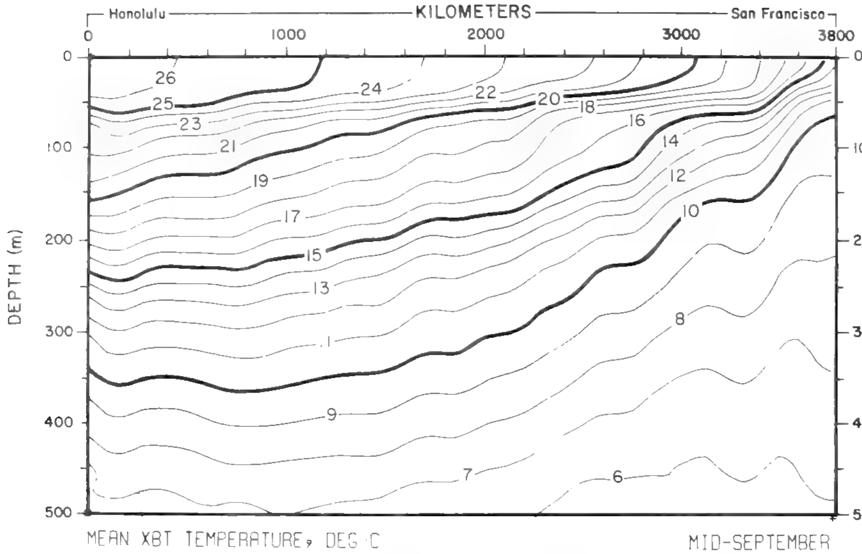
MEAN XBT TEMPERATURE CHANGE, DEG-C 01 AUGUST TO 01 SEPTEMBER

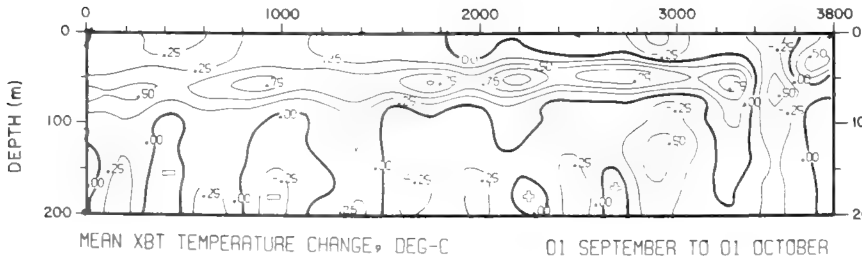


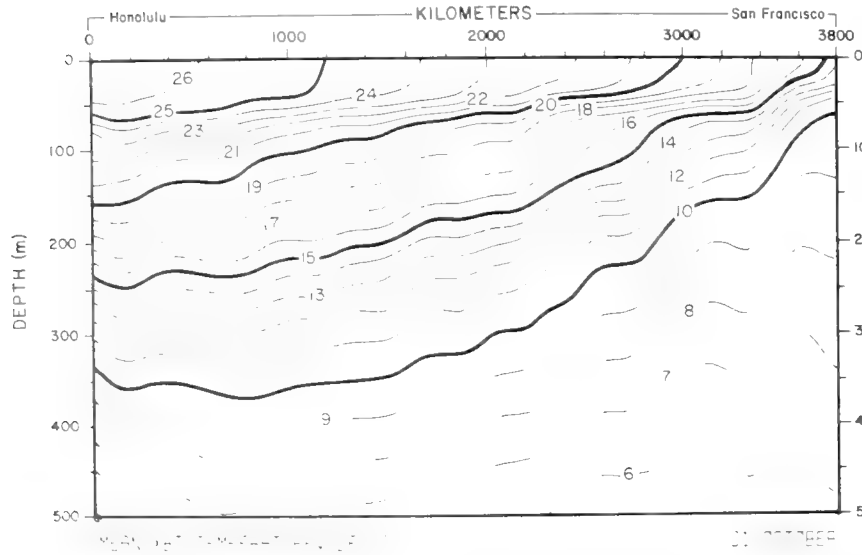
MEAN XBT TEMPERATURE, DEG-C 01 SEPTEMBER

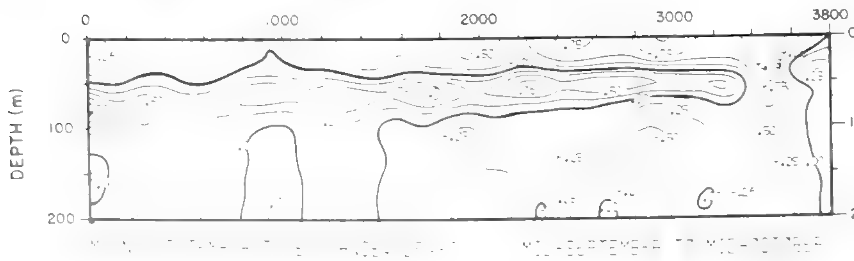


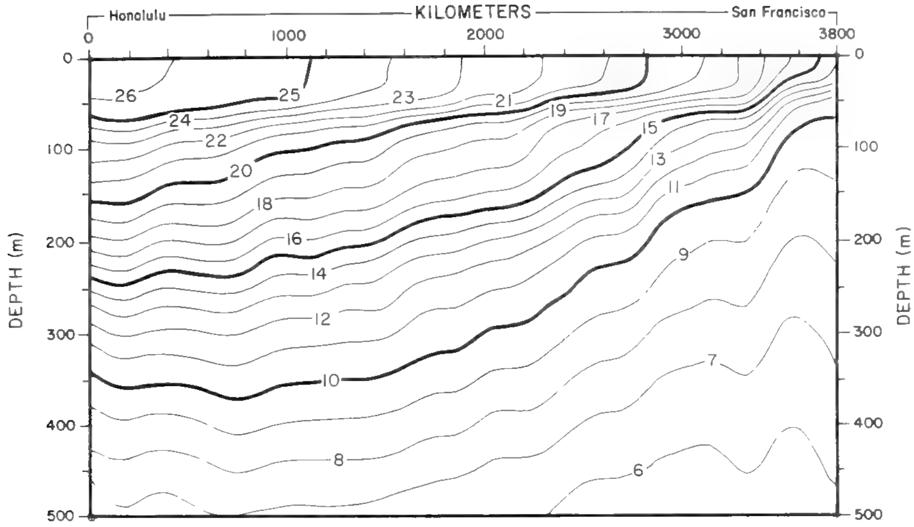
MEAN XBT TEMPERATURE CHANGE, DEG-C MID-AUGUST TO MID-SEPTEMBER


Honolulu
KILOMETERS
San Francisco
0
1000
2000
3000
3800
DEPTH (m)
MEAN XBT TEMPERATURE, DEG C
MID-SEPTEMBER

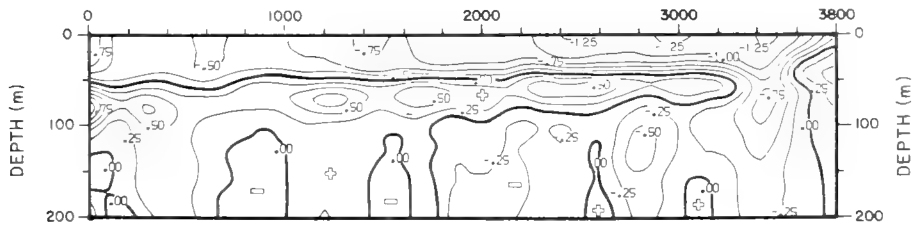

DEPTH (m)
MEAN XBT TEMPERATURE CHANGE, DEG-C
01 SEPTEMBER TO 01 OCTOBER


Honolulu
KILOMETERS
San Francisco
0
1000
2000
3000
3800
DEPTH (m)

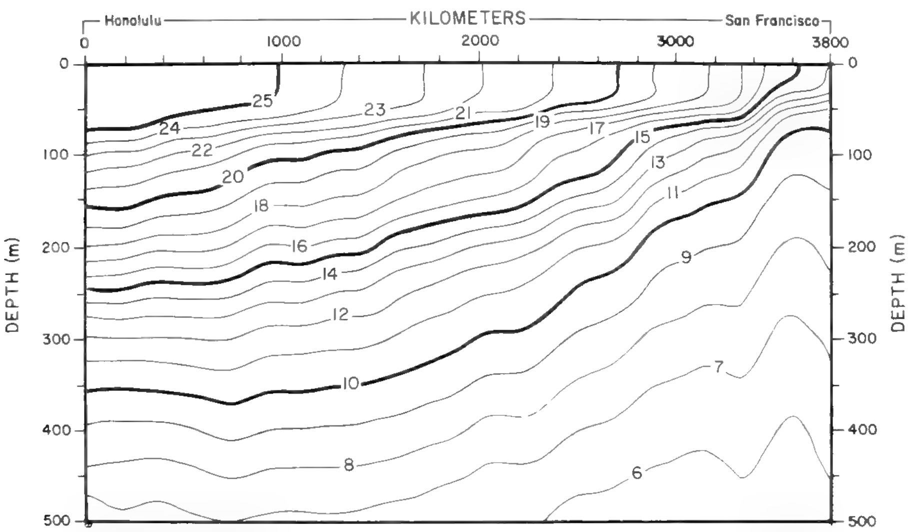

DEPTH (m)



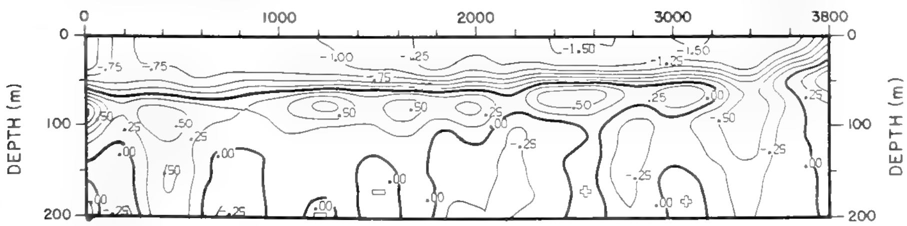
MEAN XBT TEMPERATURE, DEG C MID-OCTOBER



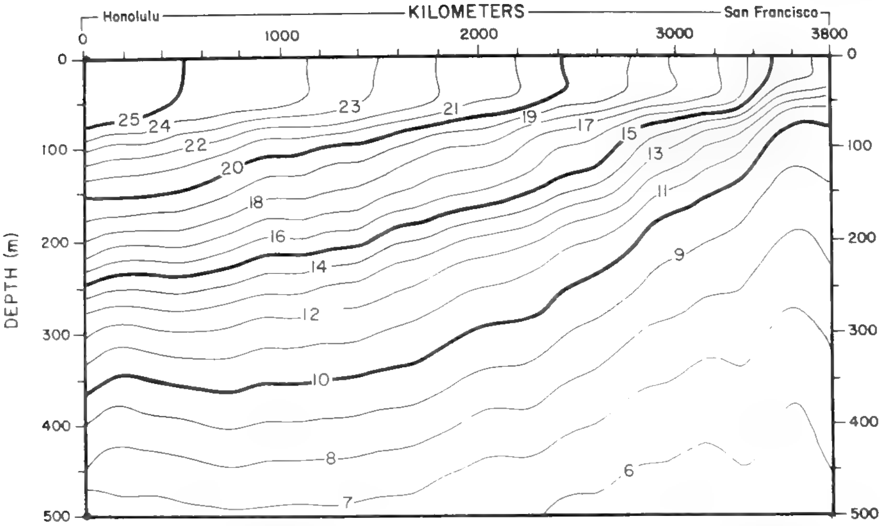
MEAN XBT TEMPERATURE CHANGE, DEG-C 01 OCTOBER TO 01 NOVEMBER



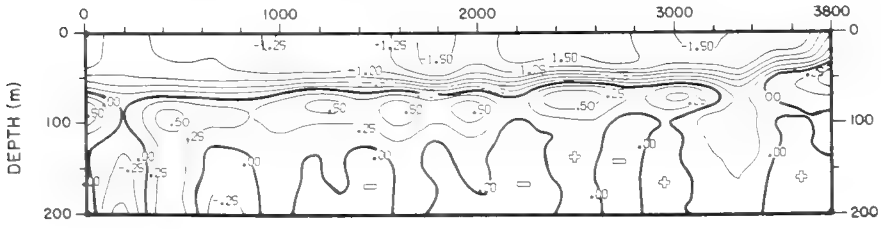
MEAN XBT TEMPERATURE, DEG-C 01 NOVEMBER



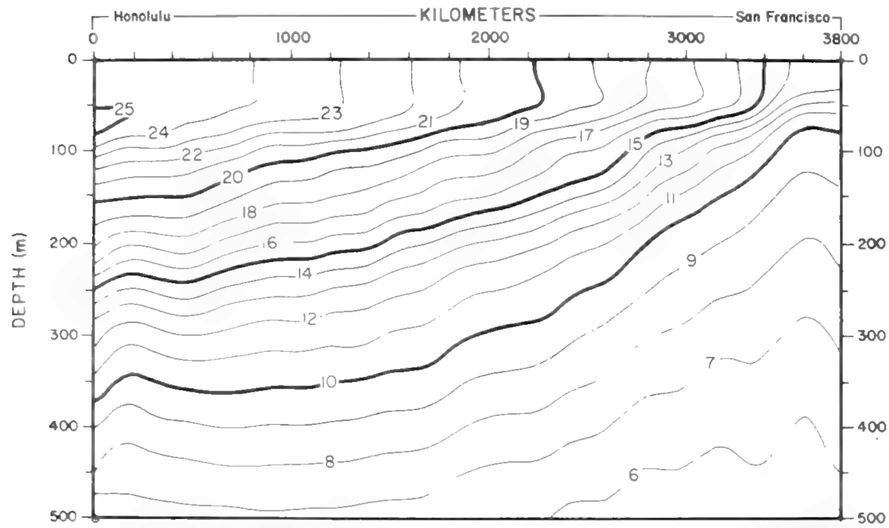
MEAN XBT TEMPERATURE CHANGE, DEG-C MID-OCTOBER TO MID-NOVEMBER



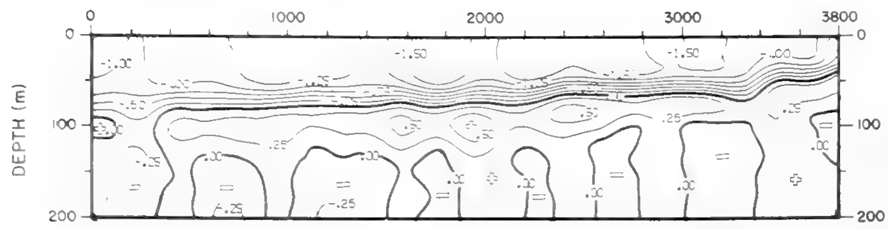
MEAN XBT TEMPERATURE, DEG-C MID-NOVEMBER



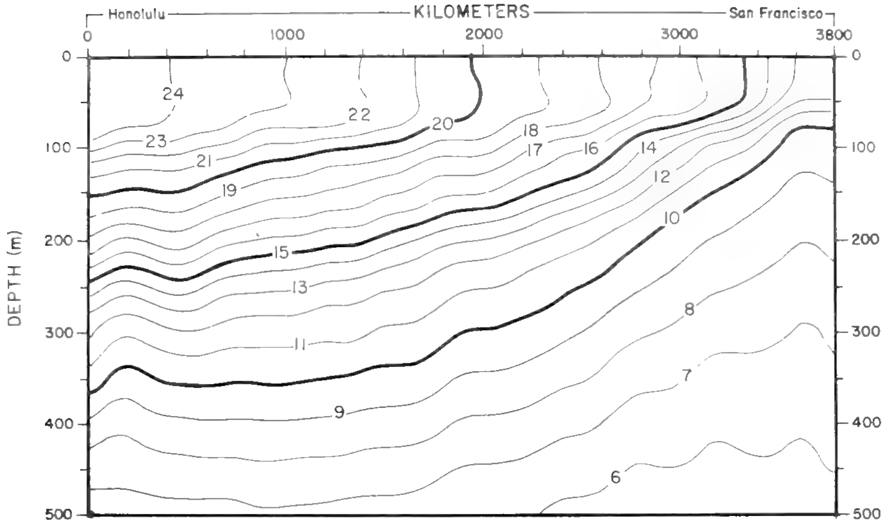
MEAN XBT TEMPERATURE CHANGE, DEG-C 01 NOVEMBER TO 01 DECEMBER



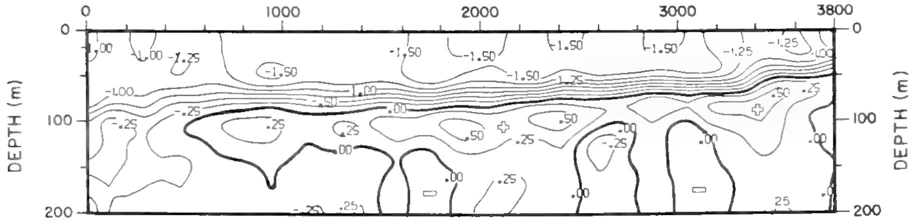
MEAN XBT TEMPERATURE, DEG-C 01 DECEMBER



MEAN XBT TEMPERATURE CHANGE, DEG-C MID-NOVEMBER TO MID-DECEMBER



MEAN XBT TEMPERATURE, DEG-C MID-DECEMBER



MEAN XBT TEMPERATURE CHANGE, DEG-C 01 DECEMBER TO 01 JANUARY

APPENDIX 2

Tables of Mean XBT Temperature

This Appendix contains 24 tables of mean temperatures (°C) spaced at equal intervals throughout the year, corresponding to the temperature sections of Appendix 1. Each table contains, at alternating grid points, i.e., intervals of 185 km (100 n.mi.) on the San Francisco-Honolulu route, the mean temperature for selected depths, in meters. The mean temperatures are those computed from the fitted three-component harmonic function for the given distance and depth. These temperatures were abstracted from the complete grid, without smoothing.

MEAN XBT TEMPERATURE, DEG-C 01 JANUARY

DEPTH (M)																				
0	23.9	23.9	23.2	23.0	22.6	22.3	21.8	21.4	20.9	19.8	19.3	18.9	18.2	17.7	16.7	16.4	15.5	14.9	13.7	12.3
10	23.9	23.8	23.2	23.0	22.6	22.3	21.8	21.4	20.8	19.8	19.3	18.9	18.2	17.6	16.7	16.3	15.5	14.9	13.8	12.3
20	23.9	23.8	23.2	23.1	22.5	22.3	21.8	21.4	20.8	19.7	19.3	18.9	18.2	17.6	16.7	16.3	15.5	15.0	13.8	12.2
30	23.9	23.8	23.2	23.1	22.5	22.3	21.8	21.4	20.8	19.7	19.3	18.9	18.1	17.6	16.8	16.2	15.5	15.0	13.8	12.2
40	23.9	23.8	23.2	23.1	22.5	22.2	21.8	21.3	20.8	19.7	19.3	18.9	18.1	17.7	16.9	16.1	15.6	15.0	13.9	12.1
50	24.0	23.8	23.2	23.1	22.5	22.2	21.8	21.4	20.9	19.7	19.3	19.0	18.3	17.8	17.0	16.3	15.7	15.0	13.9	11.9
60	24.0	23.7	23.2	23.1	22.5	22.2	21.9	21.4	20.9	19.8	19.4	19.0	18.4	17.9	17.1	16.2	15.7	14.8	13.5	11.4
70	24.0	23.7	23.2	23.1	22.4	22.1	21.9	21.4	21.0	19.8	19.5	18.9	18.3	17.8	16.8	15.7	15.4	14.5	12.8	10.6
80	23.8	23.4	23.1	22.9	22.1	21.8	21.6	21.1	20.7	19.6	19.4	18.8	18.0	17.5	16.4	15.4	14.4	13.7	11.9	10.0
90	23.3	22.9	22.8	22.5	21.6	21.4	21.0	20.7	20.2	19.2	19.2	18.4	17.6	17.0	15.7	14.5	13.3	12.7	11.3	9.7
100	22.8	22.4	22.3	22.0	21.1	20.8	20.3	20.1	19.7	18.8	18.8	17.9	17.2	16.4	15.0	13.9	12.6	12.0	11.0	9.5
120	21.5	21.1	21.1	20.6	20.1	19.7	19.1	18.9	18.6	17.5	17.9	17.1	16.2	15.3	14.2	13.0	11.7	11.0	10.1	9.1
150	20.0	19.6	19.7	19.2	18.6	18.2	17.7	17.4	17.0	16.2	16.2	15.8	14.7	13.9	12.8	11.6	10.4	9.9	9.4	8.8
200	17.2	17.2	17.4	16.5	16.1	15.8	15.2	15.0	14.5	13.4	13.2	12.9	12.0	11.3	10.5	9.9	9.2	9.0	8.6	8.1
250	13.9	14.1	14.7	13.6	13.4	13.2	12.7	12.5	12.3	11.6	11.1	11.0	10.4	10.0	9.4	9.0	8.4	8.1	7.9	7.5
300	11.4	11.5	11.9	11.6	11.6	11.5	11.2	11.1	10.9	10.5	9.9	9.9	9.4	9.0	8.4	8.0	7.6	7.4	7.2	7.0
400	8.4	8.6	8.8	8.9	8.9	8.9	8.8	8.6	8.6	8.3	7.8	7.8	7.4	7.1	6.7	6.5	6.4	6.2	6.2	6.2
500	6.7	6.6	6.6	6.6	6.8	6.8	6.7	6.5	6.6	6.4	6.2	6.3	5.9	5.7	5.5	5.6	5.5	5.5	5.6	5.5
N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C MID-JANUARY

DEPTH (M)																				
0	23.6	23.6	22.9	22.7	22.2	21.9	21.5	20.9	20.4	19.4	18.9	18.5	17.8	17.2	16.4	15.9	15.0	14.6	13.4	12.1
10	23.6	23.6	22.9	22.7	22.2	21.9	21.5	20.9	20.4	19.4	18.9	18.5	17.7	17.2	16.3	15.9	15.0	14.5	13.5	12.0
20	23.6	23.6	22.9	22.7	22.1	21.4	21.4	20.9	20.4	19.4	18.9	18.5	17.7	17.1	16.3	15.9	15.0	14.6	13.5	11.9
30	23.6	23.6	22.8	22.7	22.1	21.4	21.4	20.9	20.3	19.3	18.9	18.5	17.7	17.1	16.4	15.8	14.9	14.5	13.5	11.9
40	23.6	23.5	22.8	22.7	22.1	21.8	21.4	20.8	20.3	19.3	18.8	18.5	17.6	17.1	16.5	15.7	15.0	14.5	13.6	11.9
50	23.5	23.5	22.8	22.7	22.1	21.8	21.4	20.8	20.3	19.3	18.9	18.5	17.7	17.2	16.5	15.8	15.1	14.6	13.6	11.8
60	23.5	23.4	22.8	22.7	22.0	21.7	21.4	20.8	20.4	19.4	19.0	18.6	17.8	17.3	16.6	15.9	15.2	14.5	13.4	11.5
70	23.5	23.3	22.8	22.7	22.0	21.7	21.4	20.9	20.4	19.4	19.1	18.6	17.9	17.3	16.6	15.7	15.1	14.5	12.8	10.8
80	23.3	23.0	22.7	22.6	21.9	21.6	21.2	20.8	20.3	19.4	19.1	18.6	17.9	17.3	16.3	15.5	14.3	13.9	12.1	10.1
90	23.1	22.6	22.4	22.3	21.6	21.3	20.9	20.5	20.0	19.3	19.0	18.4	17.7	17.0	15.7	14.7	13.3	13.0	11.5	9.8
100	22.6	22.2	22.1	21.9	21.2	20.8	20.3	20.0	19.5	19.0	18.8	18.0	17.3	16.4	15.0	14.0	12.5	12.3	11.1	9.6
120	21.4	21.1	21.0	20.7	20.2	19.8	19.2	18.9	18.6	17.7	18.0	17.1	16.2	15.1	14.0	13.0	11.5	11.1	10.3	9.2
150	20.0	19.7	19.5	19.3	18.6	18.2	17.7	17.3	17.1	16.2	16.2	15.9	14.8	13.7	12.7	11.5	10.2	10.0	9.5	8.8
200	17.3	17.4	17.2	16.7	16.1	15.4	15.2	14.9	14.5	13.4	13.3	12.9	12.0	11.1	10.5	9.8	9.1	9.0	8.6	8.1
250	14.1	14.3	14.6	13.6	13.5	13.2	12.7	12.4	12.3	11.5	11.1	11.0	10.4	9.9	9.4	8.9	8.4	8.2	7.9	7.6
300	11.5	11.7	11.4	11.7	11.6	11.4	11.2	11.1	11.0	10.4	9.9	10.0	9.3	8.9	8.4	8.0	7.5	7.4	7.2	7.0
400	8.4	8.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.6	8.7	8.2	7.9	7.9	7.3	7.0	6.6	6.4	6.3	6.2	6.1	6.3
500	6.8	6.6	[illegible]	6.7	6.7	[illegible]	6.5	6.5	6.6	6.4	6.2	6.3	5.8	5.6	5.5	5.5	5.5	5.4	5.5	5.5
N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C — 01 FEBRUARY

	0	23.4	23.5	22.7	22.4	21.9	21.7	21.2	20.4	19.9	19.1	18.6	18.2	17.4	16.8	16.1	15.5	14.6	14.3	13.2	12.1
	10	23.3	23.4	22.7	22.4	21.9	21.6	21.1	20.4	19.9	19.1	18.5	18.2	17.4	16.7	16.0	15.4	14.6	14.2	13.2	12.0
	20	23.3	23.4	22.6	22.4	21.8	21.6	21.1	20.4	19.9	19.1	18.5	18.1	17.4	16.7	16.0	15.4	14.5	14.2	13.2	11.9
	30	23.3	23.4	22.6	22.4	21.8	21.6	21.1	20.4	19.9	19.1	18.5	18.1	17.3	16.6	16.1	15.4	14.5	14.1	13.2	11.9
	40	23.2	23.3	22.5	22.3	21.8	21.5	21.0	20.3	19.9	19.1	18.4	18.1	17.3	16.6	16.1	15.4	14.5	14.1	13.2	11.8
	50	23.2	23.3	22.5	22.4	21.7	21.4	21.0	20.2	19.8	19.0	18.5	18.1	17.2	16.5	16.0	15.4	14.5	14.1	13.2	11.8
D	60	23.1	23.1	22.4	22.3	21.7	21.3	20.9	20.2	19.8	19.0	18.5	18.1	17.3	16.6		15.5	14.6	14.2	13.0	11.5
E	70	23.0	23.0	22.4	22.3	21.6	21.3	20.8	20.3	19.7	19.1	18.6	18.2	17.4	16.7	16.1	15.5	14.6	14.3	12.7	10.9
P	80	22.9	22.7	22.2	22.2	21.6	21.2	20.8	20.3	19.7	19.1	18.6	18.2	17.5	16.7	16.0	15.4	14.1	13.9	12.1	10.2
T	90	22.7	22.4	22.0	22.0	21.4	21.0	20.7	20.1	19.5	19.2	18.6	18.2	17.5	16.6	15.6	14.8	13.4	13.2	11.6	9.8
H	100	22.3	22.0	21.8	21.7	21.1	20.7	20.3	19.8	19.2	19.0	18.6	17.9	17.3	16.3	14.9	14.1	12.6	12.5	11.2	9.6
	120	21.3	21.2	20.9	20.7	20.2	19.8	19.3	18.9	18.5	17.9	18.0	17.1	16.3	15.0	13.8	12.9	11.5	11.2	10.4	9.2
(M)	150	19.9	19.8	19.4	19.4	18.6	18.4	17.8	17.3	17.1	16.4	16.1	15.8	14.8	13.5	12.6	11.4	10.1	10.1	9.5	8.8
	200	17.4	17.6	17.1	16.9	16.1	15.9	15.3	14.7	14.4	13.5	13.3	12.9	12.0	10.9	10.4	9.7	9.1	9.0	8.6	8.1
	250	14.3	14.5	14.6	14.0	13.5	13.2	12.8	12.4	12.2	11.5	11.1	11.1	10.4	9.7	9.3	8.8	8.3	8.2	7.9	7.6
	300	11.7	11.9	12.0	11.8	11.6	11.4	11.3	11.0	11.0	10.3	9.9	10.0	9.3	8.8	8.3	7.8	7.5	7.4	7.2	7.0
	400	8.6	8.8	8.9	8.9	9.0	8.8	8.8	8.6	8.7	8.2	7.9	7.9	7.3	6.8	6.6	6.2	6.2	6.1	6.2	6.2
	500	6.9	6.6	6.6	6.7	6.6	6.6	6.7	6.5	6.6	6.4	6.1	6.2	5.9	5.5	5.4	5.4	5.4	5.3	5.4	5.6
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C — MID-FEBRUARY

	0	23.3	23.3	22.7	22.3	21.7	21.5	20.9	20.0	19.6	19.0	18.3	17.9	17.2	16.4	15.8	15.1	14.3	14.0	13.1	12.1
	10	23.2	23.3	22.6	22.3	21.7	21.5	20.9	20.0	19.6	19.0	18.3	17.9	17.2	16.3	15.8	15.1	14.3	13.9	13.1	12.1
	20	23.2	23.3	22.6	22.2	21.7	21.4	20.9	20.0	19.6	19.0	18.3	17.9	17.1	16.3	15.8	15.1	14.3	13.9	13.0	12.1
	30	23.1	23.3	22.5	22.2	21.6	21.4	20.8	20.0	19.6	18.9	18.2	17.8	17.2	16.2	15.8	15.2	14.3	13.8	13.0	12.0
	40	23.1	23.2	22.4	22.1	21.6	21.3	20.8	19.9	19.5	18.9	18.2	17.8	17.1	16.2	15.8	15.2	14.2	13.8	12.9	11.8
	50	23.0	23.2	22.3	22.1	21.5	21.2	20.7	19.9	19.5	19.0	18.2	17.7	17.0	16.1	15.7	15.1	14.2	13.7	12.7	11.7
D	60	22.8	23.0	22.2	22.0	21.4	21.1	20.6	19.8	19.3	18.9	18.2	17.7	16.9	16.0	15.7	15.2	14.2	13.9	12.6	11.5
E	70	22.7	22.8	22.1	21.9	21.3	21.0	20.5	19.8	19.2	18.8	18.2	17.7	17.0	16.1	15.7	15.3	14.2	13.9	12.4	11.0
P	80	22.6	22.6	22.0	21.9	21.3	21.0	20.4	19.8	19.2	18.8	18.2	17.8	17.2	16.2	15.7	15.2	13.9	13.7	12.0	10.3
T	90	22.4	22.3	21.8	21.8	21.2	20.8	20.4	19.7	19.1	18.9	18.2	17.8	17.2	16.2	15.4	14.8	13.5	13.1	11.6	9.9
H	100	22.1	22.0	21.6	21.5	20.9	20.6	20.1	19.5	18.9	18.9	18.3	17.6	17.1	16.0	14.9	14.1	12.8	12.5	11.1	9.6
	120	21.3	21.3	20.9	20.7	20.2	19.9	19.4	18.8	18.3	18.1	17.9	16.9	16.4	14.9	13.6	12.9	11.6	11.3	10.4	9.2
(M)	150	19.9	20.0	19.5	19.5	18.6	18.5	17.9	17.3	17.0	16.6	16.0	15.7	14.9	13.3	12.3	11.3	10.2	10.1	9.4	8.8
	200	17.5	17.7	17.1	17.1	16.1	16.0	15.4	14.6	14.2	13.7	13.2	12.7	12.1	10.7	10.3	9.6	9.2	9.0	8.5	8.1
	250	14.5	14.7	14.6	14.2	13.4	13.3	12.9	12.3	12.1	11.5	11.1	11.0	10.5	9.6	9.2	8.7	8.3	8.2	7.8	7.5
	300	11.9	12.1	12.1	11.9	11.6	11.4	11.3	11.0	10.9	10.3	10.0	9.9	9.3	8.6	8.3	7.7	7.5	7.4	7.2	7.0
	400	8.6	8.9	8.9	9.0	9.0	8.8	8.8	8.6	8.6	8.1	7.9	7.8	7.3	6.7	6.6	6.2	6.2	6.1	6.2	6.1
	500	6.8	6.7	6.7	6.8	6.5	6.5	6.7	6.6	6.6	6.4	6.1	6.1	5.9	5.5	5.5	5.3	5.4	5.3	5.4	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C — 01 MARCH

DEPTH (M)	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614
0	23.3	23.2	22.6	22.2	21.6	21.3	20.7	19.8	19.3	18.8	18.1	17.6	17.0	16.0	15.6	14.9	14.2	13.8	13.0	12.2
10	23.2	23.2	22.6	22.2	21.6	21.3	20.7	19.7	19.3	18.8	18.1	17.6	17.0	15.9	15.5	14.9	14.1	13.7	12.9	12.2
20	23.1	23.2	22.6	22.1	21.6	21.3	20.6	19.7	19.3	18.8	18.1	17.6	16.9	15.9	15.6	14.9	14.1	13.6	12.9	12.2
30	23.1	23.2	22.5	22.1	21.5	21.2	20.6	19.7	19.3	18.8	18.1	17.5	17.0	15.9	15.6	15.0	14.2	13.6	12.8	12.1
40	23.0	23.1	22.4	22.0	21.5	21.2	20.6	19.7	19.3	18.8	18.1	17.5	17.0	15.9	15.5	15.0	14.1	13.6	12.7	11.9
50	22.9	23.1	22.3	21.9	21.4	21.1	20.6	19.7	19.2	18.9	18.1	17.4	16.9	15.8	15.4	15.0	14.1	13.5	12.5	11.7
60	22.7	22.9	22.2	21.8	21.3	21.0	20.4	19.6	19.1	18.8	18.0	17.4	16.8	15.7	15.3	14.9	14.0	13.5	12.3	11.4
70	22.6	22.8	22.1	21.7	21.1	20.9	20.3	19.5	18.9	18.6	17.9	17.3	16.8	15.7	15.4	15.0	14.0	13.5	12.2	11.0
80	22.4	22.6	21.9	21.7	21.0	20.8	20.2	19.4	18.8	18.6	17.9	17.3	16.8	15.7	15.3	14.9	13.9	13.4	12.0	10.4
90	22.2	22.3	21.7	21.5	20.9	20.7	20.1	19.3	18.7	18.6	17.9	17.4	16.9	15.8	15.2	14.7	13.7	13.0	11.5	9.9
100	21.9	22.0	21.5	21.3	20.7	20.5	19.9	19.2	18.6	18.6	17.9	17.3	16.9	15.7	14.9	14.1	13.1	12.4	11.0	9.6
120	21.3	21.5	21.0	20.7	20.1	19.9	19.3	18.6	18.1	18.1	17.7	16.7	16.5	14.9	13.6	13.0	11.9	11.2	10.3	9.2
150	19.9	20.1	19.8	19.6	18.6	18.6	18.0	17.3	16.9	16.7	15.9	15.5	15.0	13.1	12.2	11.3	10.5	10.1	9.3	8.7
200	17.4	17.7	17.3	17.1	16.1	16.2	15.5	14.6	14.0	13.9	13.2	12.5	12.1	10.7	10.2	9.6	9.3	9.0	8.5	8.0
250	14.5	14.7	14.7	14.3	13.4	13.4	12.9	12.3	12.0	11.6	11.2	10.9	10.5	9.6	9.2	8.6	8.3	8.2	7.8	7.5
300	11.9	12.1	12.1	11.9	11.6	11.5	11.3	10.9	10.8	10.3	10.0	9.8	9.3	8.6	8.3	7.7	7.5	7.4	7.1	6.9
400	8.7	8.9	8.9	9.0	8.9	8.9	8.8	8.6	8.5	8.2	7.9	7.7	7.4	6.7	6.6	6.2	6.2	6.1	6.2	6.1
500	6.7	6.7	6.7	6.8	6.5	6.6	6.6	6.5	6.5	6.3	6.1	6.0	6.0	5.5	5.6	5.3	5.4	5.3	5.4	5.5

Column heads are distance in N MI (row above) and KM (row below).

DISTANCE

MEAN XBT TEMPERATURE, DEG-C — MID-MARCH

DEPTH (M)	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614
0	23.4	23.2	22.7	22.2	21.6	21.2	20.5	19.7	19.1	18.7	17.9	17.3	16.8	15.8	15.4	14.8	14.1	13.5	12.9	12.2
10	23.3	23.1	22.6	22.1	21.6	21.2	20.5	19.7	19.1	18.7	17.9	17.3	16.8	15.7	15.3	14.8	14.1	13.5	12.8	12.2
20	23.2	23.1	22.6	22.1	21.5	21.1	20.5	19.6	19.1	18.7	17.9	17.2	16.7	15.7	15.3	14.8	14.1	13.4	12.7	12.2
30	23.2	23.1	22.6	22.1	21.5	21.1	20.4	19.6	19.1	18.7	17.9	17.2	16.8	15.7	15.3	14.8	14.2	13.4	12.7	12.1
40	23.1	23.1	22.5	22.0	21.4	21.1	20.4	19.6	19.1	18.7	18.0	17.2	16.8	15.7	15.3	14.8	14.2	13.4	12.6	11.9
50	23.0	23.0	22.4	21.9	21.4	21.1	20.4	19.6	19.1	18.8	18.0	17.2	16.8	15.7	15.2	14.8	14.1	13.3	12.4	11.6
60	22.8	22.9	22.3	21.8	21.2	21.0	20.3	19.6	19.0	18.7	17.9	17.1	16.8	15.6	15.2	14.8	14.0	13.2	12.3	11.3
70	22.6	22.7	22.1	21.7	21.0	20.8	20.2	19.4	18.8	18.5	17.8	17.1	16.7	15.5	15.2	14.8	14.0	13.1	12.2	11.0
80	22.4	22.6	21.9	21.6	20.9	20.7	20.1	19.2	18.7	18.4	17.8	17.1	16.6	15.5	15.1	14.8	14.0	13.0	12.0	10.5
90	22.1	22.3	21.8	21.4	20.7	20.6	19.9	19.1	18.6	18.3	17.7	17.0	16.7	15.5	15.1	14.7	13.9	12.7	11.6	10.0
100	21.9	21.9	21.6	21.2	20.5	20.4	19.7	19.0	18.4	18.3	17.7	17.0	16.7	15.5	14.9	14.3	13.5	12.2	11.0	9.6
120	21.3	21.5	21.1	20.8	19.9	19.8	19.1	18.5	18.0	18.0	17.5	16.6	16.5	14.9	13.9	13.3	12.4	11.0	10.2	9.2
150	20.0	20.1	20.0	19.6	18.6	18.6	18.0	17.3	16.8	16.8	15.9	15.5	15.1	13.2	12.1	11.5	10.8	10.0	9.3	8.7
200	17.3	17.6	17.5	17.2	16.1	16.3	15.6	14.6	13.9	14.0	13.2	12.4	12.1	10.8	10.2	9.6	9.4	8.9	8.5	8.1
250	14.4	14.7	14.8	14.3	13.4	13.5	12.9	12.2	11.8	11.7	11.3	10.8	10.5	9.6	9.2	8.7	8.4	8.1	7.8	7.5
300	11.8	12.0	12.1	12.0	11.7	11.5	11.2	10.9	10.7	10.3	10.1	9.7	9.4	8.6	8.3	7.8	7.6	7.3	7.1	6.9
400	8.7	8.9	8.9	9.1	8.9	8.9	8.7	8.6	8.4	8.2	7.9	7.6	7.5	6.7	6.6	6.3	6.2	6.2	6.2	6.0
500	6.6	6.6	6.7	6.9	6.6	6.6	6.6	6.5	6.5	6.3	6.2	5.9	5.9	5.6	5.7	5.3	5.4	5.3	5.5	5.5

Column heads are distance in N MI (row above) and KM (row below).

DISTANCE

MEAN XBT TEMPERATURE, DEG-C — 01 APRIL

DEPTH (M)																				
0	23.5	23.2	22.8	22.3	21.7	21.2	20.5	19.9	19.1	18.7	17.8	17.1	16.7	15.7	15.3	14.9	14.2	13.4	12.8	12.1
10	23.5	23.2	22.7	22.2	21.6	21.2	20.5	19.8	19.1	18.7	17.8	17.1	16.6	15.6	15.3	14.8	14.1	13.3	12.7	12.1
20	23.4	23.2	22.7	22.2	21.6	21.1	20.4	19.8	19.1	18.7	17.8	17.1	16.6	15.6	15.2	14.8	14.2	13.3	12.7	12.0
30	23.3	23.1	22.7	22.2	21.5	21.1	20.3	19.7	19.1	18.7	17.8	17.1	16.6	15.7	15.2	14.8	14.2	13.3	12.7	12.0
40	23.2	23.1	22.6	22.1	21.4	21.1	20.3	19.7	19.1	18.7	17.9	17.1	16.7	15.7	15.2	14.8	14.2	13.3	12.6	11.8
50	23.1	23.0	22.5	22.0	21.4	21.0	20.3	19.7	19.1	18.7	17.9	17.1	16.8	15.7	15.2	14.8	14.2	13.2	12.5	11.5
D 60	22.9	22.8	22.4	21.9	21.2	21.0	20.2	19.6	19.0	18.6	17.9	17.1	16.8	15.6	15.2	14.8	14.1	13.0	12.4	11.2
E 70	22.8	22.7	22.2	21.8	21.0	20.8	20.2	19.4	18.9	18.5	17.9	17.0	16.7	15.6	15.2	14.7	14.1	12.9	12.3	10.9
P 80	22.5	22.5	22.0	21.7	20.9	20.7	20.0	19.2	18.8	18.3	17.9	17.0	16.6	15.5	15.1	14.7	14.1	12.7	12.1	10.5
T 90	22.2	22.2	21.8	21.5	20.7	20.5	19.7	19.1	18.6	18.2	17.7	17.0	16.6	15.5	15.1	14.7	14.1	12.5	11.7	10.0
H 100	21.9	21.9	21.6	21.3	20.5	20.3	19.5	18.9	18.4	18.1	17.6	16.9	16.6	15.4	15.1	14.5	13.8	12.0	11.1	9.6
120	21.4	21.4	21.1	20.8	19.9	19.7	18.9	18.4	17.9	17.9	17.4	16.7	16.5	15.0	14.2	13.6	12.8	10.9	10.2	9.2
(M) 150	20.0	20.0	20.0	19.7	18.7	18.6	18.0	17.3	16.8	16.8	15.9	15.6	15.2	13.3	12.2	11.7	11.1	9.8	9.3	8.8
200	17.2	17.5	17.6	17.2	16.2	16.3	15.6	14.6	13.9	14.0	13.2	12.4	12.1	10.9	10.2	9.8	9.4	8.8	8.5	8.1
250	14.2	14.6	14.8	14.4	13.5	13.4	12.9	12.2	11.8	11.7	11.3	10.8	10.6	9.7	9.2	8.8	8.5	8.1	7.8	7.5
300	11.7	11.9	12.1	12.1	11.7	11.6	11.2	10.9	10.6	10.4	10.1	9.6	9.5	8.6	8.3	7.9	7.7	7.3	7.1	7.0
400	8.6	8.8	8.9	9.2	8.9	8.9	8.7	8.6	8.3	8.2	8.0	7.5	7.5	6.8	6.6	6.5	6.4	6.2	6.2	6.1
500	6.5	6.6	6.7	6.9	6.7	6.7	6.6	6.5	6.4	6.3	6.2	5.9	5.9	5.6	5.7	5.4	5.5	5.4	5.5	5.5
N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C — MID-APRIL

DEPTH (M)																				
0	23.7	23.4	23.0	22.5	21.9	21.4	20.6	20.2	19.4	18.9	17.9	17.2	16.7	15.9	15.5	15.0	14.3	13.4	12.8	12.0
10	23.7	23.4	22.9	22.4	21.9	21.4	20.6	20.2	19.3	18.8	17.9	17.1	16.7	15.8	15.3	14.9	14.3	13.4	12.7	11.9
20	23.6	23.3	22.9	22.4	21.8	21.3	20.5	20.1	19.3	18.8	17.9	17.1	16.6	15.8	15.2	14.9	14.3	13.3	12.7	11.8
30	23.6	23.2	22.8	22.4	21.7	21.2	20.4	20.1	19.2	18.8	17.8	17.1	16.6	15.8	15.2	14.8	14.3	13.3	12.7	11.8
40	23.4	23.2	22.7	22.3	21.6	21.1	20.3	20.0	19.2	18.7	17.9	17.1	16.6	15.8	15.2	14.8	14.3	13.3	12.7	11.6
50	23.3	23.0	22.6	22.2	21.5	21.0	20.2	19.9	19.2	18.6	17.9	17.2	16.7	15.8	15.2	14.9	14.3	13.2	12.7	11.3
D 60	23.1	22.8	22.4	22.0	21.3	21.0	20.2	19.7	19.1	18.6	17.9	17.2	16.8	15.8	15.3	14.8	14.3	13.0	12.6	11.1
E 70	22.9	22.6	22.3	22.0	21.1	20.9	20.1	19.5	19.1	18.5	17.9	17.2	16.8	15.8	15.3	14.8	14.2	12.8	12.4	10.8
P 80	22.6	22.4	22.1	21.8	21.0	20.7	19.9	19.3	18.9	18.3	17.9	17.1	16.7	15.7	15.2	14.8	14.2	12.7	12.1	10.5
T 90	22.3	22.1	21.9	21.6	20.7	20.5	19.7	19.2	18.7	18.1	17.8	17.1	16.6	15.7	15.2	14.7	14.1	12.4	11.7	10.0
H 100	22.1	21.8	21.6	21.4	20.5	20.3	19.4	18.9	18.5	18.0	17.6	17.0	16.6	15.5	15.2	14.6	13.9	11.9	11.1	9.7
120	21.4	21.2	20.9	20.9	19.8	19.6	18.7	18.4	17.9	17.7	17.3	16.8	16.4	15.2	14.5	13.9	13.0	10.7	10.1	9.2
(M) 150	19.9	19.9	19.6	19.8	18.7	18.4	17.9	17.3	16.8	16.7	15.9	15.8	15.2	13.5	12.5	11.8	11.2	9.7	9.4	8.8
200	17.1	17.3	17.5	17.2	16.3	16.2	15.6	14.7	14.0	14.0	13.2	12.6	12.1	11.0	10.3	9.9	9.5	8.8	8.6	8.2
250	14.1	14.5	14.6	14.5	13.7	13.3	12.9	12.3	11.8	11.7	11.4	10.8	10.5	9.8	9.3	9.0	8.6	8.1	7.9	7.6
300	11.5	11.8	11.9	12.2	11.8	11.5	11.2	10.9	10.6	10.4	10.2	9.7	9.5	8.8	8.3	8.0	7.6	7.3	7.2	7.1
400	8.5	8.8	8.9	9.2	9.0	8.9	8.7	8.6	8.3	8.2	8.0	7.6	7.5	6.9	6.6	6.6	6.5	6.3	6.2	6.2
500	6.6	6.7	6.8	7.0	6.8	6.7	6.6	6.5	6.4	6.3	6.2	5.9	5.8	5.6	5.7	5.5	5.6	5.5	5.5	5.5
N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C — 01 MAY

DEPTH (M)																				
0	24.0	23.7	23.3	22.8	22.3	21.8	21.1	20.7	19.9	19.2	18.3	17.6	17.1	16.4	15.9	15.4	14.7	13.7	12.9	12.0
10	24.0	23.7	23.2	22.8	22.3	21.7	21.0	20.7	19.8	19.2	18.2	17.5	17.0	16.3	15.7	15.3	14.6	13.6	12.9	11.9
20	23.9	23.7	23.2	22.7	22.2	21.7	20.9	20.7	19.8	19.2	18.2	17.4	16.9	16.2	15.6	15.2	14.6	13.5	12.9	11.7
30	23.9	23.5	23.0	22.6	22.0	21.5	20.8	20.5	19.7	19.1	18.0	17.4	16.8	16.1	15.4	15.0	14.4	13.4	12.8	11.6
40	23.7	23.4	22.8	22.5	21.8	21.3	20.6	20.3	19.5	19.0	18.0	17.4	16.8	16.0	15.4	15.0	14.4	13.4	12.9	11.4
50	23.5	23.1	22.6	22.4	21.6	21.1	20.4	20.1	19.4	18.8	18.0	17.4	16.8	16.0	15.4	15.0	14.3	13.3	12.8	11.2
60	23.2	22.8	22.5	22.3	21.5	21.0	20.2	19.8	19.3	18.7	18.0	17.4	16.8	16.0	15.4	14.9	14.3	13.1	12.7	10.9
70	23.0	22.6	22.2	22.1	21.3	20.8	20.1	19.6	19.2	18.6	18.0	17.4	16.9	16.0	15.5	14.9	14.3	13.0	12.4	10.7
80	22.7	22.3	22.0	21.9	21.1	20.6	19.9	19.5	19.1	18.4	18.0	17.4	16.8	16.0	15.4	14.8	14.2	12.7	12.1	10.4
90	22.4	22.1	21.8	21.8	20.8	20.4	19.6	19.3	18.8	18.2	17.9	17.3	16.7	15.9	15.3	14.7	14.0	12.4	11.7	10.0
100	22.1	21.8	21.4	21.5	20.5	20.2	19.3	19.0	18.5	18.1	17.7	17.2	16.7	15.7	15.3	14.6	13.9	11.8	11.1	9.7
120	21.4	21.1	20.7	20.9	19.9	19.5	18.7	18.4	18.0	17.7	17.2	17.0	16.4	15.3	14.7	13.9	12.9	10.7	10.1	9.3
150	19.9	19.8	19.5	19.8	18.8	18.3	17.8	17.4	16.8	16.7	15.9	16.0	15.3	13.7	12.8	11.8	11.2	9.7	9.4	8.9
200	17.1	17.3	17.2	17.4	16.4	15.8	15.6	14.8	14.2	14.0	13.1	12.8	12.1	11.1	10.5	9.9	9.5	8.7	8.6	8.3
250	14.0	14.4	14.4	14.7	13.9	13.3	12.9	12.5	12.0	11.8	11.4	10.9	10.5	9.8	9.4	9.0	8.7	8.1	7.9	7.6
300	11.4	11.8	11.8	12.3	11.9	11.5	11.3	11.0	10.7	10.5	10.2	9.8	9.5	8.9	8.4	8.1	7.8	7.4	7.2	7.2
400	9.4	8.8	[illegible]	[illegible]	9.1	[illegible]	[illegible]	8.6	8.3	8.3	8.1	7.6	7.4	7.0	6.6	6.6	6.5	6.3	6.1	6.3
500	6.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.4	6.3	6.2	5.9	5.8	5.6	5.6	5.5	5.7	5.6	5.4	5.6
N MI	50	150	250	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	93	278	463	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C — MID-MAY

DEPTH (M)																				
0	24.3	24.2	23.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.5	19.8	18.9	18.3	17.7	17.1	16.6	16.0	15.2	14.3	13.3	12.2
10	24.3	24.2	23.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.5	[illegible]	18.8	18.2	17.6	17.0	16.4	15.8	15.1	14.1	13.2	12.0
20	[illegible]	24.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.4	19.7	18.7	18.1	17.5	16.8	16.2	15.7	15.0	14.0	13.1	11.8
30	24.2	24.0	23.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.3	19.6	18.5	[illegible]	17.3	16.6	15.9	15.5	14.8	13.8	13.1	11.7
40	24.0	23.7	23.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.4	18.3	[illegible]	17.1	16.3	15.7	15.3	14.6	13.6	13.0	11.5
50	23.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.2	18.2	17.7	17.0	16.2	15.6	15.1	14.4	13.5	12.8	11.1
60	23.4	23.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.5	[illegible]	18.1	17.7	16.9	16.2	15.6	15.0	14.4	13.3	12.5	10.7
70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.3	18.8	18.0	17.6	16.9	16.2	15.6	14.9	14.3	13.2	12.2	10.5
80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19.1	18.6	18.0	17.6	16.9	16.1	15.5	14.8	14.1	12.9	11.8	10.2
90	22.5	22.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.9	18.4	17.9	17.5	16.8	16.0	15.3	14.6	13.9	12.4	11.4	10.0
100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.6	18.2	17.7	17.4	16.7	15.8	15.2	14.4	13.6	11.9	11.0	9.7
120	21.4	21.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.0	17.7	17.1	17.2	16.3	15.4	14.7	13.7	12.7	10.8	10.1	9.3
150	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.7	17.4	16.9	16.8	15.9	16.2	15.3	13.9	13.1	11.7	11.1	9.7	9.4	9.0
200	17.2	17.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.4	14.1	13.0	13.0	12.1	11.1	10.6	9.8	9.5	8.8	8.6	8.3
250	[illegible]	14.5	14.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.1	11.9	11.3	11.0	10.6	9.9	9.4	9.0	8.7	8.1	7.9	7.7
300	11.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.1	[illegible]	10.6	10.2	9.9	9.5	8.9	8.4	8.1	7.8	7.4	7.2	7.2
400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.4	8.1	7.8	7.4	7.0	6.7	6.5	6.5	6.3	6.0	6.3
500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.4	[illegible]	6.0	[illegible]	5.7	5.5	5.6	5.7	5.6	5.4	5.6
N MI	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C — 01 JUNE

	0	24.7	24.6	24.1	23.7	23.4	22.9	22.4	21.9	21.2	20.5	19.6	19.1	18.5	17.9	17.3	16.6	15.9	14.9	13.8	12.6
	10	24.6	24.6	24.1	23.6	23.3	22.8	22.3	21.8	21.1	20.4	19.5	19.0	18.4	17.8	17.1	16.5	15.8	14.8	13.6	12.4
	20	24.6	24.5	23.9	23.5	23.2	22.7	22.2	21.7	21.1	20.3	19.4	18.9	18.2	17.5	16.9	16.3	15.6	14.6	13.5	12.2
	30	24.5	24.3	23.6	23.3	22.9	22.5	22.0	21.5	20.9	20.1	19.1	18.5	17.9	17.1	16.5	16.0	15.3	14.2	13.4	12.0
	40	24.3	24.1	23.3	23.1	22.6	22.1	21.6	21.0	20.4	19.9	18.7	18.2	17.6	16.7	16.1	15.7	15.0	14.0	13.1	11.6
	50	23.9	23.7	22.9	22.8	22.3	21.6	21.1	20.5	20.1	19.6	18.6	18.0	17.3	16.5	15.9	15.3	14.6	13.8	12.7	11.1
D	60	23.5	23.3	22.5	22.5	21.9	21.2	20.6	20.1	19.7	19.2	18.3	17.9	17.1	16.3	15.8	15.1	14.4	13.6	12.3	10.6
E	70	23.1	23.0	22.1	22.2	21.6	20.9	20.3	19.8	19.4	19.0	18.1	17.7	17.0	16.3	15.7	14.9	14.2	13.4	11.9	10.4
P	80	22.7	22.6	21.7	21.9	21.2	20.6	20.0	19.5	19.1	18.7	18.0	17.7	16.9	16.2	15.5	14.7	14.0	12.9	11.5	10.1
T	90	22.4	22.2	21.4	21.7	20.9	20.3	19.7	19.3	18.9	18.5	17.8	17.6	16.9	16.0	15.3	14.5	13.7	12.5	11.1	9.9
H	100	22.1	21.9	21.1	21.4	20.6	20.0	19.5	19.0	18.6	18.3	17.6	17.5	16.7	15.9	15.2	14.2	13.4	11.9	10.7	9.7
	120	21.3	21.2	20.3	20.8	20.0	19.4	18.8	18.5	18.1	17.8	17.1	17.2	16.3	15.4	14.6	13.4	12.4	10.9	10.0	9.4
(M)	150	19.9	20.1	19.0	19.8	18.9	18.3	17.8	17.5	17.0	16.9	15.8	16.2	15.2	14.0	13.1	11.6	11.0	9.8	9.3	9.0
	200	17.4	17.6	16.6	17.5	16.6	15.8	15.5	15.1	14.5	14.3	12.8	13.1	12.2	11.2	10.6	9.8	9.5	8.8	8.5	8.3
	250	14.1	14.7	14.0	14.9	14.0	13.4	13.0	12.7	12.3	12.1	11.3	11.1	10.6	9.9	9.4	8.9	8.7	8.1	7.8	7.7
	300	11.5	12.1	11.8	12.4	12.0	11.6	11.5	11.2	10.9	10.7	10.2	10.0	9.5	9.0	8.4	8.0	7.8	7.4	7.1	7.1
	400	8.4	8.9	9.0	9.2	9.3	8.9	9.0	8.8	8.6	8.5	8.1	7.9	7.4	7.0	6.7	6.5	6.5	6.3	6.0	6.2
	500	6.8	6.7	6.9	6.9	6.9	6.8	6.8	6.7	6.7	6.5	6.1	6.1	5.9	5.7	5.5	5.5	5.7	5.5	5.3	5.6
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C — MID-JUNE

	0	25.0	25.0	24.5	24.1	23.9	23.4	23.0	22.4	21.9	21.2	20.5	20.0	19.5	18.8	18.2	17.5	16.7	15.8	14.5	13.2
	10	25.0	24.9	24.5	24.0	23.8	23.4	23.0	22.3	21.8	21.1	20.3	19.9	19.3	18.7	18.1	17.3	16.6	15.6	14.3	13.0
	20	24.9	24.8	24.3	23.9	23.7	23.3	22.8	22.2	21.8	21.1	20.2	19.7	19.0	18.4	17.8	17.0	16.3	15.3	14.1	12.8
	30	24.9	24.7	24.0	23.7	23.4	23.1	22.6	21.9	21.5	20.8	19.9	19.3	18.7	17.7	17.3	16.6	16.0	14.9	13.8	12.5
	40	24.6	24.5	23.6	23.4	23.1	22.6	22.1	21.3	21.0	20.4	19.4	18.7	18.2	17.1	16.6	16.0	15.4	14.5	13.3	11.9
	50	24.1	24.1	23.1	23.0	22.6	21.9	21.5	20.7	20.4	20.0	19.0	18.3	17.7	16.7	16.2	15.4	14.9	14.1	12.7	11.2
D	60	23.6	23.7	22.6	22.6	22.1	21.4	20.9	20.2	19.9	19.5	18.6	18.0	17.3	16.5	16.0	15.1	14.5	13.8	12.1	10.6
E	70	23.2	23.3	22.1	22.2	21.6	21.0	20.5	19.8	19.5	19.1	18.3	17.8	17.1	16.3	15.7	14.8	14.2	13.4	11.6	10.3
P	80	22.8	22.8	21.7	21.8	21.2	20.6	20.1	19.5	19.2	18.8	18.0	17.7	16.9	16.1	15.5	14.5	13.8	13.0	11.2	10.0
T	90	22.4	22.5	21.3	21.5	20.9	20.3	19.8	19.2	18.9	18.6	17.8	17.6	16.8	16.0	15.3	14.3	13.6	12.5	10.8	9.8
H	100	22.0	22.1	21.0	21.2	20.5	20.0	19.6	18.9	18.6	18.3	17.6	17.4	16.7	15.9	15.1	14.0	13.2	12.0	10.5	9.7
	120	21.2	21.3	20.3	20.6	19.9	19.4	19.0	18.4	18.1	17.9	17.0	17.2	16.3	15.4	14.5	13.2	12.3	11.0	9.9	9.3
(M)	150	19.9	20.2	19.0	19.6	18.8	18.4	17.9	17.5	17.1	17.0	15.8	16.2	15.2	14.1	13.0	11.5	10.9	10.0	9.3	8.9
	200	17.4	17.8	16.6	17.4	16.5	15.9	15.5	15.1	14.5	14.5	12.8	13.1	12.3	11.3	10.6	9.7	9.5	8.9	8.5	8.3
	250	14.2	14.8	14.0	14.8	13.9	13.5	13.0	12.7	12.4	12.2	11.2	11.2	10.7	10.0	9.4	8.8	8.6	8.2	7.8	7.6
	300	11.6	12.2	11.8	12.3	12.0	11.6	11.5	11.2	11.0	10.8	10.2	10.0	9.5	9.0	8.5	8.0	7.8	7.4	7.1	7.1
	400	8.4	9.0	9.0	9.1	9.3	8.9	9.0	8.8	8.7	8.6	8.1	7.9	7.5	7.0	6.8	6.4	6.4	6.3	6.1	6.1
	500	6.8	6.7	6.8	6.8	6.8	6.9	6.9	6.8	6.8	6.6	6.1	6.1	6.0	5.8	5.5	5.5	5.7	5.5	5.4	5.6
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C 01 JULY

	0	25.4	25.3	24.9	24.5	24.3	23.9	23.6	22.9	22.6	22.0	21.4	21.0	20.6	19.9	19.2	18.6	17.7	16.8	15.4	14.0
	10	25.4	25.2	24.8	24.5	24.3	23.9	23.5	22.8	22.5	21.9	21.3	20.9	20.4	19.7	19.1	18.4	17.6	16.6	15.2	13.9
	20	25.3	25.2	24.7	24.4	24.2	23.8	23.4	22.7	22.4	21.8	21.2	20.7	20.1	19.4	18.8	18.0	17.3	16.2	14.9	13.6
	30	25.3	25.1	24.5	24.1	24.0	23.6	23.2	22.4	22.2	21.6	20.9	20.1	19.7	18.5	18.1	17.5	17.0	15.7	14.6	13.0
	40	25.0	24.8	24.1	23.8	23.5	23.1	22.6	21.8	21.6	21.1	20.2	19.2	18.8	17.6	17.1	16.4	16.0	15.1	13.7	12.2
	50	24.4	24.4	23.5	23.2	22.9	22.3	21.9	21.1	20.8	20.3	19.5	18.6	18.0	17.0	16.5	15.7	15.2	14.5	12.9	11.3
D	60	23.8	24.0	22.8	22.6	22.2	21.6	21.2	20.4	20.2	19.7	19.0	18.2	17.6	16.7	16.2	15.2	14.7	13.9	12.2	10.7
E	70	23.4	23.5	22.3	22.1	21.6	21.1	20.7	19.9	19.7	19.3	18.5	17.9	17.2	16.4	15.8	14.8	14.2	13.4	11.5	10.3
P	80	22.9	23.1	21.8	21.7	21.1	20.7	20.3	19.5	19.3	18.9	18.2	17.7	16.9	16.1	15.5	14.5	13.8	12.9	11.0	10.0
T	90	22.4	22.7	21.4	21.3	20.7	20.4	19.9	19.1	19.0	18.6	17.9	17.5	16.7	16.0	15.3	14.2	13.5	12.4	10.7	9.8
H	100	22.0	22.2	21.1	21.0	20.4	20.1	19.6	18.8	18.7	18.3	17.7	17.3	16.6	15.8	15.1	13.9	13.2	12.0	10.4	9.6
	120	21.2	21.4	20.4	20.4	19.8	19.5	19.1	18.4	18.2	18.0	17.1	17.0	16.3	15.4	14.4	13.1	12.3	11.1	9.9	9.3
(M)	150	20.0	20.3	19.2	19.4	18.8	18.6	18.0	17.4	17.2	17.1	15.9	16.0	15.1	14.2	12.9	11.6	10.9	10.1	9.2	8.9
	200	17.5	17.9	16.8	17.1	16.5	16.1	15.5	15.1	14.6	14.6	12.9	13.1	12.3	11.5	10.5	9.8	9.5	9.0	8.5	8.2
	250	14.3	14.8	14.1	14.4	13.7	13.7	13.0	12.7	12.4	12.3	11.3	11.2	10.7	10.2	9.4	8.8	8.7	8.3	7.8	7.6
	300	11.6	12.2	11.9	12.1	11.9	11.7	11.5	11.1	11.0	10.9	10.2	10.0	9.6	9.0	8.4	8.0	7.8	7.5	7.2	7.0
	400	8.5	8.9	8.9	9.0	9.2	9.0	9.0	8.8	8.7	8.7	8.2	8.0	7.6	7.1	6.8	6.5	6.4	6.3	6.2	6.0
	500	6.7	6.6	6.7	6.7	6.6	7.0	6.9	6.8	6.9	6.6	6.2	6.2	6.0	5.8	5.7	5.5	5.5	5.5	5.5	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C MID-JULY

	0	25.7	25.4	25.1	24.8	24.6	24.3	24.0	23.4	23.0	22.6	22.1	21.7	21.3	20.6	20.0	19.4	18.5	17.5	16.2	14.7
	10	25.7	25.4	25.1	24.8	24.6	24.2	23.9	23.3	23.0	22.5	22.0	21.6	21.1	20.5	19.8	19.2	18.4	17.3	15.9	14.5
	20	25.6	25.3	25.0	24.7	24.5	24.1	23.8	23.1	22.9	22.4	21.9	21.3	20.8	20.2	19.6	18.8	18.1	17.0	15.6	14.1
	30	25.6	25.3	24.8	24.5	24.3	24.0	23.6	22.8	22.7	22.2	21.6	20.7	20.4	19.2	18.8	18.1	17.7	16.5	15.3	13.4
	40	25.4	25.1	24.5	24.2	23.8	23.5	23.0	22.2	22.0	21.6	20.8	19.7	19.2	18.1	17.5	16.8	16.5	15.6	14.3	12.4
	50	24.8	24.7	23.9	23.5	23.1	22.6	22.2	21.5	21.1	20.5	19.8	18.8	18.3	17.3	16.7	15.9	15.5	14.8	13.4	11.4
D	60	24.1	24.2	23.1	22.7	22.2	21.8	21.5	20.7	20.4	19.8	19.3	18.4	17.7	16.9	16.3	15.4	14.9	14.0	12.6	10.8
E	70	23.5	23.6	22.5	22.2	21.6	21.3	20.9	20.0	19.9	19.3	18.8	18.0	17.3	16.5	15.9	14.9	14.4	13.4	11.8	10.3
P	80	23.0	23.1	22.0	21.7	21.1	20.9	20.4	19.5	19.5	18.9	18.4	17.7	16.9	16.2	15.6	14.5	13.8	12.8	11.2	10.0
T	90	22.5	22.7	21.6	21.3	20.7	20.5	20.0	19.1	19.1	18.5	18.1	17.5	16.7	16.0	15.3	14.3	13.5	12.3	10.8	9.8
H	100	22.1	22.2	21.2	20.9	20.3	20.2	19.6	18.8	18.8	18.2	17.8	17.3	16.6	15.9	15.1	13.9	13.2	11.9	10.5	9.6
	120	21.2	21.4	20.5	20.2	19.7	19.6	19.1	18.3	18.3	17.9	17.2	17.0	16.3	15.5	14.5	13.2	12.4	11.2	10.0	9.3
(M)	150	20.0	20.2	19.4	19.2	18.7	18.7	18.1	17.4	17.3	17.0	16.1	15.9	15.1	14.2	12.8	11.8	11.0	10.1	9.3	8.8
	200	17.4	17.8	16.9	16.8	16.4	16.3	15.6	15.0	14.6	14.6	13.1	13.1	12.3	11.7	10.5	9.9	9.5	9.1	8.6	8.2
	250	14.3	14.7	14.1	14.0	13.6	13.8	13.1	12.6	12.4	12.3	11.4	11.2	10.7	10.3	9.4	8.9	8.7	8.3	7.9	7.5
	300	11.7	12.0	11.9	11.8	11.8	11.8	11.4	11.1	11.0	10.9	10.3	10.0	9.6	9.1	8.4	8.1	7.8	7.5	7.3	6.9
	400	8.6	8.9	8.8	8.9	9.0	9.1	9.0	8.8	8.7	8.7	8.2	8.0	7.6	7.2	6.8	6.5	6.4	6.4	6.3	6.0
	500	6.7	6.6	6.6	6.6	6.6	7.1	6.9	6.8	6.8	6.6	6.3	6.2	6.1	5.8	5.8	5.5	5.5	5.5	5.6	5.6
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C — 01 AUGUST

	0	25.9	25.6	25.2	25.1	24.9	24.5	24.2	23.8	23.5	23.1	22.7	22.2	22.0	21.3	20.6	20.2	19.3	18.1	16.9	15.3
	10	25.9	25.6	25.3	25.1	24.9	24.5	24.2	23.8	23.4	23.0	22.6	22.1	21.8	21.2	20.5	20.0	19.1	17.9	16.7	15.1
	20	25.9	25.5	25.2	25.0	24.8	24.4	24.1	23.6	23.3	22.9	22.5	21.9	21.5	20.9	20.3	19.6	18.9	17.7	16.4	14.6
	30	25.9	25.5	25.1	24.9	24.7	24.3	23.9	23.3	23.1	22.7	22.2	21.4	20.9	20.0	19.4	18.8	18.3	17.2	16.1	13.7
	40	25.7	25.3	24.9	24.6	24.2	23.9	23.3	22.7	22.5	22.0	21.4	20.2	19.6	18.7	18.1	17.2	17.0	16.2	15.1	12.5
	50	25.2	24.9	24.3	23.8	23.3	22.9	22.5	21.9	21.5	20.7	20.2	19.2	18.5	17.6	17.0	16.1	15.8	15.0	14.0	11.5
D	60	24.5	24.3	23.5	23.0	22.3	22.1	21.6	20.9	20.6	19.8	19.5	18.7	17.8	17.0	16.5	15.6	15.1	14.1	13.2	11.0
E	70	23.7	23.6	22.8	22.3	21.6	21.5	21.0	20.2	20.1	19.3	18.9	18.2	17.4	16.7	16.1	15.1	14.5	13.4	12.3	10.4
P	80	23.1	23.1	22.3	21.8	21.1	21.0	20.5	19.7	19.7	18.8	18.6	17.9	17.0	16.3	15.8	14.7	13.9	12.8	11.6	10.1
T	90	22.7	22.6	21.8	21.3	20.7	20.6	20.0	19.3	19.3	18.5	18.3	17.6	16.7	16.1	15.5	14.4	13.6	12.3	11.2	9.9
H	100	22.2	22.2	21.4	20.9	20.3	20.2	19.6	18.9	19.0	18.2	18.0	17.4	16.6	15.9	15.3	14.1	13.3	11.9	10.8	9.6
	120	21.4	21.2	20.6	20.1	19.7	19.6	19.0	18.3	18.3	17.8	17.4	17.0	16.3	15.6	14.6	13.4	12.5	11.2	10.3	9.2
(M)	150	20.1	20.0	19.5	19.0	18.6	18.7	18.1	17.4	17.4	16.9	16.3	16.0	15.1	14.3	12.8	12.0	11.0	10.1	9.5	8.8
	200	17.5	17.6	17.1	16.5	16.3	16.4	15.6	14.9	14.7	14.4	13.4	13.1	12.2	11.8	10.5	10.1	9.5	9.1	8.8	8.2
	250	14.4	14.5	14.2	13.7	13.6	13.8	13.1	12.5	12.4	12.2	11.5	11.2	10.7	10.3	9.4	9.1	8.7	8.4	8.0	7.5
	300	11.8	11.8	11.8	11.6	11.7	11.8	11.3	11.0	10.9	10.8	10.3	10.0	9.6	9.2	8.5	8.2	7.8	7.6	7.4	6.9
	400	8.7	8.7	8.7	8.9	8.9	9.1	8.9	8.7	8.6	8.6	8.2	8.0	7.6	7.3	6.8	6.6	6.4	6.4	6.4	6.1
	500	6.6	6.6	6.6	6.6	6.6	7.2	6.9	6.7	6.8	6.6	6.3	6.2	6.0	5.8	5.8	5.6	5.4	5.5	5.7	5.6
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C — MID-AUGUST

	0	26.2	25.8	25.5	25.4	25.2	24.8	24.5	24.3	23.8	23.5	23.1	22.6	22.4	21.9	21.1	20.7	19.8	18.6	17.5	15.8
	10	26.2	25.7	25.5	25.4	25.1	24.8	24.5	24.2	23.7	23.5	23.1	22.5	22.2	21.8	21.0	20.5	19.7	18.4	17.3	15.6
	20	26.2	25.7	25.5	25.3	25.1	24.7	24.4	24.1	23.6	23.4	23.0	22.4	21.9	21.5	20.8	20.1	19.4	18.2	17.1	14.9
	30	26.1	25.7	25.4	25.3	25.0	24.6	24.2	23.9	23.5	23.2	22.7	21.9	21.4	20.7	20.0	19.4	18.8	17.9	16.7	13.8
	40	26.0	25.6	25.3	25.1	24.5	24.2	23.7	23.3	23.0	22.5	21.9	20.9	19.9	19.4	18.7	17.8	17.4	16.6	15.8	12.5
	50	25.5	25.1	24.7	24.3	23.5	23.3	22.8	22.4	21.9	20.9	20.5	19.8	18.7	17.9	17.3	16.5	16.0	15.3	14.7	11.5
D	60	24.8	24.4	23.8	23.3	22.5	22.3	21.8	21.3	20.9	19.8	19.6	19.0	17.9	17.2	16.6	15.8	15.2	14.2	13.8	11.1
E	70	23.9	23.6	23.0	22.6	21.7	21.6	21.0	20.5	20.3	19.2	19.0	18.5	17.4	16.8	16.2	15.3	14.6	13.5	12.9	10.4
P	80	23.3	22.9	22.4	22.0	21.2	21.1	20.5	19.9	19.8	18.8	18.7	18.1	17.1	16.5	15.9	14.9	14.0	12.9	12.1	10.1
T	90	22.9	22.4	21.9	21.5	20.8	20.6	20.0	19.5	19.4	18.5	18.4	17.8	16.8	16.3	15.6	14.6	13.6	12.4	11.6	9.9
H	100	22.4	22.0	21.5	21.0	20.3	20.3	19.6	19.1	19.1	18.2	18.1	17.5	16.6	16.1	15.4	14.3	13.3	12.0	11.2	9.6
	120	21.5	21.0	20.6	20.1	19.6	19.6	19.0	18.4	18.4	17.6	17.5	17.1	16.3	15.6	14.8	13.6	12.6	11.2	10.5	9.2
(M)	150	20.2	19.8	19.5	18.9	18.6	18.6	18.0	17.4	17.4	16.7	16.5	16.1	15.0	14.3	13.0	12.2	11.0	10.1	9.7	8.8
	200	17.5	17.3	17.1	16.4	16.3	16.3	15.7	14.9	14.7	14.1	13.7	13.2	12.2	11.8	10.6	10.2	9.4	9.1	9.0	8.2
	250	14.5	14.3	14.2	13.5	13.7	13.6	13.1	12.5	12.3	12.0	11.6	11.2	10.7	10.3	9.4	9.2	8.7	8.4	8.2	7.5
	300	11.9	11.6	11.7	11.5	11.8	11.7	11.3	11.0	10.9	10.7	10.4	10.1	9.6	9.2	8.5	8.2	7.8	7.6	7.5	6.9
	400	8.8	8.6	8.7	8.9	8.9	9.1	8.9	8.7	8.6	8.5	8.2	8.0	7.6	7.3	6.8	6.7	6.4	6.5	6.4	6.2
	500	6.7	6.7	6.6	6.6	6.6	7.2	6.9	6.7	6.7	6.5	6.4	6.1	6.0	5.7	5.8	5.6	5.4	5.6	5.7	5.7
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C 01 SEPTEMBER

	0	26.3	26.0	25.7	25.7	25.4	25.1	24.8	24.6	24.1	23.8	23.4	22.9	22.6	22.2	21.4	20.9	20.1	18.8	17.8	16.1
	10	26.4	26.0	25.7	25.6	25.4	25.1	24.7	24.5	24.0	23.8	23.3	22.8	22.5	22.1	21.3	20.7	20.0	18.7	17.7	15.8
	20	26.3	25.9	25.7	25.6	25.3	25.0	24.6	24.4	23.9	23.7	23.3	22.7	22.3	21.9	21.1	20.4	19.7	18.6	17.5	15.0
	30	26.3	25.9	25.7	25.6	25.2	24.9	24.5	24.3	23.8	23.5	22.9	22.4	21.7	21.3	20.5	19.8	19.1	18.3	17.2	13.9
	40	26.2	25.8	25.5	25.4	24.9	24.6	24.0	23.[illegible]	23.4	22.9	22.2	21.5	20.4	20.0	19.3	18.4	17.7	17.1	16.4	12.5
	50	25.8	25.3	25.1	24.7	23.9	23.7	23.1	22.8	22.3	21.3	20.8	20.4	19.0	18.3	17.7	16.9	16.2	15.6	15.2	11.5
D	60	25.1	24.5	24.2	23.6	22.9	22.[illegible]	21.9	21.6	21.1	20.1	19.7	19.4	18.0	17.3	16.7	15.9	15.2	14.4	14.2	11.0
E	70	24.1	23.6	23.3	22.9	21.9	21.7	21.0	20.7	20.3	19.2	19.0	18.7	17.5	16.8	16.3	15.4	14.6	13.6	13.3	10.5
P	80	23.4	22.9	22.5	22.2	21.4	21.1	20.4	20.1	19.8	18.8	18.7	18.3	17.1	16.6	16.0	15.1	14.0	13.0	12.4	10.1
T	90	23.1	22.3	22.0	21.6	20.9	20.6	20.0	19.7	19.4	18.5	18.4	18.0	16.9	16.4	15.7	14.7	13.6	12.5	11.9	9.9
H	100	22.5	21.9	21.5	21.2	20.4	20.2	19.6	19.3	19.0	18.2	18.1	17.8	16.7	16.2	15.5	14.4	13.2	12.0	11.4	9.6
	120	21.6	20.9	20.6	20.2	19.7	19.5	18.9	18.5	18.3	17.5	17.6	17.2	16.2	15.6	14.9	13.7	12.5	11.3	10.7	9.2
(M)	150	20.2	19.6	19.3	19.0	18.6	18.4	18.0	17.5	17.3	16.6	16.5	16.1	15.0	14.2	13.2	12.1	10.9	10.1	9.8	8.8
	200	17.7	17.2	17.0	16.5	16.4	16.1	15.8	15.0	14.7	13.9	13.9	13.3	12.1	11.6	10.7	10.2	9.4	9.1	9.0	8.2
	250	14.7	14.2	14.1	13.6	13.9	13.5	13.2	12.6	12.3	11.8	11.7	11.2	10.6	10.2	9.5	9.2	8.6	8.4	8.3	7.5
	300	12.0	11.6	11.6	11.6	11.8	11.6	11.4	11.1	10.9	10.6	10.4	10.1	9.5	9.2	8.5	8.2	7.7	7.7	7.5	7.0
	400	8.9	8.6	8.6	8.9	9.0	9.1	8.9	8.7	8.6	8.3	8.2	8.0	7.5	7.2	6.8	6.6	6.4	6.5	6.4	6.3
	500	6.7	6.7	6.6	6.7	6.7	7.1	6.8	6.7	6.6	6.5	6.4	6.1	5.9	5.6	5.7	5.6	5.5	5.6	5.7	5.7
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C MID-SEPTEMBER

	0	26.4	26.2	25.9	25.8	25.6	25.3	25.0	24.7	24.2	23.9	23.4	23.0	22.5	22.2	21.5	20.7	20.1	18.9	17.8	16.2
	10	26.5	26.2	25.9	25.8	25.6	25.3	24.9	24.7	24.2	23.9	23.4	23.0	22.5	22.1	21.4	20.6	20.0	18.8	17.8	15.9
	20	26.4	26.1	25.9	25.8	25.6	25.3	24.8	24.6	24.1	23.8	23.3	22.9	22.4	22.0	21.3	20.4	19.8	18.7	17.6	15.2
	30	26.4	26.1	25.9	25.7	25.5	25.2	24.7	24.5	24.0	23.7	23.0	22.7	21.9	21.6	20.8	19.9	19.2	18.5	17.4	14.0
	40	26.3	26.0	25.7	25.6	25.1	24.9	24.4	24.1	23.7	23.2	22.4	22.0	20.8	20.5	19.8	19.0	18.0	17.4	16.6	12.6
	50	26.0	25.5	25.3	25.1	24.2	24.2	23.6	23.2	22.7	21.8	21.1	21.0	19.4	18.7	18.1	17.3	16.5	15.9	15.3	11.5
D	60	25.4	24.8	24.5	24.3	23.2	23.0	22.2	22.0	21.4	20.5	19.9	19.8	18.2	17.5	16.9	16.1	15.2	14.7	14.2	11.0
E	70	24.4	23.8	23.5	23.[illegible]	22.3	21.9	21.1	21.1	20.4	19.4	19.0	19.0	17.5	16.9	16.3	15.4	14.5	13.8	13.3	10.4
P	80	23.6	23.0	22.6	22.4	21.6	21.1	20.4	20.4	19.7	18.8	18.6	18.4	17.2	16.6	16.0	15.1	13.9	13.1	12.5	10.1
T	90	23.2	22.4	21.9	21.[illegible]	21.0	20.6	20.1	19.9	19.3	18.5	18.3	18.1	16.9	16.4	15.7	14.7	13.5	12.6	12.0	9.9
H	100	22.6	21.9	21.4	21.3	20.5	20.2	19.7	19.5	18.9	18.2	18.0	17.9	16.7	16.2	15.5	14.4	13.1	12.1	11.5	9.6
	120	21.6	20.9	20.[illegible]	20.4	19.7	19.4	18.9	18.7	18.2	17.5	17.5	17.3	16.2	15.5	14.9	13.5	12.3	11.3	10.7	9.2
(M)	150	20.3	19.6	19.2	[illegible]	18.6	18.3	17.9	17.6	17.2	16.4	16.4	16.1	14.9	14.0	13.4	11.9	10.7	10.1	9.8	8.7
	200	17.[illegible]	17.1	16.9	16.[illegible]	16.4	15.9	15.8	15.1	14.7	13.7	13.9	13.3	12.1	11.4	10.8	10.1	9.3	9.1	9.0	8.1
	250	14.[illegible]	14.1	14.0	13.[illegible]	14.0	13.4	13.3	12.7	12.3	11.7	11.6	11.2	10.6	10.0	9.5	9.2	8.5	8.3	8.3	7.5
	300	12.1	11.7	11.6	11.6	11.9	11.5	11.5	11.2	10.9	10.4	10.4	10.1	9.5	9.1	8.6	8.1	7.6	7.6	7.5	7.0
	400	9.0	8.6	8.7	9.0	9.1	9.0	8.9	8.8	8.6	8.2	8.2	7.9	7.5	7.1	6.8	6.5	6.3	6.5	6.3	6.3
	500	[illegible]	6.7	6.7	6.9	6.8	7.0	6.8	6.7	6.5	6.4	6.3	6.1	5.9	5.6	5.6	5.6	5.5	5.5	5.6	5.7
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C — 01 OCTOBER

	0	26.4	26.2	26.1	25.9	25.7	25.4	25.0	24.6	24.2	23.8	23.2	22.9	22.3	21.9	21.3	20.3	19.9	18.7	17.6	16.0
	10	26.4	26.2	26.0	25.8	25.7	25.4	25.0	24.6	24.1	23.8	23.2	22.9	22.3	21.9	21.2	20.2	19.7	18.6	17.5	15.8
	20	26.4	26.2	26.0	25.8	25.6	25.4	24.9	24.5	24.1	23.8	23.1	22.8	22.3	21.8	21.1	20.1	19.6	18.6	17.4	15.2
	30	26.4	26.2	25.9	25.7	25.6	25.3	24.8	24.5	24.1	23.7	22.9	22.7	21.9	21.5	20.9	19.9	19.1	18.4	17.2	14.1
	40	26.3	26.1	25.8	25.6	25.3	25.1	24.6	24.2	23.8	23.3	22.4	22.3	21.2	20.7	20.1	19.3	18.2	17.6	16.4	12.8
	50	26.1	25.7	25.5	25.3	24.6	24.5	23.9	23.4	23.0	22.3	21.3	21.4	19.9	19.1	18.6	17.6	16.8	16.3	15.1	11.5
D	60	25.6	25.1	24.7	24.6	23.7	23.4	22.5	22.4	21.7	21.0	20.0	20.2	18.5	17.7	17.1	16.2	15.3	15.0	14.0	10.8
E	70	24.6	24.2	23.6	23.5	22.6	22.0	21.4	21.4	20.4	19.7	19.0	19.2	17.6	16.9	16.3	15.4	14.4	13.9	13.0	10.4
P	80	23.7	23.3	22.7	22.6	21.7	21.2	20.6	20.6	19.6	18.9	18.5	18.5	17.1	16.6	15.9	14.9	13.8	13.2	12.2	10.0
T	90	23.2	22.6	22.0	21.9	21.1	20.6	20.1	20.0	19.1	18.5	18.1	18.1	16.9	16.3	15.6	14.5	13.4	12.7	11.7	9.8
H	100	22.6	22.1	21.4	21.4	20.6	20.1	19.7	19.6	18.7	18.1	17.8	17.9	16.7	16.1	15.4	14.1	13.0	12.1	11.2	9.6
	120	21.6	21.1	20.5	20.5	19.8	19.3	19.0	18.8	18.1	17.5	17.3	17.2	16.1	15.4	14.7	13.2	12.0	11.3	10.6	9.2
(M)	150	20.3	19.8	19.2	19.3	18.6	18.2	17.9	17.7	17.1	16.4	16.2	16.0	14.8	13.8	13.4	11.5	10.6	10.1	9.7	8.7
	200	17.9	17.2	16.8	17.0	16.4	15.8	15.8	15.3	14.5	13.7	13.6	13.1	12.1	11.2	10.8	9.9	9.3	9.0	8.8	8.1
	250	14.9	14.2	14.0	14.2	14.1	13.4	13.3	12.9	12.3	11.6	11.5	11.2	10.5	9.9	9.5	9.0	8.5	8.3	8.1	7.4
	300	12.2	11.8	11.7	11.9	11.9	11.5	11.5	11.2	10.9	10.4	10.3	10.0	9.5	8.9	8.6	7.9	7.6	7.6	7.4	7.0
	400	8.9	8.6	8.7	9.1	9.2	9.0	8.9	8.8	8.7	8.2	8.1	7.8	7.5	7.0	6.8	6.4	6.3	6.4	6.3	6.2
	500	6.9	6.7	6.8	6.9	6.8	6.9	6.8	6.8	6.5	6.4	6.2	6.1	6.0	5.6	5.6	5.5	5.5	5.5	5.5	5.7
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C — MID-OCTOBER

	0	26.3	26.1	26.0	25.7	25.5	25.3	24.8	24.3	23.9	23.5	22.8	22.5	21.9	21.4	20.8	19.7	19.3	18.3	17.0	15.6
	10	26.3	26.1	25.9	25.7	25.5	25.3	24.8	24.2	23.9	23.4	22.8	22.5	21.9	21.3	20.7	19.6	19.2	18.3	17.0	15.5
	20	26.3	26.1	25.9	25.6	25.5	25.3	24.7	24.2	23.9	23.4	22.7	22.5	21.9	21.3	20.7	19.6	19.1	18.2	16.9	15.1
	30	26.2	26.1	25.8	25.5	25.5	25.2	24.7	24.2	23.9	23.4	22.6	22.5	21.7	21.2	20.6	19.5	18.9	18.1	16.7	14.2
	40	26.2	26.0	25.7	25.4	25.3	25.1	24.6	24.0	23.7	23.2	22.3	22.2	21.3	20.7	20.1	19.3	18.3	17.6	16.0	13.0
	50	26.0	25.8	25.5	25.2	24.8	24.7	24.1	23.4	23.1	22.6	21.4	21.5	20.3	19.4	18.8	17.8	17.0	16.5	14.8	11.6
D	60	25.6	25.3	24.8	24.7	24.0	23.7	22.9	22.7	21.9	21.4	20.3	20.4	18.9	17.9	17.3	16.3	15.6	15.2	13.5	10.7
E	70	24.9	24.6	23.8	23.7	22.9	22.3	21.8	21.7	20.6	20.0	19.2	19.3	17.8	17.1	16.3	15.2	14.4	13.9	12.6	10.3
P	80	24.0	23.8	22.8	22.8	21.9	21.3	20.9	20.7	19.7	19.1	18.5	18.5	17.2	16.6	15.8	14.6	13.8	13.1	11.8	10.0
T	90	23.3	23.0	22.1	22.0	21.2	20.7	20.3	20.1	19.1	18.5	18.1	18.1	16.8	16.3	15.5	14.3	13.4	12.6	11.3	9.7
H	100	22.5	22.3	21.5	21.4	20.6	20.1	19.8	19.7	18.7	18.1	17.7	17.8	16.6	16.0	15.2	13.8	12.9	12.0	10.9	9.5
	120	21.6	21.3	20.7	20.6	19.8	19.3	19.0	18.9	18.0	17.5	17.1	17.1	16.1	15.3	14.5	12.9	11.9	11.2	10.3	9.2
(M)	150	20.3	19.9	19.4	19.4	18.7	18.2	17.9	17.8	17.0	16.4	16.0	15.8	14.8	13.7	13.3	11.2	10.5	10.1	9.5	8.6
	200	17.9	17.3	17.0	17.2	16.4	15.8	15.8	15.5	14.4	13.7	13.3	12.9	12.1	11.1	10.8	9.7	9.3	9.0	8.6	8.0
	250	14.8	14.3	14.2	14.4	14.0	13.4	13.3	13.0	12.3	11.7	11.4	11.1	10.6	9.8	9.5	8.9	8.4	8.2	7.9	7.4
	300	12.1	11.9	11.8	12.1	11.8	11.5	11.5	11.3	10.9	10.4	10.2	9.9	9.5	8.9	8.6	7.8	7.6	7.5	7.3	6.9
	400	8.8	8.7	8.7	9.1	9.2	8.9	8.9	8.8	8.7	8.2	8.1	7.7	7.5	7.0	6.8	6.3	6.3	6.3	6.3	6.1
	500	6.8	6.7	6.8	6.9	6.8	6.8	6.8	6.8	6.6	6.3	6.2	6.0	6.0	5.6	5.6	5.5	5.5	5.5	5.4	5.6
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

D I S T A N C E

MEAN XBT TEMPERATURE, DEG-C 01 NOVEMBER

0	26.0	25.8	25.6	25.3	25.2	24.9	24.4	23.8	23.5	22.9	22.2	21.9	21.3	20.6	20.1	19.0	18.6	17.7	16.3	15.1
10	26.0	25.8	25.6	25.3	25.1	24.9	24.4	23.8	23.5	22.8	22.2	21.9	21.3	20.6	20.0	19.0	18.6	17.7	16.3	15.0
20	26.0	25.8	25.6	25.3	25.1	24.9	24.4	23.7	23.5	22.8	22.2	21.9	21.3	20.6	20.0	19.0	18.6	17.7	16.2	14.8
30	25.9	25.8	25.6	25.2	25.1	24.9	24.4	23.7	23.4	22.8	22.1	21.9	21.3	20.6	20.0	19.0	18.5	17.6	16.1	14.1
40	25.9	25.7	25.5	25.1	25.0	24.8	24.4	23.7	23.4	22.8	22.0	21.8	21.1	20.4	19.7	19.0	18.2	17.4	15.4	13.1
50	25.8	25.6	25.3	25.0	24.8	24.6	24.0	23.3	23.0	22.5	21.4	21.4	20.4	19.5	18.9	17.9	17.2	16.6	14.5	11.7
D 60	25.5	25.4	24.7	24.6	24.2	23.8	23.1	22.8	22.1	21.6	20.4	20.4	19.3	18.2	17.6	16.3	15.8	15.4	13.2	10.7
E 70	25.1	24.9	23.9	23.8	23.1	22.5	22.3	21.9	20.9	20.3	19.4	19.3	18.1	17.4	16.4	15.1	14.7	13.9	12.2	10.2
P 80	24.2	24.2	23.1	22.9	22.0	21.6	21.3	20.9	20.0	19.3	18.7	18.5	17.3	16.7	15.7	14.5	13.9	13.1	11.4	9.9
T 90	23.4	23.4	22.4	22.1	21.2	20.8	20.4	20.3	19.3	18.6	18.2	18.0	16.8	16.3	15.4	14.0	13.3	12.4	10.9	9.7
H 100	22.6	22.6	21.8	21.5	20.7	20.3	19.9	19.7	18.7	18.1	17.7	17.6	16.5	15.9	15.1	13.5	12.8	11.9	10.5	9.4
120	21.6	21.4	20.9	20.6	19.8	19.4	19.1	18.9	18.0	17.5	17.0	16.9	16.0	15.3	14.4	12.6	11.9	11.1	10.0	9.1
(M) 150	20.2	20.1	19.7	19.4	18.6	18.2	18.0	17.8	16.9	16.3	15.9	15.6	14.7	13.7	13.1	11.1	10.6	10.0	9.3	8.6
200	17.7	17.4	17.3	17.1	16.3	15.8	15.7	15.6	14.2	13.8	13.0	12.7	12.1	11.1	10.7	9.6	9.3	9.0	8.5	7.9
250	14.6	14.3	14.4	14.3	13.8	13.4	13.2	13.0	12.2	11.7	11.3	11.0	10.6	9.8	9.5	8.8	8.5	8.2	7.8	7.3
300	11.9	11.9	11.9	12.0	11.7	11.5	11.4	11.3	10.9	10.5	10.1	9.8	9.5	8.8	8.5	7.8	7.6	7.4	7.2	6.8
400	8.7	8.7	8.8	9.1	9.1	9.0	8.9	8.8	8.7	8.3	7.9	7.7	7.6	7.0	6.8	6.3	6.3	6.2	6.3	6.0
500	6.7	6.6	6.8	6.9	6.8	6.7	6.8	6.8	6.6	6.3	6.1	6.0	6.1	5.7	5.6	5.6	5.5	5.5	5.5	5.5
N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C MID-NOVEMBER

0	25.6	25.3	25.1	24.8	24.6	24.3	23.8	23.2	22.9	22.1	21.5	21.1	20.5	19.8	19.2	18.3	17.8	17.0	15.6	14.3
10	25.5	25.3	25.1	24.8	24.6	24.3	23.8	23.2	22.9	22.1	21.4	21.1	20.5	19.8	19.1	18.3	17.8	17.0	15.6	14.3
20	25.5	25.3	25.1	24.8	24.6	24.3	23.8	23.2	22.9	22.1	21.5	21.2	20.6	19.8	19.1	18.3	17.9	17.0	15.5	14.3
30	25.5	25.3	25.1	24.7	24.6	24.3	23.8	23.2	22.8	22.1	21.5	21.1	20.6	19.9	19.2	18.3	17.9	17.0	15.4	13.8
40	25.5	25.3	25.0	24.7	24.5	24.4	23.8	23.1	22.8	22.1	21.5	21.1	20.6	19.9	19.1	18.4	17.8	17.0	14.9	13.1
50	25.4	25.3	24.9	24.6	24.5	24.2	23.7	23.1	22.6	22.0	21.1	20.9	20.3	19.4	18.7	17.7	17.2	16.5	14.3	11.8
D 60	25.3	25.2	24.6	24.3	24.0	23.7	23.2	22.8	22.1	21.5	20.5	20.2	19.5	18.5	17.7	16.4	16.1	15.3	13.1	10.8
E 70	25.1	25.0	24.0	23.8	23.1	22.7	22.6	22.1	21.2	20.5	19.7	19.3	18.4	17.7	16.6	15.2	15.0	14.0	12.1	10.2
P 80	24.4	24.4	23.3	23.1	22.1	21.8	21.7	21.1	20.3	19.5	19.0	18.6	17.5	17.0	15.8	14.5	14.1	13.0	11.3	9.9
T 90	23.5	23.6	22.7	22.2	21.3	21.1	20.7	20.4	19.6	18.7	18.5	18.0	16.9	16.4	15.4	13.9	13.3	12.3	10.7	9.7
H 100	22.7	22.8	22.1	21.6	20.7	20.4	20.0	19.8	19.0	18.1	17.9	17.5	16.5	15.9	15.0	13.4	12.8	11.8	10.3	9.4
120	21.5	21.5	21.1	20.6	19.8	19.4	19.0	18.9	18.1	17.5	17.1	16.8	16.0	15.3	14.3	12.6	11.9	10.9	9.8	9.1
(M) 150	20.2	20.1	19.9	19.3	18.6	18.2	17.9	17.8	16.9	16.3	15.9	15.4	14.7	13.7	12.9	11.2	10.7	10.0	9.2	8.6
200	17.5	17.3	17.5	17.0	16.2	15.9	15.5	15.5	14.2	13.8	12.9	12.6	12.1	11.2	10.7	9.7	9.3	8.9	8.4	7.9
250	14.3	14.2	14.6	14.1	13.7	13.5	13.0	12.9	12.2	11.7	11.2	10.9	10.6	9.9	9.5	8.8	8.5	8.1	7.7	7.3
300	11.7	11.7	12.0	11.9	11.6	11.6	11.3	11.3	10.9	10.5	10.0	9.8	9.6	8.9	8.5	7.9	7.7	7.4	7.2	6.8
400	8.5	8.7	8.8	9.1	9.0	9.0	8.9	8.8	8.6	8.3	7.9	7.6	7.6	7.1	6.8	6.4	6.3	6.2	6.3	6.0
500	6.6	6.6	6.7	6.8	6.8	6.8	6.7	6.7	6.6	6.3	6.1	6.1	6.1	5.8	5.7	5.6	5.5	5.5	5.5	5.5
N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

DISTANCE

MEAN XBT TEMPERATURE, DEG-C — 01 DECEMBER

	0	25.1	24.8	24.5	24.2	23.9	23.7	23.2	22.6	22.2	21.3	20.7	20.4	19.8	19.1	18.3	17.7	17.1	16.3	14.9	13.6
	10	25.1	24.8	24.5	24.2	23.9	23.7	23.1	22.6	22.2	21.3	20.7	20.4	19.8	19.1	18.3	17.7	17.1	16.3	14.9	13.6
	20	25.1	24.8	24.5	24.2	23.9	23.7	23.2	22.6	22.2	21.3	20.8	20.4	19.8	19.1	18.3	17.6	17.1	16.3	14.9	13.6
	30	25.1	24.8	24.5	24.2	23.9	23.7	23.2	22.6	22.2	21.3	20.8	20.4	19.8	19.1	18.3	17.6	17.3	16.4	14.8	13.4
	40	25.0	24.8	24.5	24.2	23.9	23.7	23.2	22.6	22.2	21.3	20.9	20.4	19.9	19.2	18.4	17.7	17.3	16.4	14.6	12.9
	50	25.0	24.8	24.5	24.2	24.0	23.7	23.2	22.7	22.2	21.3	20.6	20.3	19.8	19.1	18.3	17.4	17.0	16.2	14.2	11.9
D	60	25.0	24.9	24.3	24.0	23.7	23.4	23.0	22.5	22.0	21.1	20.4	20.0	19.4	18.6	17.7	16.4	16.2	15.2	13.2	10.9
E	70	25.0	24.8	23.9	23.7	23.0	22.7	22.7	22.0	21.4	20.4	19.8	19.3	18.6	18.0	16.8	15.3	15.3	14.1	12.2	10.3
P	80	24.4	24.3	23.5	23.1	22.2	22.0	21.9	21.3	20.7	19.6	19.4	18.7	17.7	17.3	16.0	14.7	14.3	13.1	11.3	9.9
T	90	23.5	23.6	22.9	22.4	21.4	21.3	20.9	20.6	19.9	18.8	18.9	18.1	17.1	16.6	15.5	14.0	13.3	12.3	10.8	9.7
H	100	22.8	22.8	22.4	21.7	20.8	20.6	20.1	19.9	19.3	18.3	18.2	17.5	16.7	16.0	15.0	13.5	12.8	11.7	10.4	9.4
	120	21.5	21.4	21.3	20.6	19.9	19.5	19.0	18.9	18.2	17.4	17.3	16.8	16.1	15.3	14.3	12.7	12.0	10.8	9.7	9.0
(M)	150	20.1	19.9	20.0	19.3	18.6	18.2	17.9	17.7	16.9	16.2	16.0	15.4	14.7	13.8	12.8	11.3	10.7	9.9	9.1	8.6
	200	17.3	17.3	17.7	16.7	16.1	15.9	15.4	15.4	14.2	13.7	12.9	12.6	12.1	11.3	10.6	9.7	9.3	8.9	8.4	8.0
	250	14.0	14.2	14.7	13.9	13.5	13.4	12.9	12.8	12.2	11.7	11.1	10.9	10.6	10.0	9.5	8.9	8.5	8.1	7.7	7.4
	300	11.5	11.6	12.0	11.8	11.6	11.6	11.2	11.2	10.8	10.5	10.0	9.8	9.6	8.9	8.4	8.0	7.7	7.3	7.2	6.8
	400	8.4	8.7	8.8	9.0	9.0	9.0	8.8	8.7	8.6	8.4	7.8	7.6	7.6	7.2	6.7	6.5	6.4	6.2	6.3	6.0
	500	6.6	6.6	6.6	6.7	6.8	6.8	6.7	6.7	6.7	6.3	6.1	6.1	6.0	5.9	5.7	5.6	5.5	5.6	5.6	5.4
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
	KM	93	278	463	649	834	1019	1205	1390	1575	1761	1946	2131	2317	2502	2687	2872	3058	3243	3428	3614

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MEAN XBT TEMPERATURE, DEG-C — MID-DECEMBER

	0	24.5	24.3	23.8	23.6	23.2	22.9	22.4	22.0	21.5	20.5	20.0	19.6	18.9	18.3	17.4	17.0	16.3	15.5	14.3	12.9
	10	24.5	24.3	23.8	23.6	23.2	22.9	22.4	22.0	21.5	20.4	20.0	19.5	18.9	18.3	17.4	17.0	16.3	15.6	14.3	12.9
	20	24.5	24.3	23.8	23.6	23.2	22.9	22.4	22.0	21.5	20.4	20.0	19.5	18.9	18.3	17.4	16.9	16.3	15.6	14.3	12.8
	30	24.5	24.2	23.8	23.6	23.2	22.9	22.4	22.0	21.5	20.4	20.0	19.6	18.9	18.4	17.5	16.9	16.4	15.7	14.3	12.8
	40	24.5	24.3	23.9	23.7	23.2	23.0	22.4	22.0	21.5	20.5	20.1	19.6	19.0	18.5	17.6	16.8	16.5	15.7	14.2	12.5
	50	24.5	24.3	23.9	23.6	23.3	23.0	22.5	22.1	21.5	20.5	20.0	19.7	19.1	18.5	17.7	16.9	16.5	15.7	14.1	11.9
D	60	24.6	24.3	23.8	23.6	23.1	22.9	22.6	22.1	21.6	20.5	20.0	19.6	19.1	18.4	17.5	16.4	16.1	15.1	13.4	11.2
E	70	24.6	24.3	23.7	23.5	22.8	22.5	22.5	21.8	21.4	20.2	19.8	19.2	18.6	18.1	16.9	15.5	15.5	14.3	12.5	10.5
P	80	24.2	23.9	23.4	23.1	22.2	22.0	21.9	21.3	20.9	19.6	19.5	18.8	17.9	17.5	16.2	15.0	14.4	13.3	11.6	9.9
T	90	23.5	23.3	23.0	22.5	21.5	21.4	21.0	20.8	20.2	19.1	19.2	18.3	17.4	16.9	15.7	14.2	13.3	12.4	11.0	9.7
H	100	22.9	22.6	22.5	21.9	21.0	20.8	20.2	20.0	19.6	18.5	18.6	17.7	16.9	16.2	15.0	13.7	12.7	11.8	10.6	9.5
	120	21.5	21.2	21.2	20.6	20.0	19.6	19.0	18.9	18.4	17.4	17.6	16.9	16.1	15.3	14.3	12.9	11.9	10.9	9.9	9.1
(M)	150	20.1	19.7	19.9	19.2	18.6	18.2	17.8	17.5	17.0	16.1	16.1	15.6	14.7	13.9	12.8	11.5	10.6	9.9	9.2	8.7
	200	17.2	17.2	17.6	16.6	16.1	15.8	15.3	15.2	14.4	13.5	13.1	12.7	12.0	11.4	10.5	9.8	9.3	8.9	8.5	8.0
	250	13.9	14.1	14.7	13.7	13.4	13.3	12.8	12.6	12.2	11.7	11.1	10.9	10.5	10.0	9.5	8.9	8.5	8.1	7.8	7.4
	300	11.4	11.5	12.0	11.7	11.5	11.5	11.2	11.2	10.9	10.5	9.9	9.8	9.5	9.0	8.4	8.0	7.7	7.3	7.2	6.9
	400	8.3	8.6	8.8	8.9	8.9	8.9	8.8	8.7	8.6	8.3	7.8	7.7	7.5	7.2	6.7	6.5	6.4	6.2	6.2	6.1
	500	6.6	6.6	6.6	6.7	6.9	6.8	6.7	6.6	6.6	6.4	6.2	6.2	5.9	5.8	5.7	5.6	5.5	5.6	5.6	5.5
	N MI	50	150	250	350	450	550	650	750	850	950	1050	1150	1250	1350	1450	1550	1650	1750	1850	1950
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NOAA Technical Report NMFS SSRF-730

Surface Circulation in the Northwestern Gulf of Mexico as Deduced From Drift Bottles

Robert F. Temple and John A. Martin

May 1979

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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NOAA Technical Report NMFS SSRF-730

Surface Circulation in the Northwestern Gulf of Mexico as Deduced From Drift Bottles

Robert F. Temple and John A. Martin

May 1979

U.S. DEPARTMENT OF COMMERCE
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CONTENTS

Figures

Tables

Surface Circulation in the Northwestern Gulf of Mexico as Deduced From Drift Bottles[1]

ROBERT F. TEMPLE and JOHN A. MARTIN[2]

ABSTRACT

Drift bottles were released monthly at predetermined stations in the northwestern Gulf of Mexico from February 1962 to December 1963. Of the total 7,863 bottles released, 12% (953) were recovered within 30 days after release. Analysis of the monthly recoveries revealed seasonal shifts in the flow of surface waters. Between September and February the dominant flow was west along the Louisiana and east Texas coasts, shifting southwest along the southern Texas coast. Between March and May, currents underwent a transitional period, shifting to the north and onshore, particularly along the south and central Texas coast. Converging currents, also apparent along the south Texas coast, appeared to progress up the coast with time. In June and July the surface flow was to the northeast and east. August was another transitional period with currents appearing to weaken and turning onshore. Movements of surface waters appeared directly related to prevailing winds.

INTRODUCTION

As part of an expanded research effort in 1962 (Kutkuhn 1963), the Bureau of Commercial Fisheries, now the National Marine Fisheries Service, NOAA, initiated a drift bottle study to determine the direction and rate of flow of surface waters in the northwestern Gulf of Mexico. The objectives of this study were: 1) to document on a monthly basis surface current direction and velocity; and 2) to attempt to relate monthly variations in current direction and speed with the success or failures of the yearly shrimp crops. Shrimp are planktonic, and may be dependent upon currents for transportation to the estuarine nursery grounds, which are essential for successful completion of their life cycle. The drift bottle study reported herein began in 1962 and continued through 1963.

Seasonal difference in direction and speed of surface currents in the Gulf of Mexico have been generally described by Smith et al. (1951), Leipper (1954), Curray (1960), Chew et al. (1962), and Ichiye (1962). More recent works on current include those by Drennan (1963), Drennan et al. (1963), Armstrong et al. (1967), Watson and Behrens (1970), Ichiye and Sudo (1971),[3] and Moore (1973). Many of the above studies, however, although contributing to an understanding of ocean currents in the Gulf, were restricted to limited geographic areas and completed over relatively short time periods. The data presented in this report are unique in that they were generated from the entire northwestern Gulf of Mexico and on a monthly basis for a 2-yr period, thus providing a time series heretofore unavailable.

METHODS

Cruises were conducted monthly with chartered shrimp vessels from February 1962 to November 1963 to stations located over the continental shelf (Fig. 1). The monthly schedule was followed as closely as possible, the only exceptions being due to adverse weather conditions or mechanical breakdowns. Operations were similar between years except that fewer stations were occupied in 1963, and one vessel was used to cover the entire study area rather than two as in 1962. The general overall effects of these modifications were that in 1963 the areal coverage was slightly reduced, and the time required to provide total coverage of the study area was increased. The latter effect explains seeming discrepancies in the date labeling of figures used in the analysis to follow. For example, the April cruise in 1963 extended into May.

Drift bottles used throughout the study were made of clear glass, about 22 cm in height, 6 cm in diameter, and had a capacity of about 240 cm^3. Each bottle contained a bright reddish-orange card on which was a brief message in Spanish and English. A reward of 50 cents was paid for the return of the card with information of location and date of recovery. In most cases, half the bottles released at a station were ballasted (odd numbers) and half were unballasted (even numbers). Those ballasted floated at or just under the surface. The reason for the use of the two types of bottles was an attempt to determine the direct effects of winds.

The number of bottles released during each cruise varied during the 2-yr study. Generally, 12 bottles were released at each station in 1962; 4-10 bottles were released per station in 1963. This modification did not affect the rate of recovery for bottles within 30 days after release for the percent recovered in 1963 was greater than

[1]The compilation, tabulation, and analysis of part of the data reported herein were supported under the Department of Interior's Bureau of Land Management Interagency Agreement No. 08550-1A5-19.

[2]Gulf Fisheries Center, National Marine Fisheries Service, NOAA, Galveston, TX 77550.

[3]Ichiye, T., and H. Sudo. 1971. Mixing processes between shelf and deep sea waters of the Texas coast. Dep. Oceanogr., Texas A&M University, Ref. 71-19-T, p. 30.

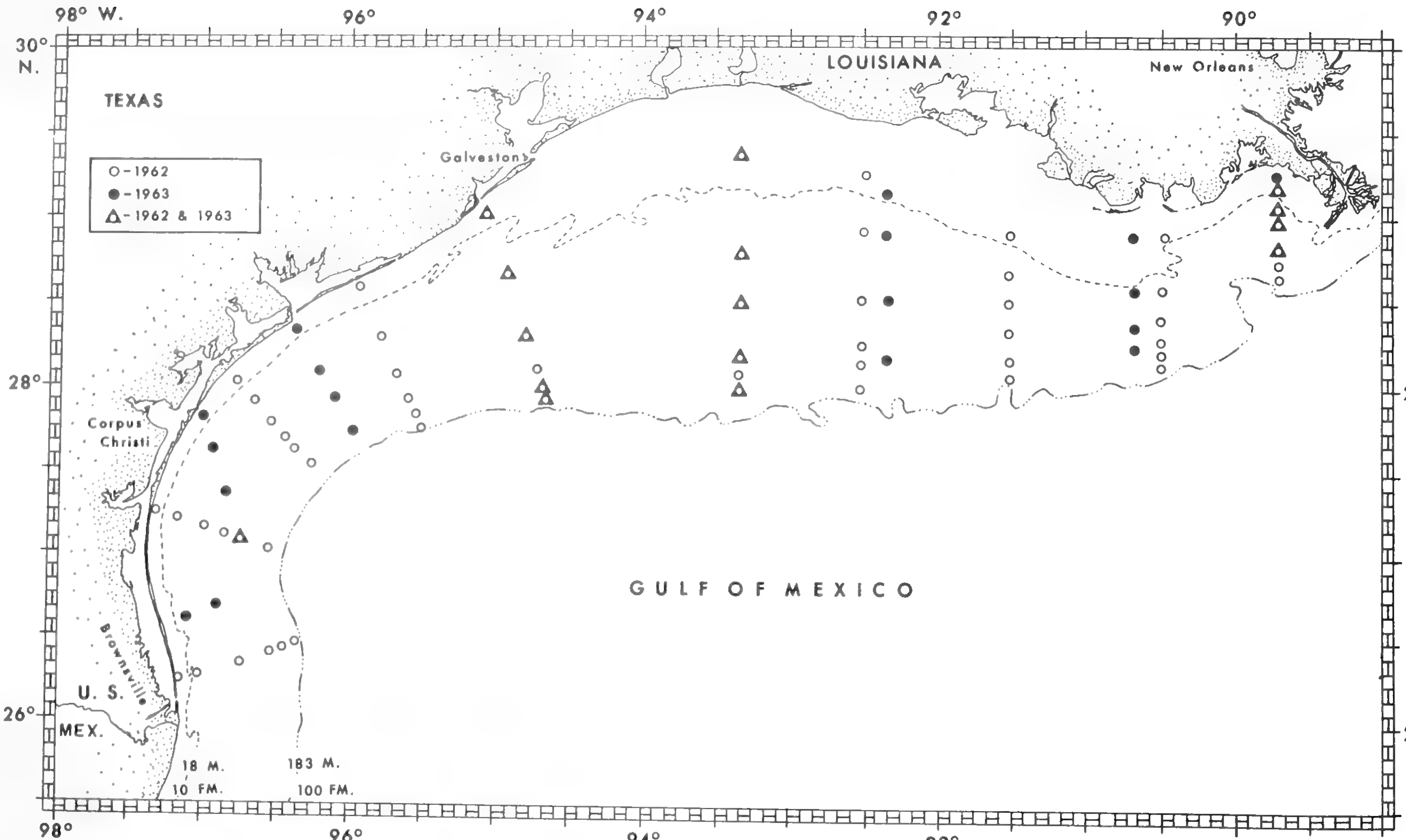

Figure 1.—The drift bottle study area in the northwestern Gulf of Mexico with the location of stations occupied in 1962 and 1963.

in 1962 (Table 1). This increase was probably due to greater public awareness of the program in 1963 than in 1962.

The technique used to depict surface currents was the same as used by Day (1958). Recovered bottles were grouped into two time periods of 15 days each, i.e., 0-15 days and 16-30 days. The 0-15 day recoveries were first plotted as straight lines connecting points of release and recovery. These lines were resolved into directional arrows, and over these arrows we then plotted, as straight lines, the 16-30 day recoveries. The final step was to reduce the 16-30 day straight lines to flow arrows conforming with the 0-15 directional arrows, thus depicting residual drift, not the actual path traversed by a bottle. The reason for the selected groupings and the exclusion of bottles recovered after 30 days was the existence of the sand or sand-shell beaches throughout the northwestern Gulf of Mexico, and the possibility of bottles drifting ashore, remaining intact, but not being found until some later date.

Rates of drift, killometers per day, were determined from recoveries made within 15 days after release. In instances where several bottles were returned from a single station, the bottle or bottles adrift for the shortest time period were used to determine rate of drift. Also, if two or more bottles, recovered from the same release, were adrift for the same period of time but had traveled different distances, these distances were averaged before determination of drift rate. Consequently, one directional arrow may represent the recovery of several bottles, and the speed an average speed.

Daily wind data from the climatological records published monthly by the U.S. Weather Bureau, now the National Weather Service, were used to depict prevailing wind conditions over the study area during each cruise (U.S. Department of Commerce 1962-1963a, 1962-1963b, 1962-1963c). This information was recorded at weather stations in Brownsville and Galveston, Tex., and New Orleans, La. Since the time required to complete each cruise varied, it was arbitrarily decided to construct resultant wind vectors for the time period between the first and last days of each cruise plus an additional 15 consecutive days. These data were converted to Beaufort units and incorporated into progressive vector analysis, the lengths of which measured in Beaufort units were divided by the total number of days to give a vector average for each period under consideration.

All drift bottle release and recovery data used in this report are on file in the National Oceanographic Data Center, Department of Commerce, Washington, D.C. 20235, under Ref. 78-0035.

Table 1.—Numbers of drift bottles released and recovered in the Gulf of Mexico within 0-15 and 16-30 days, by cruises, 1962 and 1963.

Cruise	Inclusive Dates	Total Deposited	Recoveries 0-15	Recoveries 16-30	% Recovered Within 30 days
1-62	Feb. 17-Feb. 27	651	25	12	6
2-62	Mar. 20-Mar. 27	697	27	53	11
3-62	Apr. 18-Apr. 26	690	33	39	10
4-62	May 18-May 22	525	26	11	7
5-62	June 18-July 1	691	32	25	8
6-62	July 18-Aug. 1	276	21	10	11
7-62	Sep. 7-Sep. 25	663	45	26	11
8-62	Oct. 16-Oct. 30	594	13	8	4
9-62	Nov. 14-Dec. 5	697	74	19	13
10-62	Dec. 4-Dec. 19	583	30	1	5
1962 Totals		6,067	326	204	9
1-63	Jan. 22-Feb. 5	305	13	5	6
2-63	Feb. 19-Mar. 9	203	14	20	17
3-63	Mar. 27-Apr. 6	254	21	61	32
4-63	Apr. 21-May 7	180	46	24	39
5-63	May 13-May 23	209	57	21	37
6-63	June 19-June 27	192	25	31	29
7-63	July 10-July 16	50	1	1	4
8-63	Aug. 17-Aug. 31	118	9	6	13
9-63	Sep. 22-Oct. 4	86	10	35	42
10-63	Oct. 20-Nov 4	111	0	13	12
11-63	Nov. 20-Dec. 1	88	1	9	11
1963 Totals		1,796	197	226	24

RESULTS AND DISCUSSION

Comparison of Ballasted and Unballasted Drift Bottles

Because of the use of two types of bottles, i.e., ballasted and unballasted, data were grouped by bottle type to determine if differences existed between rates of recovery (Table 2), direction of drift, and speed of drift.

Cruise values of percent recovery fluctuated from 22 to 54% between Cruise 1-62 and Cruise 6-63. Thereafter, values fluctuated from 0 to 76%, reflecting probably the reduced number of bottles released during this period (Table 1). It was readily apparent that in general fewer ballasted than unballasted bottles were recovered within 30 days after release (Table 2). For a comparison of direction and speed of ballasted and unballasted bottle drift, we arbitrarily selected 10 "test groups" for analysis, i.e., stations from which several ballasted and unballasted bottles were recovered within 15 days from a single release (Table 3).

The average direction of both types of bottles was usually similar. One exception was "test 8" in which several ballasted bottles moved southward down the coast, while several unballasted bottles moved northward up the coast. Average speeds were also generally similar with no definite indication that unballasted bottles drifted at a greater rate than did unballasted bottles.

Surface Circulation

Over the 2-yr period, surface currents underwent distinct directional shifts which were, in general, similar between years. Because of this, specific months, although illustrated individually, have been grouped, irrespective of years: January-February; March-May; June-July; August; and September-December.

January-February.—Currents during this period generally paralleled the northwestern Gulf coast, flowing west off Louisiana and becoming southwest off Texas (Fig. 2). Slight deviations from this pattern were apparent in 1962 in two areas. Just west of the Mississippi River the flow was to the north and onshore, whereas off the south Texas coast there were indications of an inshore countercurrent to the north.

Current velocities ranged from a low of 4 km/day to a high of 14 km/day. Greatest velocities (9-14 km/day) were observed in waters over the central portion of the study area, i.e., off western Louisiana and eastern Texas. Lowest velocities occurred just west of the Mississippi River (5 km/day) and off south Texas (4 km/day) in the vicinity of Brownsville.

Table 2.--Comparison by cruise of recovery of ballasted and unballasted drift bottles within 30 days after release in the Gulf of Mexico

Cruise	Recoveries: Ballasted	Recoveries: Unballasted	Recoveries: Total	Ballasted / Total Recovered
1-62	8	29	37	22
2-62	27	53	80	34
3-62	17	55	72	24
4-62	9	28	37	24
5-62	21	36	57	37
6-62	7	24	31	23
7-62	19	52	71	27
8-62	7	14	21	33
9-62	50	43	93	54
10-62	9	22	31	29
1-63	9	9	18	50
2-63	17	17	34	50
3-63	31	51	82	38
4-63	25	45	70	36
5-63	33	45	78	42
6-63	25	31	56	45
7-63	0	2	2	0
8-63	3	12	15	20
9-63	34	11	45	76
10-63	8	5	13	62
11-63	7	3	10	70
Totals	366	587	953	38

Table 3.—Comparison of the direction and speed of ballasted (B) and unballasted (U) bottles recovered within 15 days after release in the Gulf of Mexico.

Test	Type Bottle	Number Recovered	Direction (True) Range	Direction (True) Average	Speed (km/day) Range	Speed (km/day) Average
#1	B	4	--	276°	--	4.6
	U	6	230°-276°	268°	1.9.-4.6	4.1
#2	B	4	007°-016°	013°	3.7-18.5	9.3
	U	5	347°-007°	357°	3.7-15.7	11.7
#3	B	6	244°-359°	263°	0.9-3.9	1.7
	U	6	--	244°	--	1.1
#4	B	6	204°-215°	207°	17.0-21.1	19.8
	U	2	204°-205°	204°	18.3-19.1	18.7
#5	B	5	--	339°	5.9-6.3	6.1
	U	4	331°-339°	334°	2.6-6.3	3.7
#6	B	5	292°-307°	302°	2.4-4.8	4.3
	U	6	292°-317°	305°	2.9-9.3	5.0
#7	B	3	--	298°	--	6.3
	U	5	--	298°	6.3-8.3	7.0
#8	B	5	180°-195°	187°	5.6-6.5	6.1
	U	5	195°-009°	334°	5.6-26.8	10.7
#9	B	4	--	291°	25.9-38.9	32.4
	U	3	--	291°	5.9-38.9	20.0
#10	B	3	336°-354°	346°	4.4-7.9	6.7
	U	4	341°-012°	360°	8.3-14.6	9.8

Resultant wind vectors for the cruise periods revealed differences between areas in the northwestern Gulf as well as differences between months. In January 1963, winds at New Orleans were generally northerly or offshore, those at Galveston northeasterly or alongshore, and those at Brownsville southeasterly or onshore. This circulation pattern of winds may account for the absence of recoveries of bottles released east of Galveston.

In February 1962 and 1963 winds were generally similar over the entire study area, i.e., east to southeast flowing west alongshore at New Orleans and Galveston and onshore at Brownsville. Strongest winds occurred at Brownsville in both years and probably accounted for the reduced rate of alongshore flow of surface waters observed in that area.

March-May.—Drift bottle movements indicated a transitional period for surface currents in the study area during both years with several distinct features (Figs. 3, 4). First, the flow of surface waters off Louisiana was predominately to the west in March of both years, but as time progressed, the flow direction generally shifted to the north and became onshore in May. This onshore component was more pronounced in May 1962 than in May 1963 when some east to west movement was still apparent. Apparent monthly differences in the timing of the breakdown of the dominant east to west movement between years may be accounted for by the difference in cruise dates between years or may reflect real yearly differences. Associated with this dominant flow off Louisiana was a generally weak northward onshore movement of nearshore waters just west of the Mississippi River.

The second prominent feature during this period was the movement of waters off the south Texas coast. Recoveries during both years indicated an area of convergence of currents. Furthermore, as the season progressed, this arc of convergence moved northward up the Texas coast until the flow of surface waters became almost directly onshore. In May 1963, however, this pattern can only be inferred due to the paucity of drift bottle releases off the south Texas coast.

The third distinct feature of the circulation pattern was the indication of the presence of an oceanic surface current that existed in waters beyond the continental shelf. This was particularly apparent in March of both years and April 1962 when several bottles deposited on the edge of the shelf apparently moved against (straight line trajectory) prevailing shelf currents. From this set of data, it appeared that in the surface waters three current systems may have been present in the study area: a nearshore countercurrent, a shelf current, and an oceanic current.

Current velocities varied depending on location within the study area. Speeds of the dominant east to west drift off Louisiana ranged between 7 and 14 km/day whereas the weak onshore current just west of the Mississippi River ranged from 1 to 3 km/day. Within the area of convergence off Texas, speeds ranged from 3 to 17 km/

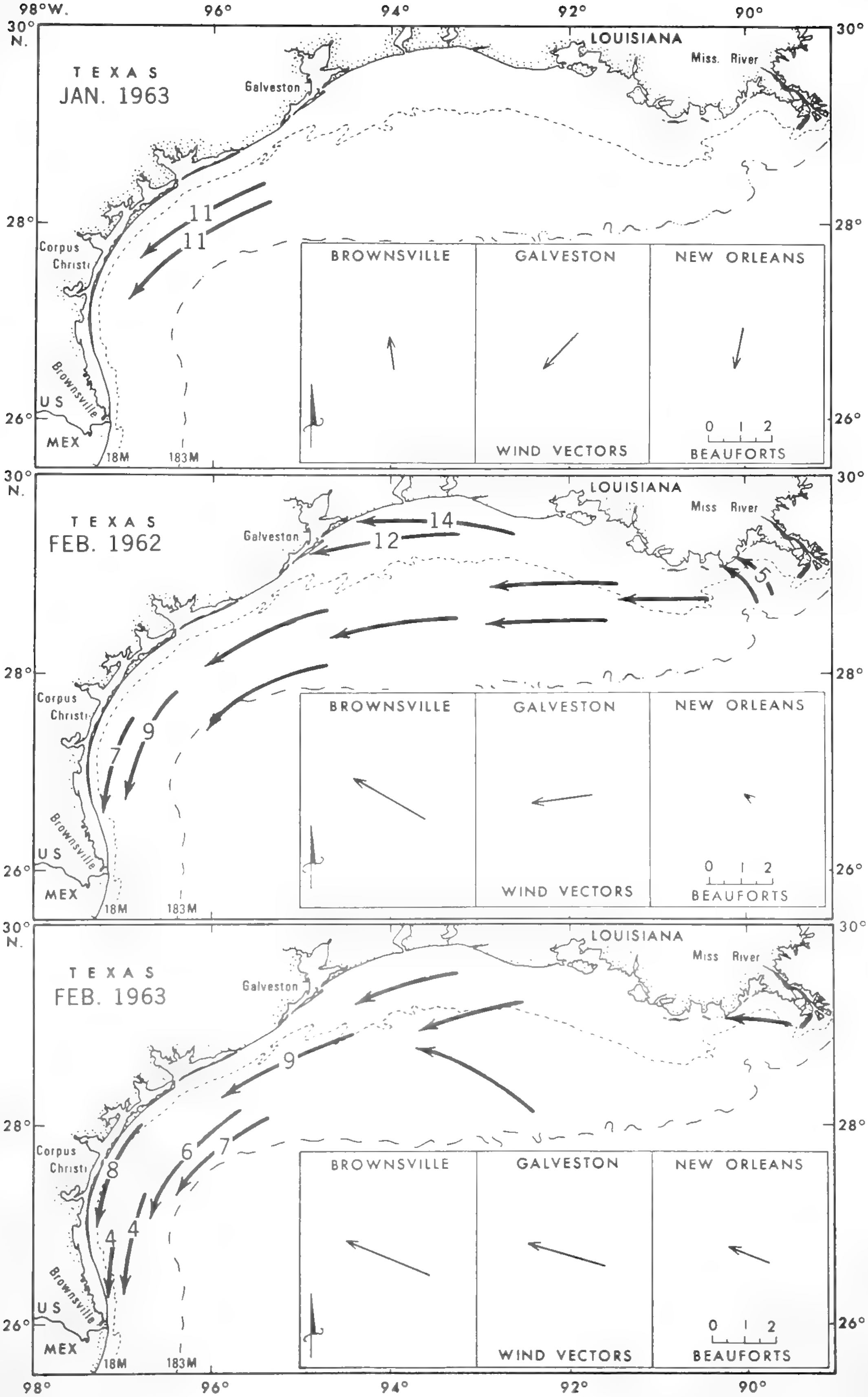

Figure 2.—Surface circulation deduced from recoveries of drift bottles released in January 1963 and February 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

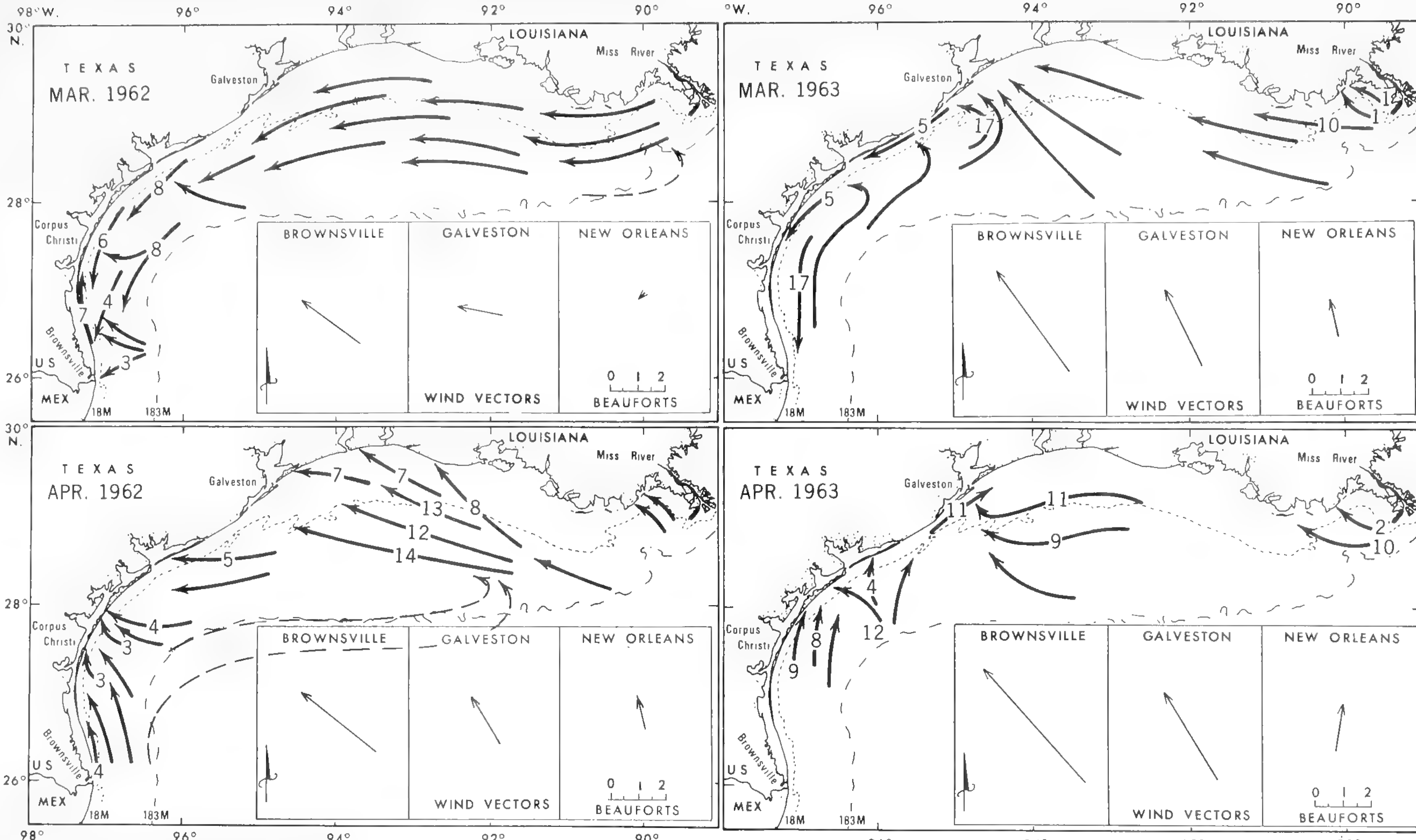

Figure 3.—Surface circulation deduced from recoveries of drift bottles released in March and April 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

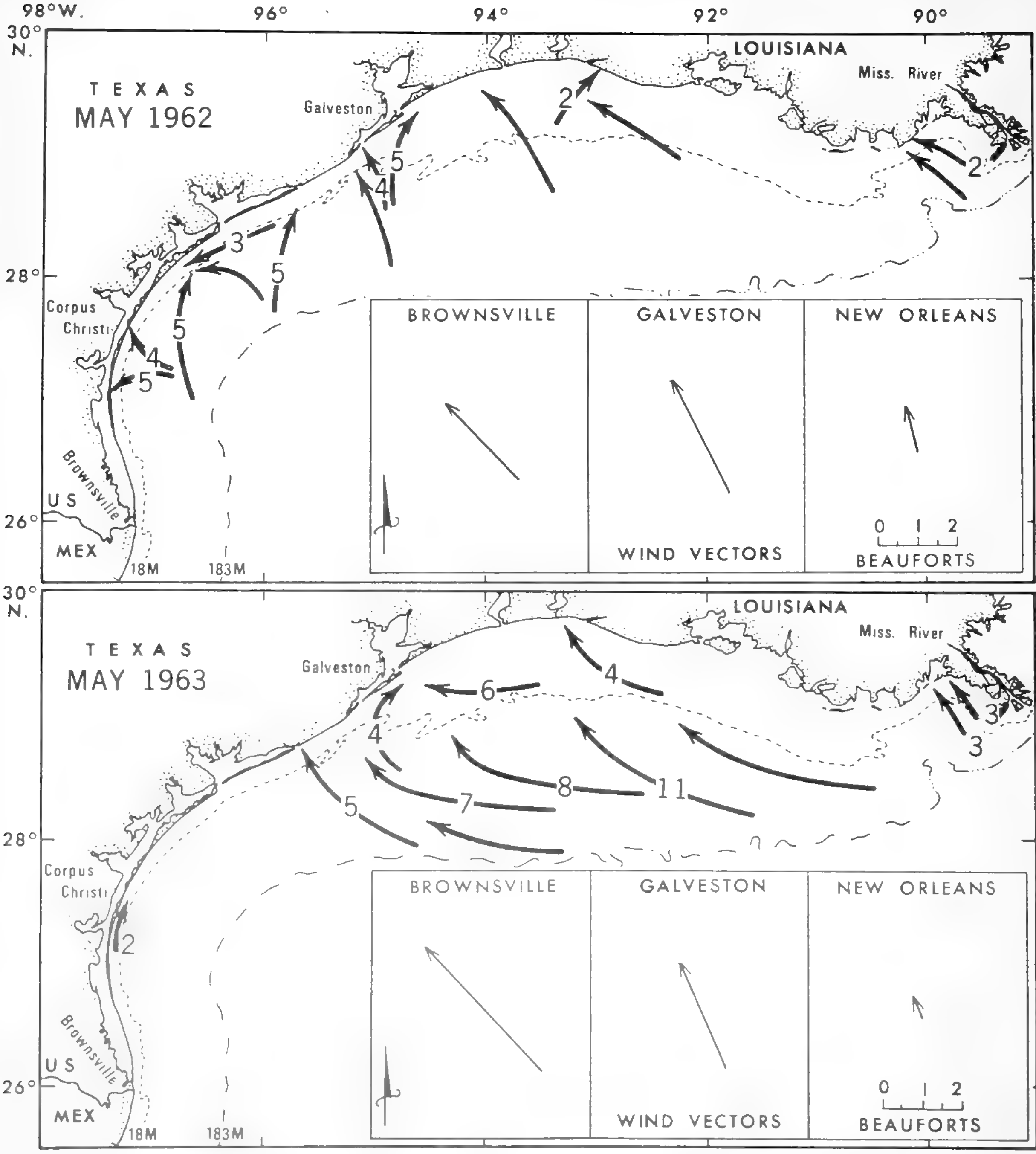

Figure 4.—Surface circulation deduced from recoveries of drift bottles released in May 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

day with an overall average of about 6. In general velocities of surface currents decreased from March to May as currents became more onshore.

With few exceptions, winds were generally similar between years over the study area, but a marked seasonal shift in direction was apparent. Resultant wind vectors indicated that the winds became more southerly or onshore during this 3-mo period and may account for the general weakening of the east to west flow of surface waters off Louisiana and east Texas as well as a shift in surface currents to the north off south Texas. With the exception of May 1962, wind force was greatest at Brownsville.

June-July.—Following the March-April transitional period, the dominant east to west flow of January-February had in essence reversed (Fig. 5). Currents flowed northward along the south Texas coast, whereas

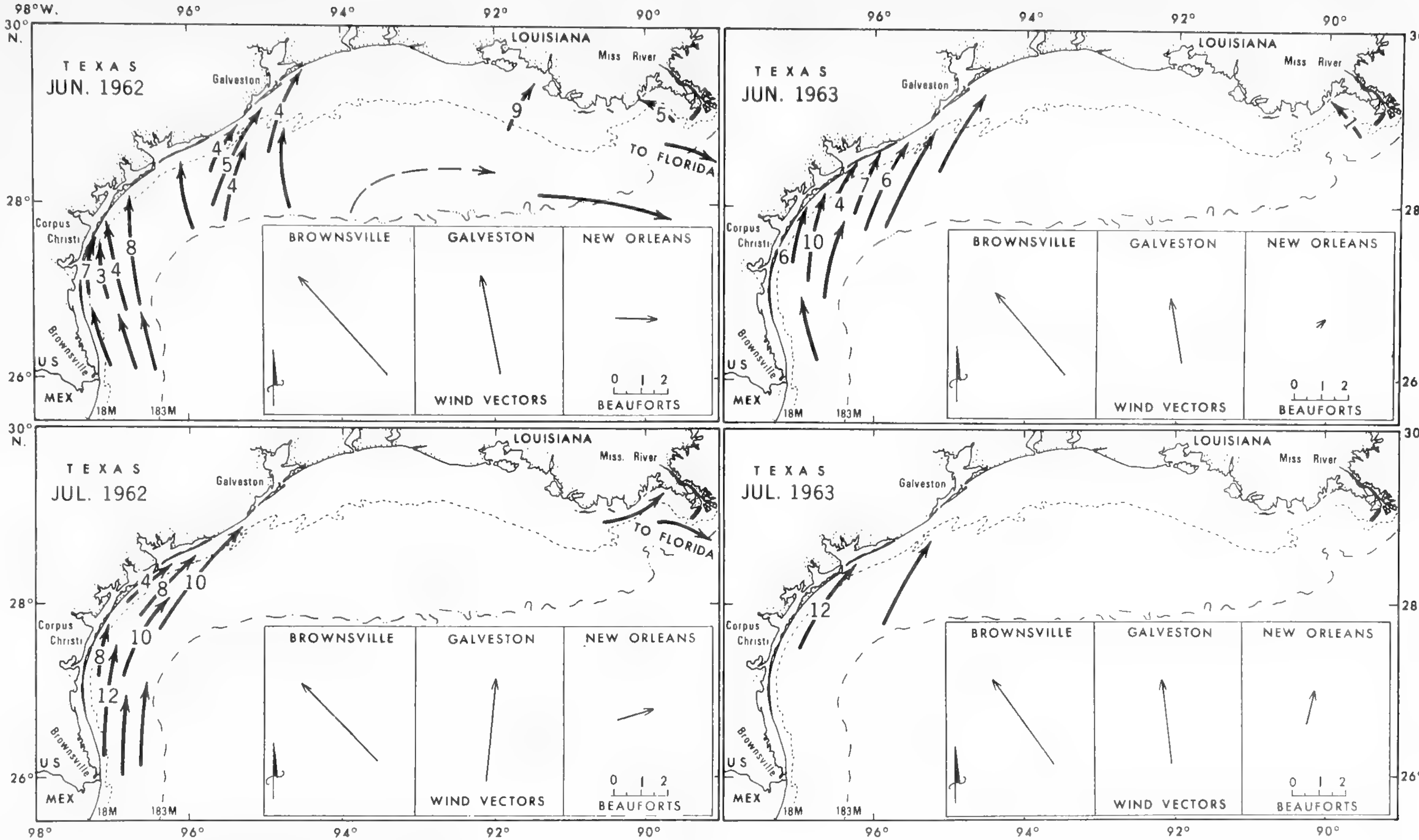

Figure 5.—Surface circulation deduced from recoveries of drift bottles released in June and July 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

off Louisiana currents were to the north or east with the northerly current generally restricted to nearshore waters and the eastward movement restricted to the deeper waters over the shelf. The strength of this eastward flow was apparently greater in 1962 than in 1963 as evidenced by the recovery of bottles as far away as Florida within 30 days after release. In 1963, bottles were also recovered in Florida but time adrift exceeded 30 days and the recoveries therefore are not shown in Figure 5.

Current velocities varied throughout the study area with values ranging from 3 to 12 km/day along the Texas coast and averaging 7 km/day. Onshore currents along the Louisiana coast ranged from 1 to 9 km/day with an average of 3 km/day. Monthly velocities were similar between years.

The influence of the prevailing southerly wind so characteristic of the summer in the northwestern Gulf of Mexico was readily apparent at Brownsville and Galveston for June and July of both years. Surface water currents off Texas were observed flowing either directly downwind or slightly to the right of the prevailing wind direction. Off Louisiana, however, the wind direction varied between years. In 1962, air flow was to the east whereas in 1963 it was more to the north. This variation generally supports the stronger eastward movement of surface waters off Louisiana in 1962.

August.—Drift bottles were released during this time period only in 1963, and their movements indicated still another transitional period in current direction and velocity (Fig. 6). Surface currents, rather than moving alongshore and to the north, had shifted to onshore toward the west; velocities had slowed to a rate of 2-3 km/day, a marked decrease from those velocities observed in the June-July period.

At Brownsville and Galveston winds were generally southeasterly. At New Orleans, winds were variable, as evidenced by the relatively small resultant vector, and were northwesterly.

September-December.—The release and recovery of drift bottles indicated that surface currents had returned to the dominant flow noted in January-February, i.e., a general west to southwesterly flow (Figs. 7, 8). Several features of the circulation pattern, however, should be noted. First, recoveries of bottles in the vicinity of Brownsville, Texas, in 1962 indicated a westerly onshore movement that dissipated as the season progressed.

Second, the onshore component of the prevailing southwest current was not as apparent in 1963 as in 1962. Few bottles released in the study area were recovered within 30 days, and of those that were, most were released at nearshore stations. Whether this was due to the lack of areal coverage or the total number of bottles released is not known, but the results were similar to those observed in December 1962 (Fig. 8), a period when a large number of bottles were released and areal coverage was extensive. This absence of recoveries may indicate either an along- or offshore movement of surface waters.

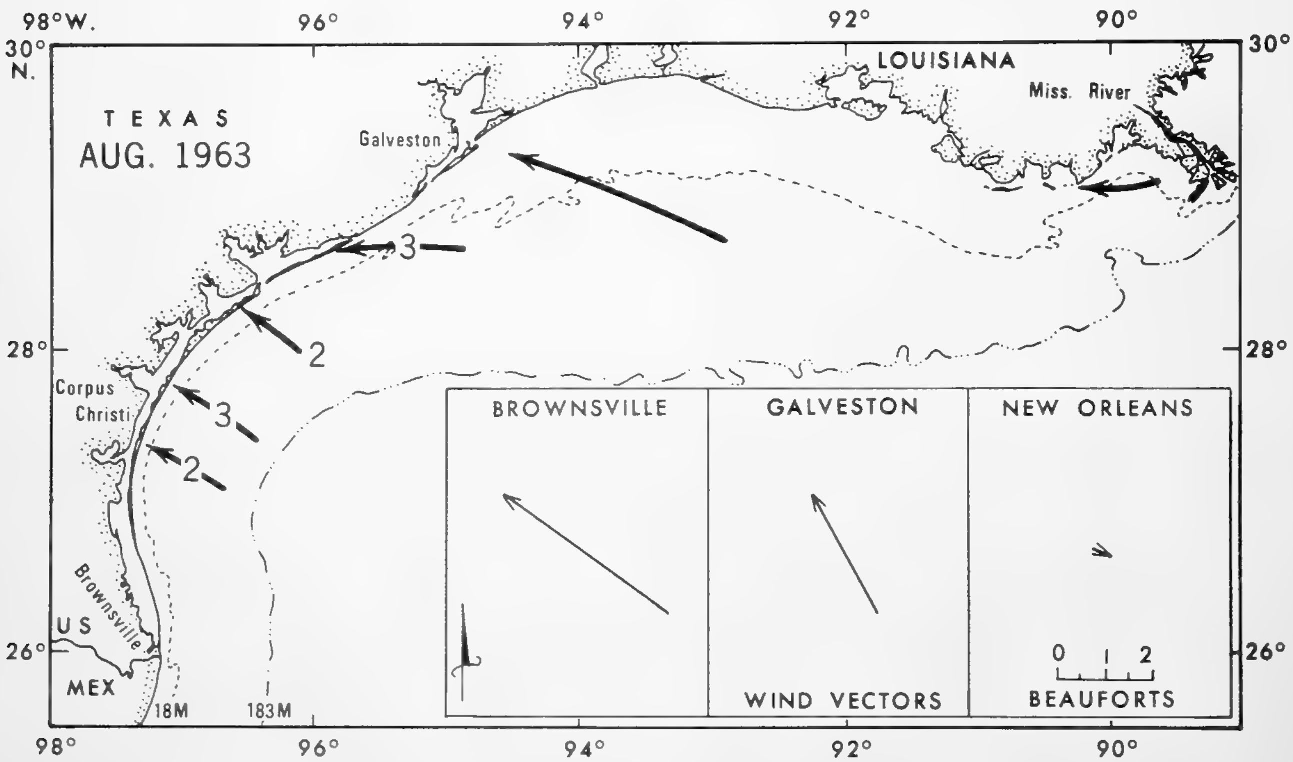

Figure 6.—Surface circulation deduced from recoveries of drift bottles released in August 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

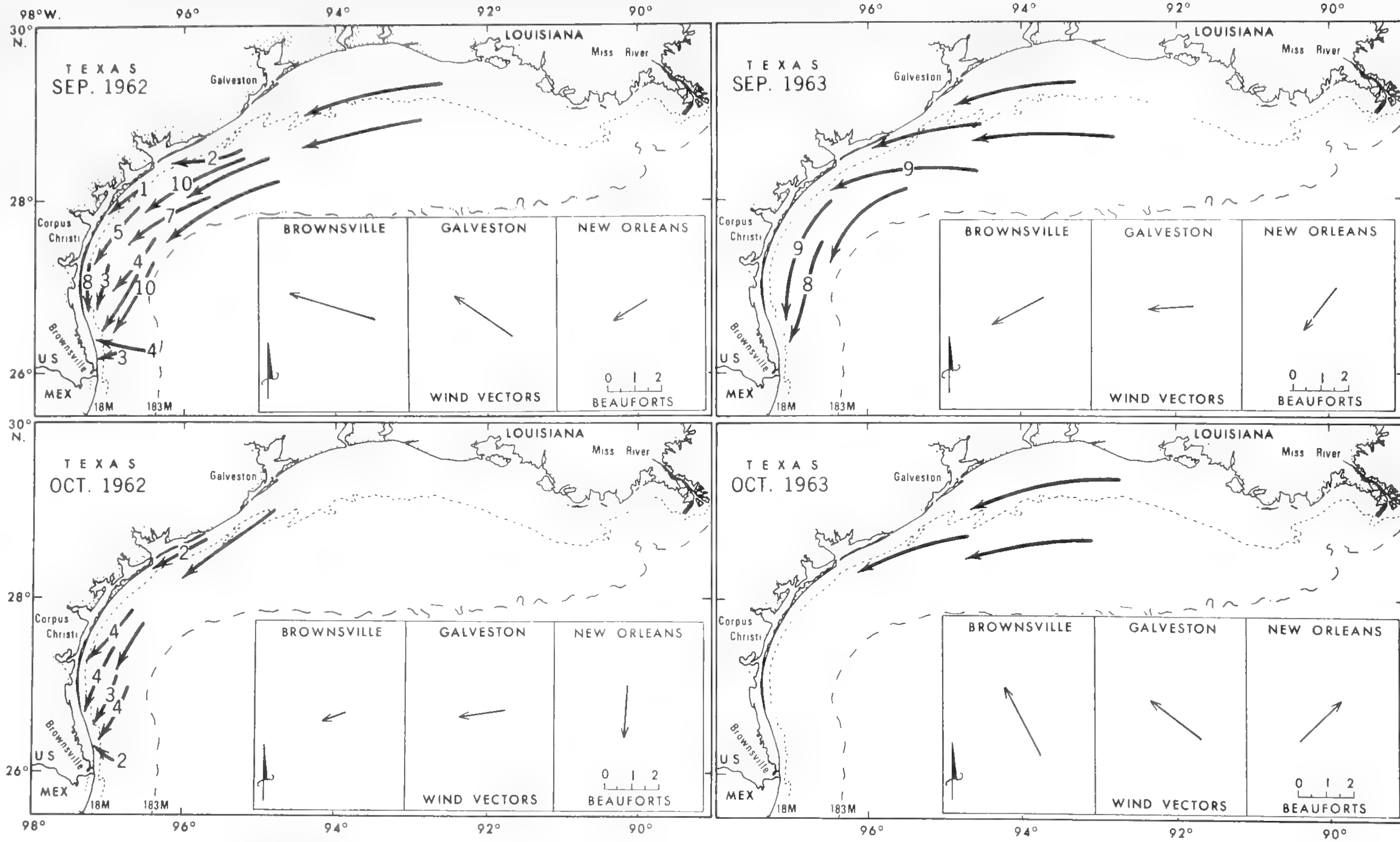

Figure 7.—Surface circulation deduced from recoveries of drift bottles released in September and October 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate a average km/day).

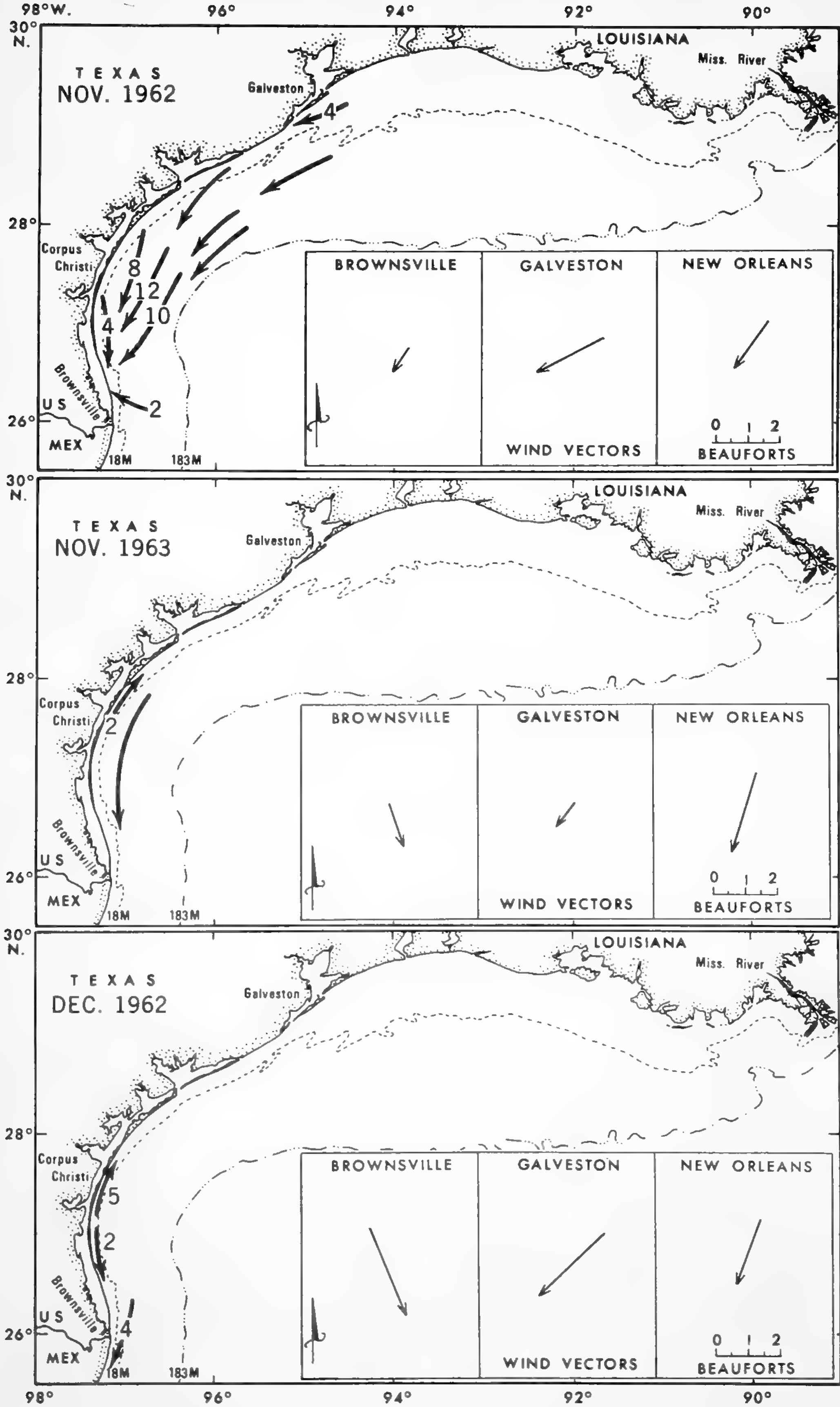

Figure 8.—Surface circulation deduced from recoveries of drift bottles released in November 1962 and 1963, and December 1962 in the northwestern Gulf of Mexico. Arrows indicate direction of flow; numbers indicate average km/day).

Table 4.—Estimated range and average current velocity for September-December 1962-63 in the northwestern Gulf of Mexico.

	1962		1963	
	Range	Average	Range	Average
September	1-10	5	8-9	9
October	2-4	3	no data	
November	2-12	7	no data	
December	2-5	3	no data	

Information on current velocities was generally restricted to the 1962 data, but no distinct trend was readily apparent. Ranges and averages for each month are shown in Table 4.

The seasonal shift in wind circulation over the study area during this period agreed generally with the direction of surface water movement. With few exceptions, east to southeast winds became more northerly until in November 1963 and December 1962 north winds dominated over the entire study area. The lack of drift bottle recoveries during this period supports the implied offshore southerly flow of surface waters.

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685. An annotated list of larval and juvenile fishes captured with surface-towed meter net in the South Atlantic Bight during four RV *Dolphin* cruises between May 1967 and February 1968. By Michael P. Fahay. March 1975, iv + 39 p., 19 figs., 9 tables, 1 app. table. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

686. Pink salmon, *Oncorhunchus gorbuscha*, tagging experiments in southeastern Alaska, 1938-42 and 1945. By Roy E. Nakatani, Gerald J. Paulik, and Richard Van Cleve. April 1975, iv + 39 p., 24 figs., 16 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

687. Annotated bibliography on the biology of the menhadens, Genus *Brevoortia*, 1963-1973. By John W. Reintjes and Peggy M. Keney. April 1975, 92 p. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

688. Effect of gas supersaturated Columbia River water on the survival of juvenile chinook and coho salmon. By Theodore H. Blahm, Robert J. McConnell, and George R. Snyder. April 1975, iii + 22 p., 8 figs., 5 tables, 4 app. tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

689. Ocean distribution of stocks of Pacific salmon, *Oncorhynchus* spp., and steelhead trout, *Salmo gairdnerii*, as shown by tagging experiments. Charts of tag recoveries by Canada, Japan, and the United States, 1956-69. By Robert R. French, Richard G. Bakkala, and Doyle F. Sutherland. June 1975, viii + 89 p., 117 figs., 2 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

690. Migratory routes of adult sockeye salmon, *Oncorhynchus nerka*, in the eastern Bering Sea and Bristol Bay. By Richard R. Straty. April 1975, iv + 32 p., 22 figs., 3 tables, 3 app. tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

691. Seasonal distributions of larval flatfishes (Pleuronectiformes) on the continental shelf between Cape Cod, Massachusetts, and Cape Lookout, North Carolina, 1965-66. By W. G. Smith, J. D. Sibunka, and A. Wells. June 1975, iv + 68 p., 72 figs., 16 tables.

692. Expendable bathythermograph observations from the NMFS/MARAD Ship of Opportunity Program for 1972. By Steven K. Cook. June 1975, iv + 81 p., 81 figs. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

693. Daily and weekly upwelling indices, west coast of North America, 1967-73. By Andrew Bakun. August 1975, iii + 114 p., 3 figs., 6 tables.

694. Semiclosed seawater system with automatic salinity, temperature and turbidity control. By Sid Korn. September 1975, iii + 5 p., 7 figs., 1 table.

695. Distribution, relative abundance, and movement of skipjack tuna, *Katsuwonus pelamis*, in the Pacific Ocean based on Japanese tuna longline catches, 1964-67. By Walter M. Matsumoto. October 1975, iii + 30 p., 15 figs., 4 tables.

696. Large-scale air-sea interactions at ocean weather station V, 1951-71. By David M. Husby and Gunter R. Seckel. November 1975, iv + 44 p., 11 figs., 4 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

697. Fish and hydrographic collections made by the research vessels *Dolphin* and *Delaware II* during 1968-72 from New York to Florida. By S. J. Wilk and M. J. Silverman. January 1976, iii + 159 p., 1 table, 2 app. tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

698. Summer benthic fish fauna of Sandy Hook Bay, New Jersey. By Stuart J. Wilk and Myron J. Silverman. January 1976, iv + 16 p., 21 figs., 1 table, 2 app. tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

699. Seasonal surface currents off the coasts of Vancouver Island and Washington as shown by drift bottle experiments, 1964-65. By W. James Ingraham, Jr. and James R. Hastings. May 1976, iii + 9 p., 4 figs., 4 tables.

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James G. Hoff

April 1979

U.S. DEPARTMENT OF COMMERCE
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650. Effects of some antioxidants and EDTA on the development of rancidity in Spanish mackerel (*Scomberomorus maculatus*) during frozen storage. By Robert N. Farragut. February 1972, iv + 12 p., 6 figs., 12 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

651. The effect of premortem stress, holding temperatures, and freezing on the biochemistry and quality of skipjack tuna. By Ladell Crawford. April 1972, iii + 23 p., 3 figs., 4 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

653. The use of electricity in conjunction with a 12.5-meter (Headrope) Gulf-of-Mexico shrimp trawl in Lake Michigan. By James E. Ellis. March 1972, iv + 10 p., 11 figs., 4 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

654. An electric detector system for recovering internally tagged menhaden, genus *Brevoortia*. By R. O. Parker, Jr. February 1972, iii + 7 p., 3 figs., 1 app. table. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

655. Immobilization of fingerling salmon and trout by decompression. By Doyle F. Sutherland. March 1972, iii + 7 p., 3 figs., 2 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

656. The calico scallop, *Argopecten gibbus*. By Donald M. Allen and T. J. Costello. May 1972, iii + 19 p., 9 figs., 1 table. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

657. Making fish protein concentrates by enzymatic hydrolysis. A status report on research and some processes and products studied by NMFS. By Malcolm B. Hale. November 1972, v + 32 p., 15 figs., 17 tables, 1 app. table. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

658. List of fishes of Alaska and adjacent waters with a guide to some of their literature. By Jay C. Quast and Elizabeth L. Hall. July 1972, iv + 47 p. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

659. The Southeast Fisheries Center bionumeric code. Part I: Fishes. By Harvey R. Bullis, Jr., Richard B. Roe, and Judith C. Gatlin. July 1972, xl + 95 p., 2 figs. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

660. A freshwater fish electro-motivator (FFEM)-its characteristics and operation. By James E. Ellis and Charles C. Hoopes. November 1972, iii + 11 p., 2 figs.

661. A review of the literature on the development of skipjack tuna fisheries in the central and western Pacific Ocean. By Frank J. Hester and Tamio Otsu. January 1973, iii + 13 p., 1 fig. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

662. Seasonal distribution of tunas and billfishes in the Atlantic. By John P. Wise and Charles W. Davis. January 1973, iv + 24 p., 13 figs., 4 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

663. Fish larvae collected from the northeastern Pacific Ocean and Puget Sound during April and May 1967. By Kenneth D. Waldron. December 1972, iii + 16 p., 2 figs., 1 table, 4 app. tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

664. Tagging and tag-recovery experiments with Atlantic menhaden, *Brevoortia tyrannus*. By Richard L. Kroger and Robert L. Dryfoos. December 1972, iv + 11 p., 4 figs., 12 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

665. Larval fish survey of Humbolt Bay, California. By Maxwell B. Eldrige and Charles F. Bryan. December 1972, iii + 8 p., 8 figs., 1 table. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

666. Distribution and relative abundance of fishes in Newport River, North Carolina. By William R. Turner and George N. Johnson. September 1973, iv + 23 p., 1 fig., 13 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

667. An analysis of the commercial lobster (*Homarus americanus*) fishery along the coast of Maine, August 1966 through December 1970. By James C. Thomas. June 1973, v + 57 p., 18 figs., 11 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

668. An annotated bibliography of the cunner, *Tautogolabrus adspersus* (Wilbaum). By Fredric M. Serchuk and David W. Frame. May 1973, ii + 43 p. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

669. Subpoint prediction for direct readout meterological satellites. By L. E. Eber. August 1973, iii + 7 p., 2 figs., 1 table. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

670. Unharvested fishes in the U.S. commercial fishery of western Lake Erie in 1969. By Harry D. Van Meter. July 1973, iii + 11 p., 6 figs., 6 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

671. Coastal upwelling indices, west coast of North America, 1946-71. By Andrew Bakun. June 1973, iv + 103 p., 6 figs., 3 tables, 45 app. figs. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Continued on inside back cover

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Annotated Bibliography and Subject Index on the Shortnose Sturgeon, *Acipenser brevirostrum*

James G. Hoff

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U.S. DEPARTMENT OF COMMERCE
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CONTENTS

Annotated Bibliography and Subject Index on the Shortnose Sturgeon, *Acipenser brevirostrum*

JAMES G. HOFF[1]

ABSTRACT

A bibliography that consists of 165 references on the classification, distribution, abundance, life history, and ecology of the shortnose sturgeon, *Acipenser brevirostrum*. Brief annotations and a subject index are included for this rare and endangered species.

INTRODUCTION

This bibliography consists of 165 references on the systematics, distribution, life history, and ecology of the shortnose sturgeon, *Acipenser brevirostrum* LeSueur.

Arrangement of the references is alphabetical by author's surname. With multiple authors, the entry is made only under the senior author's name. Each author's works are listed chronologically by year of publication and those published in the same year are given alphabetical sequence by title. Anonymous articles are listed by the name of the journal or the originating agency.

Brief annotations of the contents of the publications that apply to the shortnose sturgeon and its scientific name are given. This annotation is not done to make value judgments of the papers but to give clearer descriptions of the contents than can be obtained from their titles.

In the task of examining the vast number of scattered references in the ichthyological literature, I have received aid from many individuals. Thanks go to the librarians at the Marine Biological Laboratory at Woods Hole, Mass., and to the librarians at the Museum of Comparative Zoology at Harvard University. My indebtedness to those persons and institutions is great. I acknowledge the help I received from Brian Kinnear and Mike Dadswell, comembers of the shortnose sturgeon endangered species recovery team.

I wish to give special thanks to the Southeastern Massachusetts University biology students who helped throughout the preparation of this bibliography, notably Susan Faria, James Hoff, Jr., and Michael Murphy. And finally, I thank the typist, Rita Sasseville.

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ALEXANDER, A. B.
1905. Statistics of the fisheries of the New England states. Rep. U.S. Comm. Fish. 1904:245-326.

Catch and market statistics for sturgeon in Maine, New Hampshire, Massachusetts, and Connecticut are given. Since species are not mentioned, the shortnose sturgeon is probably included.

ANONYMOUS.
1975. Threatened wildlife of the United States. U.S. Fish Wildl. Serv. Resour. Publ., 289 p.

The shortnose sturgeon is listed as being endangered and a recommendation was made by the Department of the Interior to locate and protect shortnose sturgeon spawning sites.

APPY, R. G., and M. J. DADSWELL.
1978. Parasites of *Acipenser brevirostrum* LeSueur and *Acipenser oxyrhynchus* Mitchill (Osteichthyes: Acipenseridae) in the Saint John River Estuary, N. B., with a description of *Caballeronema pseudoargumentosus* sp. n., (Nematoda: Spirurida). Can. J. Zool. 56:1382-1391.

Shortnose, juvenile Atlantic, and mature Atlantic sturgeons have distinct parasite faunas which may reflect their contrasting life histories.

ATZ, J. W., and C. L. SMITH.
1976. Hermaphrodism and gonadal teratoma-like growths in sturgeon (*Acipenser*). Bull. South. Calif. Acad. Sci. 75:119-126.

An adult *Acipenser brevirostrum* from the Hudson River exhibited ovotestes. This teratoma-like structure may have been the result of the abnormal development of a parthogenetic or self-fertilized egg.

BAIRD, S. F.
1873. List of fishes collected at Woods Hole. Rep. U.S. Comm. Fish. 1871-1872:823-827.

[1]Southeastern Massachusetts University, North Dartmouth, MA 02747.

The shortnose sturgeon was collected in 1871 at Woods Hole. A complete collection of the 121 fish species was deposited in the U.S. National Museum.

BEAN, T. H.

1897. Notes upon New York fishes received at the New York Aquarium, 1895-1897. Bull. Am. Mus. Nat. Hist. 9:327-375.

A single shortnose sturgeon from Gravesend Bay was brought to the aquarium on 13 May 1896. It had taken food regularly, and was living (7 December 1897). The species proved to be well adapted to aquarium life.

1901. Catalogue of the fishes of Long Island. Rep. Forest Fish Game Comm. N.Y. State 1900:251-260.

Range and differentiation from the common sturgeon is provided.

1902. Food and game fishes of New York. Rep. Forest Fish Game Comm. N.Y. State 7:251-260 .

The shortnose sturgeon is only positively recognized in the Delaware and Gravesend Bay. In 1817, it was brought in the shad season to Philadelphia and sold from 25 to 75 cents each.

1904. Catalogue of the fishes of New York. Bull. N.Y. State Mus. 60, 784 p.

Includes an erroneous description of shortnose sturgeon spawning and feeding habits, misquoted directly from Ryder (1888).

BERG, L. S.

1904. Zyr systmatik der Acipenseridae. Zool. Anz. 27:665-667.

A taxonomic account of the shortnose sturgeon is given.

1940. Classification of fishes both recent and fossil. Applied Scientific Research Corporation of Thailand, Bangkok (1965):346-517.

Comments on Acipenserini: *Acipenser* L., Upper Cretaceous (scutes) to recent; Europe, Asia, N. America.

BERTIN, L.

1939. Revision des Stromiatiformes (Téléostéens, Isopondyles) du muséum. Bull. Mus. Hist. Nat., Paris 2(11):378-382.

The article includes a synonymy of *Acipenser brevirostrum.*

BIGELOW, H. B., and W. C. SCHROEDER.

1936. Supplemental notes on fishes of the Gulf of Maine. Bull. U.S. Bur. Fish. 48:319-348.

A 30-inch specimen, taken at Provincetown about 1907, now in the collection at the Museum of Comparative Zoology, was the only reliable record for the Gulf of Maine. This record was omitted from "Fishes of the Gulf of Maine" (Bigelow and Welsh 1925).

1953. Fishes of the Gulf of Maine. U.S. Fish Wildl. Serv., Fish. Bull. 53, 577 p.

A description, life history, and coastal distribution of the shortnose sturgeon. The only locality records given are from Provincetown and Waquoit, Mass.; from the Hudson River, N.Y.; from the Delaware Bay and River; and from Charleston, S.C.

BLAIR, W. F., A. P. BLAIR, P. BRODKORB, F. R. CAGLE, and G. A. MOORE.

1957. Vertebrates of the United States. 2d ed. McGraw-Hill Book Co., N.Y., 616 p.

A brief description and range for *A. brevirostrum.*

BOWERS, G. M.

1907. Statistics of the fisheries of the New England states for 1905. Rep. U.S. Comm. Fish. 1906:1-93.

Catch and market statistics for sturgeon in Maine, Massachusetts, and Connecticut are given. Since species are not mentioned, the shortnose sturgeon is probably included.

BOYLE, R. H.

1969. The Hudson River, a natural and unnatural history. W. W. Norton and Co., N.Y., 304 p.

According to the Interior Department, all recent catches of shortnose sturgeon, except for one Florida specimen, have been from the Hudson. Occasional specimens exceed the published record size in the scientific literature. In 1965 and again in 1969, a hermaphroditic specimen was caught. Information on their natural history, caviar preparation, cooking, and demand at aquariums is provided.

BREDER, C. M., Jr.

1938. The species of fish in New York Harbor. Bull. N.Y. Zool. Soc. 41(1):26-28.

The shortnose sturgeon is included in a list of fishes inhabiting the New York harbor.

1948. Field book of marine fishes of the Atlantic coast, from Labrador to Texas. G. P. Putnam's Sons, N.Y., 332 p.

The shortnose sturgeon is briefly described with its range.

BRICE, J. J.
1898. A manual of fish-culture, based on the methods of the United States Commission of Fish and Fisheries. Rep. U.S. Comm. Fish. 1897:1-340.

Experimental work indicates that there are no insurmountable obstacles in the way of extensive artificial propagation, although the work presents some unusual difficulties.

BUMPUS, H. C.
1898. The breeding of animals at Woods Hole during the months of June, July and August. Science 8:850-858.

Acipenser brevirostrum was occasionally taken in June, the females bearing ripe eggs.

CHUTE, W. H.
1944. Guide to the John G. Shedd Aquarium. 4th ed. Shedd Aquarium, Chicago, 236 p.

The shortnose sturgeon is one of the species held in the Shedd Aquarium.

COBB, S. N.
1900. The sturgeon fishery of the Delaware River and Bay. Rep. U.S. Comm. Fish. 1899:369-380.

Both species are found in the Delaware River, but only the common sturgeon is put to commercial use. *Acipenser brevirostris* rarely exceeds 3 ft and therefore is not gilled. Some are taken at the shore seine fisheries and in the shad gill nets.

COLLINS, J. W., and H. M. SMITH.
1892. Report on the fisheries of the New England states. Bull. U.S. Fish. Comm. 10:73-176.

The common sturgeon is included as one of the products of the fisheries of Massachusetts. Since size was not mentioned, it is possible that shortnose sturgeons were processed also.

COMMITTEE ON NAMES OF FISHES.
1970. A list of common and scientific names of fishes from the United States and Canada. 3rd ed. Am. Fish. Soc. Spec. Publ. 6,150 p.

Acipenser brevirostrum is listed.

COMMITTEE ON RARE AND ENDANGERED WILDLIFE SPECIES.
1966. Rare and endangered fish and wildlife of the United States. U.S. Dep. Inter. Res. Publ. 34, var. pag.

Information for the shortnose sturgeon is presented on distinguishing characteristics, present distribution, former distribution, endangered status, estimated numbers, fecundity, reason for decline, protective measures already taken, measures proposed, number in captivity, and culture potential in captivity.

COPE, E. D.
1883. The fisheries of Pennsylvania. Rep. State Comm. Fish. 1881 and 1882:103-183.

Sturgeon are sold in the markets of Philadelphia and adjacent cities. Numerous fishing boats are engaged in taking them in strong nets, the catch is often very large.

CUERRIER, J. P.
1947. Quelques indications sur la taille de maturité la fréquence des pontes et la saison de ponte de l'Esturgeon de lac. Annals ACFAS 13, 100 p.

The article deals with *Acipenser* spawning season and size at maturity.

1951. The use of pectoral fin rays to determine age of sturgeon and other fish species. Can. Fish Cult. 11:10-18.

The aging method is applicable to shortnose sturgeon.

CURRIAN, H. W., and D. T. RIES.
1937. Fisheries investigation in the lower Hudson River IV. *In* A biological survey of the lower Hudson watershed, p. 125-145. Rep. N.Y. State Conserv. Dep., Suppl. 26 (11).

Ninety-five shortnose sturgeons ranging in length from 450 to 884 mm were examined. The diet of sturgeon in the lower Hudson included insects, crustaceans, mollusks, and annelids.

DADSWELL, M. J.
1975. The biology and resource potential of certain fishes in the St. Johns Estuary. (Mimeogr.) A report to the Department of Environment, Canada, from the Huntsman Marine Laboratory, 98 p.

The shortnose sturgeon is included as a potential fisheries resource in the St. Johns River.

1976. Biology of the shortnose sturgeon (*Acipenser brevirostrum*) in the St. John River estuary, New Brunswick, Canada. Trans. Atl. Chap. Can. Soc. Environ. Biol. Annu. Meet. 1975:20-72.

Information on growth, length-weight relationships, food, fecundity, population estimates, and migrations.

DAHLBERG, M.
1975. Guide to coastal fishes of Georgia and nearby states. Univ. Georgia Press, Athens, 186 p.

A brief description and range of the shortnose sturgeon and a note that it is commonly caught in gill nets in the Altamaha River.

DEAN, B.
1894. Recent experiments in sturgeon hatching on the Delaware River. Bull. U.S. Fish Comm. 13:335-339.

Fish size is not mentioned, some shortnose sturgeon may have been used in the experiments.

1895. Fishes, living and fossil. An outline of their forms and probable relationships. Macmillan and Co., N.Y., 161 p.

A review of the internal and external anatomy of *Acipenser* is given. *Acipenser brevirostrum* is included in the classification.

DEES, L. T.
1961. Sturgeons. U.S. Fish Wildl. Serv., Fish. Leafl. 526, 8 p.

A review of the general life history and commercial value of sturgeons along with a brief description and more specific life history of each species, including the shortnose sturgeon.

DeKAY, J. E.
1842. Zoology of New York or the New York fauna. Part III. Reptiles and Amphibia. Albany, N.Y., 415 p.

The description given by LeSueur agrees with the Hudson River species. DeKay had seen it also in the markets of Norfolk, Va.

DIVISION OF LANDS AND FORESTS AND FISH AND GAME (New York).
1913. Third annual report of the conservation commission. J. B. Lyon Co., Albany, N.Y., 366 p.

Snails make up a large part of the food of the shortnose sturgeon in one of the ponds at the Linlithgo Hatchery.

DUMÊRIL, A.
1867. Prodrome d'une monographie des esturgeons et description des espèces de l'Amérique du Nord qui appartienment au sous genre *Antaceus*. Nouv. Arch. Mus. Hist. Nat., Paris, p. 131-188.

Notes are presented on the general characters, distribution, and other points of sturgeon natural history. He adopts six subgenera, with *Huso, Acipenser,* and *Antaceus* forming a group "Mésocentres."

1870. Histoire naturelle des poissons ou ichthyologie générale. Tome II. Ganoides, Dipnés, Lophobranches. Librairie Encyclopédique de Roret, Paris, p. 170-173.

The shortnose sturgeon is described.

EDDY, S.
1957. How to know the freshwater fishes. Wm. C. Brown Co., Dubuque, Iowa, 286 p.

A brief description and range of the shortnose sturgeon is given.

EVERMANN, B. W., and B. A. BEAN.
1896. Indian River and its fishes. Rep. U.S. Comm. Fish. 1897:227-248.

The shortnose sturgeon is recorded from the Indian River.

EVERMANN, B. W., and W. C. KENDALL.
1900. Check-list of the fishes of Florida. Rep. U.S. Comm. Fish. 1899:35-103.

The occurrence of sturgeons in Florida is cited in three references: St. John's River as *Acipenser* sp. (Goode 1879), Key West as *Acipenser* sp. (Jordan 1884), and Indian River as *Acipenser brevirostris* (Evermann and Bean 1896).

1902. An annotated list of the fishes known to occur in the St. Lawrence River. Rep. U.S. Comm. Fish. 1901:217-225.

The occurrence of the shortnose sturgeon in the St. Lawrence is erroneously cited in two references: in the St. Lawrence and streams flowing into it (Fortin 1864) and in the St. Lawrence and lacs St. Pierre, St. Louis, and St. Froid (Montpetit 1897).

FEGELY, T.
1977. Taking a closer look: Pennsylvania's endangered cold-blooded animals. Pa. Angler 46(12):4-5.

The shortnose sturgeon is on both state and federal endangered lists. A picture is included.

FORTIN, P.
1864. Continuation of the list of fish of the Gulf and River St. Lawrence. Annu. Rep. Fish. Append., p. 60-72.

The first occurrence of the shortnose sturgeon in the St. Lawrence River is recorded. Vladykov and Greeley (1963) report that this record is *A. fulvescens*.

FOWLER, H. W.
1905. The fishes of New Jersey. Rep. N.J. Mus., 477 p.

Fowler to date had not collected it from New Jersey. He reports a record from shallow water at the island by Trenton in the Delaware.

1910. Notes on chimaeroid and ganoid fishes. Proc. Acad. Nat. Sci. Phila. 62:603-612.

The article gives a list of the species collected with descriptions and location where found. Three examples of *A. brevirostrum* were examined.

1912. Records of fishes from the middle Atlantic states and Virginia. Proc. Acad. Nat. Sci. Phila. 64:34-59.

The shortnose sturgeon is reported at Torresdale, Philadelphia County. The author also found one at Bristol, Bucks County, in May 1908.

1919. Notes on New Jersey, Pennsylvania, and Virginia fishes. Proc. Acad. Nat. Sci. Phila. 17:292-300.

The shortnose sturgeon is included.

1920. A list of the fishes of New Jersey. Proc. Biol. Soc. Wash. 33:139-170.

The shortnose sturgeon is listed as occurring at Burlington, Cape May, Mercer, and Gloucester counties.

1945. A study of the fishes of the Southern Piedmont and coastal plain. Wickersham Printing Co., Phila., 408 p.

The shortnose sturgeon is known in the Potomac, Neuse, and St. John's Rivers.

1952. A list of fishes of New Jersey, with off-shore species. Proc. Acad. Nat. Sci. Phila. 104:89-151.

The shortnose sturgeon is listed with its range.

FRIED, S. M., and J. D. McCLEAVE.
1973. Occurrence of the shortnose sturgeon (*Acipenser brevirostrum*), an endangered species, in Montsweag Bay, Maine. J. Fish. Res. Board Can. 30:563-564.

Thirty-one shortnose sturgeons were caught in the summers of 1971 and 1972. Of nine fish preserved for study, six were stated to be longer than any previously documented and four exceeded the maximum total length previously postulated, but they overlooked Gorham's (1971) report of a 1,295-mm specimen. These specimens represent the second population of this species found in the Gulf of Maine.

GEOLOGICAL SURVEY OF NEW JERSEY.
1890. Final report of the state geologist. Vol. II. Mineralogy. Botany. Zoology. The John L. Murphy Publishing Co., Trenton, N.J., p. 668-669.

The shortnose sturgeon is found in the Delaware in proportion to the common sturgeon at about 5 to 1.

GILL, T.
1862. Catalogue of the fishes of the eastern coast of North America from Greenland to Georgia. Proc. Acad. Nat. Sci. Phila. 13(Suppl.):1-63.

Acipenser brevirostrum is included.

1873. Catalogue of the fishes of the east coast of North America. Rep. U.S. Comm. Fish. 1871-1872:779-814.

The shortnose sturgeon is listed with its range.

GOODE, G. B.
1879. Catalog of the collections to illustrate the animal resources and the fisheries of the United States. Bull. U.S. Natl. Mus. 14, 64 p.

Acipenser brevirostrum is included in a list of animals of North America which are beneficial or injurious to man.

GOODE, G. B., and T. H. BEAN.
1879. A list of the fishes of Essex County including those of Massachusetts Bay. Bull. Essex Inst. 11, 351 p.

The species is represented in the museum of the Essex Institute by a stuffed skin obtained at Rockport.

GOODE, G. B., and a Staff of Associates.
1884. The fisheries and fishery industries of the United States. Sec. I. Natural history of useful aquatic animals. Gov. Print. Off., Wash., D.C., 895 p.

The shortnose sturgeon is described along with a brief natural history. The sturgeon's ability to leap out of the water is mentioned. Plate 243 is from a drawing from a photograph of a specimen of shortnose sturgeon collected from Woods Hole, Mass., 1871.

1887. The fisheries and fishery industries of the United States. Sec. V. History and methods of the fisheries. Gov. Print. Off., Wash., D.C., 881 p.

Sturgeon are included in a review of the river fisheries of the Atlantic States. Size and species were not mentioned and the shortnose sturgeon is probably included.

GORDON, B. L.
1960. The marine fishes of Rhode Island. The Bait and Tackle Shop, Watch Hill, R.I., 136 p.

A 2.5-ft shortnose sturgeon was taken in May 1956 in the traps at Point Judith. A 28-in fish believed to be a shortnose sturgeon was taken in Narragansett Bay in 1957.

GORHAM, S. W.
1965a. Distributional checklist of the fishes of New Brunswick. New Brunswick Museum, Canada, p. 1-32.

The shortnose sturgeon is included with a locality record.

1965b. Notes on the fishes from the Browns Flat area, Kings County, New Brunswick. Can. Field-Nat. 79:137-142.

Eight specimens were collected using salmon nets.

1971. The shortnose sturgeon, *Acipenser brevirostrum*, an endangered species in New Brunswick? Mus. Mem. N.B. Mus. 3:13-15.

The article presents new records of specimens in the St. John system and data on length and weight. The longest specimen is recorded to this date.

GORHAM, S. W., and D. E. McALLISTER.
1974. The shortnose sturgeon, *Acipenser brevirostrum*, in the Saint John River, New Brunswick, Canada, a rare and possibly endangered species. Natl. Mus. Nat. Sci., Syl. 5:5-16.

The paper provides new information for a series of specimens from the St. John system on distribution, length, and weights. A taxonomic description of the Canadian population is given for the first time. Pictures are included. A new maximum size, greater than that reported by Gorham (1971), is reported.

GREELEY, J. R.
1937. Fishes of the area with annotated list. *In* A biological survey of the lower Hudson watershed, p. 45-103. Rep. N.Y. State Conserv. Dep., Suppl. 26(11).

The article includes information on length-weight relationships, spawning times, growth, and distribution in the Hudson River estuary.

GRUNCHY, C. G., B. PARKER, and D. E. McALLISTER.
In press. Shortnose sturgeon. *In* D. S. Lee, C. R. Carter, D. E. McAllister, J. R. Stauffer, C. H. Hocutt, R. E. Jenkins, and J. McCann, Atlas of North American freshwater fishes. J. N.C. State Mus.

A spot distribution map, illustration, and species account of shortnose sturgeon is given.

GRZIMEK'S ANIMAL LIFE ENCYCLOPEDIA.
1973. Polypterids, sturgeons and related forms. Van Nostrand Reinhold Co., N.Y., Vol. 4, 531 p.

A very brief description of *A. brevirostrum* with a comment on its commercial value.

GÜNTHER, A.
1870. Catalogue of the fishes of the British Museum. Taylor and Francis, Lond., Vol. 8, 549 p.

A taxonomic description is given.

HALKETT, A.
1913. Checklist of the fishes of the Dominion of Canada and Newfoundland. King's Printer, Ottowa, 138 p.

Acipenser brevirostrum is contained in the list, with its general range of distribution including the erroneous St. Lawrence record.

HARKNESS, W. J. K.
1923. The rate of growth and the food of the lake sturgeon (*Acipenser rubicundus* (LeSueur)). Publ. Ont. Fish. Res. Lab. 18:13-42.

The author found the earstones or otoliths of the sturgeon to form growth lines. Technique for aging was employed later for the shortnose sturgeon.

HARKNESS, W. J. K., and J. R. DYMOND.
1961. The lake sturgeon. Ont. Dep. Lands Forests, 97 p.

Acipenser brevirostrum, with its range, is included in a list of the sturgeons of the world.

HILDEBRAND, S. F., and W. C. SCHROEDER.
1928. Fishes of Chesapeake Bay. Bull. Bur. Fish. 43, 366 p.

The shortnose sturgeon is discussed from published accounts and a specimen taken off Provincetown, Mass., now in the Museum of Comparative Zoology, Cambridge, Mass., is described.

HOFF, J. G.
1965. Two shortnose sturgeon, *Acipenser brevirostris*, from the Delaware River, Scudder's Falls, New Jersey. Bull. N.J. Acad. Sci. 10:23.

A ripe shortnose sturgeon of each sex was examined.

HOLLAND, B. F., Jr., and G. F. YELVERTON.
1973. Distribution and biological studies of anadromous fishes offshore North Carolina. N.C. Dep. Nat. Econ. Res., S. S. R. No. 24, 132 p.

Between 1968 and 1971, eight shortnose sturgeon were caught offshore between Cape Fear, N.C., and Cape Henry, Va.

HOLLY, M.
1936. Pisces 4. Ganoidei. Das Tierreich (67), Berlin, 65 p.

A systematic review of the sturgeon family.

HOVEY, H. C.
1883. The sturgeon fishery. Bull. U.S. Fish Comm. 4:346-348.

Information on the sturgeon fishery of the Delaware River is given along with the sturgeon's preparation for market and the table.

JENKINS, R. E., and J. A. MUSICK.
In press. Fishes. *In* D. Linzey (editor), Threatened and endangered plants and animals of Virginia. Va. Polytech. Inst.

Shortnose sturgeon endangered animal of Virginia.

JEROME, W. C., Jr., A. P. CHESMORE, and C. O. ANDERSON, Jr.
1968. A study of the marine resources of the Parker River-Plum Island Sound Estuary. Division of Marine Fisheries, Department of Natural Resources, The Commonwealth of Massachusetts, 79 p.

An Atlantic and a shortnose sturgeon were taken by Bill Sibley on the *Peggybell* in Ipswich Bay near the mouth of Plum Island Sound in 1966. A picture of the shortnose sturgeon is included.

JORDAN, D. S.
1876. Manual of the vertebrates of the northern United States, including the district east of the Mississippi River, and north of North Carolina and Tennessee, exclusive of marine species. 1st ed. Jansen, McClurg and Co., Chicago, 342 p.

A brief description and range is given.

1878, 1880, 1884. Manual of the vertebrates of the northern United States, including the district east of the Mississippi River, and north of North Carolina and Tennessee, exclusive of marine species. 2d, 3rd, 4th ed. Jansen, McClurg & Co., Chicago.

A brief description and range is given.

1886. Notes on fishes collected at Beaufort, North Carolina, with a revised list of the species known from that locality. Proc. U.S. Natl. Mus. 9:25-30.

Shortnose sturgeon is included in the list.

1887. A catalogue of the fishes known to inhabit the waters of North America north of the Tropic of Cancer, with notes on the species discovered in 1883 and 1884. Rep. U.S. Comm. Fish. 1885:789-973.

The shortnose sturgeon is listed.

1897, 1899, 1904. A manual of the vertebrate animals of the northern United States including the district north and east of the Ozark Mountains, south of the Laurentian Hills, north of the southern boundary of Virginia, and east of the Missouri River, inclusive of marine species. 7th, 8th, 9th ed. A. C. McClurg and Co., Chicago.

A brief description and range is given.

1929. Manual of the vertebrate animals of the northeastern United States inclusive of marine species. 13th ed. World Book Company, N.Y., 446 p.

Description and range are given.

JORDAN, D. S., and B. W. EVERMANN.
1896a. A checklist of the fishes and fish-like vertebrates of North and Middle America. Rep. U.S. Comm. Fish. 1894:207-584.

The range of the shortnose sturgeon is given.

1896b. The fishes of North and Middle America. Bull. U.S. Natl. Mus. 47, 3313 p.

The shortnose sturgeon is described with its range. The specimen described is from South Carolina.

1904. American food and game fishes. Doubleday, N.Y., 572 p.

The range is from Texas to Cape Cod and the habits are similar to the common Atlantic.

1937. American food and game fishes. Doubleday, N.Y., 512 p.

The shortnose sturgeon is included with a brief description and distribution.

JORDAN, D. S., B. W. EVERMANN, and H. W. CLARK.
1930. Check list of the fishes and fishlike vertebrates of North and Middle America, north of the northern boundary of Venezuela and Colombia. Rep. U.S. Comm. Fish. 1928 (Part 2), 670 p.

Shortnose sturgeon is included in the checklist.

JORDAN, D. S., and C. H. GILBERT.
1882. Synopsis of the fishes of North America. Bull. U.S. Natl. Mus. 16, 1018 p.

A description and range is given.

KENDALL, W. C.
1908. Fauna of New England. 8. List of the Pisces. Occas. Pap. Boston Soc. Nat. Hist. 7, 152 p.

The shortnose sturgeon is recorded in New England.

KILBY, J. D., E. CRITTENDEN, and L. E. WILLIAMS.
1959. Ichthyological notes: Several fishes new to Florida freshwaters. Copeia 1959:77-78.

The shortnose sturgeon was incorporated in Florida's faunal list in 1896. In recent years authors have been inclined to exclude Florida from the range of the species. However, one adult shortnose sturgeon was taken in 1949 by commercial seine from the St. John's River and donated to the University of Florida collections.

KIRSCH, P. H., and M. W. FORDICE.
1889. A review of the American species of sturgeons (Acipenseridae). Proc. Acad. Nat. Sci. Phila. 41:245-257.

A review of the American Acipenseridae, based on species belonging to the Museum of the University of Indiana.

KOSKI, R. T., E. C. KELLEY, and B. E. TURNBOUGH.
1971. A record-sized shortnose sturgeon from the Hudson River. N.Y. Fish Game J. 18:75.

A shortnose sturgeon measuring 932 mm in total length was caught in January 1970 in the Hudson River (from Tappan Zee Bridge to Bear Mountain Bridge).

LEACH, G. C.
1920. Artificial propagation of sturgeon. Part 1. Review of sturgeon culture in the United States. Rep. U.S. Comm. Fish. 1919:3-5.

A review of the attempts and drawbacks in sturgeon culture in the United States is provided. Species were not mentioned; however, this material is applicable to the shortnose sturgeon.

LEIM, A. H., and L. R. DAY.
1959. Records of uncommon and unusual fishes from eastern Canadian waters, 1950-1958. J. Fish. Res. Board Can. 16:503-514.

The first authentic Canadian record is given for the shortnose sturgeon. The specimen, 69 cm long, was caught by the MV *Harengus* in the Long Reach, Saint John River, N.B., on 20 May 1957. Identification was made by V. D. Vladykov.

LEIM, A. H., and W. B. SCOTT.
1966. Fishes of the Atlantic Coast of Canada. Bull. Fish. Res. Board Can. 155, 485 p.

A general description and natural history of the shortnose sturgeon is given.

LELAND, J. G., II.
1968. A survey of the sturgeon fishery of South Carolina. Contrib. Bears Bluff Labs. 47, 27 p.

The history and present situation of the sturgeon fishery of South Carolina is presented. Individual species were not mentioned; however, it is stated that there is practically no market for small sturgeon (3-12 pounders) and that these are not taken in the sturgeon nets. They do become enmeshed in shad nets and are killed by the shad fisherman. These small sturgeon may include shortnose sturgeon.

LeSUEUR, C. A.
1818. Description of several species of Chondropterygious fishes of North America, with their varieties. Trans. Am. Philos. Soc. 1:383-395.

The author gives the original description of the species, with three varieties, from specimens caught in the Delaware River.

MacCALLUM, G. A.
1921. Studies in helminthology. Zoopathalogica 1:137-284.

Three individuals of the trematode *Nitzschia superba* were found on the gills of a male and female shortnose sturgeon from the New York Aquarium on 22 September 1915.

MAGNIN, E.
1959. Répartition actuelle de Acipensérides. Revue Trav. Inst. (Sci. Tech.) Pêch. Marit. 23:277-285.

A distribution of the Acipenseridae is presented.

1963. Notes sur la répartition, la biologie et particuliérement la croissance de l'*Acipenser brevirostris* LeSueur 1817. Nat. Can. (Que.) 90:87-96.

Magnin presents data on the age, length, and biology of 10 specimens from the St. John River near Fredericton, N.B.

1964. Croissance en longeur de trois esturgeons d'Amérique du Nord: *Acipenser oxyrhynchus* Mitchill, *Acipenser fulvescens* Raffinesque, et *Acipenser brevirostris* LeSueur. Verh. Int. Verein. Theor. Angew. Limnol. 15:968-974.

A growth comparison of three eastern North American species is presented.

MASSMANN, W. H.
1958. A checklist of fishes of the Virginia waters of Chesapeake Bay and its tidal tributaries. Va. Fish. Lab., Fin Fish Prog. Rep. 60, 14 p.

The shortnose sturgeon is on the checklist.

McALLISTER, D. E.
1960. List of the marine fishes of Canada. Bull. Natl. Mus. Can. 168, 8 p.

Shortnose sturgeon is included in the list.

1970. Rare and endangered Canadian fishes. Can. Field-Nat. 84:5-8.

At this time, shortnose sturgeon is known only in the lower St. John River, N.B., from the mouth to Gagetown. Increasing pollution and a hydroelectric dam may be of significance in their survival.

McALLISTER, D. E., and C. G. G. GRUNCHY.
1977. Status and habitats of Canadian fishes in 1976. *In* T. Mosquin (editor), Canada's threatened species and habitats, 185 p. Canadian Nature Federation, Ottawa.

Listed shortnose sturgeon as rare with moderate population in St. John River, N.B. Unanswered questions on its spawning and population trends.

McCLEAVE, J. D., and S. M. FRIED.
1974. Three unusual shortnose sturgeon (*Acipenser brevirostrum*) from Montsweag Bay, Me. Can. Field-Nat. 88:359-360.

Three unusual specimens were captured: one with only one barbel, one with forked barbels, and one bilaterally blind. The blind specimen appeared to be in good condition and it is noted that blind, dark, healthy shortnose sturgeon have also been observed.

McCLEAVE, J. D., S. M. FRIED, and A. K. TOWT.
1977. Daily movements of shortnose sturgeon, *Acipenser brevirostrum* in a Maine estuary. Copeia 1977:149-157.

The daily summer movements of 15 shortnose sturgeon in Montsweag Bay were studied by ultrasonic telemetry.

McLANE, W. M.
1955. Fishes of the St. John's River System. Ph.D. Thesis, Univ. Fla. Tallahassee, 367 p.

Both common and shortnose sturgeon are reported to be extremely rare on the Atlantic coast of Florida.

MEEHAN, W. E.
1896. Fish, fishing and fisheries of Pennsylvania. Rep. State Comm. Fish. 1895, 245 p.

Chapter 5 is entitled *The Sturgeon Fisheries of the Delaware.*

1910. Experiments in sturgeon culture. Trans. Am. Fish. Soc. 39:85-91.

The shortnose sturgeon used in the experiment were from the Delaware River. The experiment showed that shortnose sturgeon can be carried from year to year in ponds 200 or more feet long and proportionately wide and deep, and their eggs can be taken safely in sufficient number to warrant fish cultural work.

METH, F. F.

1971. Ecology of St. John River Basin II. Catalogue of estuary fish species for the Saint John River. Environment Canada (Mimeogr. rep.), 28 p.

Shortnose sturgeon recorded for the Saint John River.

1972. Ecology of Saint John River Basin V. Status of estuary fisheries. Environment Canada (Mimeogr. rep.), 6 p.

Shortnose sturgeon recorded for the Saint John River.

1973. Sport and commercial fisheries of the St. John estuary. Rep. St. John River Basin Board 76:1-70.

The paper includes a general account of the shortnose sturgeon.

MIGDALSKI, E. C., and G. S. FICHTER.

1976. The fresh and salt water fishes of the world. Alfred A. Knopf, N.Y., 316 p.

Its range and differentiation from the common sturgeon are given.

MILLER, R. R.

1972. Threatened freshwater fishes of the United States. Trans. Am. Fish. Soc. 101:239-252.

Connecticut, Delaware, Maryland, Massachusets, New Jersey, and Pennsylvania list shortnose sturgeon as being an endangered species.

MONTPETIT, A. N.

1897. Les poisson d'eau douce du Canada. Montreal, 553 p.

The shortnose sturgeon is erroneously reported as occurring in the St. Lawrence and lacs St. Pierre, St. Louis, and St. Froid.

NEW YORK MARKET INDEX AND JOURNAL.

1880. Report for 1879 and 1880 of the sale of fish in Fulton Market, New York. Bull. U.S. Fish Comm. 3, 426 p.

It is reported that 70,633 pounds of sturgeon were sold between March 1878 and March 1879 and 68,858 pounds between March 1879 and March 1880. Species and size were not mentioned; therefore, shortnose sturgeon may be included in the sale.

NICHOLS, J. T.

1918. Fishes of the vicinity of New York City. Am. Mus. Nat. Hist. Handb. Ser., No. 7, 118 p.

A small sturgeon, *Acipenser brevirostris,* that reaches a length of 2 ft occurs in the New York City area.

NICHOLS, J. T., and C. B. BREDER, JR.

1927. The marine fishes of New York and southern New England. Zoologica (N.Y.) 9, 192 p.

The shortnose sturgeon is briefly described with its distribution.

OFFICE OF ENDANGERED SPECIES AND INTERNATIONAL ACTIVITIES.

1973. Threatened wildlife of the U.S. U.S. Dep. Inter. Res. Publ. 114, 289 p.

This is a revision of Resource Publication 34 (1966) (see Committee on Rare and Endangered Wildlife Species (1966)).

PERLMUTTER, A.

1961. Guide to marine fishes. New York Univ. Press, 431 p.

A short description of the color, distribution, size, general information, and economic importance of the shortnose sturgeon is provided.

PRATT, H. S.

1935. A manual of land and fresh water vertebrate animals of the United States (exclusive of birds). 2d ed. P. Blakiston's Son and Co., Inc., Phila., 416 p.

A brief description of the species is given.

PROVANCHER, L'ABBÉ.

1876. Faune canadienne. Les poissons. Nat. Can. (Que.) 7:361-363.

Fortin's erroneous record of the shortnose sturgeon in the St. Lawrence River is cited.

RICHARDSON, J.
1836. Fauna boreali-Americana, or the zoology of the northern parts of British America. Part III. The fish. Richard Bentley, Lond., 278 p.

The shortnose sturgeon is described.

ROSTLUND, E.
1952. Freshwater fish and fishing in native North America. Univ. Calif. Press, Berkeley, 248 p.

The range is given for the shortnose sturgeon.

RYDER, R. A.
1888. The sturgeons and sturgeon industries of the eastern coast of the United States, with an account of experiments bearing upon sturgeon culture. Bull. U.S. Fish Comm. 8:231-328.

This is the first diagnosis of the species since LeSueur's original description in 1817. From specimens caught in the Delaware River, the author gives distinctive characters by which the species might be recognized. He also notes that the species is always small, confirmed by the fact that sexual maturity is reached much earlier than in the common form.

SCHAEFER, R. H.
1967. Species composition, size and seasonal abundance of fish in the surf waters of Long Island. N.Y. Fish Game J. 14:1-46.

One shortnose sturgeon was caught off Fire Island, N.Y., in 1962.

SCHRENKELSEN, R.
1938. Field book of the freshwater fishes of North America north of Mexico. Putnam, N.Y., 312 p.

A general account of the shortnose sturgeon is presented.

SCHWARTZ, F. J., W. W. HASSLER, J. W. REINTJES, and M. W. STREET.
1975. Endangered and threatened plants and animals of North Carolina: Marine fishes. Proceedings of the symposium on endangered and threatened biota of North Carolina. 1. Biological concerns. N.C. State Mus. Nat. Hist., p. 250-264.

These are unconfirmed reports of the shortnose sturgeon from offshore; once sporadically known from Albemarle and Pamlico Sounds, and other North Carolina waters, but today it is believed extirpated.

SCHWARTZ, F. J., and G. W. LINK, JR.
1976. Status of Atlantic, *Acipenser oxyrhynchus,* and shortnose, *Acipenser brevirostrum,* sturgeons in North Carolina (Pisces, Acipenseridae). ASB (Assoc. Southeast. Biol.) Bull. 23:94.

The shortnose sturgeon is believed extinct in North Carolina.

SCOTT, W. B.
1954, 1967. Freshwater fishes of eastern Canada. 1st, 2d ed. Univ. Toronto Press.

Distribution in Canada for the shortnose sturgeon and variation from the common sturgeon is provided.

SCOTT, W. B., and E. J. CROSSMAN.
1959. The freshwater fishes of New Brunswick: A checklist with distributional notes. R. Ont. Mus. Life Sci. Contrib. 51, 37 p.

The only shortnose sturgeon caught in Canada up to this date is Vladykov's catch in 1957 in the St. John River.

1973. Freshwater fishes of Canada. Bull. Fish. Res. Board Can. 184, 966 p.

A more detailed description and natural history than Leim and Scott (1966) is given. It is noted that the largest shortnose sturgeon on record was a 1,006-mm female from the Connecticut River.

SCOTT, W. B., and M. G. SCOTT.
1965. A checklist of Canadian Atlantic fishes with keys for identification. R. Ont. Mus. Life Sci. Contrib. 66, 106 p.

The shortnose sturgeon is included in the list and a key to the family Acipenseridae is provided.

SLASTENENKO, E. P.
1958. The freshwater fishes of Canada. Kiev Printers, Toronto, 383 p.

A general account of the shortnose sturgeon.

SMITH, H. M.
1891. Report on the fisheries of the South Atlantic states. Bull. U.S. Fish Comm. 11:269-356.

Size is not reported; therefore, shortnose sturgeon may have been caught. The sturgeon fishery is noted as having the most noticeable decline in the river fisheries of the South Atlantic States during the past decade. A decrease of 80% in the yield of sturgeon during the past 10 yr is reported.

1892. Economic and natural-history notes on fishes of the northern coast of New Jersey. Bull. U.S. Fish Comm. 12:365-380.

Only the common sturgeon is cited. However, in its discussion it is mentioned that small fish called "moose" are sold whole; the name appears to be a corruption of "mammoose" which is current in Delaware Bay, and is applied to young fish that are too small to dress and are usually sold whole. These small sturgeon may be the shortnose species.

1894. A statistical report of the fisheries of the middle Atlantic states. Bull. U.S. Fish Comm. 14:339-467.

The common sturgeon is included in a list of the important fishes of the middle Atlantic states. However, the species is broken into three groups: sturgeon, mammoose—Delaware River, and moose (young)—New Jersey. The latter two groups most likely include the shortnose sturgeon.

1897. Fishes found in the vicinity of Woods Hole. Bull. U.S. Fish Comm. 17:85-111.

The shortnose sturgeon is found in company with the common sturgeon but is less numerous than the latter. It is taken in traps.

1907. The fishes of North Carolina. N.C. Geol. Econ. Surv. 2, 445 p.

Actual records of its occurrence in North Carolina are rare.

1914. Passing of the sturgeon. Rep. U.S. Comm. Fish. 1913:66-67.

A review of the overfishing of the sturgeon, which is applicable to the shortnose sturgeon.

1915. Report of the commissioner of fisheries for the fiscal year ended June 30, 1914. Sturgeon Fishery of Delaware River. Rep. U.S. Comm. Fish. 1914, 81 p.

Some sturgeon with large roe are caught as late as September, but a large portion of such fish are of the smaller species (*A. brevirostrum*), locally called "bottlenose."

SMITH, H. M., and B. A. BEAN.
1899. List of fishes known to inhabit the waters of the district of Columbia and vicinity (1898). Bull. U.S. Fish Comm. 18:179-187.

Shortnose sturgeon are found in this area but are not as abundant as the common sturgeon and have undergone the same decrease in recent years. It is probably not recognized by fishermen as a different species.

STORER, D. H.
1846. A synopsis of the fishes of North America. Mem. Am. Acad. Sci., New. Ser. 2(7):253-550.

A brief description of the shortnose sturgeon is presented.

SUMNER, F. B., R. C. OSBURN, and L. J. COLE.
1911. A biological survey of the waters of Woods Hole and vicinity. Part II. Bull. U.S. Bur. Fish. 31:549-794.

The common sturgeon is listed, however the shortnose sturgeon is included in its references. When listing parasites of the common sturgeon, it is noted that the spiny-headed worm, *Echinorhynchus attenuatus*, is listed for the shortnose sturgeon.

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672. Seasonal occurrence of young Guld menhaden and other fishes in a northwestern Florida estuary. By Marlin E. Tagatz and E. Peter H. Wilkins. August 1973, iii + 14 p., 1 fig., 4 tables. For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

673. Abundance and distribution of inshore benthic fauna off southwestern Long Island, N.Y. By Frank W. Steimle, Jr. and Richard B. Stone. December 1973, iii + 50 p., 2 figs., 5 app. tables.

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NOAA Technical Report NMFS SSRF-732

Assessment of the Northwest Atlantic Mackerel, *Scomber scombrus*, Stock

Emory D. Anderson

April 1979

U.S. DEPARTMENT OF COMMERCE
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Continued on inside back cover

NOAA Technical Report NMFS SSRF-732

Assessment of the Northwest Atlantic Mackerel, *Scomber scombrus*, Stock

Emory D. Anderson

April 1979

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CONTENTS

Figures

Tables

Assessment of the Northwest Atlantic Mackerel, *Scomber scombrus*, Stock

EMORY D. ANDERSON[1]

ABSTRACT

The status of the Atlantic mackerel, *Scomber scombrus,* stock in the International Commission for the Northwest Atlantic Fisheries (ICNAF) convention area is analyzed in this paper. Total catch declined from a high of 431,606 t in 1972 to an estimated 92,000 t in 1977. The U.S. spring bottom trawl survey has shown a continuous decrease in Atlantic mackerel abundance since 1968. Fishing mortality (*F*) in 1977 was estimated at 0.39, nearly one-half of the 1976 level and the lowest since 1972. The 1974 year class appears to be the strongest since 1969, whereas the 1975 and 1976 year classes appear to be very weak. Spawning stock biomass decreased from 1.8 million t in 1970-72 to an estimated 402,500 t at the beginning of 1978, which is slightly below the 1962-67 level when catches averaged only about 25,000 t. A zero catch in 1978 would increase the 1979 spawning stock by 6%; a catch of 23,500 t (*F* = 0.07) would maintain the spawning stock at the 1978 level.

INTRODUCTION

The following report analyzes the status of the Northwest Atlantic mackerel, *Scomber scombrus,* stock inhabiting the waters from Cape Hatteras, N.C., to Newfoundland, which is the area included in ICNAF (International Commission for the Northwest Atlantic Fisheries) Subareas 3, 4, and 5 and Statistical Area 6 (SA 3-6) (Fig. 1). This assessment provided the basis for establishing the allowable level of catch in 1978 in the southern part of this area (SA 5-6) and was used by the National Marine Fisheries Service for its environmental impact statement/preliminary fishery management plan for the Atlantic mackerel fishery and by the Mid-Atlantic Fishery Management Council for its environmental impact statement/fishery management plan for this fishery.

In previous years, this stock was managed through ICNAF, and assessments were completed jointly by scientists from various member nations within the ICNAF Assessments Subcommittee. The last such assessment, on which the 1977 total allowable catch (TAC) was based, was made at the time of the Ninth Special Meeting of ICNAF held at Puerto de la Cruz, Tenerife, Canary Islands, Spain, in November-December 1976 (ICNAF 1977). Separate assessments submitted by Anderson et al.,[2] Isakov et al.,[3] and Ivanov[4] provided the basis for the 1976 assessment. In addition to this paper, catch projections for 1978 were provided by Isakov[5] and several unpublished Canadian reports (Hunt[6]; Lett and Hunt[7]; and Lett and Marshall[8]).

Data utilized here include international commercial and U.S. recreational catch statistics for 1961-77 and U.S. research vessel bottom trawl survey results for 1963-77. Results include estimates of fishing mortality, stock size, recruitment, and projected catch options for 1978, with the resulting spawning stock biomass levels for 1979.

METHODS

International commercial Atlantic mackerel catches for 1961-76 were obtained from *ICNAF Statistical Bulletins* published in 1963-77 (volumes 11-26), provisional catches for January-March 1977 were obtained from *ICNAF Circular Letters*, and catches for the remainder of 1977 were estimated.

Various marine angler surveys provided estimates of the 1960, 1965, 1970, 1974, and 1976 U.S. recreational catches of Atlantic mackerel (Clark 1962; Deuel and Clark 1968; Deuel 1973; Deuel[9]; Christensen et al.[10]).

[1]Northeast Fisheries Center Woods Hole Laboratory, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543.

[2]Anderson, E. D., P. W. Wood, B. B. Ackerman, and F. P. Almeida. 1976. Assessment of the mackerel stock in ICNAF Subareas 3-6. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/XII/137, Ser. No. 4033 (mimeogr.), 21 p.

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[7]Lett, P. F., and J. J. Hunt. 1977. A preliminary study of some biological factors related to the assessment of mackerel. Can. Atl. Fish. Sci. Adv. Comm., Working Pap. 77/19, 16 p.

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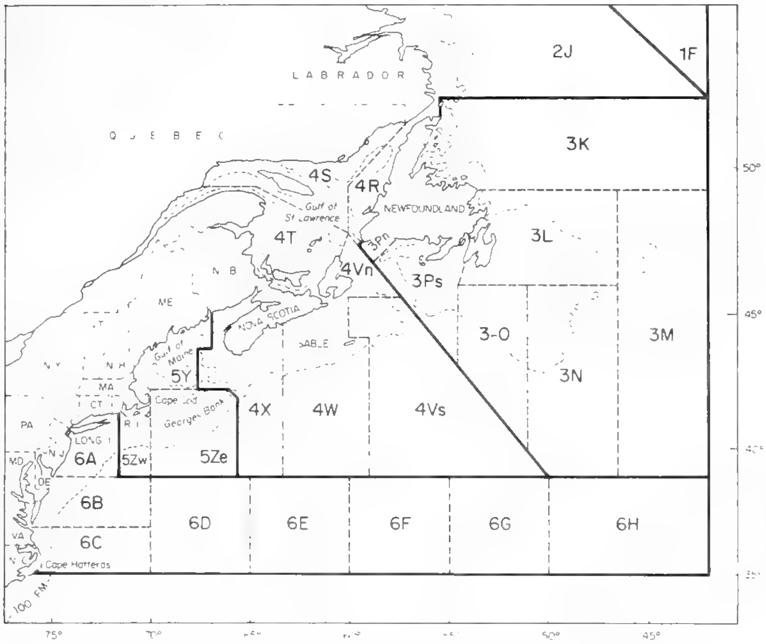

Figure 1.—Northwest Atlantic from North Carolina to Labrador showing ICNAF Subareas 3, 4, and 5 and Statistical Area 6.

Catches in the intervening years were estimated by assuming that the ratio between catch and stock biomass from cohort analysis using only commercial data (ICNAF 1977) in each of the above years was the same in the preceding and succeeding 2 yrs, with the exception that the mean of the 1970 and 1974 ratios was used for 1972, and the mean of 1974 and 1976 was used for 1975.

The 1962-75 numbers at age from the commercial catch were taken from Anderson et al. (see footnote 2). The 1976 numbers at age were revised from those used in the last ICNAF assessment (ICNAF 1977). The general procedure used previously was to: 1) apply the length frequencies and age-length keys reported by individual countries to their catches to obtain numbers at age by country, 2) combine all such numbers at age for respective countries, and 3) prorate the summed numbers at age upwards to include catches from countries lacking sampling data. However, since significant differences were evident among age-length keys submitted by various countries for 1976 (Anderson et al.[11]), it was decided to combine country age-length keys by quarter. The procedure used was to: 1) determine numbers at length by country by month from available length frequencies and corresponding catches, 2) combine the numbers at length by quarter and prorate upwards to include country catches lacking sampling data, 3) apply the combined quarterly age-length key to the quarterly numbers at length to obtain quarterly numbers at age, and 4) combine the quarterly numbers at age to obtain the annual numbers at age. The estimated numbers at age for 1977 were determined by applying the above procedure to the available January-March catch and sampling data and then prorating the results upwards to include the catch expected to be taken during the remainder of the year. Numbers at age for the 1962-77 commercial catches were prorated upwards to include the added U.S. recreational catches.

Mean weights at age (Table 1) adopted by ICNAF (1974) and used in previous assessments were employed in the present analysis. These values were applied to the numbers-at-age catch data for 1962-77 to obtain calculated catches which were compared with the observed catches. These values were also applied to the stock size numbers at age calculated from cohort analysis to obtain stock biomass values. The summed biomass values for each year were adjusted using the appropriate observed/calculated catch ratios. The mean weights at age were used unadjusted in the projections of catch and stock biomass for 1978-79.

Table 1.—Mean weights at age (kilograms) for Atlantic mackerel (ICNAF 1974).

Age	Mean weight	Age	Mean weight
1	0.095	6	0.506
2	0.175	7	0.564
3	0.266	8	0.615
4	0.350	9	0.659
5	0.432	10+	0.693

Stratified mean catch-per-tow (kilograms) indices for Atlantic mackerel were calculated from U.S. research vessel spring (1968-77) and autumn (1963-76) bottom trawl surveys conducted in SA 5-6 in which sampling is based on a stratified random design (Cochran 1953) and strata (Fig. 2) constitute different depth zones and areas (Grosslein 1969). Survey methods, procedures, and gear

United States recreational fishery for Atlantic mackerel. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/XII/142, Ser. No. 4038 (mimeogr.), 7 p.

[11]Anderson, E. D., C. F. Cole, and P. W. Wood. 1976. Variability in mackerel age data reported to ICNAF. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/XII/146, Ser. No. 4042 (mimeogr.), 13 p.

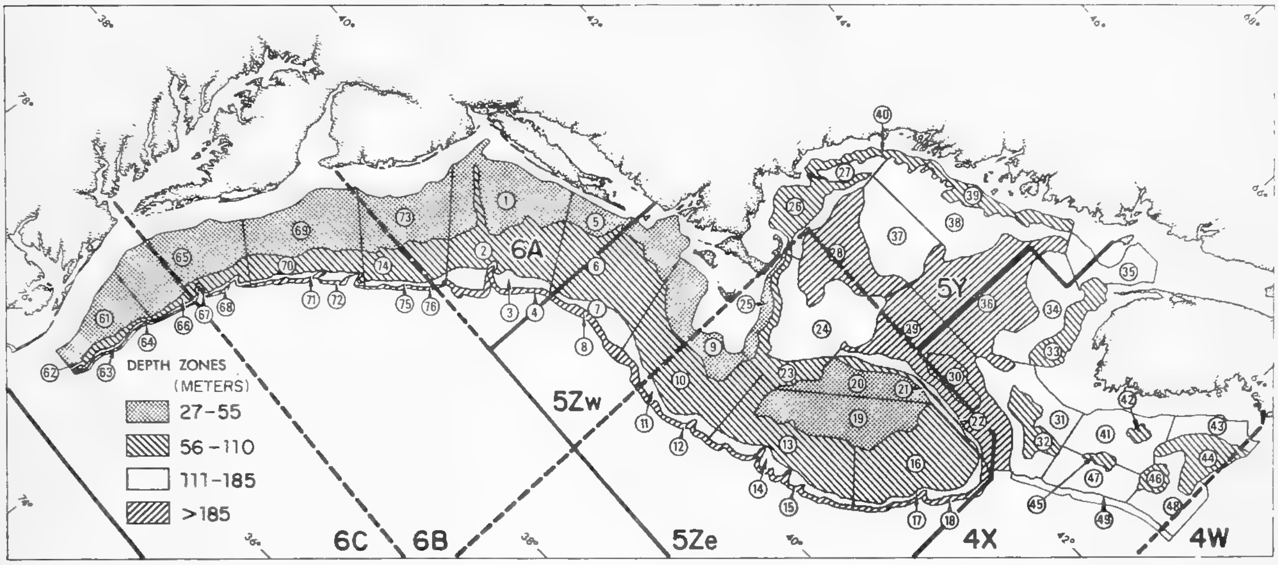

Figure 2.—Northwest Atlantic off the U.S. coast showing bottom trawl survey sampling strata and ICNAF Subarea 5 and Statistical Area 6.

were described by Grosslein.[12] Spring indices were calculated from catches in strata 1-25 and 61-76, and autumn indices from catches in strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, and 25-26 (Fig. 2). All autumn catches and the 1968-72 spring catches were made with a No. 36 Yankee trawl, and the 1973-77 spring catches were made with a larger No. 41 trawl. The 1968-72 spring catches were adjusted upwards to equivalent No. 41 trawl catches using a 3.25:1 ratio between the No. 41 and No. 36 trawls (Anderson 1976) to establish a standardized time-series of catches. A ln $(x + 1)$ transformation of the station catches (kilograms) was made before calculation of the mean catch-per-tow indices. The ln indices were then retransformed to the original scale for compatibility with other data used in the assessment. Retransformation was accomplished by the method described by Finney (1941) using the equation:

$$\bar{y} = \exp(\bar{x} + \frac{S^2}{2}) - 1 \qquad (1)$$

where $\bar{y}$ = retransformed catch per tow, $\bar{x}$ = ln catch per tow, and S^2 = population variance (ln scale).

Stratified mean catch per tow (numbers) by age for the 1973-77 spring surveys was determined by applying age-length keys to the length frequency of the stratified mean catch per tow (Anderson et al. see footnote 2). Since age samples were not taken prior to the 1973 spring survey, only the mean catch per tow for ages 0, 1, and 2 was determined prior to 1973. From the 1968-72 spring surveys, age 1 fish were defined as those measuring 22 cm and less (fork length) and age 2 fish were defined as those measuring 23-29 cm. Age 0 fish from the autumn surveys were defined as those measuring 23 cm or less.

[12]Grosslein, M. D. 1974. Bottom trawl survey methods of the Northeast Fisheries Center, Woods Hole, Mass., USA. Int. Comm. Northwest Atl. Fish. Res. Doc. 74/96, Ser. No. 3332 (mimeogr.), 27 p.

Standardized U.S. commerical catch per day (metric tons) was calculated for 1964-76 as described by Anderson (1976).

Instantaneous fishing mortality (F) in 1977 was estimated using a technique developed by Anderson et al. (see footnote 2) which assumes a linear relationship between fishing effort and fishing mortality. The lack of an adequate measure of fishing effort or catch per effort was circumvented by calculating, as an index of fishing effort, the quotient of total catch divided by the spring survey catch per tow (Table 2). Because of the aberrant 1969 spring value (Anderson 1976; Anderson and Almeida 1977) and the year-to-year fluctuations in the remaining values, the 1968-77 time-series (Fig. 3) was smoothed by

Table 2.—Estimation of fishing mortality (F) in 1977 for the ICNAF Subareas 3, 4, and 5 and Statistical Area 6 Atlantic mackerel fishery.

	Spring survey catch/tow			Fishing	
Year	Actual[1]	Calculated[2]	Catch[3] (t)	effort index[4]	Mean F[5] age 3+
1968	3.998	4.518	109,940	24,334	0.155
1969	0.065	3.199	165,113	51,614	0.144
1970	2.039	2.265	262,681	115,974	0.185
1971	1.969	1.604	403,675	251,668	0.268
1972	1.332	1.135	431,606	380,270	0.316
1973	0.748	0.804	429,250	533,893	0.451
1974	0.769	0.569	347,220	610,228	0.515
1975	0.255	0.403	293,740	728,883	0.532
1976	0.317	0.285	243,033	852,747	[6,7](0.626)
1977	0.199	0.202	92,000	455,446	[6](0.391)

[1]Stratified mean catch (kilograms) per tow (retransformed from ln to linear scale).

[2]Values predicted from exponential curve calculated using actual values for 1968-77 (except 1969). See Figure 4.

[3]Includes commercial and recreational catch.

[4]Catch divided by calculated spring survey catch/tow.

[5]Obtained from cohort analysis assuming F = 0.39 in 1977.

[6]Calculated from regression of fishing effort index on mean F for 1968-75: $Y = 0.121 + 0.00000059X$, $r = 0.991$.

[7]Actual value calculated from cohort analysis was 0.745, assuming F = 0.39 in 1977.

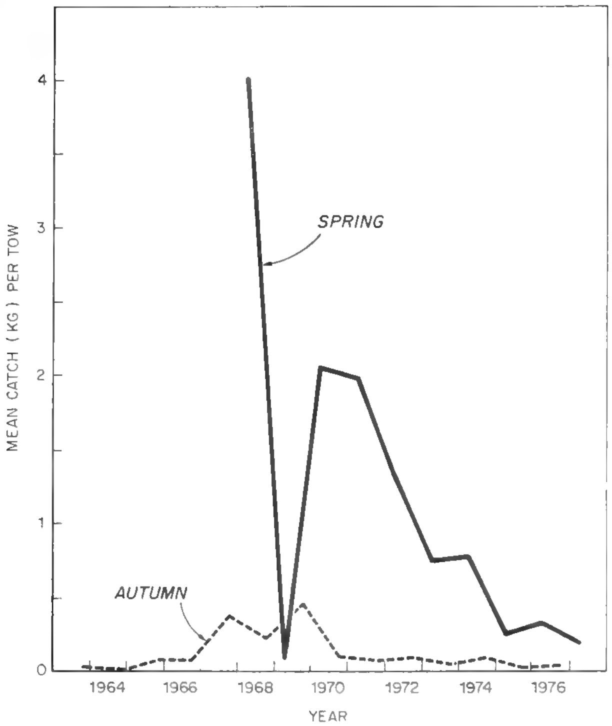

Figure 3.—Stratified mean catch (kilograms) per tow of Atlantic mackerel from the U.S. spring (1968-77) and autumn (1963-76) bottom trawl surveys.

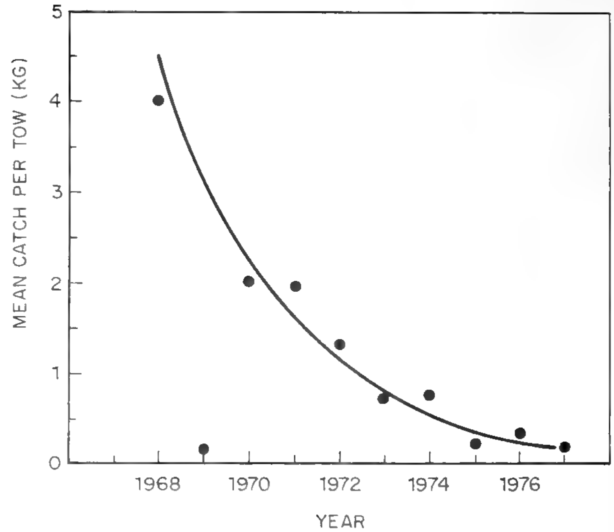

Figure 4.—Exponential curve calculated through 1968-77 time-series (1969 point omitted from calculation of curve) of spring survey catch-per-tow (kilograms) indices for Atlantic mackerel. Equation for the curve is: $Y = 6.382 \exp(-0.345\ X)$, $r = 0.976$.

fitting an exponential curve by least squares to the data points (Fig. 4), and the predicted values calculated from the curve were used in place of the original values to determine the fishing effort index. Cohort analysis (Pope 1972) was performed using $F = 0.30$ for ages 4 and older

Table 3.—Fishing mortality rates (F) for Atlantic mackerel in ICNAF Subareas 3, 4, and 5 and Statistical Area 6 derived from cohort analysis with natural mortality (M) = 0.30.

Year class	Year 1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
1951	[1](.038)	—	—	—	—	—	—	—	—	—		—	—	—	—	
1952	.030	[1](.042)					—					—		—	—	
1953	.088	[1](.042)							—			—		—	—	—
1954	.073	.019	[1](.039)	—	—	—	—	—							—	—
1955	.043	.006	[1](.039)	—	—	—	—	—	—	—	—	—	—	—	—	—
1956	.050	.006	.033	[1](.052)											—	—
1957	.051	.017	.321	.713	[1](.060)	—	—	—							—	—
1958	.127	.313	.374	.946	.288	.357	(.155)	—	—	—	—	—	—	—	—	—
1959	.030	.067	.066	.095	.163	.446	.156	.336	[1](.185)					—	—	—
1960	.006	.004	.014	.025	.054	.060	.013	.039	.090	[1](.268)	—	—	—	—	—	—
1961	.030	.010	.012	.016	.026	.040	.007	.042	.195	.262	[1](.316)		—	—	—	—
1962	—	.004	.032	.018	.023	.041	.119	.049	.369	.291	.500	[1](.451)	—	—	—	—
1963	—	—	.044	.017	.034	.032	.200	.059	.145	.150	.670	.892	[1](.515)	—	—	—
1964	—	—	—	.024	.042	.107	.351	.081	.142	.290	.239	.426	.575	[1](.532)	—	—
1965	—	—	-	-	.028	.045	.149	.249	.162	.342	.470	.449	.596	.503	[1](.745)	—
1966	—	—	—	—	—	<.001	.039	.136	.207	.472	.419	.283	.454	.474	2.002	.390
1967	—	—	—	—	—	—	.027	.064	.181	.327	.441	.465	.580	.686	.888	.390
1968	—	—	-	-	—	—	—	.003	.030	.097	.215	.409	.507	.536	.990	.390
1969	—	—	—	—	—	—	—	—	.077	.173	.246	.410	.410	.523	.787	.390
1970	—	—	—	—	—	—	—	—	—	.056	.091	.545	.430	.547	.598	.390
1971	—	—	—	—	—	—	—	—	—	—	.015	.305	.598	.551	.708	.390
1972	—	—	—	—	—	—	—	—	—	—	—	.168	.463	.469	.916	.390
1973	—	—	—	—	—	—	—	—	—	—	—	—	.058	.452	.652	.390
1974	—	—	—	—	—	—	—	—	—	—	—	—	—	[2].202	[2].330	[2].220
1975	—	—	—	—	—	—	—	—	—	—	—	—	—	—	[2].018	[2].067
1976	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	[2].006
$\bar{F}$ (age 3+)	.038	.042	.039	.052	.060	.111	.155	.144	.185	.268	.316	.451	.515	.532	.745	[4].390

[1]Mean F for age 3+ assumed.
[2]Determined from assumed stock size and known catch.
[3]Weighted by stock numbers at age from Table 12.
[4]Age 4+.

in 1977 with instantaneous natural mortality (M) = 0.30 for all ages (ICNAF 1974). This level of F was chosen as a first approximation since the fishing effort index in 1977 was about half the 1976 index implying a similar reduction in fishing mortality from earlier estimates for 1976 of about 0.60-0.70. A linear regression between the 1968-75 fishing effort indices and the mean F values for ages 3 and older from the cohort analysis predicted an F of 0.374 for 1977 based on the fishing effort index for 1977. A second cohort analysis was performed using 0.38 as the terminal F in 1977. A second linear regression using the revised F values from this cohort analysis predicted F = 0.389 for 1977. A third cohort analysis was performed using F = 0.39 for 1977 (Table 3). A third linear regression predicted F = 0.391 for 1977 (Table 2, Fig. 5); therefore, F = 0.39 was accepted as the best estimate.

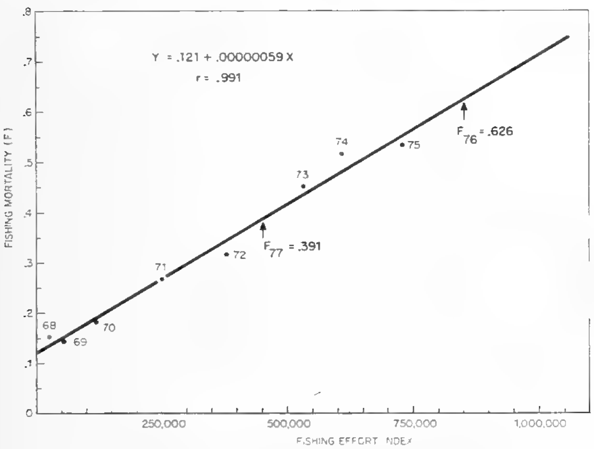

Figure 5.—Relationship between fishing mortality for Atlantic mackerel from cohort analysis and fishing effort derived from spring survey catch per tow and total catch.

Power curve relationships, fitted by least squares, between 1) autumn survey catch per tow (numbers) at age 0 and year-class size at age 1 determined from cohort analysis for 1963-73 (Table 4, Fig. 6), 2) spring survey catch per tow at age 1 and year-class size at age 1 for 1967-73 (Table 5, Fig. 7), and 3) spring survey catch per tow at age 2 and year-class size at age 2 for 1966-73 (Table 5, Fig. 8) were used to estimate the sizes of the 1974-76 year classes.

For age groups incompletely recruited to the fishery, the ratio of fishing mortality at each such age to fishing mortality of fully recruited ages (the latter considered here to be the mean F for ages 3 and older) was used as a measure of partial recruitment to the fishery. Partial recruitment coefficients were calculated for ages 1 and 2 for calendar years 1962-77.

Age-specific F and stock size (N) values were determined for 1962-77 using cohort analysis. The value for N at each age in 1978 was calculated using the relationship:

$$N_{t+1} = N_t e^{-Z_t} \qquad (2)$$

Table 4.—Catch per tow (number) of age 0 Atlantic mackerel from the U.S. autumn bottom trawl surveys (strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, 25-26) and year-class size (millions of fish) at age 1 from cohort analysis.

Year class	Autumn survey age 0	Cohort analysis age 1
1963	0.087	429.5
1964	0.022	542.2
1965	0.134	1,212.9
1966	0.170	3,165.3
1967	15.709	7,786.5
1968	0.215	3,114.3
[1]1969	38.504	3,244.9
1970	0.027	1,657.5
1971	0.517	1,711.9
1972	0.119	1,212.6
1973	0.339	1,981.2
1974	0.648	[2](2,515.6)
1975	0.012	[2](614.3)
1976	0.000	[2](0)

[1]Not used.
[2]Calculated.

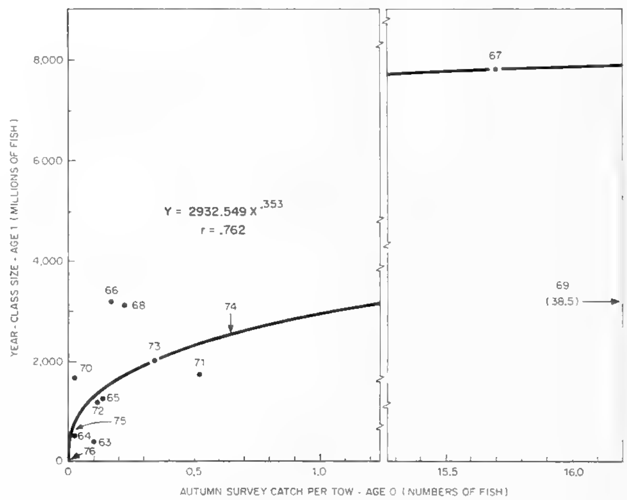

Figure 6.—Power curve relationship between Atlantic mackerel year-class size at age 1 from cohort analysis and autumn survey catch per tow at age 0. The 1969 point was not used in calculating the curve.

Table 5.—Catch per tow (number) of age 1 and 2 Atlantic mackerel from the U.S. spring bottom trawl surveys (strata 1-25, 61-76) and year-class size (millions of fish) at ages 1 and 2 from cohort analysis.

	Age 1		Age 2	
Year class	Spring survey	Cohort analysis	Spring survey	Cohort analysis
1966	—	3,165.3	21.661	2,344.1
1967	197.993	7,786.5	[1]1.190	5,617.3
1968	[1]0.299	3,114.3	12.435	2,300.1
1969	6.208	3,244.9	13.390	2,226.5
1970	2.954	1,657.5	5.545	1,161.4
1971	12.093	1,711.9	6.683	1,248.9
1972	1.949	1,212.6	0.749	759.4
1973	2.067	1,981.2	1.101	1,385.1
1974	5.330	[2](2,103.9)	4.928	[2](1,488.3)
1975	0.447	[2](915.3)	0.254	[2](651.8)
1976	0.043	[2](416.9)	—	—

[1]Not used.
[2]Calculated.

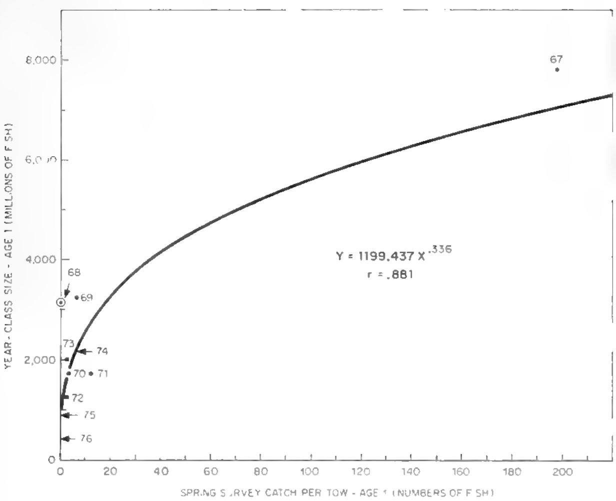

Figure 7.—Power curve relationship between Atlantic mackerel year-class size at age 1 from cohort analysis and spring survey catch per tow at age 1. The 1968 point was not used in calculating the curve.

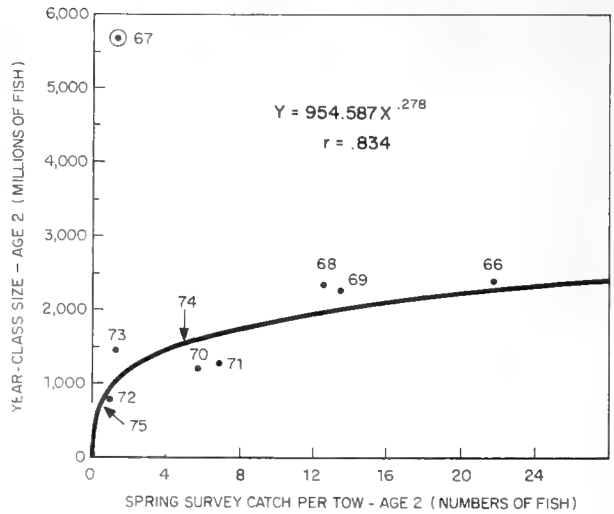

Figure 8.—Power curve relationship between Atlantic mackerel year-class size at age 2 from cohort analysis and spring survey catch per tow at age 2. The 1967 point was not used in calculating the curve.

where Z = instantaneous total mortality = $F + M$. Catch (in weight) options for 1978 were calculated for a range of F values by applying mean weights at age to the catch at age in numbers (C_i) determined using the catch equation:

$$C_i = N_i \frac{F_i}{Z_i} (1 - e^{-Z_i}) \qquad (3)$$

and summing over all ages. Resultant stock sizes at age in 1979 were determined using Equation (2).

RESULTS

Catch

Table 6 contains a summary of annual Atlantic mackerel catches by the United States, Canada, and other countries during 1961-77. International catches increased from 13,700 t in 1961 to 431,600 t in 1972 and then declined to 243,000 t in 1976. United States commercial catches varied from 900 to 4,400 t during this period and averaged 2,300 t/yr. Estimated U.S. recreational catches increased from 6,800 t in 1961 to a high of 33,300 t in 1969 and then declined to 5,000 t in 1976; the yearly average for the period was about 15,000 t. Canadian catches ranged between 5,500 and 21,200 t and averaged 12,600 t.

A total allowable catch (TAC) of 105,000 t was allocated by ICNAF for the international commercial fishery in 1977. The provisional reported catch for January-March was 52,114 t (Table 7). Because of the considerable reduction in TAC from 1976 (310,000 t) and the high demand for Atlantic mackerel by the distant-water fleets, it was assumed that all countries, except Canada, the United States, and "Others," would harvest their full catch allocations during the remainder of 1977. Based on past performance, the Canadian catch was con-

Table 6.—Atlantic mackerel catch (metric tons) from ICNAF Subareas 3, 4, and 5 and Statistical Area 6 during 1961-77.

	United States			Other	
Year	Commercial	Recreational	Canada	countries	Total
1961	1,361	6,828	5,459	11	13,659
1962	938	8,698	6,801	175	16,612
1963	1,320	8,348	6,363	1,299	17,330
1964	1,644	8,486	10,786	801	21,717
1965	1,998	[1]8,583	11,185	2,945	24,711
1966	2,724	10,172	11,577	7,951	32,424
1967	3,891	13,527	11,181	19,047	47,646
1968	3,929	29,130	11,134	65,747	109,940
1969	4,364	33,303	13,257	114,189	165,113
1970	4,049	[1]32,078	15,690	210,864	262,681
1971	2,406	30,642	14,735	355,892	403,675
1972	2,006	21,882	16,254	391,464	431,606
1973	1,336	9,944	21,247	396,723	429,250
1974	1,042	[1]7,640	16,701	321,837	347,220
1975	1,974	6,503	13,544	271,719	293,740
[2]1976	2,345	[1]4,947	15,744	219,997	243,033
[3]1977	3,000	5,000	20,000	64,000	92,000

[1]From angler survey; remaining years estimated (see text).
[2]Provisional.
[3]Estimated.

Table 7.—Estimated Atlantic mackerel catches (metric tons) in 1977 by country from ICNAF Subareas 3, 4, and 5 and Statistical Area 6.

Country	Reported through March	Estimated remainder	Total	Allocation
Bulgaria	3,110	890	4,000	4,000
Canada	—	20,000	20,000	30,000
Cuba	683	1,317	2,000	2,000
F.R.G.	—	1,100	1,100	1,100
G.D.R.	7,981	4,419	12,400	12,400
Italy	50	250	300	300
Poland	17,167	3,033	20,200	20,200
Romania	—	1,100	1,100	1,100
Spain	10	—	10	—
U.S.S.R.	22,586	214	22,800	22,800
U.S.A. (comm.)	527	2,473	3,000	6,000
U.S.A. (rec.)	—	5,000	5,000	—
Others	—	90	90	5,100
Total	52,114	39,886	92,000	105,000

sidered to be 20,000 t (30,000 t allocated), and the U.S. commercial catch 3,000 t (6,000 t allocated). The catch by countries without specific allocations ("Others") which were expected to take some Atlantic mackerel as by-catch was chosen as 100 t (5,100 t allocated) because of severe catch restrictions for many other species. The U.S. recreational catch was arbitrarily considered to be the same in 1977 as in 1976 (5,000 t). The total catch in 1977 was, therefore, taken to be 92,000 t for the purpose of this assessment.

Table 8.—Atlantic mackerel catch (commercial and recreational) (millions of fish) from ICNAF Subareas 3, 4, and 5 and Statistical Area 6 during 1962-77.

Year class	Year															
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
1951	0.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1952	0.2	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1953	0.6	0.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1954	1.1	0.2	0.3	—	—	—	—	—	—	—	—	—	—	—	—	—
1955	2.1	0.2	1.0	—	—	—	—	—	—	—	—	—	—	—	—	—
1956	2.3	0.2	0.8	0.9	—	—	—	—	—	—	—	—	—	—	—	—
1957	1.7	0.4	4.8	4.8	0.2	—	—	—	—	—	—	—	—	—	—	—
1958	5.5	8.1	5.1	5.1	0.6	0.4	0.1	—	—	—	—	—	—	—	—	—
1959	22.1	35.2	24.0	23.6	26.4	39.8	7.6	9.5	3.0	—	—	—	—	—	—	—
1960	4.0	1.7	4.9	6.3	9.6	7.5	1.2	2.5	4.0	7.5	—	—	—	—	—	—
1961	23.3	5.6	5.1	4.9	5.7	6.3	0.8	3.5	10.6	8.4	5.7	—	—	—	—	—
1962	—	1.5	8.6	3.5	3.2	4.1	8.2	2.3	10.5	4.4	3.8	1.6	—	—	—	—
1963	—	—	15.9	4.3	6.4	4.3	17.8	3.4	5.6	3.7	8.3	3.8	0.8	—	—	—
1964	—	—	—	10.9	13.9	24.4	47.3	6.5	7.5	9.2	4.3	4.1	2.5	1.0	—	—
1965	—	—	—	—	29.0	33.0	73.6	75.0	29.4	35.8	24.4	10.9	6.4	2.3	1.4	—
1966	—	—	—	—	—	1.0	76.3	183.2	173.5	210.8	88.6	31.1	25.7	12.5	13.2	0.5
1967	—	—	—	—	—	2.2	175.5	298.8	556.0	579.0	396.2	196.7	108.3	50.7	22.4	3.8
1968	—	—	—	—	—	—	1.4	8.1	58.1	132.0	185.3	191.9	111.8	52.1	34.2	4.9
1969	—	—	—	—	—	—	—	4.5	206.1	304.8	260.0	232.9	114.3	68.1	40.0	8.1
1970	—	—	—	—	—	—	—	—	5.1	77.3	87.0	284.2	101.5	58.9	27.0	8.0
1971	—	—	—	—	—	—	—	—	—	2.5	22.4	282.3	264.4	101.3	51.8	12.2
1972	—	—	—	—	—	—	—	—	—	—	3.6	161.4	242.2	114.2	84.7	13.7
1973	—	—	—	—	—	—	—	—	—	—	—	4.0	95.9	433.3	269.4	71.0
1974	—	—	—	—	—	—	—	—	—	—	—	—	2.0	375.4	349.5	130.5
1975	—	—	—	—	—	—	—	—	—	—	—	—	—	3.7	12.3	33.0
1976	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.1
Total	63.3	53.5	70.5	64.3	95.0	123.0	409.8	597.3	1,069.4	1,375.4	1,089.6	1,404.9	1,075.8	1,273.5	905.9	287.8
Obs. wt.[1]	16.6	17.3	21.7	24.7	32.4	47.6	109.9	165.1	262.7	403.7	431.6	429.2	347.2	293.7	243.0	92.0
Calc. wt.[1,2]	15.3	18.2	23.1	25.5	30.7	48.0	84.4	144.7	276.8	429.2	396.2	435.3	346.9	308.7	268.1	93.3
Obs./calc. wt.	1.085	0.951	0.939	0.969	1.055	0.992	1.302	1.141	0.949	0.941	1.089	0.986	1.001	0.951	0.906	0.986
Mean age	2.8	3.9	3.8	4.7	3.9	4.8	2.3	2.8	3.0	3.6	4.2	3.6	3.8	2.8	3.5	3.8

[1]Thousands of tons.
[2]Using mean weights at age from Table 1.

Catch Composition

Table 8 contains estimates of the Atlantic mackerel catch in numbers at age during 1962-77. Ages ranged between 0 and 10+. Average age of the catch during the period was 3.6 yr, with annual mean ages ranging between 2.3 and 4.8 yr. In 1977, 45% of the catch in numbers was age 3 fish, with a mean age of 3.8 yr. Predominant age groups in the catches have varied, generally reflecting the passage of dominant year classes through the fishery.

Abundance Indices

United States research vessel bottom trawl survey catch-per-tow data (Table 9) indicate a continued decline in Atlantic mackerel abundance. The spring survey catch-per-tow (kilograms) index decreased 37% from 1976 to 1977. Both the spring and autumn indices have demonstrated a continuous biomass decline since 1968-69 (Fig. 3). The spring survey mean catch per tow in numbers has also declined continuously (Table 10) and has shown a marked decrease in the number of age 1 Atlantic mackerel in 1976 and 1977.

The standardized U.S. commercial catch-per-day index (Table 11) has generally been consistent with estimates of abundance from survey data and with stock biomass estimates obtained from cohort analysis (Table 12), although it increased in 1975 and 1976 while the other indices continued to decrease. The U.S. commercial index may be limited as a measure of overall stock abundance because it has been based on small inshore catches, and particularly since these catches have comprised an increasingly smaller proportion of the total catch in recent years. The U.S. Atlantic mackerel catch from directed effort averaged 3.6% of the international catch each year during 1964-67, 1.4% in 1968-69, 0.2% during 1970-76, and <0.1% in 1974-75. The increase in the index in 1975-76 may reflect only localized improvements in abundance.

Distant-water fleet catch-per-effort data are considered to be unreliable as a measure of Atlantic mackerel abundance. Previous analysis of distant-water fleet statistics by Anderson (1976) indicated that various country-vessel tonnage classes experienced different patterns of catch per hour fished during 1968-74, most of which were not in agreement with the change in stock biomass determined by cohort analysis. Total stock biomass peaked in 1969 (Table 12) and then declined sharply, whereas distant-water fleet catch per effort generally increased or was erratic in year-to-year changes. Anderson (1976) suggested that learning, improvements in vessel efficiency through technological changes, or both occurred in varying degrees for nearly all country-tonnage classes engaged in the Atlantic mackerel fishery which invalidates their catch rates as consistent measures of stock abundance. In view of the previous inconsistency in these data, it is difficult to interpret the current catch rates. Although 1977 data are not available, 1976 data indicated increases in catch per effort for certain Bulgarian, German Democratic Republic, and Polish vessel classes and decreases for some U.S.S.R. vessels. The difficulty in interpreting distant-water fleet catch rates was recognized at the time of the last ICNAF assessment (ICNAF 1977), and it was also felt that a schooling species such as Atlantic mackerel was subject to continued accessibility to fishing gear even at low levels of abundance.

Table 9.—Stratified mean catch (kilograms) per tow (ln and retransformed) of Atlantic mackerel from United States bottom trawl surveys in the spring (strata 1-25, 61-76) and autumn (strata 1-2, 5-6, 9-10, 13, 16, 19-21, 23, 25-26).

Year	Spring[1] ln	Spring[1] Retransformed	Autumn[2] ln	Autumn[2] Retransformed
1963	—	—	.013	.016
1964	—	—	<.001	<.001
1965	—	—	.046	.073
1966	—	—	.057	.085
1967	—	—	.195	.372
1968	.575	3.998	.117	.217
1969	.029	0.065	.154	.459
1970	.471	2.039	.068	.099
1971	.425	1.969	.052	.073
1972	.354	1.332	.070	.107
1973	.228	0.748	.034	.043
1974	.277	0.769	.046	.108
1975	.121	0.255	.010	.016
1976	.144	0.317	.028	.039
1977	.118	0.199	—	—

[1]Based on catches with No. 41 trawl; 1968-72 catches were with No. 36 trawl and were adjusted to equivalent No. 41 catches using a 3.25:1 ratio (41/36).

[2]Based on catches with No. 36 trawl.

Table 11.—Atlantic mackerel catch per standardized U.S. day fished.

Year	Catch per day (metric tons)	Year	Catch per day (metric tons)
1964	0.43	1971	1.29
1965	0.49	1972	0.84
1966	0.84	1973	0.53
1967	1.75	1974	0.17
1968	2.80	1975	0.53
1969	1.92	1976	0.59
1970	2.07		

Table 10.—Stratified mean catch (number) per tow of Atlantic mackerel by year class from the 1973-76 U.S. spring bottom trawl surveys in ICNAF Subarea 5 and Statistical Area 6, strata 1-25, 61-76.

Year	Year class 1976	1975	1974	1973	1972	1971	1970	1969	1968	1967	1966	1965	1964	1963+	Total
1973	—	—	—	—	1.949	6.683	8.188	15.957	3.669	21.081	6.309	3.319	0.365	0.574	68.094
1974	—	—	—	2.067	0.749	1.347	0.185	0.492	0.249	1.401	0.440	0.237	0.107	—	7.274
1975	—	—	5.330	1.101	0.141	0.128	0.030	0.028	0.020	0.014	0.001	—	—	—	6.793
1976	—	0.447	4.928	0.365	0.070	0.014	0.006	0.009	—	0.004	—	—	—	—	5.843
1977	0.043	0.254	0.340	0.153	0.050	0.017	0.010	0.024	0.011	0.018	0.007	0.019	—	—	0.946

Table 12.—Atlantic mackerel stock size by age in ICNAF Subareas 3, 4, and 5 and Statistical Area 6 (millions of fish) derived from cohort analysis assuming natural mortality (M) = 0.30 and fishing mortality (F) = 0.39 at ages 4 and older in 1977. Values in parentheses estimated.

Year class	Year																
	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
1951	12.4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1952	7.8	5.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1953	8.3	5.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1954	18.1	12.5	9.1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1955	57.8	41.0	30.2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1956	55.2	38.9	28.6	20.5	—	—	—	—	—	—	—	—	—	—	—	—	—
1957	39.7	27.9	20.3	10.9	4.0	—	—	—	—	—	—	—	—	—	—	—	—
1958	53.7	35.1	19.0	9.7	2.8	1.5	0.8	—	—	—	—	—	—	—	—	—	—
1959	877.3	630.9	437.1	303.2	204.3	128.6	61.0	38.7	20.5	—	—	—	—	—	—	—	—
1960	741.0	545.5	402.6	294.1	212.4	149.1	104.0	76.0	54.2	36.7	—	—	—	—	—	—	—
1961	920.5	661.9	485.5	355.3	259.0	187.0	133.1	97.9	69.5	42.4	24.2	—	—	—	—	—	—
1962	—	429.5	316.9	227.3	165.4	119.8	85.2	56.1	39.6	20.3	11.2	5.0	—	—	—	—	—
1963	—	—	429.5	304.5	221.9	158.9	114.0	69.1	48.3	30.9	19.7	7.5	2.3	—	—	—	—
1964	—	—	—	542.2	392.3	278.7	185.4	96.7	66.0	42.4	23.5	13.7	6.6	2.8	—	—	—
1965	—	—	—	—	1,212.9	873.6	618.8	395.0	228.1	143.7	75.6	35.0	16.6	6.8	3.0	—	—
1966	—	—	—	—	—	3,165.3	2,344.1	1,670.8	1,080.1	650.8	300.7	146.5	81.8	38.5	17.7	1.8	0.9
1967	—	—	—	—	—	—	7,786.5	5,617.3	3,904.2	2,413.8	1,289.8	614.5	285.9	118.6	44.2	13.5	6.8
1968	—	—	—	—	—	—	—	3,114.3	2,300.1	1,654.0	1,111.7	664.1	326.8	145.9	63.2	17.4	8.7
1969	—	—	—	—	—	—	—	—	3,244.9	2,226.5	1,387.1	803.8	395.0	194.2	85.3	28.8	14.4
1970	—	—	—	—	—	—	—	—	—	1,657.5	1,161.4	785.5	337.3	162.5	69.7	28.4	14.2
1971	—	—	—	—	—	—	—	—	—	—	1,711.9	1,248.9	682.2	277.8	118.6	43.3	21.7
1972	—	—	—	—	—	—	—	—	—	—	—	1,212.6	759.4	354.1	164.1	48.6	24.4
1973	—	—	—	—	—	—	—	—	—	—	—	—	1,981.2	1,385.1	653.2	252.0	126.4
1974	—	—	—	—	—	—	—	—	—	—	—	—	—	(2,360.0)	1,428.6	760.9	452.4
1975	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(810.0)	589.4	408.3
1976	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(415.0)	305.6
1977	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(415.0)
Stock size (age 1+)																	
Total (10^6)	2,791.8	2,434.4	2,178.8	2,067.7	2,675.0	5,062.5	11,432.9	11,231.9	11,055.5	8,919.0	7,116.8	5,537.1	4,875.1	5,046.3	3,457.6	2,199.1	1,798.8
Wt (10^3 tons)[1]	626.7	584.9	582.2	577.3	674.9	886.7	2,150.3	2,404.2	2,285.6	2,161.3	2,099.5	1,522.1	1,186.5	964.1	702.2	524.4	468.6
Spawning stock (50% age 2, 100% age 3+)																	
Total (10^6)	1,500.8	1,674.0	1,590.9	1,373.3	1,266.0	1,460.0	2,474.4	5,309.0	6,660.6	6,148.3	4,824.2	3,700.1	2,514.2	1,993.8	1,933.3	1,489.4	1,231.0
Wt (10^3 tons)[1]	461.4	491.0	517.8	501.6	517.1	512.6	920.2	1,505.8	1,802.1	1,829.9	1,811.7	1,300.8	931.6	635.6	519.3	434.7	402.5

[1]Adjusted using ratio of observed to calculated weights in Table 8.

Fishing Mortality

Instantaneous fishing mortality (F) for ages 4 and older in 1977 was estimated to be 0.39 (see section on Methods). Age-specific F values computed from cohort analysis, assuming instantaneous natural mortality (M) = 0.30, for 1962-76 are given in Table 3. Mean annual F values for ages 3 and older were stable during 1962-64, averaging 0.04, and then increased steadily to a peak of 0.74 in 1976.

Recruitment

The estimated sizes of the 1961-73 year classes at age 1, computed by cohort analysis, are given in Table 12 and plotted in Figure 9. Sizes ranged between 430 million fish (1962 and 1963 year classes) and 7,786 million fish (1967 year class) and averaged 2,108 million. Only 4 of these 13 year classes were above the mean. The median size was 1,658 million.

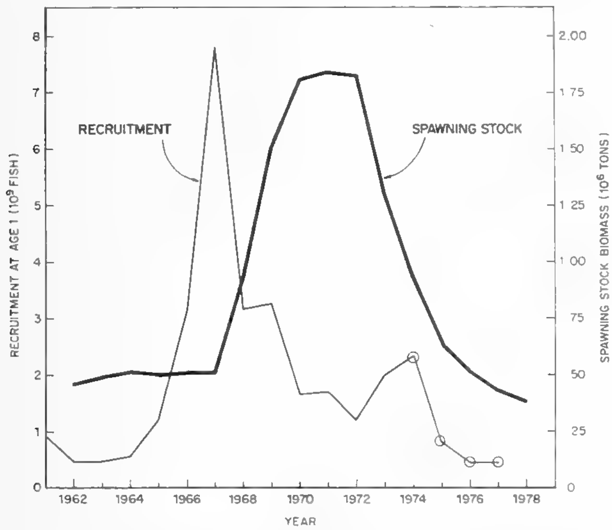

Figure 9.—Atlantic mackerel spawning stock biomass (metric tons) in 1962-77 and abundance at age 1 of the 1961-77 year classes from cohort analysis. Open circles indicate estimated year-class sizes.

The 1974 year class at age 1 was estimated to be 2,516 million fish based on the autumn survey age 0 index (Table 4, Fig. 6) and 2,104 million based on the spring survey age 1 index (Table 5, Fig. 7). At age 2 this year class was estimated to be 1,488 million fish based on the spring survey age 2 index (Table 5, Fig. 8). The corresponding catch of 349.5 million fish at age 2 in 1976 (Table 8) implies, using Equation (3), an F of 0.314. It then follows that the size of this year class at age 1 (from cohort analysis) would be 2,447 million fish. The mean of the above three estimates at age 1 was 2,356 million fish. The catch of 375.4 million fish at age 1 in 1975 (Table 8) and the year-class estimates of 2,516 and 2,104 million fish at age 1 result, using Equations (2) and (3), in year-class estimates at age 2 of 1,543 and 1,238 million fish, respectively. The mean of these two estimates and the other estimate of 1,488 million at age 2 was 1,423 million fish. The reported catch of 349.5 million at age 2 from a year-class size of 1,423 million fish requires, from Equation (3), an F of 0.331. Cohort analysis, using this F at age 2 in 1976, results in a year-class size of 2,358 million fish at age 1 in 1975. Given this estimate and the mean (2,356 million) of the three other estimates, the 1974 year class at age 1 was set at 2,360 million fish.

The 1975 year class at age 1 was estimated to be 614 million fish based on the autumn survey age 0 index (Table 4, Fig. 6) and 915 million based on the spring survey age 1 index (Table 5, Fig. 7). At age 2 this year class was estimated to be 652 million fish based on the spring survey age 2 index (Table 5, Fig. 8). The catch of 33.0 million fish at age 2 in 1977 (Table 8) implies, from Equation (3), an F of 0.060, which then infers (from cohort analysis) a year-class size of 898 million fish at age 1 in 1976. The mean of the above three estimates at age 1 was 809 million fish. The catch of 12.3 million fish at age 1 in 1976 (Table 8) and the year-class estimates of 614 and 915 million fish at age 1 result, from Equations (2) and (3), in year-class estimates at age 2 of 444 and 667 million fish, respectively. The mean of these two estimates and the other estimate of 652 million at age 2 was 588 million fish. The reported catch of 12.3 million fish at age 2 from a year-class size of 588 million fish requires an F of 0.067. Cohort analysis, using this F at age 2 in 1977, results in a year-class size of 809 million fish at age 1 in 1976. Given this estimate and the mean (809 million) of the three other estimates, the estimated size of the 1975 year class at age 1 was considered to be 810 million fish.

The 1976 year class at age 1 was estimated to be 417 million fish based on the spring survey age 1 index (Table 5, Fig. 7). There were no fish from this year class caught at age 0 (Table 4) during the 1976 autumn survey. The survey catch-per-tow index for this year class at both ages 0 and 1 was lower than for any other year class during 1963-77 (Tables 4, 5). This indicates that this year class may be very weak. Previously the weakest year classes since 1961 appeared in 1962 and 1963 (430 million fish at age 1). Based on the single estimate from the 1977 spring survey data, the size of the 1976 year class at age 1 was set at 415 million fish.

There are no estimates of the size of the 1977 year class available. Since the contribution of age 1 fish to the 1978 catch is expected to be low, estimation of the size of the 1977 year class is not particularly critical to the results of the assessment. However, the consequences of overestimating the size of this year class are more detrimental to conservation management than of underestimating it. If the year class is underestimated, any unrealized catches at age 1 can be regained in later years since yield per recruit reaches a maximum at about age 4 (ICNAF 1973). However, if the year class is overestimated, the 1978 allowable catch may be set too high to achieve management objectives and the 1979 stock size would be less than projected. The 1977 year class at age 1 was, therefore, set at the minimum level of the weak 1976 year class.

Partial Recruitment

Atlantic mackerel appear to have been fully recruited to the fishery at age 3 and older in recent years, based on age-specific mortality rates (Table 3). Partial recruitment at ages 1 and 2 varied considerably during 1963-77 (Table 13). Partial recruitment at age 1 ranged from 1 to 100% and at age 2 from 16 to 90%. Values prior to 1968 are less precise than those since because the numbers-at-age data for 1962-67 are based on very limited sampling data and are not as reliable as later data (Anderson et al.

Table 13.—Percentage of fishing mortality (F) of Atlantic mackerel at ages 1 and 2 compared with mean F at ages 3 and older (partial recruitment).

Year	Age 1	Age 2	Year	Age 1	Age 2
1962	78.9	15.8	1970	41.6	16.2
1963	9.5	23.8	1971	20.9	64.6
1964	100.0	82.1	1972	4.7	28.8
1965	46.2	32.7	1973	37.3	67.6
1966	46.7	70.0	1974	11.3	89.9
1967	0.9	40.5	1975	38.0	85.0
1968	17.4	25.2	1976	2.4	44.3
1969	2.1	44.4	1977	1.5	17.2

see footnote 2). Partial recruitment at ages 1 (1.5%) and 2 (17.2%) in 1977 was near the low end of the range of values. In view of the wide fluctuations evident in previous years, the 1977 partial recruitment coefficients may not reflect the situation that would actually occur in 1978. An average of the 1968-77 values (except 1970, 1973, and 1975) was used for age 1 in 1978 (9%). The high values in 1970 and 1975 were excluded from this average because they occurred as a result of large catches taken from strong incoming year classes which does not represent the expected situation in 1978. The high 1973 value was also excluded because it resulted from a large harvest of age 1 fish from a year class of below-averge size. This catch reflected a shifting of intensive fishing effort onto younger age groups in an attempt to maintain high levels of catch at a time when older age groups exhibited a sharp drop in abundance.

An average of the 1968-77 values (except 1974-75) was used for age 2 in 1978 (39%). The 1974-75 values were excluded because they were unusually high and do not represent the expected situation for 1978. Such high values may have resulted from: 1) large catches being taken from strong year classes, and 2) apparent diversion of fishing effort onto that age group from older age groups in an attempt to maintain high levels of catch. Partial recruitment in 1978 was, therefore, predicted to be 9% at age 1, 39% at age 2, and 100% at ages 3 and older (Table 14).

Table 14.—Summary of parameters used in the Atlantic mackerel assessment.

Parameter		Value
Fishing mortality in 1977 (age 4+)		0.39
Recruitment at age 1:	1974 year class	2,360.0×10⁶
	1975 year class	810.0×10⁶
	1976 year class	415.0×10⁶
	1977 year class	415.0×10⁶
Partial recruitment in 1978 (%):	age 1	9
	age 2	39
	age 3+	100
1978 spawning stock (10^3 tons) projection		402.5

Stock Size

Age-specific stock size estimates generated from cohort analysis and summed biomass values determined by applying mean weights at age to these estimates are given in Table 12. Total stock biomass (age 1 and older) increased from about 600,000 t in 1962-66 to a peak of 2.4 million t in 1969 and then declined steadily to an estimated 524,400 t in 1977. Spawning stock biomass, consisting of 50% of the age 2 fish and 100% of the age 3 and older fish (Isakov[13]; Moores [14]), increased from around 500,000 t during 1962-67 to 1.8 million t in 1970-72 before decreasing to 434,700 t in 1977 (Fig. 9).

Catch and Stock Size Projections

Under the assumption that the 1977 catch would be 92,000 t, the total stock biomass at the beginning of 1978 was estimated to be 468,600 t (11% decrease from 1977) with a spawning stock biomass of 402,500 t (7% decrease from 1977). Catch options for 1978 and resultant spawning stock biomass levels in 1979 were calculated for values of F ranging from 0 to 0.70 (Table 15). In the absence of any catch in 1978 (F = 0.00), the spawning stock biomass would increase about 6% from 1978 to 428,000 t in 1979. A catch of 23,500 t (F = 0.07) would maintain the spawning stock in 1979 at the 1978 level.

Table 15.—Projected Atlantic mackerel catch (metric tons) in ICNAF Subareas 3, 4, and 5 and Statistical Area 6 in 1978 with fishing mortality ranging from 0.00 to 0.70, and the resulting spawning stock in 1979 and its percentage change from 1978.

Fishing mortality (F)	Total mortality (Z)	Catch in 1978 (10^3 tons)	Spawning stock in 1979 (10^3 tons)	% change in spawning stock from 1978 (by weight)
0.00	0.30	0.0	428.0	+6.3
0.05	0.35	16.9	409.6	+1.8
0.07	0.37	23.5	402.5	0.0
0.10	0.40	33.0	392.6	−2.5
0.15	0.45	48.5	376.3	−6.5
0.20	0.50	63.2	360.8	−10.4
0.25	0.55	77.3	346.0	−14.0
0.30	0.60	90.8	331.9	−17.5
0.35	0.65	103.7	318.5	−20.9
0.40	0.70	116.0	305.6	−24.1
0.45	0.75	127.8	293.4	−27.1
0.50	0.80	139.0	281.7	−30.0
0.55	0.85	149.8	270.6	−32.8
0.60	0.90	160.1	260.0	−35.4
0.65	0.95	170.0	249.8	−37.9
0.70	1.00	179.5	240.1	−40.3

Equilibrium yield calculations, assuming a constant level of recruitment at age 1 and partial recruitment of 9, 39, and 100% at ages 1, 2, and 3+, respectively, indicate that $F_{0.1}$ = 0.40. The $F_{0.1}$ level, defined as the level of F at which the change in yield per recruit with respect to the change in F is only 10% of that which would occur if the fishery began on the virgin stock (Gulland and Boerema 1973), has been used recently within ICNAF as a basis for setting catch quotas. Fishing mortality at $F_{0.1}$ = 0.40 would result in a 1978 catch of 116,000 t and would reduce the spawning stock by 24% in 1979.

An assessment assuming a total catch of 110,000 t in 1977 (TAC of 105,000 plus 5,000 for the U.S. recreational catch) instead of 92,000 t has no significant effect on the

[13]Isakov, V. I. 1976. On some results of biological studies on mackerel from the Northwest Atlantic. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/VI/52, Ser. No. 3838 (mimeogr.), 14 p.

[14]Moores, J. A. 1976. Mackerel research in the Newfoundland area during 1975. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/VI/18, Ser. No. 3798 (mimeogr.), 10 p.

catch projections for 1978. The fishing mortality estimate for 1977 would be 0.435 instead of 0.39 and the projected spawning stock biomass in 1978 would be about 390,000 t instead of 402,500 t. A catch of about 25,000 t, instead of 23,500 t, could be taken in 1978 and still maintain the spawning stock in 1979 at the 1978 level.

DISCUSSION

The accuracy of the projected catch options for 1978 and the resultant spawning stock biomass levels in 1979 (Table 15) is dependent upon the accuracy of the data and parameters used in the analysis. The variability and bias associated with these data and parameters are evident.

The U.S. recreational catches (Table 6) are estimated and lack any measure of accuracy or reliability, and the validity of the international commercial statistics is uncertain. The numbers at age in the catch (Table 8) were generated from length and age samples contributed by various countries, and although ICNAF established recommended sampling procedures, the validity of the samples is unknown. Anderson et al. (see footnote 11) found significant differences in age interpretation and age-length keys between countries during 1970-76, particularly in 1976. As indicated earlier, country age-length keys for 1976 were combined in an attempt to modulate these differences. The procedure recommended by ICNAF specifies stratified age samples, whereas Kimura (1977) showed that random age samples are more accurate.

The U.S. bottom trawl survey data provided the basis for estimating the size of the recruiting year classes (Tables 4 and 5, Figs. 6-8) and also for predicting fishing mortality in 1977 (Table 2, Fig. 5). Although confidence limits were not given for any of these estimates, survey catch-per-tow data in general are subject to high variability (Grosslein 1971), and particularly so for Atlantic mackerel (Anderson 1976; Sissenwine 1978) since it is a pelagic schooling species. Therefore, even though the relationships using survey catch-per-tow data to predict year-class sizes and fishing mortality are statistically significant, the predicted values are necessarily somewhat imprecise.

The values for instantaneous natural mortality (M = 0.30) and partial recruitment coefficients, although having a basis for being chosen, introduce additional uncertainty to the final results.

In view of all the variability and uncertainty in the data, the results of this assessment must be treated with appropriate caution. Given the catch and stock size projections, fishery managers may set allowable catch levels for 1978 appropriate to management objectives which they have adopted. Since highly precise projections are currently not available, the decision process should include consideration of the acceptable level of risk of failing to achieve management objectives. If an objective is to rebuild the stock by a certain percentage from 1978 to 1979, it may be wise to set the catch in 1978 at a level corresponding to a greater percentage increase in stock size as a safety factor to guard against the probability that the predicted stock size and recruitment levels are, in fact, overestimated. According to the Fishery Conservation and Management Act of 1976 enacted by Congress, the level of catch must consider relevant economic, social, or ecological factors. Since economic and social factors are beyond the scope of this paper, only ecological or biological considerations will be discussed.

The historical relationship between Atlantic mackerel spawning stock and recruitment is shown in Figure 9. The spawning biomass estimated for 1978 is slightly below the 1962-67 level when, prior to the recent decade of intensive international fishing, catches averaged only about 25,000 t and stock size was relatively stable. The spawning biomass of about 500,000 t present in 1962-67 produced year classes ranging from the weakest (1962-63) to the strongest (1967). The large spawning stocks present during the late 1960's-early 1970's produced both above- and below-average year classes. It appears that for Atlantic mackerel, as for most species, spawning stock size alone exerts little influence on the size of a year class unless perhaps the spawning stock is reduced to extremely low levels. Lett and Kohler[15] found in population simulations of Atlantic herring, *Clupea harengus,* in the Gulf of St. Lawrence that recruitment was independent of spawning stock size over a fairly wide range, and that a stock-recruitment relationship emerged only when the stock was collapsing due to overfishing. Environmental factors are obviously a major influence on Atlantic mackerel year-class size, but the present state of knowledge concerning this influence is inadequate for assessment use. Consequently, it is virtually impossible to define an optimum or minimum spawning stock size at or above which level adequate recruitment can be predicted or below which weak recruitment is likely. However, since spawning stock size has continued a steady decline and recent year classes (1975-76) appear to be as weak as any observed previously, there is reason for concluding that the spawning stock should not be allowed to fall much below the projected 1978 level.

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NOAA Technical Report NMFS SSRF-736

A Historical and Descriptive Account of Pacific Coast Anadromous Salmonid Rearing Facilities and a Summary of Their Releases by Region, 1960-76

Roy J. Wahle and Robert Z. Smith

September 1979

U.S. DEPARTMENT OF COMMERCE
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NOAA Technical Report NMFS SSRF-736

A Historical and Descriptive Account of Pacific Coast Anadromous Salmonid Rearing Facilities and a Summary of Their Releases by Region, 1960-76

Roy J. Wahle and Robert Z. Smith

September 1979

U.S. DEPARTMENT OF COMMERCE
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CONTENTS

Figures

Tables

A Historical and Descriptive Account of Pacific Coast Anadromous Salmonid Rearing Facilities and a Summary of Their Releases by Region, 1960-76

ROY J. WAHLE and ROBERT Z. SMITH[1]

ABSTRACT

A brief history of the artificial culture of salmonid fishes in North America is presented. The report contains a Pacific coast section followed by sections for each of six major regions on the coast: Alaska, British Columbia, Washington coastal and Puget Sound, Columbia Basin, Oregon coastal, and California. The Columbia Basin is further divided into three subregions. The Pacific coast section provides information on current production of anadromous salmon (*Oncorhynchus* spp.) and trout (*Salmo* spp.). Each regional or subregional section contains a short history and background, a map with current rearing facilities located, a general hatchery information table, and migrant release tables summarized by species. In the final portion of the report, changes in numbers of facilities, species reared, rearing techniques, and size at time of release are discussed.

INTRODUCTION

When the report on the "Releases of Anadromous Salmon and Trout from Pacific Coast Rearing Facilities, 1960 to 1973" by Roy J. Wahle, William D. Parente, Paula J. Jurich, and Robert R. Vreeland (1975) was published, it had three main objectives: 1) to provide past and present trends in artificial production of Pacific coast anadromous fish, 2) to supply base information needed for analysis of production practices, and 3) to bring together in a single source, detailed release information from all anadromous fish rearing facilities in Alaska, British Columbia, Washington, Idaho, Oregon, and California. In fulfilling these objectives, it was necessary for Wahle et al. (1975) to be very detailed. We have prepared this summary report to provide the reader with a more readily usable, quick reference to anadromous fish production on the Pacific coast, Alaska to California, from 1960 to 1976.

In addition to a section on interpretation and organization, this report includes a general history section covering artificial salmonid propagation in North America. The history is followed by a coast-wide summary and sections for Alaska, British Columbia, Washington coastal and Puget Sound, Columbia Basin, Oregon coastal, and California. The last portion of this report deals with hatchery production trends. These include changes in numbers of hatcheries, species reared, rearing techniques, and the size of fish at time of release.

The two appendix tables have been provided to allow maximum use of the informational tables in each regional section. Appendix Table 1 has an alphabetized list of Pacific coast rearing facilities along with the region for each. This table can be used as an index for locating individual facilities in the report. Appendix Table 2 contains information on all State, Federal, or Provincial agencies rearing anadromous fish on the Pacific coast. It includes addresses, phone numbers, and people to contact with each of these agencies.

The Columbia Basin, containing portions of Washington, Idaho, and Oregon, has been handled separately because of: 1) the large geographical area drained by a common river system; 2) the constant interaction of diverse resource agencies and interested user groups; 3) the need for evaluation of production and habitat improvement measures within the Basin; and 4) the contribution and value of Columbia Basin anadromous salmonids to Pacific coast fisheries.

Each regional section includes a short history and background, a map with the facilities located, a general hatchery information table, and a release summary table. The general information table lists the approximate location, species reared, operating and funding agencies, year of construction, and the operational status in 1976 for the facilities in each region.

Unless otherwise cited, all historical information on early hatcheries has been based on Cobb (1931). One area of possible confusion to the reader concerns the use of agencies "names." During the years fish have been artificially propagated in the United States, many of the agencies concerned have undergone name changes. In this report, we have attempted to use agency names as taken from the literature rather than the names that may be in current use.

INTERPRETATION AND ORGANIZATION

Six species of salmon (*Oncorhynchus* spp.) and two of anadromous trout (*Salmo* spp.) are included in this report. Because of their current economic and recreational importance, the primary species considered are chinook, *O. tshawytcha,* and coho, *O. kisutch,* salmon,

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and steelhead trout, *S. gairdneri.* The other species: chum, *O. keta,* pink, *O. gorbusha,* sockeye, *O. nerka,* and cherry, *O. masu,* salmon, and sea-run cutthroat trout, *S. clarki,* are presently reared on a limited basis and are included only if they were raised in the region being considered.

We have further divided chinook salmon into three races (spring, summer, and fall) and steelhead trout into two races (summer and winter). These designations are commonly used by all fisheries agencies rearing anadromous salmonids and are based for the most part on the season during which the adult fish return to freshwater. Rearing periods differ among the races of chinook salmon.

Releases of fish included in Wahle et al. (1975) were divided into two categories: migrants and submigrants. This was done to separate production releases from those necessitated by reducing numbers of fish to achieve "optimum" pond capacity levels. The definitions used were based on the best available knowledge of the ideal size at release for obtaining the greatest immediate seaward migration, but were not used as hard and fast rules. Exceptions were made in special cases if it was felt that a group of fish belonged in a different category than indicated by the definition.

The migrant and submigrant classifications used in this report should not be confused with the terms "fry," "fingerling," and "yearling" that we have included in the various history sections. "Fry" normally refers to fish released without any rearing, as soon as the yolk sac has been absorbed. "Fingerlings" can refer to any number of different sizes depending on the author and the species. Often "fry" and "fingerlings" refer to fish we would call submigrants. "Yearlings" in the historical literature normally refers to fish reared for a year in the hatchery before release. Depending on species, we might call these fish migrants.

As reported by Wahle et al. (1975), our definitions of migrants for each species are:

Spring and summer chinook salmon—those released after 12 mo of rearing or larger than 30/lb (15.1 g/fish).
Fall chinook salmon—those released after 90 days of rearing or larger than 300/lb (1.5 g/fish).
Coho salmon—those released after 12 mo of rearing or larger than 30/lb (15.1 g/fish).
Pink and chum salmon—those released after any period of feeding at the rearing facility.
Steelhead and sea-run cutthroat trout—those released after 12 mo of rearing or larger than 10/lb (45.4 g/fish).

Migrant criteria for sockeye and cherry salmon were not presented in Wahle et al. (1975). For those species, we have relied on the hatcheries or agencies involved to indicate whether each release was migrant in nature.

We define submigrants as those releases that do not meet migrant specifications. In the case of pink and chum salmon, submigrants would be any unfed fry released.

Data for this report was obtained from Wahle et al. (1975) and the appropriate State, Federal, and Canadian fishery management agencies.

HISTORY

Artificial propagation of salmonids began in North America in the mid-1800's. Theodatus Garlick of Cleveland, Ohio, in conjunction with H. A. Ackley, Successfully artificially bred brook trout, *Salvelinus fontinalis* (Milner 1874). The first hatchery in North America was established by Seth Green at Mumford, N.Y., in 1864, and the first anadromous fish hatchery was built in New Castle, Canada, in 1866 for the purpose of taking Atlantic salmon, *Salmo salar,* eggs (Atkins 1874).

In the late 19th and early 20th centuries, efforts were made by Federal and various State commissions to introduce Pacific coast salmon into eastern waters. In 1872, Livingston Stone was sent to California by the U.S. Commission of Fish and Fisheries to obtain salmon eggs for shipment to the east coast. He established the first Pacific fish cultural station in 1872 on the McCloud River, named after the then Commissioner of Fisheries, Spencer F. Baird. While the main purpose of this station was the shipment of eggs east, the Commission made a cooperative agreement with the State of California in which the State furnished part of the operating expense money in return for the station's releasing native fingerlings into the McCloud River. Eggs taken for shipment were kept in baskets at the hatchery until the eyes of the embryo were visible. They were then packed in moss, crated, and taken by stagecoach to Red Bluff, Calif. From there, they traveled by train to San Francisco and then on to the east coast. To assure the survival of the eggs, it was necessary to continually dampen the moss in which they were packed. In the first year of operation, 50,000 eggs were taken, but 20,000 were lost due to difficulties experienced in keeping the eggs cool prior to shipment. The remaining 30,000 eggs were shipped east and from these 7,000 fry were planted in Pennsylvania's Susquehanna River (Stone 1874).

Before the attempts to transplant Pacific salmon to the eastern United States were discontinued, Pacific coast salmon had been planted in a large number of major streams on the Atlantic coast, in the Mississippi drainage, and in the Great Lakes. Some of these transplants were moderately successful. From approximately 10,000 chinook salmon fingerlings planted in Lake Quinsigamond, Mass., 600 fish weighing between 0.68 and 2.27 kg were caught. Early plants of pink salmon in selected New England streams also met with some success. A female pink salmon weighing approximately 1.9 kg was taken in the Penobscot River. Most of these transplants resulted in failures as the selected waters were either too warm or too turbid for salmon to survive. The few runs that did become established either had so few returnees that they were not self sustaining or fishermen caught all the fish (Cobb 1931).

These early efforts at transplanting fish created a large demand for eggs. This demand resulted in construction of hatcheries in all the Pacific Coast States. After a short time, the taking of eggs for transportation became secondary to augmenting runs in Pacific coast streams by rearing and releasing the fish (Stone 1874). From these beginnings emerged the Pacific coast salmon rearing industry.

PACIFIC COAST

With today's increasing use of the fishery resource and the continuing degradation of the environment necessary for proper spawning and freshwater rearing of anadromous salmonids, it has become necessary to augment natural production if we are to maintain viable sport and commercial fisheries. From 1960 through 1976 a total of 189 facilities, including 120 hatcheries and 69 rearing ponds and net pens, have made production releases for at least 1 yr. During this period, 3.44 billion migrant salmon and steelhead trout weighing over 105 million lb (47.6 million kg) have been released (Tables 1, 2). Annual migrant production of all species increased from 152 million fish weighing 1.7 million lb (0.77 million kg) at release in 1960 to 294 million fish weighing 11.1 million lb (5.03 million kg) in 1976.

Alaska

Most early Alaska hatcheries were located in the

Table 1.—Migrant releases of chinook and coho salmon and steelhead trout—Pacific coast[1] (in thousands).

Release year	Fall chinook		Spring chinook		Summer chinook		Coho		Winter steelhead		Summer steelhead	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	117,680.3	556.6	7,636.3	228.8	0.0	0.0	14,490.7	444.3	2,593.5	315.2	233.0	31.0
1961	103,220.8	672.7	5,315.2	197.9	0.0	0.0	26,148.8	864.6	2,522.8	314.6	674.5	97.3
1962	86,121.5	544.5	5,690.7	244.8	0.0	0.0	27,333.4	995.8	3,509.1	390.5	723.8	73.4
1963	99,806.7	658.9	9,421.1	370.1	0.0	0.0	30,987.2	1,123.5	2,922.8	332.9	1,336.4	146.8
1964	106,684.2	752.1	13,963.7	499.8	0.0	0.0	30,275.5	1,309.0	4,221.9	556.6	1,784.5	221.0
1965	95,918.6	740.6	7,302.7	303.7	0.0	0.0	34,746.8	1,516.8	4,216.2	536.5	1,660.4	185.2
1966	95,712.4	891.7	11,645.7	477.1	0.0	0.0	40,422.2	1,931.2	6,166.6	829.1	1,770.2	223.3
1967	96,386.1	885.8	14,063.7	644.6	0.0	0.0	40,276.6	2,059.9	5,784.1	774.2	3,316.5	401.2
1968	112,534.2	1,174.8	13,877.8	863.3	2,138.3	13.6	38,371.4	2,119.1	6,077.0	828.6	4,860.0	580.0
1969	124,125.1	1,266.4	10,392.1	804.6	2,121.3	20.2	47,988.0	2,814.4	6,380.0	886.1	4,814.1	593.9
1970	137,757.4	1,603.8	16,879.7	1,478.1	4,228.2	35.4	48,209.4	2,751.3	7,101.9	1,047.7	6,795.4	1,041.3
1971	168,388.9	1,706.2	14,726.1	1,151.0	2,184.5	37.0	51,182.3	3,039.6	8,733.5	1,090.6	8,143.4	1,091.5
1972	166,678.2	2,019.1	16,546.0	1,401.3	2,604.9	42.6	58,858.9	3,772.7	9,247.3	1,263.9	6,399.9	998.7
1973	162,515.8	2,266.4	17,604.5	1,761.6	2,312.6	34.3	53,400.0	3,178.5	8,680.1	1,243.3	8,111.9	972.5
1974	149,968.2	2,504.4	16,506.1	1,353.1	1,202.8	43.0	56,580.9	3,453.1	8,060.6	1,088.7	10,048.1	1,285.3
1975	157,707.6	2,554.7	21,389.5	1,848.6	120.8	3.1	60,936.3	3,854.5	7,376.7	1,067.2	7,126.3	1,068.1
1976	163,110.3	2,775.9	22,462.0	1,974.0	880.5	42.7	62,928.3	3,710.3	8,895.7	1,360.6	7,043.2	1,035.2
Total	2,144,316.3	23,574.6	225,422.9	15,602.4	17,793.9	271.9	723,136.7	38,938.6	102,489.8	13,926.3	74,841.6	10,045.7

[1]Data derived from Wahle et al. (1975) prior to 1974 and from appropriate State, Federal, and Provincial records thereafter.
[2]1 lb = 0.454 kg.

Table 2.—Migrant releases of chum, pink, sockeye, and cherry salmon and sea-run cutthroat trout—Pacific coast[1] (in thousands).

Release year	Chum		Pink		Sockeye		Cherry		Sea-run cutthroat	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	5,031.6	8.8	555.5	2.5	3,177.0	69.2	0.0	0.0	155.4	42.8
1961	4,774.1	13.0	0.0	0.0	2,788.0	72.5	0.0	0.0	189.4	52.6
1962	1,859.3	4.6	145.7	0.5	2,224.0	43.8	0.0	0.0	292.0	77.6
1963	5,454.4	9.3	0.0	0.0	3,125.4	67.8	0.0	0.0	139.8	48.0
1964	3,358.5	6.9	525.3	0.9	3,364.0	58.8	0.0	0.0	258.7	64.3
1965	3,116.7	5.8	0.0	0.0	3,301.0	73.6	0.0	0.0	231.9	52.4
1966	1,785.4	6.0	421.0	1.3	73.0	1.6	0.0	0.0	395.9	95.3
1967	1,827.0	6.4	0.0	0.0	0.0	0.0	0.0	0.0	554.2	128.7
1968	1,264.3	3.7	602.8	1.4	0.0	0.0	0.0	0.0	561.6	121.3
1969	2,448.0	5.8	0.0	0.0	23.4	0.7	0.0	0.0	531.9	126.3
1970	1,563.0	4.4	774.9	2.4	0.0	0.0	0.0	0.0	639.5	139.8
1971	3,839.6	9.0	0.0	0.0	0.0	0.0	0.0	0.0	815.6	169.1
1972	5,624.2	17.2	1,957.9	5.1	2.5	([3])	0.0	0.0	491.8	122.0
1973	6,565.5	20.5	0.0	0.0	0.0	0.0	26.1	3.2	585.9	151.8
1974	10,012.1	34.1	1,211.9	3.5	0.0	0.0	44.4	4.3	462.3	112.4
1975	29,637.5	88.2	0.0	0.0	0.0	0.0	1.0	0.1	471.8	118.2
1976	23,779.9	86.6	4,850.4	8.7	16.2	0.6	0.5	0.1	496.9	132.5
Total	111,941.1	330.3	11,045.4	26.3	18,094.5	388.6	72.0	7.7	7,274.6	1,755.1

[1]Data derived from Wahle et al. (1975) prior to 1974 and from appropriate State, Federal, and Provincial records thereafter.
[2]1 lb = 0.454 kg.
[3]Less than 100 lb.

southeastern part of the State. They were funded by fish canneries and reared primarily sockeye salmon. The first hatchery in the State was a co-op built in 1891 by several canneries in Karluk, Kodiak Island. This was not an auspicious beginning for salmon culture in Alaska as the hatchery stopped production after only 1 yr because of violent disagreements among the canneries' personnel over fishing rights in the area.

By the early 1900's private hatcheries were in operation on Kodiak, Kuiu, Baranof, Etolin, Revillagigedo, Chichagof, and Prince of Wales Islands, as well as on the mainland. These facilities operated for varying periods of time through 1936. The world's largest and most costly facility to that time, the Fortmann Hatchery, was constructed in 1901 by the Alaska Packer's Association at Loring, Revillagigedo Island. It had a capacity of hatching 110 million eggs.

From 1893, when records were first kept, to 1912, releases of fry increased from 600,000 to a maximum of 156 million, and then declined to 32.5 million in 1936 when the last facility closed. During the peak years, from 1905 to 1912, the private hatchery annual releases averaged over 106 million fish. Although most of the fish were sockeye, a few pink salmon were released from several of the facilities.

Until 1900, the operation of private hatcheries was voluntary. Thereafter, a Congressional Act required salmon canning companies in Alaska to operate hatcheries and, each year, release four sockeye salmon fry for each adult salmon of any species taken during the previous year. In addition, the companies were required to keep records of the numbers of fish spawned, eggs taken, percentage hatched, fry planted, and release locations. In 1902, the release ratio was increased to 10 fry for each salmon taken. Most companies either ignored the requirement or found it impossible to follow. Because of this, the regulation was modified in 1906 to reduce license fees and taxes for complying companies.

In 1905, the U.S. Bureau of Fisheries erected Alaska's first Federal hatchery on Yes Bay near Ketchikan. This station, along with another Bureau hatchery on Afognak Bay, Afognak Island, hatched and released primarily sockeye salmon along with a few pinks, coho, and steelhead trout fry. Numbers of fish released ranged from 6 million in 1906 to 142 million in 1910 and then declined to 22 million in 1928. In addition, these two hatcheries shipped at least 150 million eyed eggs to Oregon, Washington, and the New England States including Maine, as well as the Province of British Columbia. The two hatcheries operated until 1933 when, because of the Depression, funding at Federal hatcheries was cut by 40%. All over the country, rearing programs were cut back and nine hatcheries, including the two in Alaska, were shut down (Leach and James 1934).

Little effort other than some experiments with planting eyed eggs was expended on anadromous salmonid production between 1936 and 1955. In 1955, the Deer Mountain Hatchery at Ketchikan hatched and reared coho and sockeye salmon. Some of the eggs for these plants, as well as those for some chinook salmon plants in 1965-66, came from the Green River in Washington. A hatchery near Fairbanks and the Deer Mountain Hatchery, as well as one operated on the Karluk River by a sports group, released fall chinook salmon and steelhead trout during the late 1950's. Fire Lake Hatchery, near Anchorage, opened in 1956. While this facility mainly reared trout for planting into lakes for resident fisheries, steelhead trout were also included in its program. Besides releasing a small number of steelhead trout fry, the hatchery also supplied eggs to the Fairbanks facility. All these hatcheries except Fire Lake have ceased anadromous rearing operations. Since 1960, one additional hatchery, Crystal Lake, and four experimental rearing facilities (one rearing pond and three saltwater net pens) have become operational (Table 3). Of the six, five are operated by the Alaska Department of Fish and Game (ADFG) and one by the National Marine Fisheries Service (NMFS). Four are located in southeastern Alaska and two are near Anchorage (Fig. 1).

In addition to these rearing stations, ADFG also operates several chum and pink salmon incubation facilities which release unfed fry. One, Kitoi Bay Hatchery on Afognak Island, has been in operation since 1953 and has also released large numbers of sockeye salmon fry. Others have been constructed in the past 3 yr by ADFG Fisheries Rehabilitation Enhancement and Development (FRED) Division using special monies appropriated by the State legislature. These incubation stations are being built to offset dramatic drops in Alaska's fish stocks (Alaska Department of Fish and Game 1976).

Table 3.—Anadromous fish rearing facilities—Alaska, 1960-76.

Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[1]
Hatcheries						
Crystal Lake	Petersburg	ADFG	sc, co, sh	Yes	1972	ADFG, Anadromous Fish Act[3]
Fire Lake	Anchorage	ADFG	sc, co	Yes	1956	ADFG
Ponds and net pens						
Halibut Cove Lagoon net pen	Homer	ADFG	sc, co	Yes	1972	ADFG
Little Port Walter net pen	S.E. Baranof Island	NMFS	sc, co, sk	Yes	1967	NMFS
Mendenhall Pond	Juneau	ADFG	sc, co	Yes	1972	ADFG
Starrigavan net pens	Sitka	ADFG	sc, co	Yes	1971	ADFG

[1]ADFG = Alaska Department of Fish and Game, NMFS = National Marine Fisheries Service.
[2]sc = spring chinook salmon, co = coho salmon, sh = steelhead trout, sk = sockeye salmon.
[3]U.S. Fish and Wildlife Service monies.

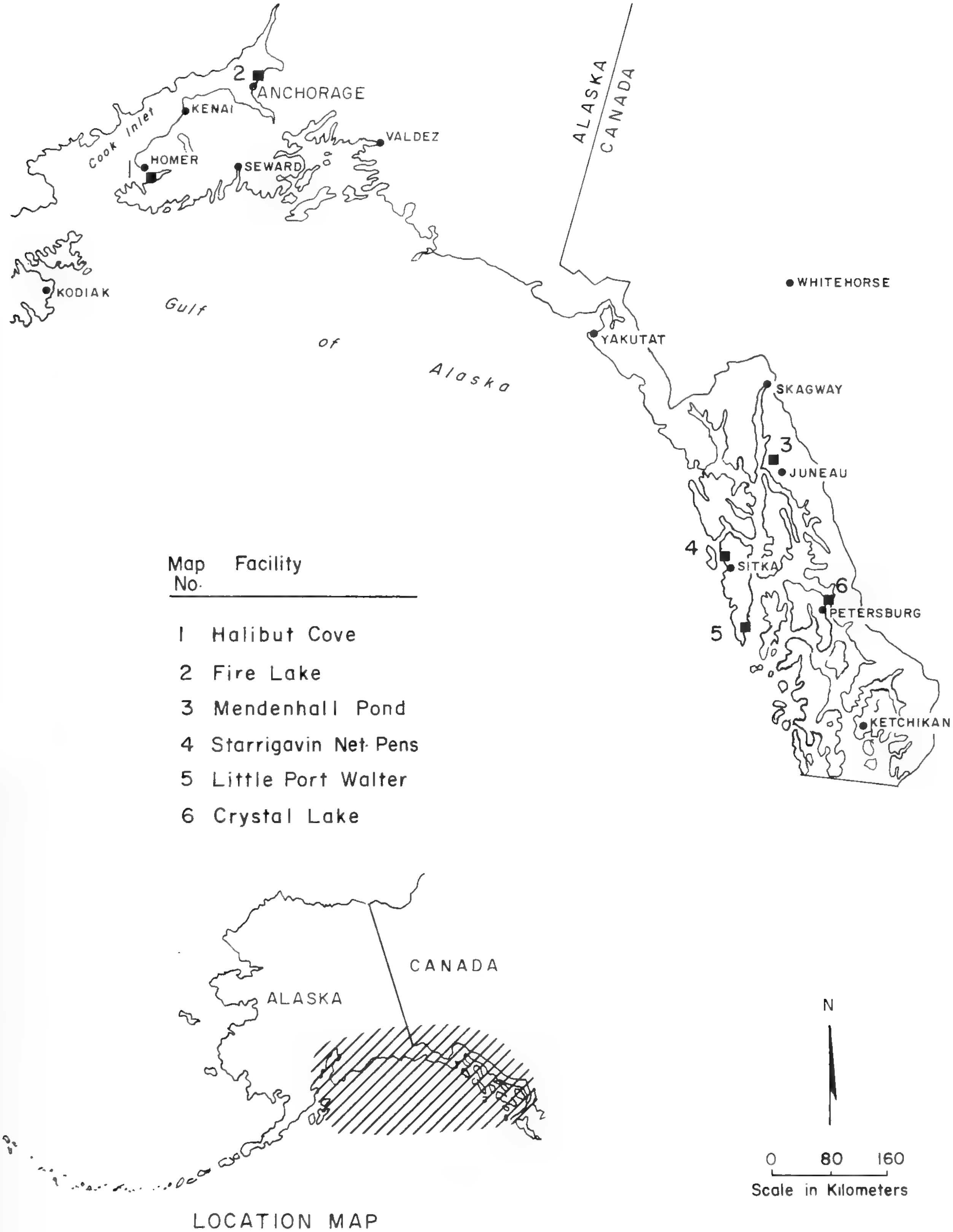


Figure 1.—Map of locations of Alaskan salmonid rearing facilities, 1960-76.

The State legislature also appropriated monies to be used to finance nonprofit, low-interest, State-secured loans for fish culture. The initial facilities built with these funds are still in the developmental stage. Releases made from both these private facilities and the FRED Division incubation stations are not included in this report because they normally consist of unfed fry.

Presently, the two agencies rearing fish in Alaska are concentrating on chinook and coho salmon (Table 4). Since a large majority of the chinook salmon plants have resulted from eggs taken from native stocks which closely approximate the spring race as we have defined it, we have called all of the chinook salmon plants spring chinook.

In 10 yr, releases of migrant chinook salmon went from a meager 400 fish weighing 4 lb (1.8 kg) to almost 600,000 fish weighing 33,000 lb (15,000 kg) in 1974. Coho salmon have also increased, from 171,000 migrants weighing 9,000 lb (4,000 kg) released in 1968 to approximately 1 million migrants weighing 50,000 lb (27,700 kg) in 1974.

Five of the Alaskan rearing facilities presently operating are noteworthy. The first of these, Fire Lake Hatchery, is actually a complex made up of a main hatchery and satellite ponds located at nearby Ft. Richardson and Elmendorf Air Force Base. These ponds are unique as they are the only ones currently using condenser cooling water heated as a byproduct during the thermal generation of electricity. This free supply of warm water allows fish to easily reach migrant size in an area were extreme weather conditions and cold-water temperatures would normally necessitate the use of expensive heating equipment to achieve similar growth.

Little Port Walter is a NMFS Research Station which was established in the late 1930's. It was expanded to include saltwater net pen rearing of coho salmon in the mid-1960's. The net pens are suspended from a floating platform anchored near the shore of a small saltwater bay. The salinities of the net pens are controlled using freshwater piped from nearby Sashin Creek. To obtain the initial supply of coho salmon for rearing, fingerlings were seined from the bay and placed in the pens. After migrating to the ocean, the adult fish return to the area of the net pens where they are trapped and spawned.

Table 4.—Migrant releases of chinook, coho, and sockeye salmon and steelhead trout—Alaska[1] (in thousands).

Release year	Spring chinook		Coho		Sockeye		Winter steelhead	
	No.	Lb.[2]	No.	Lb.	No.	Lb.	No.	Lb.
1960	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1961	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964	0.4	([3])	0.0	0.0	0.0	0.0	0.0	0.0
1965	8.8	0.3	0.0	0.0	0.0	0.0	0.0	0.0
1966	166.9	1.7	0.0	0.0	0.0	0.0	0.0	0.0
1967	538.3	11.6	0.0	0.0	0.0	0.0	0.0	0.0
1968	82.4	2.8	171.7	8.9	0.0	0.0	0.0	0.0
1969	95.9	5.7	187.4	13.8	0.0	0.0	0.0	0.0
1970	45.7	1.6	227.0	21.5	0.0	0.0	0.0	0.0
1971	217.4	11.6	92.7	6.5	0.0	0.0	0.0	0.0
1972	71.8	3.8	309.7	20.1	0.0	0.0	0.0	0.0
1973	177.3	11.0	143.3	15.9	0.0	0.0	0.0	0.0
1974	598.8	33.3	969.0	50.1	0.0	0.0	0.0	0.0
1975	154.8	6.9	1,032.1	72.1	0.0	0.0	17.5	0.6
1976	225.7	9.7	930.6	48.1	16.2	0.6	16.5	1.4
Total	2,384.2	100.0	4,063.5	257.0	16.2	0.6	34.0	2.0

[1]Derived from Wahle et al. (1975) prior to 1974 and from Alaska Department of Fish and Game and National Marine Fisheries Service release reocrds thereafter.

[2]1 lb = 0.454 kg.

[3]<100 lb.

The Starrigavan net pens are patterned after the Little Port Walter facility. They are anchored in the bay near Sitka. Like its prototype, the facility pipes water from a nearby creek to control salinity. Local and Crystal Lake Hatchery coho salmon fry were initially reared. As they become more available, endemic stocks are replacing those from Crystal Lake.

Halibut Cove is the saltwater net pen facility southwest of Anchorage. It is also an offshoot of the Little Port Walter and Starrigavan facilities. Rearing salmon in this near Arctic environment is challenging because the lagoon freezes in the winter and the water temperature drops to −2°C (18°F). Freshwater from a nearby lake is available only during the warmer months. There are no local salmon stocks available and no hatching facilities on the site, so Fire Lake chinook and coho salmon fry are brought in for rearing.

Mendenhall Rearing Pond is located just off the Mendenhall River near Juneau. It is supplied with water from the melting Mendenhall Glacier. This pond is covered by ice each year from October to May so fish can be fed only during the warmer months. During the winter, water under the ice must be aerated with an electric pump. Coho salmon eggs are obtained from returns to the rearing pond. Because of the cold water, eggs taken from Mendenhall Pond are transferred to Crystal Lake Hatchery near Petersburg for hatching. The fry are then brought back to the pond for rearing and release.

British Columbia

The program of anadromous fish propagation in British Columbia began in 1884 with the establishment of a hatchery on the Fraser River near the town of New Westminster. From 1901 through the mid-1930's additional facilities were constructed and operated by the Provincial government and private fisheries organizations on the Finger and Skeena Rivers, at Rivers Inlet, and on Vancouver Island. As in Alaska, all of these hatcheries concentrated on sockeye salmon production, but also intermittently hatched a few chum, coho, chinook, and pink salmon. All fish were released as fry. From 1885 to 1927 more than 2 billion sockeye salmon fry were released.

The operation of hatcheries decreased and then finally stopped completely in the late 1930's due to the Depression and the outbreak of World War II. Nothing was done on a production basis again until 1967 when a pilot project began at the newly constructed Big Qualicum Hatchery on Vancouver Island. At present, Canadian Fisheries and Marine Services (CFMS) operates six facilities in British Columbia (Table 5). Five of these are on Vancouver Island and the sixth, Capilano, is on the mainland just north of the city of Vancouver (Fig. 2).

Hatchery emphasis has been placed on fall chinook and coho salmon (Table 6) rather than sockeye salmon as was the case in the early years. In 9 yr (1968-76) fall chinook salmon migrant releases have increased twentyfold (from 147,000 to 30 million fish). Coho salmon releases also increased, from almost 70,000 migrants in 1970 to over 2.3 million in 1976. In addition, the CFMS has begun a steelhead trout rearing program with the first migrant fish released in 1973 and has been experimenting with summer chinook salmon.

While numbers and pounds released by British Columbia hatcheries each year have been small when compared with the production of the large Columbia River complexes, results have been encouraging. To date, the most dramatic success has been the survival of the 1971-brood coho salmon released from Capilano hatchery. Of 284,000 fish released, there was a return of 2,700 jacks (fish returning as 2-yr olds) in 1973 and 37,000 adults in 1974. This is a hatchery return of almost 14%. In addition, these fish contributed heavily in the fishery, exhibiting a 1:1 catch to escapement ratio. The total survival for this brood of fish was almost 28%.[2]

It is interesting to note that of the six CFMS facilities, three began as spawning channels. All three of these have either been modified to include rearing facilities or have been converted to hatcheries. Big Qualicum Hatchery originally had two spawning channels; one is still being used for that purpose for chum salmon and the other has been converted to a rearing channel. Puntledge and Robertson Creek were unsuccessful as spawning channels primarily due to unsuitable water supplied during egg incubation. After several years of operation with poor results, the two facilities were converted to hatcheries.

Washington Coastal and Puget Sound

The Baker Lake Hatchery built in 1896 by the State of Washington on a tributary of the Skagit River, was the State's first facility located outside the Columbia River system. At this hatchery sockeye salmon were spawned, the eggs hatched, and the fry released back into the Skagit River. After several years, the hatchery was sold to the U.S. Fish Commission and was operated as part of the Federal hatchery system.

Between 1899 and 1925 more than 50 different salmon facilities were constructed and operated in this region by State and Federal agencies. Most were eventually failures due in part to lack of suitable water supplies, an insufficient supply of eggs, lack of funds, or, in many cases, lack of knowledge. A few, such as the Quilcene National Fish Hatchery (1911) operated by the U.S. Fish and Wildlife Service (USFWS) and the Dungeness (1902), Green River (1901), Nooksack (1899), Puyallup Salmon (1917), Samish (1899), Skykomish (1905), and Willapa (1899) hatcheries operated by Washington Department of Fisheries (WDF), are still in operation today.

All species of salmon were reared at these early facilities with coho and fall chinook salmon being predominant at the State hatcheries and fall chinook, coho, and sockeye salmon at the Federal hatcheries. In addition, both State and Federal hatcheries raised steelhead trout. In 1932, responsibility for steelhead and other anadromous trout was transferred to the newly formed Washington Department of Game (WDG) (Berg 1968). The majority of fish from the early State hatcheries were released as unfed fry while the Federal hatcheries reared a considerable number to larger sizes before release.

Due to the serious decline of the fishery resource, WDF, WDG, and USFWS have constructed new facilities to improve the runs of salmon and steelhead trout (Chaney and Perry 1976). Since 1960, these three agencies have operated or supervised a total of 26 hatcheries and 32 rearing ponds or net pens (Table 7). Of these, all of the hatcheries and 19 of the rearing ponds and net pens released anadromous fish in 1976. The rearing facilities in this region are located in two areas: Puget Sound (Fig. 3) and Pacific coast (Fig. 4).

This region has produced a large percentage of the total anadromous salmonids raised on the Pacific coast. The 921 million migrant fish that have been released over the 17 yr since 1960, constitute 27% of the total coastal releases by number (Tables 8, 9). By weight, the 23.4 million lb (10.6 million kg) of migrants are 22% of the coastal total. Migrant releases in 1976 totaled 89.4 mil-

[2]K. Sandercock, Department of Environment, Fisheries and Marine Service, Vancouver 1, B.C., Canada U6E 2P1, pers. commun. November 1976.

Table 5.—Anadromous fish rearing facilities—British Columbia, 1960-76.

Hatcheries	General location	Operation agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operations began
Big Qualicum	Qualicum Beach	CFMS	fc, co, sh	Yes	1967
Capilano River	North Vancouver	CFMS	fc, co, sh	Yes	1971
Puntledge	Courtenay	CFMS	fc	Yes	1971
Quinsam	Campbell River	CFMS	fc, co, sh	Yes	1975
Robertson Creek	Port Alberni	CFMS	fc, co, sh	Yes	1972
Rosewall[3]	Fanny Bay	CFMS	co	Yes	1972

[1]CFMS = Canadian Fisheries and Marine Service.
[2]fc = fall chinook salmon, co = coho salmon, sh = steelhead trout, sc = spring chinook salmon.
[3]Operated as research facility.

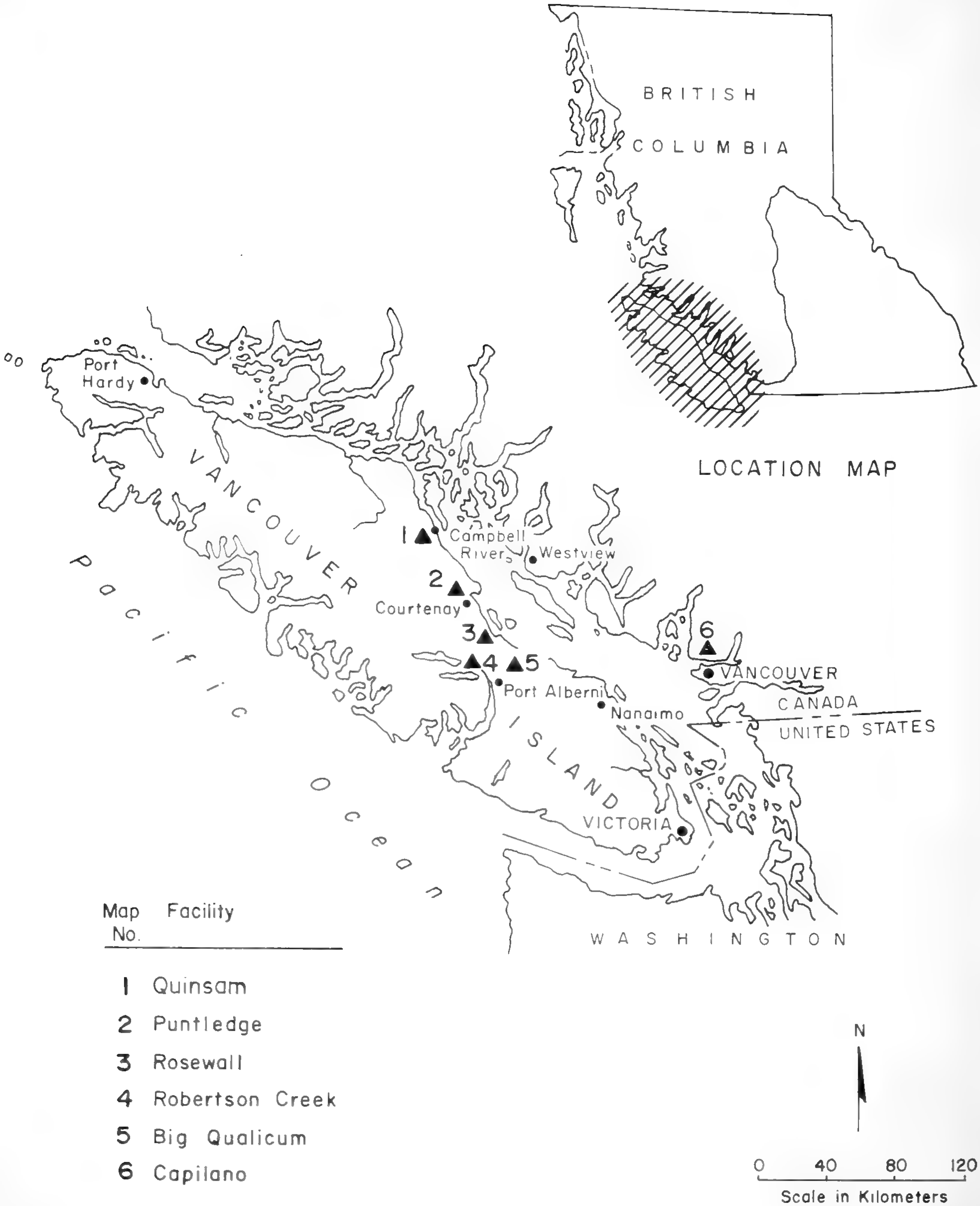


Figure 2.—Map of locations of British Columbian salmonid rearing facilities, 1960-76.

Table 6.—Migrant releases of chinook and coho salmon and steelhead trout—British Columbia[1] (in thousands).

Release year	Fall chinook		Coho		Winter steelhead	
	Number	Pounds[2]	Number	Pounds	Number	Pounds
1960	0.0	0.0	0.0	0.0	0.0	0.0
1961	0.0	0.0	0.0	0.0	0.0	0.0
1962	0.0	0.0	0.0	0.0	0.0	0.0
1963	0.0	0.0	0.0	0.0	0.0	0.0
1964	0.0	0.0	0.0	0.0	0.0	0.0
1965	0.0	0.0	0.0	0.0	0.0	0.0
1966	0.0	0.0	0.0	0.0	0.0	0.0
1967	0.0	0.0	0.0	0.0	0.0	0.0
1968	147.0	1.3	0.0	0.0	0.0	0.0
1969	460.0	4.7	0.0	0.0	0.0	0.0
1970	67.5	0.7	69.0	2.5	0.0	0.0
1971	299.0	3.0	88.0	2.7	0.0	0.0
1972	822.7	9.0	210.0	7.5	0.0	0.0
1973	2,038.3	23.4	507.6	19.6	41.7	2.0
1974	2,361.1	31.7	517.7	20.7	23.0	3.1
1975	2,220.1	36.3	998.4	43.8	25.8	2.8
1976	3,005.5	36.8	2,385.7	143.8	80.5	6.3
Total	11,421.2	146.9	4,776.4	240.6	171.0	14.2

[1]Derived from Wahle et al. (1975) prior to 1974 and from Canadian Fisheries and Marine Service records thereafter.
[2]1 lb = 0.454 kg.

lion fish and 2.7 million lb (1.2 million kg). In 1976, fall chinook salmon were the most numerous with 35 million released, followed by coho salmon, steelhead trout, and chum salmon. By weight, coho salmon were dominant with 1.3 million lb (0.59 million kg) stocked, followed in order by fall chinook salmon, steelhead trout, and spring chinook salmon. No summer chinook salmon are reared in this region.

As noted in Table 7, the two State fisheries agencies use Dingell-Johnson Act and Anadromous Fish Act monies to partially fund some of their hatchery programs. Dingell-Johnson monies come from a Federal tax on recreational fishing gear and are divided among the States based on the number of fishing licenses sold. It is administered by the U.S. Fish and Wildlife Service (USFWS).

The Anadromous Fish Act (Public Law 89-304) is administered jointly by the USFWS and the National Marine Fisheries Service. Under this Act, cooperative agreements with States are made and other non-Federal interests for the conservation, development, and enhancement of, among others, the anadromous fishery resources of the Nation. Federal matching funds of up to 50% may be used to finance project costs if one state is

Table 7.— Anadromous fish rearing facilities—Washington coastal and Puget Sound, 1960-76.

Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[1]
Hatcheries						
Aberdeen	Aberdeen	WDG	sh, src	Yes	1936	WDG
Arlington	Oso	WDG	sh (src)	Yes	1956	WDG
Bellingham	Bellingham	WDG	sh (src)	Yes	1935	WDG
Chambers Creek	Tacoma	WDG	sh	Yes	1973	WDG, Anadromous Fish Act[3]
Dungeness	Sequim	WDF	fc, sc, co (ch, pi)	Yes	1902	WDF
George Adams	Shelton	WDF	fc, sc, co, ch (pi)	Yes	1960	WDF, Tacoma PUD
Green River	Auburn	WDF	fc, co (sc, ch)	Yes	1901	WDF
Hood Canal	Hoodsport	WDF	fc, sc, co, ch, pi	Yes	1953	WDF
Issaquah	Issaquah	WDF	fc, co (sk)	Yes	1937	WDF
Minter Creek	Purdy	WDF	fc, co, ch (sc, pi, ce)	Yes	1937	WDF
Nemah	Nemah	WDF	fc, co, ch	Yes	1953	WDF
Nooksack	Kendall	WDF	fc, co	Yes	1899	WDF
Puyallup salmon	Orting	WDF	fc, co (sc, pi)	Yes	1917	WDF
Puyallup trout	Puyallup	WDG	sh	Yes	1947	WDG
Quilcene	Quilcene	USFWS	fc, co, ch (sh)	Yes	1911	USFWS
Quinault	Neilton	USFWS	fc, co, ch, sh	Yes	1968	USFWS
Samish	Burlington	WDF	fc, co (ch)	Yes	1899	WDF
Seward Park	Seattle	WDG	sh	Yes	1935	WDG
Shelton	Shelton	WDG	sh, src	Yes	1947	WDG, Anadromous Fish Act[3]
Simpson	Matlock	WDF	fc, co (ch)	Yes	1949	WDF, PP&L
Skagit	Marblemount	WDF	fc, sc, co, ch (pi, sh)	Yes	1947	WDF
Skykomish	Startup	WDF	fc, sc, co (ch, pi)	Yes	1905	WDF
Soleduck	Sappho	WDF	fc, sc, co	Yes	1970	WDF
South Tacoma	Lakewood	WDG	sh	Yes	1933	WDG
Tokul Creek	Fall City	WDG	sh	Yes	1933	WDG
Willapa	Lebam	WDF	fc, co (ch, sk)	Yes	1899	WDF
Rearing ponds and net pens						
Barnaby Pond	Rockport	WDG	sh	Yes	1961	WDG, Dingell-Johnson[3]
Blue Slough Pond	Darrington	WDG	sh	No	1961	WDG
Bogachiel Pond	Forks	WDG	sh	Yes	1968	WDG, Anadromous Fish Act[3]
Garrison Creek (Western State)	Steilacoom	WDF	fc, co, pi (sc, ch)	Yes	1973	WDF, Sports Club
Green River pond	Palmer	WDG	sh	Yes	1968	WDG, Anadromous Fish Act[3]

Table 7.—Continued.

Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[1]
Harrison	Rockport	WDG	sh	No	1970	WDF, Dingell-Johnson[3]
Mayr Bros. pond	Aberdeen	WDG, Private	sh	Yes	1974	WDG, Private
Olympic rearing channel	Port Angeles	WDF	fc, co	Yes	1975	WDF
Percival-Deschutes Complex (including Capital Lake)	Olympia	WDF	fc, sc, co	Yes	1949	WDF, Olympic Salmon Club
Salt Creek pond	Joyce	WDG	sh	No	1964	WDG, Sportsmen's Group
Skykomish ponds	Gold Bar	WDG	sh	Yes	1974	WDG
South Sound net pens	Tacoma	WDF	fc, co, ch	Yes	1972	WDF
Squaxin	Squaxin Island	WDF, Squaxin Tribe	fc, sc, co	Yes	1971	WDF, Squaxin Tribe
Tualip	Marysville	WDF, Tualip Tribe	fc, co	Yes	1973	WDF, Tualip Tribe
Whitehorse	Darrington	WDG	sh (src)	Yes	1962	WDG, Dingell-Johnson[3]
WDF minor facilities and coops						
Bay Center	Bay Center	Bay Center Mariculture	fc, ch, pi	No	1972	Private
Bowmans Bay	Anacortes	WDF	fc, sc, co, ch	No	1947	WDF
Domsea Farms	Manchester	Domsea Farms Mariculture	co	No	1969	Domsea Farms Mariculture
Elliot Pond	Seattle	WDF, NW Steelheaders	fc, co	No	1974	WDF, NW Steelheaders
Gig Harbor net pens	Gig Harbor	WDF, Puget Sound Herring Sales, Peninsula High Key Club	fc, ch	Yes	1975	WDF, Puget Sound herring sales
Gorst Creek	Bremerton	WDF, Sports Club	fc	No	1962	WDF
Little Clam Bay	Port Orchard	WDF	co	No	1962	WDF
Lummi	Bellingham	Lummi Tribe	co	Yes	1972	Lummi Tribe
Manchester	Port Orchard	WDF	fc, co	No	1973	WDF
NW Steelheaders	Palmer, Renton	WDF, NW Steelheaders	sc, co	No	1971	WDF, NW Steelheaders
Ocean Shores pond	Ocean Shores	Sports Group	co	Yes	1974	Sports Group
Peninsula	Port Angeles	Peninsula Jr. College	co	Yes	1975	Peninsula Jr. College
Sultan Pond	Sultan	WDF, Sultan Sportsmen's Club	co	Yes	1973	Sultan Sportsmen's Club
Tacoma net pens (including Totem Marina)	Tacoma	WDF, City of Tacoma	fc, co	Yes	1973	WDF, City of Tacoma
Westport boat basin	Westport	WDF, Ocosta School	co	Yes	1972	WDF
Whidby Island	Oak Harbor	WDF, Sports Club	fc, sc, co	No	1972	WDF, Sports Club
Wynoochee Pond	Montesano	WDF, NW Steelheaders	fc, co	No	1974	WDF, NW Steelheaders

[1]WDG = Washington Department of Game, WDF = Washington Department of Fisheries, Tacoma PUD = Tacoma Public Utility District, USFWS = U.S. Fish and Wildlife Service, PP&L = Pacific Power and Light.

[2]fc = fall chinook salmon, sc = spring chinook salmon, co = coho salmon, sh = steelhead trout, ch = chum salmon, pi = pink salmon, ce = cherry salmon, src = sea-run cutthroat trout, sk = sockeye salmon (minor species in parentheses).

[3]Dingell-Johnson Act monies administered by U.S. Fish and Wildlife Service, Anadromous Fish Act monies administered by National Marine Fisheries Service and U.S. Fish and Wildlife Service.

involved. If two states cooperate on a project, the matching funds can total 66 2/3%.[3]

State and Federal anadromous salmonid rearing programs in this region are augmented by: 1) State and private cooperative efforts, 2) commercial enterprises, 3) regulated Indian tribe rearing programs, and 4) unregulated Indian tribe rearing programs.

The WDF cooperates with sport and school groups in salmon rearing programs. The agency supplies surplus fry for rearing in saltwater net pens or ponds. The cooperating groups supply equipment, fish food, and labor needed to rear the fish to migrant size. Releases are made directly from the pens or ponds. Facilities operated in this manner include Northwest Steelheader (various Puget Sound areas), Gorst Creek, Percival, Salt Creek, Whidby Island, and Westport boat basin.

Two commercial fish rearing companies, Domsea Farms and Bay Center Mariculture, have released salmon in this region. Normally these companies buy surplus eggs from State hatcheries, rear the fish to smolt size in freshwater, and then transfer the fish to saltwater net pens for final rearing to market size. Although emphasis is placed on commercial production, cooperative experimental releases have been made. Under Washington law,

[3]E. Wold, Director, Columbia River Fisheries Development Program, National Marine Fisheries Service, NOAA, Portland, OR 97208, pers. commun. June 1979.

the companies have no special harvest rights to fish returning to the release site.[4]

While the private companies are prohibited by State law from engaging in "ocean ranching," (see Oregon Coastal section), the treaty Indian tribes are not. Many tribal councils have become active in this form of aquaculture. The operations take place either on streams completely within reservation boundaries or on streams where the tribe has been granted exempt status through treaty. In one example of this type of operation, the Quinault Indians, as a tribal enterprise, hatch and rear salmon and release them into the Quinault River system. After maturing in the ocean, adult fish return to the Quinault River where many are caught in the exclusively Indian river net fishery.[5]

The fish released by these Indian operated facilities do contribute to ocean sports and commercial catches before they return to the rivers where only tribal members may fish for them. Because of difficulties in obtaining accurate release information from some of the operations, we have included in this report only the releases from facilities that provide information to WDF.

Columbia Basin

The Columbia Basin, as referred to in this report, contains the portions of Washington, Idaho, and Oregon drained by the Columbia River (Fig. 5). The five State and Federal fish management agencies in this region account for 54% (by number) and 55% (by weight) of the total Pacific coast anadromous releases made in 1976 (Tables 10, 11). Migrant releases for the 17-yr period starting in 1960 amount to over 2 billion fish and 61 million lb (27.7 million kg), raised at a total of 81 facilities—63 hatcheries and 18 rearing ponds. During the 17-yr, all species of fish included in this report, except pink salmon, were released into streams of the basin. During 1976, anadromous migrants were released from 53 hatcheries and 14 rearing ponds.

The Columbia Basin is unique in the number of hatcheries constructed and operated as compensation for habitat destroyed by water use projects on the Columbia River and its tributaries. Compensation was initiated on the Columbia River by the Mitchell Act passed by Congress in 1938. The Act provided for a cooperative fisheries management program involving the Federal Government and the States of Oregon and Washington. Initially a small amount of money was appropriated for the implementation of the Act under the Department of Commerce. Little was accomplished until 1946 when the Act was amended to create the Lower Columbia River Development Program (subsequently referred to as the Program) at the time under the Department of Interior. Initial funding came from the U.S. Army Corps of Engineers and the Program was administered by the USFWS. The funds were used for stream clearance and construction and modernization of hatcheries.

In 1956, the Program was expanded to include the upper Columbia and Snake River drainages extending into Idaho. The word "Lower" was subsequently dropped from the Program name. The funding is now administered by the National Marine Fisheries Service, Department of Commerce, Portland, Oreg.

Since 1960, releases from Program hatcheries have accounted for 74% of the Columbia Basin migrant release by number and 57% by weight (Tables 12, 13).

In recent years, an additional source of funds for construction and operation of hatcheries in the basin has been the power producing agencies and companies. The U.S. Army Corps of Engineers has funded the construction or modernization of nine hatcheries as mitigation and compensation for their hydroelectric projects and is presently providing operational monies for these facilities. Also in the basin, 17 facilities were constructed by public utility districts or private power companies in connection with the effects of their water related projects.

Columbia Basin-Washington.—The State Fish Commissioner, James Crawford (1890), stated in his first report to the Governor of Washington concerning artificial propagation: "To foster and replenish the streams of our state with salmon and trout, the establishment of a hatchery is a positive necessity. While though much could be done by the passage and enforcement of a stringent law protecting our fish during the spawning season, still, as has been demonstrated in the older states without the aid of artificial propagation, the stock of wild fish will eventually be exhausted." This statement was based on declining populations of fish in Washington's rivers, especially the Columbia, even at that early date. Diversions and obstructions were blocking access to historically important spawning and rearing areas. Also, operators of gill nets, fish wheels, and traps, along with the Indians and their dip nets, were taking excessive numbers of fish. It was estimated that each fish wheel took more than 100 tons of fish per year (Crawford 1890). The pack of salmon by Washington canneries had increased from 4,000 cases in 1866 to a high of 629,000 cases in 1883 (Crawford 1892) and then declined to 321,000 cases in 1889 (Cobb 1931).

In light of this dwindling resource, the 1891 legislature appropriated $15,000 for securing a site and erecting a hatchery. The commission first selected a location in Okanogan County, but was unable to build there because of title and land survey problems (Crawford 1892).

In 1894, Commissioner Crawford investigated the possibility of enhancing upper Columbia stocks of salmon by taking and eyeing eggs artificially in the lower reaches of the Columbia River and transporting them to suitable hatching sites up the river. Working with fishermen using pound net traps in Baker's Bay, near the mouth of the Columbia River, he secured 150 chinook salmon which he held for spawning. He obtained only 6,000 eggs before the holding area was washed out. No

[4]H. Senn, Chief of Artificial Production, Washington Department of Fisheries, Olympia, WA 98504, pers. commun. November 1977.

[5]C. Mahnken, Manchester Field Station, National Marine Fisheries Service, NOAA, Manchester, WA 98353, pers. commun. August 1976.

Figure 3.—Map of locations of Washington-Puget Sound salmonid rearing facilities, 1960-76.

further efforts to take eggs were made that year, but the idea was proven feasible as the eggs survived the transfer (Crawford 1896).

A law passed in 1893 provided for licensing of all Washington commercial fishermen. The fishermen supported the measure. The monies were to be placed in the Fish Commission fund to be used for fishery projects. In 1895, $20,000 was appropriated from this fund and the first hatchery in Washington was built on the Kalama River, 4 mi above its junction with the Columbia River. The land was donated by the citizens of Cowlitz County. Its initial capacity, 4 million eggs, was increased to 6 million in 1896. An auxiliary station was built on the Chinook River near the mouth of the Columbia River for collecting eggs as well as for hatching additional fish (Crawford 1896).

Map No	Facility	Map No	Facility
1	Nooksack	23A	Domsea Farms–Freshwater
2	Lummi Ponds and Net Pens	23B	Domsea Farms–Saltwater
3	Bellingham	24	Seward Park
4	Samish	25	Little Clam Bay Manchester
5	Skagit	26	Issaquah
6	Harrison Pond Barnaby Pond	27	Hood Canal
7	Bowmans Bay	28	Minter Creek
8	Whidbey Island Rearing Pond	29	Green River Hatchery
9	Arlington	30	Green River Pond
10	Blue Slough	31	Gig Harbor
11	Whitehorse	32	Shelton
12	Olympic Rearing Channel	33	George Adams
13	Peninsula College	34	Totem Marine (Tacoma Net Pens)
14	Tulalip	35	South Tacoma Garrison Creek Chambers Creek
15	Dungeness		
16	Sultan Pond		
17	Skykomish Hatchery	36	South Sound Net Pens
18	Skykomish Rearing Ponds	37	Puyallup Trout
19	Quilcene	38	Squaxin Island Net Pens
20	Elliot Bay Net Pens	39	Puyallup Salmon
21	Tokul Creek Hatchery and Pond	40	Percival–Deschutes Complex (including Capital Lake)
22	Gorst Creek Pond		

Not Shown – Misc Northwest Steelheaders Net Pens

By 1900, State hatcheries were being constructed on the Wenatchee, Wind, Little Spokane, Methow, and Klickitat Rivers (Berg 1968). In addition, the U.S. Fish Commission constructed a station on the Little White Salmon River in 1897, supplemented by an auxiliary station on the Big White Salmon River. All these early hatcheries concentrated their efforts on chinook salmon fry plants. Coho salmon fry and chinook salmon fingerling releases became more prevalent after 1900, especially at the Federal facilities. In addition, some steelhead trout and chum salmon fry were also produced. In 1932, the Washington State legislature divided the anadromous fish programs between two newly created agencies. The Washington Department of Fisheries (WDF) assumed responsibility for salmon and the Washington Department of Game (WDG) became responsible for trout (steelhead and sea-run cutthroat).

The program of artificial propagation in Washington continued at about the same level until the early 1940's when the Columbia River Development Program (see Columbia Basin section) became active in this area. Under the Program, fish ladders were built over impassible barriers and log jams were removed from such Columbia River tributaries as Abernathy Creek and the Kalama, Cowlitz, Wind, and Klickitat Rivers to open up new spawning areas that were previously blocked to migrating fish. New hatcheries including Willard National Fish Hatchery (NFH), Klickitat, and Skamania were constructed, and Spring Creek NFH, Little White NFH, and Carson NFH remodeled.

From 1960 to 1976, 30 hatcheries and 12 rearing ponds raised anadromous salmonids in this region (Table 14). In 1976, the USFWS operated 3 hatcheries and 2 hatchery complexes, WDF operated 10 hatcheries and 5 ponds, and WDG operated 11 hatcheries and 4 ponds. The two USFWS hatchery complexes, Little White Salmon NFH and Leavenworth NFH, were formed in 1976 by placing one and two formerly independent stations (Willard, and Winthrop and Entiat, respectively) under the managers of these two complexes. Although the facilities in this region are scattered throughout the Columbia River drainage, there is a large concentration in the lower river and its tributaries within 75 mi of Portland, Oreg. (Fig. 6).

This region, with 1.2 billion migrant releases between 1960 and 1976, is the largest producer of salmon and steelhead trout on the coast. In 1976 releases numbered 92.6 million smolts, 31% of the coastal total, weighing 3.4 million lb (1.5 million kg), 31% of the total (Tables 15, 16).

Columbia Basin-Idaho.—Artificial production of salmon and steelhead in Idaho began around the turn of the century. A substation of Clackamas Hatchery, operated in Oregon by the U.S. Commission of Fish and Fisheries, was constructed on the Salmon River to take salmon and steelhead eggs. Additionally, eggs were shipped into the State from Clackamas Hatchery and another of its substations, Little White Salmon Hatchery, located in Washington. Fry hatched were released to the Pahsimeroi and Lemhi Rivers as well as the Salmon River (Leach 1932, 1933). This substation was phased out during the mid-1930's when the Federal hatchery system underwent a drastic budget reduction.

In addition to the Federal hatchery, the State of Idaho included a few salmon and steelhead with trout programs of their early hatcheries. In one example, the State took eggs from brood steelhead trout trapped in the Lewiston Dam fish ladder, eyed them in a spring at Hatwai Creek, and reared them at Grangeville Hatchery.[6]

All of the early hatchery efforts were minor in scope. The State relied instead on wild stocks of fish to perpetuate the anadromous fish runs. In 1956, because of the decline in the stocks, the Columbia River Development Program extended to the upper Columbia and Snake Rivers. (See the Columbia Basin section.) Under the Program, natural spawning and rearing areas were increased in Idaho through, among others, the construction of fishways over Sellway Falls and the now removed Lewiston Dam in the Clearwater River drainage and Dagger Falls on the Middle Fork Salmon River. Approximately 220 screens were built on irrigation diversions to prevent the loss of fish onto irrigated fields. Obstructions and debris were also removed from tributaries of the Clearwater River.

It had become obvious by 1960 that the increase in the number of dams in the Columbia and Snake Rivers had caused upstream passage problems for adult fish and downstream mortality for juvenile fish. About this time, Idaho Power Company was required to construct fish rearing facilities below Oxbow Dam on the Snake River, and more attention was focused on rearing anadromous fish in Idaho's hatcheries (Chaney and Perry 1976).

[6]D. Ortmann, Idaho Department of Fish and Game, Boise, ID 83707, pers. commun. September 1976.

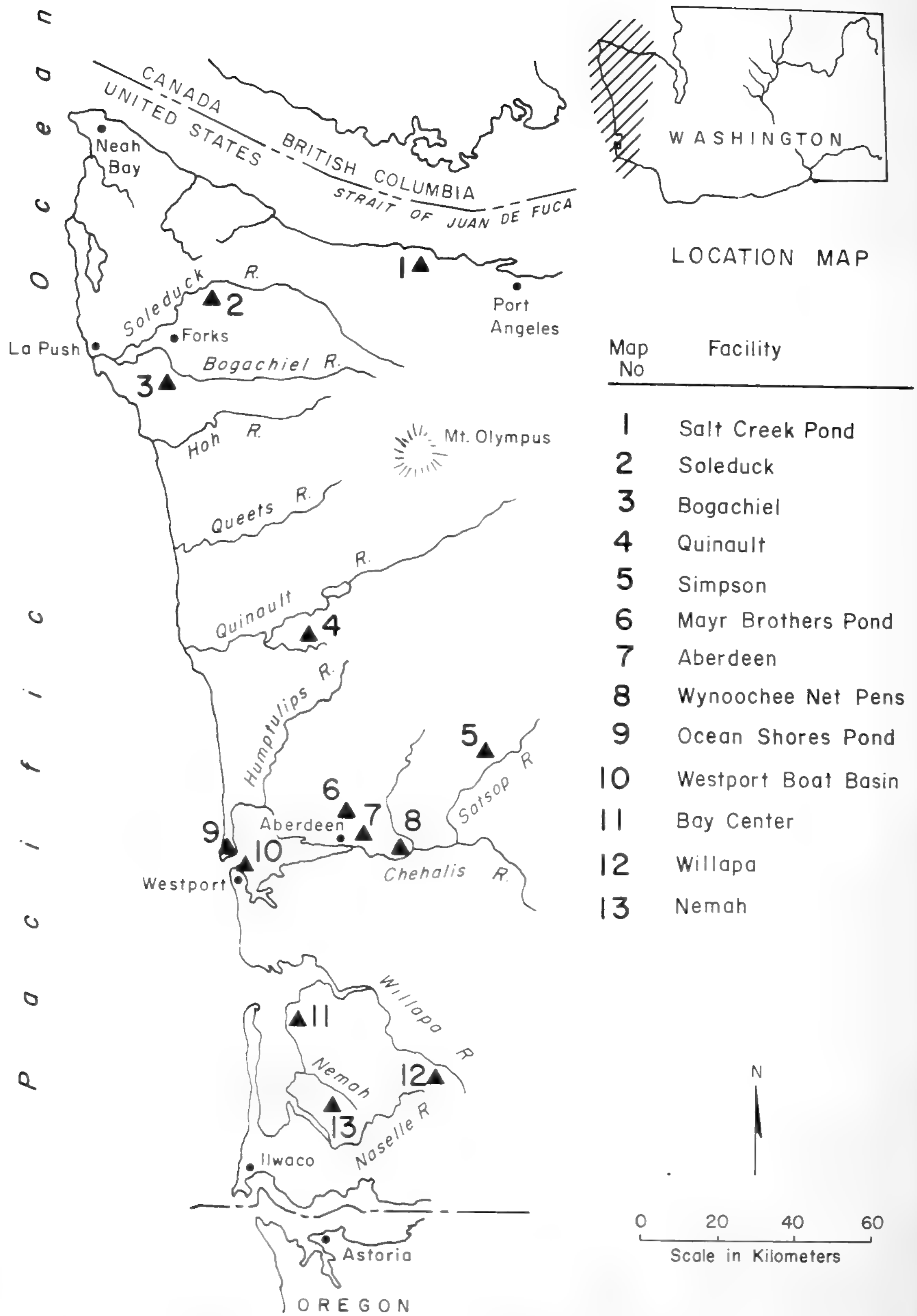


Figure 4.—Map of locations of Washington coastal salmonid rearing facilities, 1960-76.

Table 8.—Migrant releases of chinook and coho salmon and steelhead trout—Washington coastal and Puget Sound[1] (in thousands).

Release year	Fall chinook		Spring chinook		Coho		Winter steelhead		Summer steelhead	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	20,065.3	89.0	302.4	7.5	6,094.2	126.5	1,128.2	156.3	0.0	0.0
1961	19,508.0	123.9	694.7	10.6	9,612.6	243.5	847.0	135.6	20.4	1.7
1962	20,914.1	112.0	584.6	12.6	9,541.6	185.1	1,215.3	168.9	0.0	0.0
1963	19,224.1	114.1	466.3	7.1	5,297.8	96.7	1,236.0	165.4	206.6	21.4
1964	29,380.5	185.9	294.8	16.9	9,687.2	305.1	1,205.2	175.9	121.6	13.0
1965	30,955.2	196.5	491.8	15.5	10,763.3	358.1	1,204.5	177.5	132.2	13.8
1966	27,566.0	212.8	62.8	4.6	12,907.0	500.5	1,380.2	205.1	97.0	12.6
1967	29,938.7	238.3	378.5	32.7	12,787.3	634.0	1,152.9	179.0	77.3	9.2
1968	30,163.1	290.7	558.9	45.3	13,855.3	721.5	1,305.2	186.6	193.0	22.7
1969	36,030.0	320.0	256.8	21.4	14,901.0	779.8	1,960.0	278.0	124.9	17.7
1970	31,745.1	290.1	309.4	17.7	18,297.2	940.8	1,606.6	256.8	325.4	37.0
1971	47,330.8	434.2	190.1	24.0	16,497.0	928.8	1,581.0	227.4	364.7	62.9
1972	36,221.1	418.8	708.2	48.5	18,969.7	1,083.2	1,454.7	257.0	392.6	63.5
1973	43,007.7	635.2	1,267.0	170.4	18,425.3	1,049.7	1,796.1	321.2	421.7	62.4
1974	31,004.3	688.0	829.5	96.0	21,270.0	1,313.7	1,533.1	283.2	528.4	67.9
1975	33,342.7	702.1	1,030.3	164.4	22,858.7	1,263.6	1,582.4	288.7	564.4	75.3
1976	34,902.5	759.0	693.6	118.5	23,539.4	1,255.4	2,296.5	389.9	399.9	58.8
Total	521,299.2	5,810.6	9,119.7	813.7	245,304.6	11,786.0	24,484.9	3,852.5	3,970.1	539.9

[1]Derived from Wahle et al. (1975) prior to 1974, Foster et al. (Foster, R., R. Kolb, and V. Fletcher. 1975. 1974 hatchery statistical report of production and plantings. Wash. Dep. Fish., Olympia, 156 p.) for WDF 1974, Fletcher et al. (Fletcher, V., B. Kiser, B. Rogers, and B. Foster. 1976. 1975 hatchery statistical report of production and planting. Wash. Dep. Fish., Olympia, 154 p.) for WDF 1975, Foster et al. (1977) for WDF 1976, and from WDG release records and USFWS hatchery annual reports.

[2]1 lb = 0.454 kg.

Table 9.—Migrant releases of chum, pink, sockeye, and cherry salmon and sea-run cutthroat trout—Washington coastal and Puget Sound[1] (in thousands).

Release year	Chum		Pink		Sockeye		Cherry		Sea-run cutthroat	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	5,031.6	8.8	555.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0
1961	4,710.5	12.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962	1,141.8	2.8	145.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0
1963	3,683.6	6.8	0.0	0.0	4.4	([3])	0.0	0.0	0.0	0.0
1964	3,207.7	6.7	525.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0
1965	2,911.4	5.5	0.0	0.0	0.0	0.0	0.0	0.0	24.0	1.5
1966	1,047.3	3.6	421.0	1.3	0.0	0.0	0.0	0.0	134.7	24.1
1967	1,302.9	3.4	0.0	0.0	0.0	0.0	0.0	0.0	156.6	20.3
1968	1,090.7	3.1	602.8	1.4	0.0	0.0	0.0	0.0	155.4	22.3
1969	2,318.1	5.5	0.0	0.0	0.0	0.0	0.0	0.0	136.3	29.2
1970	1,500.5	4.3	774.9	2.4	0.0	0.0	0.0	0.0	85.2	16.1
1971	3,839.6	9.0	0.0	0.0	0.0	0.0	0.0	0.0	251.5	48.3
1972	4,985.7	16.0	1,957.9	5.1	2.5	([3])	0.0	0.0	111.8	26.3
1973	6,001.9	19.1	0.0	0.0	0.0	0.0	24.3	3.1	130.0	31.7
1974	9,384.8	30.7	1,211.9	3.5	0.0	0.0	44.4	4.3	107.7	19.3
1975	29,637.5	88.2	0.0	0.0	0.0	0.0	1.0	0.1	96.0	22.0
1976	22,653.1	81.9	4,850.4	8.7	0.0	0.0	0.5	0.1	79.8	21.2
Total	104,448.7	308.0	11,045.4	26.3	6.9	([3])	70.2	7.6	1,469.0	282.3

[1]Derived from Wahle et al. (1975) prior to 1974, Foster et al. (see footnote 1, Table 8) for WDF 1974, Fletcher et al. (see footnote 1, Table 8) for WDF 1975, Foster et al. (1977) for WDF 1976, and from WDG release records and USFWS hatchery annual reports.

[2]1 lb = 0.454 kg.

[3]<100 lb.

By 1976, releases had been made from two USFWS hatcheries and 11 hatcheries and 1 rearing pond operated by the Idaho Department of Fish and Game (IDFG) (Table 17). Of these, two are especially notable. Dworshak NFH was constructed at a cost of over $16 million by the U.S. Army Corps of Engineers. It was built as compensation for the loss of a large run of steelhead trout cut off by the construction of Dworshak Dam. It is one of the largest and most modern of the Pacific coast facilities. The State's Rapid River Hatchery (funded by Idaho Power Company) has been very successful as a spring chinook salmon station. From initial return of 1,039 immature male fish (jacks) in 1968, the run has grown until in 1973 the total number of returning fish reached a high in excess of 17,000.

Of the 14 facilities, only the 6 on the Clearwater and Salmon River drainages are directly accessible to returning fish (Fig. 7). The remainder are above the limits for

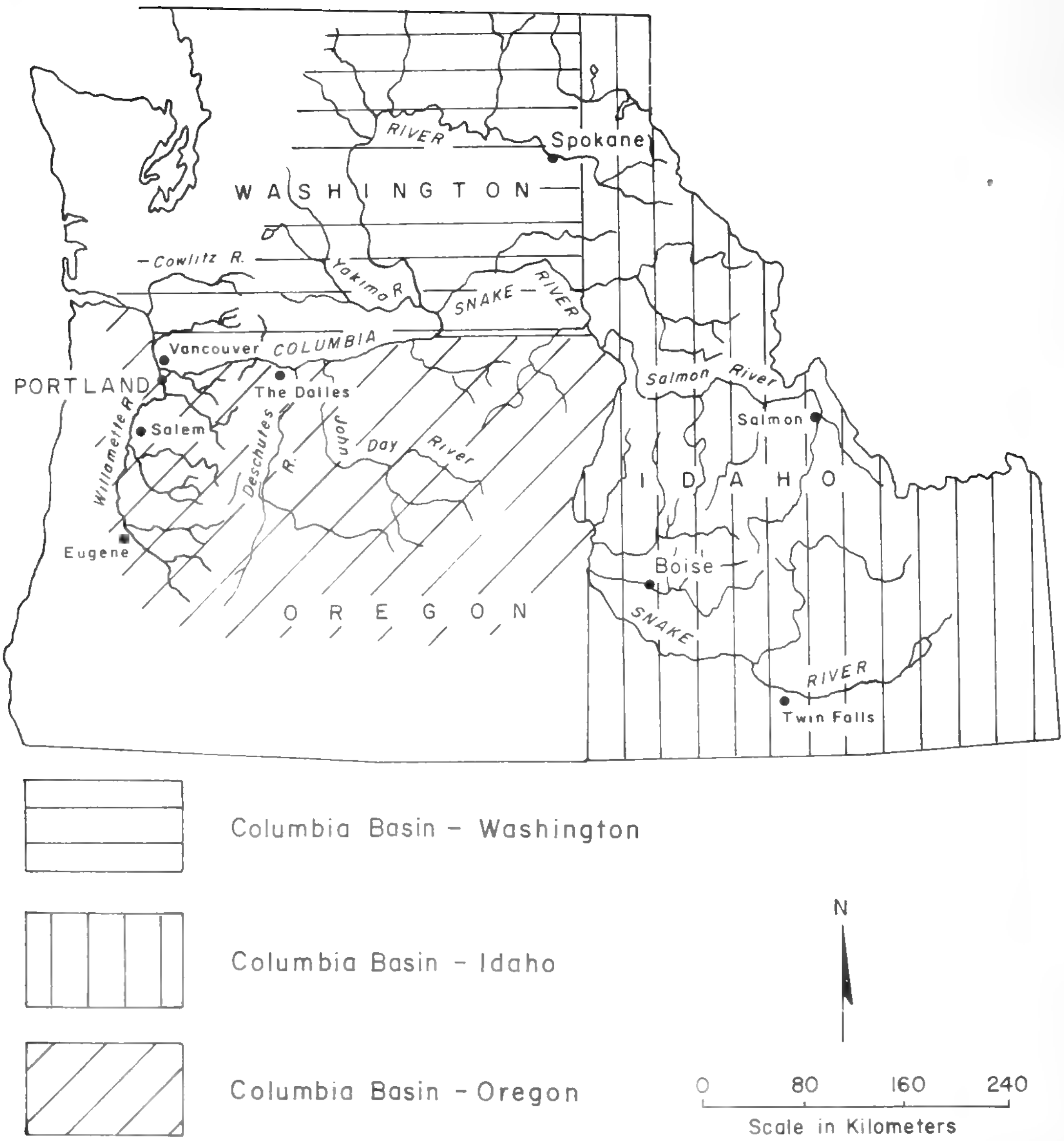


Figure 5.—Columbia Basin regions.

salmon and steelhead trout migration. In these cases, the State has been very successful with the program of transferring fish reared to suitable release sites, and trapping and returning brood stock, spawning them, and transporting the eggs back to the hatchery. In this way, IDFG has been able to make good use of off-site hatcheries on good water sources.

Summer steelhead trout and spring chinook salmon are the two species reared in the greatest numbers in Idaho. Although the facilities in the State have released only 6% of the Pacific coast migrant totals by weight since 1960, they have accounted for 42% of the summer steelhead trout and 11% of the spring chinook salmon by weight during that period (Table 18). Summer steelhead trout production has increased from an initial release in 1965 of 24,000 migrant fish weighing 2,600 lb (1,200 kg) to a high of 6.3 million fish weighing 750,000 lb (340,200 kg) in 1974. This is largely due to the opening of Dworshak NFH in 1969.

Columbia Basin-Oregon.—The first hatchery in Oregon was constructed by a private corporation, the Oregon and Washington Fish Propagating Company. Its hatchery, the first in the Columbia Basin, was built in 1876 on the Clackamas River near its confluence with the Willamette River. The company operated the hatchery from 1876 to 1880 when lack of funds forced a closure. In 1887, the Oregon Fish and Game Commission rented and renovated the facility, but was able to operate it for only 1 yr because of funding problems. In 1889, the operation of the hatchery was transferred to the U.S. Commission of Fish and Fisheries. One condition of this transfer was

Table 10.—Migrant releases of chinook and coho salmon and steelhead trout—Columbia Basin[1] (in thousands).

Release year	Fall chinook Number	Fall chinook Pounds[2]	Spring chinook Number	Spring chinook Pounds	Summer chinook Number	Summer chinook Pounds	Coho Number	Coho Pounds	Winter steelhead Number	Winter steelhead Pounds	Summer steelhead Number	Summer steelhead Pounds
1960	91,923.9	341.1	7,235.5	207.4	0.0	0.0	7,394.8	249.8	933.9	125.8	153.8	22.5
1961	49,269.2	319.6	4,483.3	171.7	0.0	0.0	15,088.2	526.0	894.2	100.5	480.7	64.1
1962	57,573.4	290.7	4,854.4	190.0	0.0	0.0	14,617.1	610.9	1,812.4	169.8	355.5	41.1
1963	60,043.0	331.8	8,742.4	327.3	0.0	0.0	22,416.9	811.2	1,314.9	120.3	837.6	101.6
1964	66,782.5	415.6	13,037.7	432.9	0.0	0.0	18,128.4	838.8	1,342.6	173.6	1,328.0	180.0
1965	58,355.8	381.4	6,387.2	251.3	0.0	0.0	20,713.8	947.9	1,701.9	227.0	1,259.8	144.4
1966	56,324.2	498.1	11,277.4	455.9	0.0	0.0	24,663.0	1,205.8	1,733.1	206.5	1,467.3	188.1
1967	57,808.3	512.9	12,881.6	560.4	0.0	0.0	23,791.9	1,181.2	1,997.7	234.7	2,940.0	348.1
1968	65,360.3	677.2	12,448.2	734.0	2,138.3	13.6	19,294.4	1,064.8	1,773.1	200.5	4,329.4	503.8
1969	68,593.1	686.3	9,190.4	692.7	2,121.3	20.2	28,043.6	1,661.9	1,665.6	197.0	4,212.0	502.9
1970	86,255.7	902.6	15,986.0	1,387.9	4,228.2	35.4	25,160.8	1,474.3	2,112.4	299.0	5,921.8	911.5
1971	84,414.2	697.3	13,336.2	991.1	2,184.5	37.0	29,424.2	1,728.2	2,241.1	257.6	7,187.5	935.6
1972	90,689.5	993.4	15,140.3	1,267.0	2,604.9	42.6	34,176.7	2,264.5	2,073.5	267.6	5,334.5	836.6
1973	93,619.3	1,122.7	15,243.9	1,450.8	2,312.6	34.3	29,235.5	1,747.8	2,640.3	392.2	7,207.3	824.7
1974	91,303.9	1,203.9	14,060.4	1,093.3	1,202.8	43.0	28,733.7	1,740.7	2,236.0	294.7	8,956.5	1,117.2
1975	92,382.6	1,239.6	19,243.5	1,538.1	120.8	3.1	30,079.6	2,016.2	1,949.4	279.8	6,177.2	915.5
1976	98,855.7	1,342.5	20,236.9	1,672.5	880.5	42.7	29,808.3	1,823.4	2,274.4	340.0	6,247.6	910.5
Total	1,269,554.6	11,956.7	203,785.3	13,424.3	17,793.9	271.9	400,770.9	21,893.4	30,696.5	3,886.6	64,396.5	8,548.2

[1]Derived from Wahle et al. (1975) prior to 1974 and from appropriate State and Federal agencies thereafter.
[2]1 lb = 0.454 kg.

Table 11.—Migrant releases of chum, sockeye, and cherry salmon and sea-run cutthroat trout—Columbia Basin[1] (in thousands).

Release year	Chum No.	Chum Lb.[2]	Sockeye No.	Sockeye Lb.	Cherry No.	Cherry Lb.	Sea-run cutthroat No.	Sea-run cutthroat Lb.
1960	0.0	0.0	3,177.0	69.2	0.0	0.0	1.2	1.3
1961	63.6	0.4	2,788.0	72.5	0.0	0.0	15.9	2.6
1962	717.5	1.8	2,224.0	43.8	0.0	0.0	9.7	3.1
1963	1,770.8	2.5	3,121.0	67.8	0.0	0.0	12.9	2.7
1964	150.8	0.2	3,364.0	58.8	0.0	0.0	82.5	10.0
1965	205.3	0.3	3,301.0	73.6	0.0	0.0	86.9	13.9
1966	738.1	2.4	73.0	1.6	0.0	0.0	87.0	17.5
1967	524.1	3.0	0.0	0.0	0.0	0.0	190.0	40.9
1968	173.6	0.6	0.0	0.0	0.0	0.0	248.2	52.5
1969	129.9	0.3	23.4	0.7	0.0	0.0	261.3	50.3
1970	62.5	0.1	0.0	0.0	0.0	0.0	303.5	59.1
1971	0.0	0.0	0.0	0.0	0.0	0.0	371.3	66.9
1972	638.5	1.2	0.0	0.0	0.0	0.0	172.9	40.6
1973	563.6	1.4	0.0	0.0	1.8	0.1	210.9	48.7
1974	627.3	3.4	0.0	0.0	0.0	0.0	150.3	31.9
1975	0.0	0.0	0.0	0.0	0.0	0.0	173.7	43.9
1976	1,126.8	4.7	0.0	0.0	0.0	0.0	192.7	45.9
Total	7,492.4	22.3	18,071.4	388.0	1.8	0.1	2,570.9	531.8

[1]Derived from Wahle et al. (1975) prior to 1974 and from appropriate State and Federal agencies thereafter.
[2]1 lb = 0.454 kg.

that no eggs or fry obtained were to be taken out of Oregon.

Around the turn of the century, several other hatcheries and egg taking stations were built on the Clackamas River by government and private organizations. Due to financial difficulties, ownership of these often changed hands, and most were operated by the Federal Government for at least part of their existence. One, built by the Columbia River Packer's Propagating Company on the upper Clackamas River, was operated privately in 1895-96, Federally in 1897-98, and finally by the State in 1899.

Propagation of steelhead trout in the State began in 1897. The U.S. Commission of Fish and Fisheries had fair success with a temporary egg taking station for steelhead trout on the Salmon River, a tributary of the Sandy River. The following year, eggs were taken at Willamette Falls and again at the Sandy River station. The State also did some experimental steelhead trout research work on the upper Columbia River and its tributaries.

In 1909, the State constructed Bonneville Hatchery on Tanner Creek near the present site of Bonneville Dam. It was designed as a central hatching station, receiving all of its eggs from other facilities on the river. With a capacity of approximately 60 million eggs, it was one of the largest on the coast. Prior to Bonneville's construction there were no significant runs of salmon into Tanner Creek. After a number of years of rearing the transferred eggs and releasing fry into Tanner Creek, adult fish began to return to Bonneville at maturity. These developed stocks of fish became the hatchery's main egg source and the transfer programs were scaled down. In the past several years Bonneville has been able to rely on its egg source and actually supply surplus for other stations.

In 1920, the Legislature split the Oregon Fish and Game Commission's responsibility for anadromous fish between two new agencies: the Fish Commission of Oregon (FCO) took over salmon production and the Oregon Game Commission (OGC) concentrated on steelhead and sea-run cutthroat trout. The existing hatcheries were realigned under these two agencies, those raising primarily steelhead trout were placed under the OGC and those raising primarily salmon under the FCO.

In 1976, there were 15 hatcheries and 4 ponds operated in this region by the USFWS and Oregon Department of Fish and Wildlife (ODFW) (Table 19). As noted in the tables, the FCO and OGC were recombined into the ODFW in 1975. Most of the current facilities are concentrated near the mouth of the Columbia River, on the Willamette and Deschutes River systems, or near Bonneville Dam (Fig. 8). Wallowa Hatchery, located in ex-

Table 12.—Migrant releases of chinook and coho salmon and steelhead trout—Pacific coast by Columbia River Development Program hatcheries[1] (in thousands).

Release year	Fall chinook		Spring chinook		Summer chinook		Coho		Winter steelhead		Summer steelhead	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	89,105.2	329.7	1,836.1	60.2	0.0	0.0	6,359.8	217.6	916.9	124.7	67.5	11.3
1961	46,640.1	305.5	827.3	30.0	0.0	0.0	14,182.8	507.4	605.1	65.2	303.1	43.2
1962	55,783.6	283.3	1,666.8	57.7	0.0	0.0	12,863.8	571.4	1,408.9	110.4	227.2	28.6
1963	58,845.0	325.8	2,391.4	85.0	0.0	0.0	19,589.1	756.8	1,027.7	83.9	366.7	53.6
1964	65,501.5	407.5	7,643.3	220.8	0.0	0.0	16,529.8	775.3	1,106.7	145.6	562.3	87.1
1965	56,191.0	370.5	3,042.4	102.0	0.0	0.0	17,919.4	853.9	1,352.9	174.8	595.3	73.5
1966	54,944.7	488.9	3,812.4	111.5	0.0	0.0	21,170.4	1,074.7	1,733.1	206.5	745.7	101.8
1967	55,118.5	497.8	5,484.8	177.5	0.0	0.0	20,208.9	1,000.3	1,411.1	161.4	855.7	126.3
1968	55,514.9	595.5	3,788.8	166.8	0.0	0.0	15,715.2	866.9	1,425.9	149.3	1,527.7	175.7
1969	57,927.3	574.1	3,496.8	164.4	0.0	0.0	18,620.3	1,103.7	1,494.9	171.6	822.7	96.6
1970	62,175.2	689.6	2,578.7	148.3	393.8	9.8	17,450.8	1,002.7	1,363.6	196.9	1,525.6	258.1
1971	63,277.3	483.3	3,784.3	238.9	400.3	13.9	21,281.2	1,207.2	1,287.4	151.7	1,130.3	156.1
1972	67,053.7	721.8	3,619.8	253.1	231.7	13.3	23,887.6	1,520.5	1,315.3	172.8	1,233.0	198.7
1973	70,384.2	831.4	4,822.9	401.3	217.1	4.3	20,879.2	1,196.4	1,385.9	223.5	1,151.4	189.4
1974	65,476.3	887.5	4,423.5	269.2	330.0	8.1	20,163.6	1,177.4	1,137.9	162.7	1,168.5	176.7
1975	70,455.2	918.9	5,229.8	326.7	114.6	2.9	21,104.2	1,382.9	937.3	144.7	1,025.3	153.9
1976	80,866.8	1,108.1	5,933.6	479.8	406.6	15.8	22,217.8	1,325.9	1,216.7	184.9	950.4	150.5
Total	1,075,260.5	9,819.2	64,382.7	3,293.2	2,094.1	68.1	310,143.9	16,541.0	21,127.3	2,630.6	14,258.4	2,081.1

[1]Derived from Wahle et al. (1975) prior to 1974, Foster et al. (see footnote 1, Table 8) for WDF 1974, Fletcher et al. (see footnote 1, Table 8) for WDF 1975, Foster et al. (1977) for WDF 1976, and from WDG release records and USFWS hatchery annual reports.

[2]1 lb = 0.454 kg.

Table 13.—Migrant releases of chum and cherry salmon and sea-run cutthroat trout—Pacific coast-Columbia River Development Program hatcheries[1] (in thousands).

Release year	Chum		Cherry		Sea-run cutthroat	
	Number	Pounds[2]	Number	Pounds	Number	Pounds
1960	0.0	0.0	0.0	0.0	0.0	0.0
1961	63.6	0.4	0.0	0.0	6.9	0.8
1962	717.5	1.8	0.0	0.0	0.0	0.0
1963	1,770.8	2.5	0.0	0.0	6.4	0.8
1964	150.8	0.2	0.0	0.0	82.5	10.0
1965	205.3	0.3	0.0	0.0	85.9	13.6
1966	738.1	2.4	0.0	0.0	41.5	6.7
1967	524.1	3.0	0.0	0.0	119.4	23.9
1968	173.6	0.6	0.0	0.0	121.2	25.8
1969	129.9	0.3	0.0	0.0	35.3	7.5
1970	62.5	0.1	0.0	0.0	50.0	10.6
1971	0.0	0.0	0.0	0.0	40.1	8.0
1972	638.5	1.2	0.0	0.0	22.8	5.7
1973	563.6	1.4	1.8	0.1	27.0	9.0
1974	627.3	3.4	0.0	0.0	4.3	1.1
1975	0.0	0.0	0.0	0.0	0.0	0.0
1976	1,126.8	4.7	0.0	0.0	0.0	0.0
Total	7,492.4	22.3	1.8	0.1	643.3	123.5

[1]Derived from Wahle et al. (1975) prior to 1974, Foster et al. (see footnote 1, Table 8) for WDF 1974, Fletcher et al. (see footnote 1, Table 8) for WDF 1975, Foster et al. (1977) for WDF 1976, and from WDG release records and USFWS hatchery annual reports.

[2]1 lb = 0.454 kg.

treme eastern Oregon near Enterprise, is the only exception.

Migrant releases from Oregon Columbia Basin hatcheries represent 20% (698 million migrants) of the 1960-76 Pacific coast total by number and 19% [20.3 million pounds (9.2 million kg)], by weight (Tables 20, 21). Fall chinook salmon, with 44 million migrants released, was the main species by number reared in 1976 followed by coho salmon, spring chinook salmon, and steelhead trout. The same year, the largest release by weight was of coho salmon, 600,000 lb (272,200 kg) followed by fall chinook salmon, spring chinook salmon, and steelhead trout.

The Columbia River Development Program ("Program") had an important impact on anadromous fish in Oregon's portion of the Columbia Basin. Funds were provided for stream clearance and improvement as well as for fishway and hatchery construction or reconstruction. Fishways were built on the Clatskanie River, Eagle Creek, and Scappoose Creek, among others, and the existing fishway at Willamette Falls was rebuilt. On streams such as the Calpooia and Clatskanie Rivers as well as Big, Tide, Goble, Eagle, Deep, Clear, Abernathy, and Delph Creeks, where needed, accumulated debris, log jams, and splash dams were removed. The State fisheries agencies screened problem irrigation diversion ditches and canals to prevent loss of trout and salmon fingerlings. Sandy, Cascade, Eagle Creek, and Gnat Creek hatcheries were constructed under the Program. Bonneville, Oxbow, Klaskanine, and Big Creek hatcheries were either renovated or completely reconstructed.

One of the major accomplishments of the Program in Oregon was the development or improvement of runs of several salmonid species in the area above Willamette Falls. A three-part project, the initial phase was a cooperative study of passage problems over Willamette Falls. Monies were then provided to stock the upper Willamette River and its tributaries as well as for stream clearance and improvement. In the final phase, the Program provided the major portion of funding the $4.1 million fishway. As a result of these efforts, runs of fall chinook salmon and summer steelhead trout have been developed and spring chinook and coho salmon have increased.

Oregon Coastal

The first anadromous fish facility on the Oregon coast

Table 14.—Anadromous fish rearing facilities—Columbia basin-Washington, 1960-76.

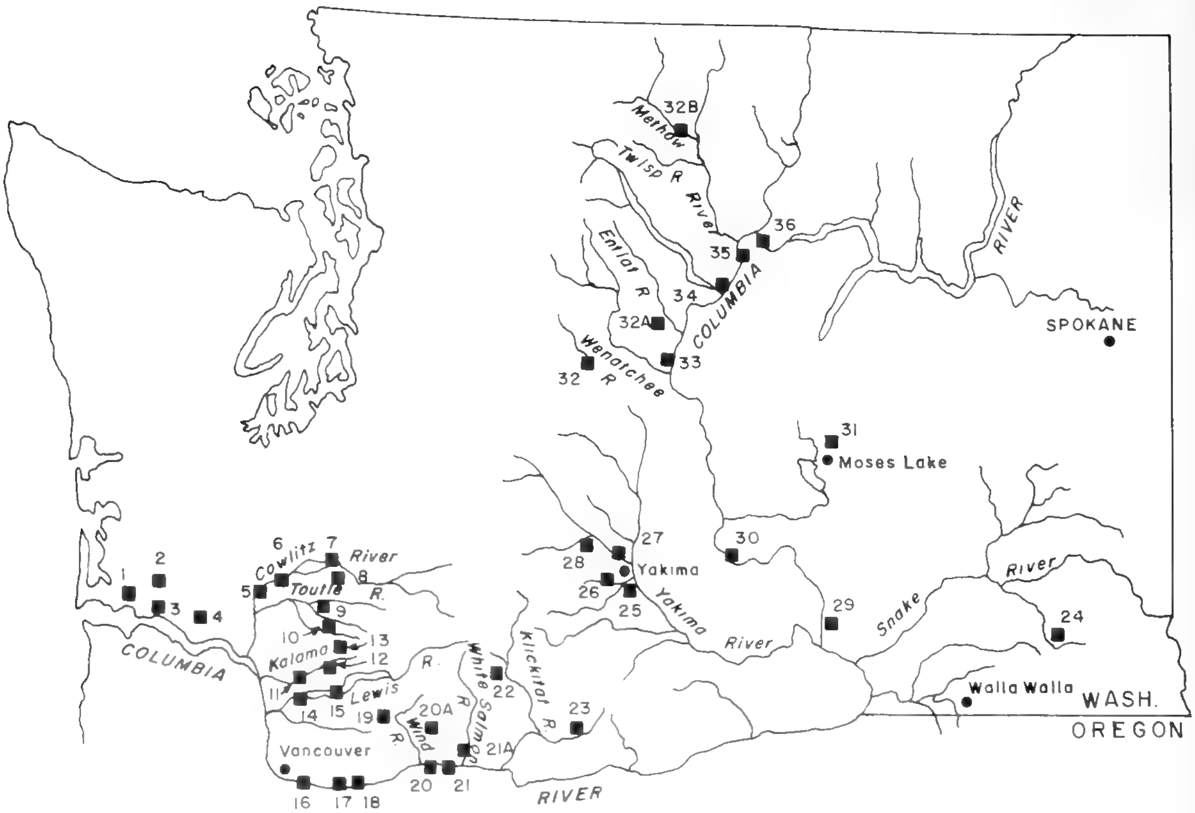
Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[1]
Hatcheries						
Abernathy	Longview	USFWS	fc (sc, co, sh)	Yes	1959	USFWS, NMFS
Beaver Creek	Cathlamet	WDG	sh, src	Yes	1958	NMFS
Carson	Carson	USFWS	sc (fc, co, sh)	Yes	1937	USFWS, NMFS
Chelan PUD	Chelan	WDG	sh	Yes	1964	Chelan PUD
Columbia Basin	Moses Lake	WDG	sh	Yes	1961	Chelan PUD
Cowlitz Salmon	Salkum	WDF	fc, sc, co	Yes	1967	Tacoma P&L
Cowlitz Trout	Ethel	WDG	sh, src	Yes	1967	Tacoma P&L
Elokomin	Cathlamet	WDF	fc, co (ch)	Yes	1954	NMFS
Goldendale	Goldendale	WDG	sh	No	1943	WDG
Grays River	Grays River	WDF	fc, co, ch	Yes	1961	NMFS
Kalama Falls	Kalama	WDF	fc, sc, co	Yes	1959	NMFS
Klickitat	Glenwood	WDF	fc, sc, co	Yes	1950	NMFS
Leavenworth complex	Leavenworth	USFWS	sc, co, sk (fc)	Yes	1938	USFWS
Entiat	Entiat	USFWS	smc (sc, co)	Yes	1942	USFWS
Winthrop	Winthrop	USFWS	sms (fc, sc, co, sh)	Yes	1967	USFWS
Lewis River	Woodland	WDF	co (fc, sc)	Yes	1909	WSF, Pacific P&L
Little White Salmon complex	Cook	USFWS	fc, sc, co (ch)	Yes	1898	USFWS, NMFS
Willard	Cook	USFWS	co (sc)	Yes	1951	NMFS, USFWS
Lower Kalama	Kalama	WDF	fc, co	Yes	1895	WDF
Mossyrock	Mossyrock	WDG	sh, src	Yes	1972	Tacoma P&L
Naches	Yakima	WDG	sh	Yes	1933	WDG
Skamania	Washougal	WDG	sh (fc)	Yes	1956	NMFS, WDG
Speelyai	Yale	WDF	sc, co (fc)	Yes	1958	Pacific P&L
Spring Creek	Underwood	USFWS	fc (co)	Yes	1901	USFWS, NMFS, Corps
Big White Salmon pond	Underwood	USFWS	fc, co	Yes	1901	USFWS, NMFS, Corps
Toutle	Toutle	WDF	fc, sc, co	Yes	1952	NMFS
Tucannon	Pomeroy	WDG	sh	Yes	1971	WDG
Vancouver	Vancouver	WDG	sh, src	Yes	1936	WDG
Washougal	Washougal	WDF	fc, co (ce)	Yes	1958	NMFS
Wells Trout	Azwell	WDG	sh	Yes	1968	Douglas Co. PUD
Yakima	Yakima	WDG	sh	Yes	1937	WDG
Rearing Ponds						
Alder Creek	Toutle	WDG	sh	Yes	1973	NMFS, WDG
Gobar	Toutle	WDG	sh	Yes	1975	NMFS, WDG
Nelson Bridge	Yakima	WDG	sh	No	1964	WDG
Nile Springs	Yakima	WDF, Sportsmen Group	sc	Yes	1976	Sportsmens Group
Priest Rapids	Priest Rapids Dam	WDF	fc	Yes	1972	Grant PUD
Ringold Salmon	Ringold	WDF	fc, sc, co	Yes	1962	NMFS
Ringold Trout	Ringold	WDG	sh	Yes	1962	NMFS
Rocky Reach	Wenatchee	WDF	fc, co	Yes	1970	Chelan PUD
Swofford Island	Mossyrock	WDG	sh	Yes	1968	WDG
Washburn Island	Brewster	WDG	sh	No	1966	Douglas PUD
Wells Salmon	Azwell	WDF	fc, sc, smc, co	Yes	1968	Douglas PUD

[1]USFWS = U.S. Fish and Wildlife Service, NMFS = National Marine Fisheries Service, WDG = Washington Department of Game, WDF = Washington Department of Fisheries, Chelan PUD = Chelan County Public Utility Division, Tacoma P & L = Tacoma Power and Light, Pacific P&L = Pacific Power and Light, Corps = U.S. Army Corps of Engineers, Douglas PUD = Douglas County Public Utility Division, Grant PUD = Grant County Public Utility Division.

[2]fc = fall chinook salmon, sc = spring chinook salmon, smc = summer chinook salmon, co = coho salmon, sh = steelhead trout, ch = chum salmon, src = sea-run cutthroat trout, sk = sockeye salmon, ce = cherry salmon.

was a private hatchery constructed by R. D. Hume. The hatchery was completed in 1877 on a site near Ellensburg on the lower Rogue River. Hume, a local salmon packer, operated the hatchery without assistance for 11 yr. In 1889, the Oregon Legislature supported his efforts with monies appropriated for enlargement as well as for operation and maintenance of the hatchery. Hume continued to operate the facility until his death in 1908 at which time it was turned over to the State. He built another hatchery in 1897 on the Rogue River at the mouth of Oak Creek. The U.S. Fish Commission, as agreed prior to construction, assumed responsibility for operating this hatchery after its completion.

Hume was an early developer of hatchery techniques. He is credited with the concept of adult holding ponds. The adult chinook salmon needed for the hatchery egg supply were trapped in tidewater on their way to the upper Rogue River. At trapping, these fish had not yet reached sexual maturity. Hume constructed a large, concrete-lined, covered holding pond to retain the fish until spawning time. Most present day hatcheries are built with a similar type adult holding facility.



Map No.	Facility	Map No	Facility
1	Grays River	21	Spring Creek
			21A Big White Salmon Pond
2	Elokomin	22	Klickitat
3	Beaver Creek	23	Goldendale
4	Abernathy	24	Tucannon
5	Cowlitz Trout	25	Nile Springs
6	Cowlitz Salmon	26	Yakima
7	Mossyrock	27	Nelson Bridge Pond
8	Swofford Pond	28	Naches
9	Toutle		
10	Alder Creek Pond	29	Ringold Trout
			Ringold Salmon
11	Lower Kalama	30	Priest Rapids
12	Kalama Falls	31	Columbia Basin
13	Gobar Pond	32	Leavenworth
14	Lewis River		32A Entiat
15	Speelyai		32B Winthrop
16	Vancouver	33	Rocky Reach
17	Skamania	34	Chelan PUD
18	Washougal	35	Wells Trout Hatchery
19	Carson		Wells Salmon Pond
20	Little White Salmon	36	Washburn Island
	20A Willard		

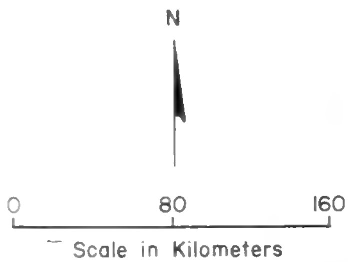


Figure 6.—Map of locations of Columbia Basin-Washington salmonid rearing facilities, 1960-76.

Table 15.—Migrant releases of chinook and coho salmon and steelhead trout—Columbia Basin-Washington[1] (in thousands).

Release year	Fall chinook		Spring chinook		Summer chinook		Coho		Winter steelhead		Summer steelhead	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	57,338.0	242.0	1,218.1	39.1	0.0	0.0	3,849.0	93.2	545.1	64.8	136.4	20.9
1961	33,531.9	241.5	667.7	27.1	0.0	0.0	9,161.6	259.3	586.5	73.1	417.6	57.2
1962	42,537.5	233.2	1,822.5	61.2	0.0	0.0	6,802.2	197.0	715.5	97.0	355.5	41.1
1963	42,646.2	238.7	1,680.9	55.3	0.0	0.0	15,096.9	428.9	568.7	74.4	767.2	95.0
1964	40,611.0	240.8	3,607.1	120.3	0.0	0.0	9,833.6	401.5	647.6	111.3	1,192.0	166.8
1965	37,073.6	234.4	2,072.4	77.7	0.0	0.0	13,950.5	557.5	943.7	151.8	1,176.7	135.4
1966	38,121.2	322.5	2,425.4	67.1	0.0	0.0	17,932.4	811.1	879.1	117.1	1,175.5	150.0
1967	34,969.8	313.1	3,269.7	122.0	0.0	0.0	15,092.7	709.6	992.8	138.1	1,460.3	214.0
1968	42,448.4	405.5	2,399.9	121.0	2,138.3	13.6	12,256.9	653.3	792.2	114.4	1,904.9	237.2
1969	45,846.5	459.1	3,876.2	317.4	2,121.3	20.2	20,808.5	1,181.1	782.6	110.0	1,948.9	257.8
1970	52,857.2	541.4	5,633.1	527.5	3,834.4	25.6	18,441.7	1,054.7	1,399.9	209.7	2,292.3	355.9
1971	50,830.3	421.3	6,706.0	530.3	1,784.2	23.1	23,336.8	1,330.6	1,493.0	184.6	1,813.8	236.5
1972	58,504.5	651.5	7,063.5	712.8	2,373.2	29.3	22,445.3	1,450.0	1,185.7	154.2	1,990.4	298.9
1973	61,036.0	751.1	5,899.1	635.5	2,095.5	30.0	21,317.9	1,266.1	1,815.9	269.0	1,578.6	249.4
1974	57,986.7	844.0	6,826.0	584.4	872.8	34.9	20,616.4	1,257.8	1,187.2	157.0	1,618.0	231.9
1975	60,938.2	867.0	7,863.2	729.7	0.0	0.0	21,785.9	1,440.6	1,099.5	153.9	1,789.0	259.3
1976	58,174.1	816.8	9,431.8	877.9	294.0	18.2	20,573.6	1,223.8	1,325.3	212.9	1,461.4	231.9
Total	815,451.1	7,823.9	72,462.6	5,606.3	15,513.7	194.9	273,301.9	14,316.1	16,960.3	2,393.3	23,078.5	3,239.2

[1]Derived from Wahle et al. (1975) prior to 1974, Foster et al. (see footnote 1, Table 8) for WDF 1974, Fletcher et al. (see footnote 1, Table 8) for WDF 1975, Foster et al. (1977) for WDF 1976, and from WDG release records and USFWS hatchery annual.
[2]1 lb = 0.454 kg.

Table 16.—Migrant releases of chum, sockeye, and cherry salmon and sea-run cutthroat trout—Columbia Basin-Washington[1] (in thousands).

Release year	Chum		Sockeye		Cherry		Sea-run cutthroat	
	No.	Lb.[2]	No.	Lb.	No.	Lb.	No.	Lb.
1960	0.0	0.0	3,177.0	69.2	0.0	0.0	0.0	0.0
1961	50.8	0.3	2,788.0	72.5	0.0	0.0	6.9	0.8
1962	402.9	1.2	2,224.0	43.8	0.0	0.0	0.0	0.0
1963	1,489.9	2.1	3,121.0	67.8	0.0	0.0	6.4	0.8
1964	150.8	0.2	3,364.0	58.8	0.0	0.0	82.5	10.0
1965	205.3	0.3	3,301.0	73.6	0.0	0.0	85.9	13.6
1966	422.7	0.4	73.0	1.6	0.0	0.0	87.0	17.5
1967	152.1	0.2	0.0	0.0	0.0	0.0	182.5	38.5
1968	38.6	0.1	0.0	0.0	0.0	0.0	248.2	52.5
1969	47.3	0.1	23.4	0.7	0.0	0.0	261.3	50.3
1970	62.5	0.1	0.0	0.0	0.0	0.0	302.3	55.2
1971	0.0	0.0	0.0	0.0	0.0	0.0	364.3	65.1
1972	638.5	1.2	0.0	0.0	0.0	0.0	159.2	37.2
1973	563.6	1.4	0.0	0.0	1.8	0.1	202.4	46.3
1974	627.3	3.4	0.0	0.0	0.0	0.0	150.3	31.9
1975	0.0	0.0	0.0	0.0	0.0	0.0	139.6	32.8
1976	1,126.8	4.7	0.0	0.0	0.0	0.0	151.8	34.6
Total	5,979.1	15.7	18,071.4	388.0	1.8	0.1	2,430.6	487.1

[1]Derived from Wahle et al. (1975) prior to 1974, Foster et al. (see footnote 1, Table 8) for WDF 1974, Fletcher et al. (see footnote 1, Table 8) for WDF 1975, Foster et al. (1977) for WDF 1976, and from WDG release records and USFWS hatchery annual reports.
[2]1 lb = 0.454 kg.

Hume was also one of the first to raise anadromous fish to larger than fry size on a production basis. Prior to his work, and in many cases afterwards, fish were released just after absorption of the yolk sac. A few fish were raised to fingerling and yearling size as a curiosity. While raising fish to larger sizes was not physically difficult, increased cost and need for larger facilities prevented the general adoption of the rearing procedure. Hume, among others, correctly predicted higher survival of larger fish with little increased costs of rearing. Presently, all anadromous facilities, with the exception of several chum and pink salmon hatcheries, rear their production fish for at least 30 days.

In the 1890's and early 1900's, there were hatcheries or egg taking stations built on most of Oregon's coastal streams. In 1902 alone, hatcheries were built on the Coquille, Siuslaw, Alsea, Yaquina, and Tillamook Rivers. One of these, built by the State on the Siuslaw River and then turned over to the U.S. Fish Commission, is interesting because of the reason for its failure. Adult fish were unable to reach the hatchery because fishermen working downstream blocked fish passage with nets stretched completely across the river. This is an extreme example of the intensive coast-wide pressure placed on the resource.

In 1920, the responsibility for rearing anadromous salmonids was split between the newly formed FCO and the OGC. By 1929, there were 10 State hatcheries and 1 Federal hatchery in operation. The total accumulated production through 1929 was almost 650 million fish with most coming from State facilities. Emphasis was placed on fall chinook and coho salmon which accounted for 56% and 31% of these releases, respectively.

There are presently 12 hatcheries in operation on the major coastal tributaries (Figs. 9, 10). Up until 1975 when the two State fisheries agencies were recombined to form the Oregon Department of Fish and Wildlife, five of these were operated by FCO and another five by OGC (Table 22). Nine of the 10 State hatcheries were built to enhance existing or depleted runs. The tenth, Cole Rivers Hatchery, is similar to many of the Columbia Basin facilities in that it was built on the Rogue River to compensate for the loss of spawning grounds and resultant fish from Lost Creek Dam.

In 1976, species reared in the greatest numbers at Oregon coastal hatcheries were coho salmon, fall chinook

Table 17.—Anadromous fish rearing facilities—Columbia Basin-Idaho, 1960-76.

Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[1]
Hatcheries						
Dworshak	Orofino	USFWS	sh	Yes	1969	USFWS, Corps
Eagle	Boise	IDFG	smc	Yes	1976	IDFG
Hagerman	Hagerman	IDFG	smc, sh (sc)	Yes	1969	IDFG
Hayden Creek	Salmon	IDFG	sc, sh	Yes	1973	NMFS, IDFG, USFWS
Kooskia	Kooskia	USFWS	sc	Yes	1966	USFWS
MacKay	MacKay	IDFG	smc	Yes	1976	NMFS
McCall	McCall	IDFG	smc	Yes	1976	IDFG, PNRC
Mullen	Mullen	IDFG	sc	Yes	1976	IDFG
Niagara Springs	Buhl	IDFG	sh	Yes	1966	Idaho Power Co.
Oxbow	Oxbow Dam	IDFG	fc	No	1964	Idaho Power Co.
Pahsimeroi	Challis	IDFG	smc, sh	Yes	1970	IDFG, NMFS
Rapid River	Riggins	IDFG	sc	Yes	1964	Idaho Power Co.
Sandpoint	Sandpoint	IDFG	sc	Yes	1972	IDFG, NMFS
Ponds						
Decker Flats	Stanley	IDFG	sc	No	1968	USFWS, NMFS, IDFG

[1]USFWS = U.S. Fish and Wildlife Service, Corps = U.S. Army Corps of Engineers, IDFG = Idaho Department of Fish and Game, NMFS = National Marine Fisheries Service, PNRC = Pacific Northwest Regional Commission.

[2]fc = fall chinook salmon, sc = spring chinook salmon, smc = summer chinook salmon, sh = steelhead trout (minor species in parentheses).

salmon, and winter steelhead trout, respectively. Summer steelhead trout and spring chinook salmon also accounted for a substantial number of releases. The first three represented 52%, 19%, and 13% of the migrant numbers released (Table 23).

There are also two private fish cultural operations active on the coast. They are a part of a new concept in commercial rearing of salmon by private companies termed "ocean ranching." Ocean ranching consists of raising fish to migrant size, releasing them into the ocean, and recovering returning adults. In Oregon, these returnees can then be sold commercially, hopefully at a profit, by the company. The enterprises are licensed by ODFW and must receive their initial egg supply from hatchery excesses at the State hatcheries. After their returns reach a sufficient number, the private hatcheries will be able to secure their own eggs without having to depend on the State. The primary species to be raised at these private facilities will be chinook, coho, and chum salmon.

California

Anadromous salmonid production on the Pacific coast began in California in 1872 with the activities of Livingston Stone. The Federally operated fish hatchery he built on the McCloud River was first used solely as a collection site for eggs to be shipped to the east coast. After several years, the U.S. Bureau of Fisheries cooperated with the State in egg shipments and fry releases in local streams to augment natural spawning. The first State operated salmon hatchery was authorized and constructed in 1885 on Hat Creek, a tributary of the Pit River. The local source of chinook salmon eggs proved inadequate so operations were transferred in 1888 to the newly constructed Mt. Shasta Hatchery on a site near Sisson in Siskiyou County. This station is still in full-scale operation producing rainbow trout, making it the oldest functional hatchery on the west coast (Leitritz 1970).

Up to the 1920's, many State and Federal hatcheries were built in northern California on the Klamath and Sacramento Rivers and their tributaries. There were also hatcheries on coastal tributaries such as the Eel, Russian, and Mad Rivers. A hatchery operated by the county of Santa Cruz at Brookdale was the most southerly location of early fish cultural operations.

Plants from these early hatcheries were made throughout the Sacramento and Klamath River drainages and most northern coastal streams. Some releases were made as far south as the Ventura River, south of Santa Barbara. While the majority of these fish were fall chinook salmon, the State hatcheries also liberated a few coho salmon fry. In 1902, the State hatcheries began a substantial steelhead trout program. As fish propagation was a cooperative effort between the Federal and State governments, the Federal hatcheries supplied a large portion of the eggs that State hatcheries reared for release. In 1914, the Federal installations began to artificially feed the small fall chinook salmon and release them as fingerlings or yearlings rather than planting them as unfed fry. This followed the example set by R. D. Hume in Oregon.

In 1976, 1 Federal, 10 State, and 2 private hatcheries and ponds were operated in California (Table 24). Of the 13, 6 are on tributaries of the Sacramento River (Fig. 11). Fall chinook salmon, coho salmon, and winter steelhead trout are the three primary species reared in California, but the hatcheries are also undertaking spring chinook salmon and summer steelhead trout programs (Table 25).

As shown in the "Funding Agency" column of Table 22, over one-half of the hatcheries and ponds are either partially or wholly supported by organizations other than the California Department of Fish and Game. While

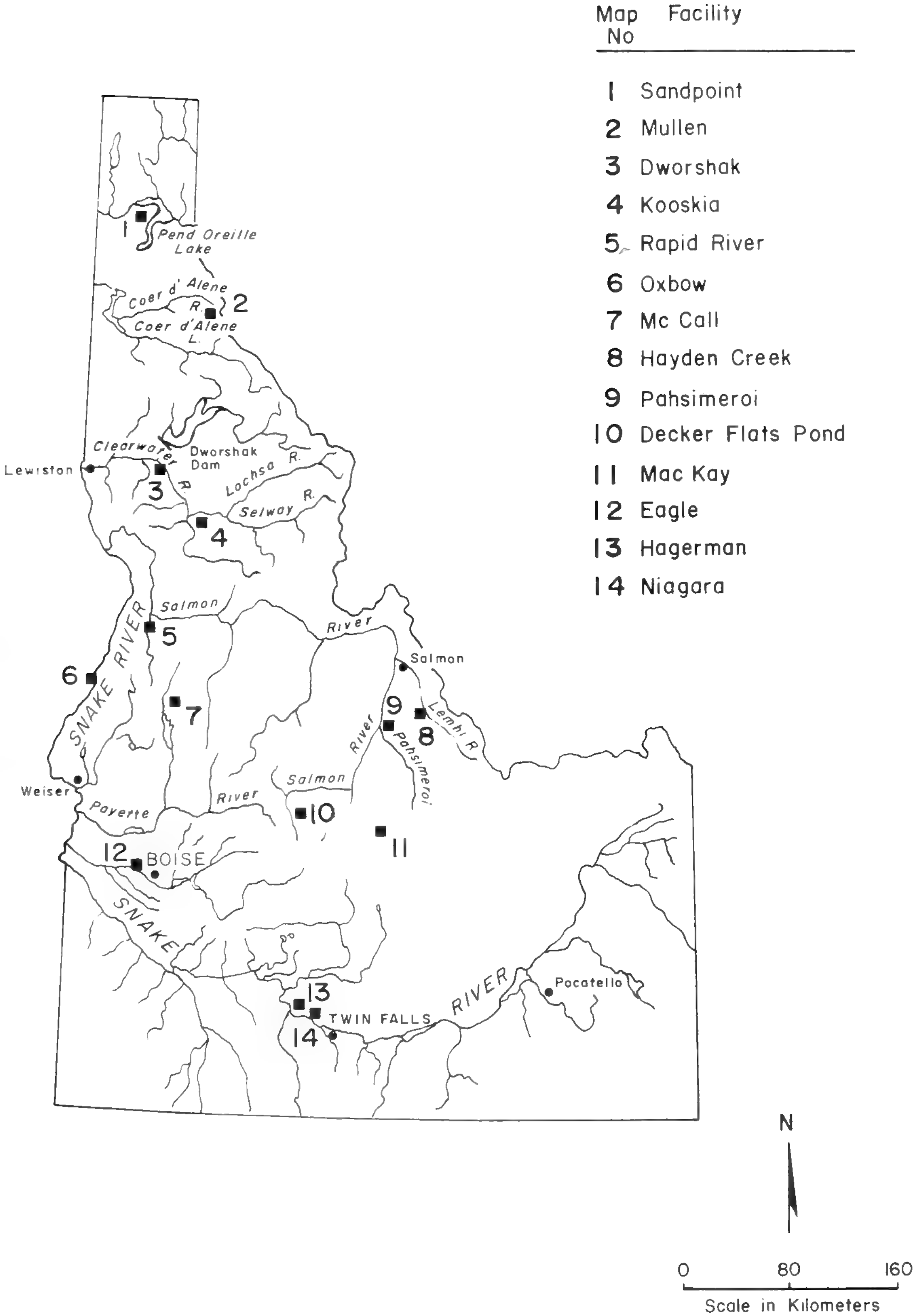


Figure 7.—Map of locations of Columbia Basin-Idaho salmonid rearing facilities, 1960-76.

Table 18.—Migrant releases of chinook salmon and steelhead trout—Columbia Basin-Idaho[1] (in thousands).

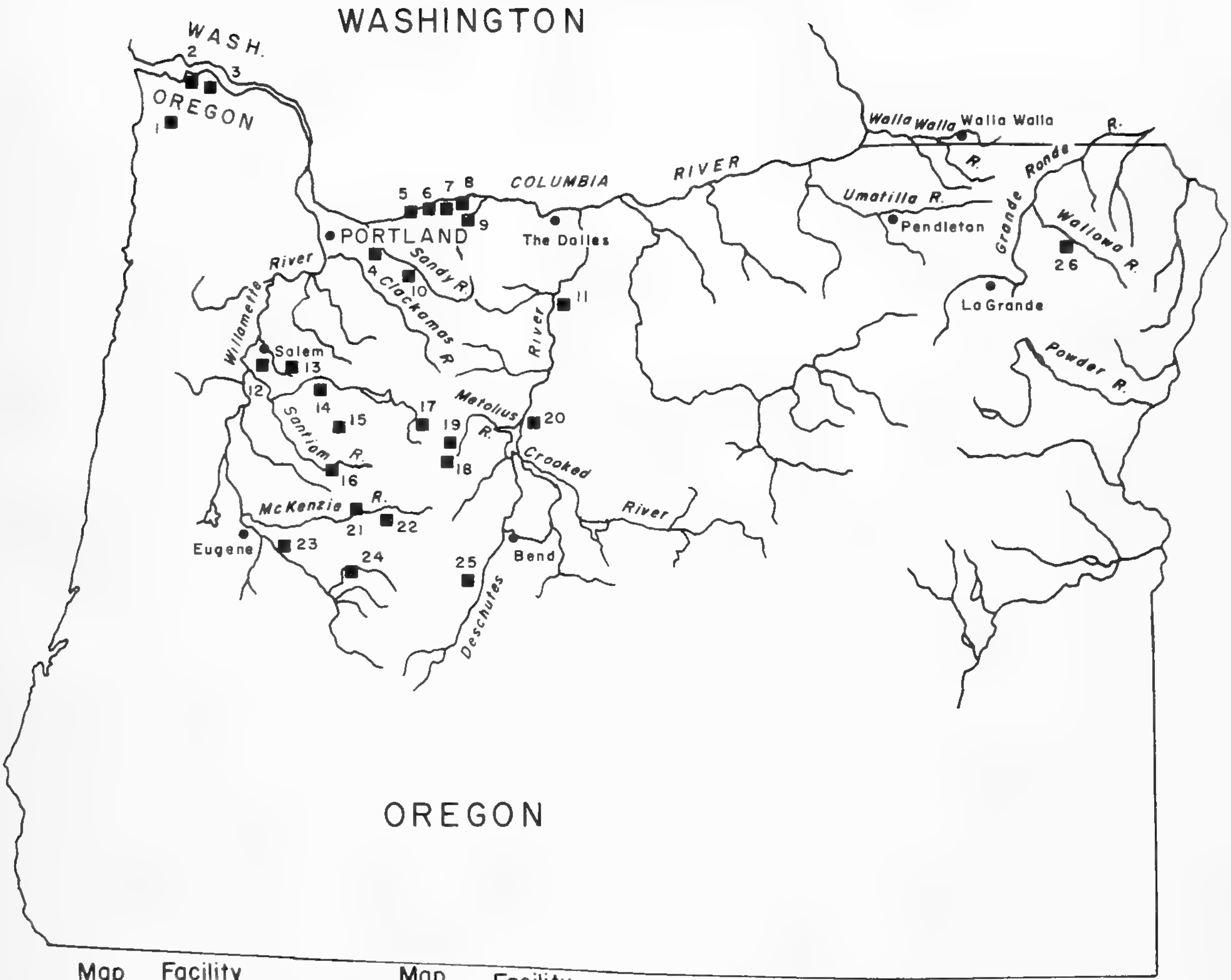
Release year	Fall chinook		Spring chinook		Summer chinook		Summer steelhead	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds
1960	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1961	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1964	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1965	1,282.3	5.7	0.0	0.0	0.0	0.0	24.1	2.6
1966	214.7	1.3	580.0	25.7	0.0	0.0	138.8	15.5
1967	1,473.5	5.9	449.3	19.4	0.0	0.0	1,364.8	121.9
1968	202.3	1.1	1,471.5	58.5	0.0	0.0	2,034.2	228.1
1969	255.5	1.9	1,057.6	40.9	0.0	0.0	1,732.5	185.3
1970	497.3	2.3	3,377.0	177.2	393.8	9.8	3,173.3	491.7
1971	0.0	0.0	3,489.3	172.5	400.3	13.9	4,932.0	634.8
1972	0.0	0.0	3,954.6	198.2	231.7	13.3	2,585.1	411.2
1973	0.0	0.0	3,830.5	206.3	217.1	4.3	4,619.6	400.0
1974	0.0	0.0	3,511.8	187.9	330.0	8.1	6,340.0	752.6
1975	0.0	0.0	5,134.1	309.9	114.6	2.9	3,511.6	520.4
1976	0.0	0.0	5,994.6	354.8	523.7	22.3	3,774.4	487.4
Total	3,925.6	18.2	32,850.3	1,751.3	2,211.2	74.6	34,230.4	4,251.5

[1]Derived from Wahle et al. (1975) prior to 1974, Idaho Department of Fish and Game release records, and U.S. Fish and Wildlife Service hatchery annual reports.
[2]1 lb = 0.454 kg.

Table 19.—Anadromous fish rearing facilities—Columbia Basin-Oregon, 1960-76.

Facility	General location	Operating agency[1,3]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding Agency[3]
Hatcheries						
Big Creek	Knappa	ODFW (FCO)	fc, co, sh (ch)	Yes	1938	NMFS, Oregon
Bonneville	Bonneville	ODFW (FCO)	fc, co (sh)	Yes	1909	NMFS, Oregon, Corps
Cascade	Cascade Locks	ODFW (FCO)	fc, co (sc, ch)	Yes	1958	NMFS
Eagle Creek	Estacada	USFWS	sc, co, sh (fc)	Yes	1957	NMFS
Fall River	LaPine	ODFW (OGC)	sc	No	1929	Oregon
Gnat Creek	Westport	ODFW (OGC)	sh (fc, sc, ch)	Yes	1960	NMFS
Hood River	Dee	ODFW (OGC)	co, sh	No	1958	Oregon
Klaskanine	Astoria	ODFW (FCO)	fc, co, sh	Yes	1911	NMFS, Oregon
Leaburg	Leaburg	ODFW (OGC)	sc (co, sh)	Yes	1954	Corps
Marion Forks	Idanha	ODFW (FCO)	sc, sh	Yes	1950	Corps, Oregon
McKenzie	Leaburg	ODFW (FCO)	sc (co)	Yes	1930	Corps, Oregon
Metolius	Camp Sherman	ODFW (FCO)	sc, sh	No	1947	Oregon
Oakridge (Willamette)	Oakridge	ODFW (FCO)	sc (co)	Yes	1911	Oregon, Corps
Oak Springs	Maupin	ODFW (OGC)	sh (sc)	Yes	1920	Oregon
Oxbow	Cascade Locks	ODFW (FCO)	fc, sc (co)	Yes	1938	NMFS, Oregon
Roaring River	Scio	ODFW (OGC)	sh	Yes	1925	Oregon
Round Butte	Madras	ODFW (OGC)	sc, smc, sh	Yes	1972	PGE
Sandy	Sandy	ODFW (FCO)	fc, co (sc, sh)	Yes	1950	NMFS
South Santiam	Foster	ODFW (FCO)	sc, sh (fc)	Yes	1923	Corps, Oregon
Wallowa	Enterprise	ODFW (OGC)	sh	No	1924	Oregon
Wizard Falls	Camp Sherman	ODFW (OGC)	sc, sh	No	1949	Oregon
Ponds						
Aumsville	Aumsville	ODFW (FCO)	fc	Yes	1970	Oregon, NMFS
Dexter	Dexter	ODFW (FCO)	sc	Yes	1955	Corps, Oregon
Salem	Salem	ODFW (FCO)	fc	No	1968	Oregon, NMFS
Stayton	Stayton	ODFW (FCO)	fc	Yes	1969	Oregon, NMFS
Wahkenn	Bonneville	ODFW (FCO)	fc, co	Yes	1961	NMFS

[1]Present agency with premerger agency in parentheses.
[2]fc = fall chinook salmon, sc = spring chinook salmon, co = coho salmon, sh = steelhead trout, ch = chum salmon (minor species in parentheses).
[3]ODFW = Oregon Department of Fish and Wildlife, OGC = Oregon Game Commission, FCO = Fish Commission of Oregon, NMFS = National Marine Fisheries Service, USFWS = U.S. Fish and Wildlife Service, Corps = U.S. Army Corps of Engineers, Oregon = State of Oregon General Funds, PGE = Portland General Electric.



Map No.	Facility	Map No.	Facility
1	Klaskanine	14	Stayton Pond
2	Big Creek	15	Roaring River
3	Gnat Creek	16	S. Santiam
4	Sandy	17	Marion Forks
5	Wakeena Pond	18	Metolius
6	Bonneville	19	Wizard Falls
7	Cascade	20	Round Butte
8	OxBow	21	McKenzie
9	Hood River	22	Leaburg
10	Eagle Creek	23	Dexter Pond
11	Oak Springs	24	Oakridge
12	Salem Pond	25	Fall River
13	Aumsville Pond	26	Wallowa

Figure 8.—Map of locations of Columbia Basin-Oregon salmonid rearing facilities, 1960-76.

Table 20.—Migrant releases of chinook and coho salmon—Columbia Basin-Oregon[1] (in thousands).

Release year	Fall chinook		Spring chinook		Summer chinook		Coho	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds
1960	34,585.9	99.1	6,017.4	168.3	0.0	0.0	3,545.8	156.6
1961	15,737.3	78.1	3,815.6	144.6	0.0	0.0	5,926.6	266.7
1962	15,035.9	57.5	3,031.9	128.8	0.0	0.0	7,814.9	413.9
1963	17,396.8	93.1	7,061.5	272.0	0.0	0.0	7,320.0	382.3
1964	26,171.5	174.8	9,430.6	312.6	0.0	0.0	8,294.8	437.3
1965	19,999.9	141.3	4,314.8	173.6	0.0	0.0	6,763.3	390.4
1966	17,988.3	174.3	8,272.0	363.1	0.0	0.0	6,730.6	394.7
1967	21,365.0	193.9	9,162.6	419.0	0.0	0.0	8,699.2	471.6
1968	22,709.6	270.6	8,576.8	554.5	0.0	0.0	7,037.5	411.5
1969	22,491.1	225.3	4,256.6	334.4	0.0	0.0	7,235.1	480.8
1970	32,901.2	358.9	6,975.9	683.2	0.0	0.0	6,719.1	419.6
1971	33,583.9	276.0	3,140.9	288.3	0.0	0.0	6,087.4	397.6
1972	32,185.0	341.9	4,122.2	356.0	0.0	0.0	11,731.4	814.5
1973	32,583.3	371.6	5,514.3	609.0	0.0	0.0	7,917.6	481.7
1974	33,317.2	359.9	3,722.6	321.0	0.0	0.0	8,117.3	482.9
1975	31,444.4	372.6	6,246.2	498.5	6.2	0.2	8,293.7	575.6
1976	40,681.6	525.7	4,810.5	439.8	62.8	2.2	9,234.7	599.6
Total	450,177.9	4,114.6	98,472.4	6,066.7	69.0	2.4	127,469.0	7,577.3

[1]Derived from Wahle et al. (1975) prior to 1974, Oregon Department of Fish and Wildlife release records, and U.S. Fish and Wildlife Service hatchery annual reports.
[2]1 lb = 0.454 kg.

Table 21.—Migrant releases of chum salmon and sea-run cutthroat trout—Columbia Basin-Oregon[1] (in thousands).

Release year	Chum		Winter steelhead		Summer steelhead		Sea-run cutthroat	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds
1960	0.0	0.0	388.8	61.0	17.4	1.6	1.2	1.3
1961	12.8	0.1	307.7	27.4	63.1	6.9	9.0	1.8
1962	314.6	0.6	1,096.9	72.8	0.0	0.0	9.7	3.1
1963	280.9	0.4	746.2	45.9	70.4	6.6	6.5	1.9
1964	0.0	0.0	695.0	62.3	136.0	13.2	0.0	0.0
1965	0.0	0.0	758.2	75.2	59.0	6.4	1.0	0.3
1966	315.4	2.0	854.0	89.4	153.0	22.6	0.0	0.0
1967	372.0	2.8	1,004.9	96.6	114.9	12.2	7.5	2.4
1968	135.0	0.5	980.9	86.1	390.3	38.5	0.0	0.0
1969	82.6	0.2	883.0	87.0	530.6	59.8	0.0	0.0
1970	0.0	0.0	712.5	89.3	456.2	63.9	1.2	3.9
1971	0.0	0.0	748.1	73.0	441.7	64.3	7.0	1.8
1972	0.0	0.0	887.8	113.4	759.0	126.5	13.7	3.4
1973	0.0	0.0	824.4	123.2	1,009.1	175.3	8.5	2.4
1974	0.0	0.0	1,048.8	137.7	998.5	132.7	0.0	0.0
1975	0.0	0.0	849.9	125.9	876.6	135.8	34.1	11.1
1976	0.0	0.0	949.1	127.1	1,011.8	191.2	40.9	11.3
Total	1,513.3	6.6	13,736.2	1,493.3	7,087.6	1,057.5	140.3	44.7

[1]Derived from Wahle et al. (1975) prior to 1974, Oregon Department of Fish and Wildlife release records, and U.S. Fish and Wildlife Service hatchery annual reports.
[2]1 lb = 0.454 kg.

some of these are voluntarily funded by county governments or private industry, most were constructed and are supported as compensation for loss of fish spawning areas due to construction of dams and other water related projects. Coleman NFH, operated by the USFWS, was built in 1942 in conjunction with Shasta Dam and the Central Valley Project which blocked salmonid access to a large area of the Sacramento River drainage. The Trinity River and Nimbus hatcheries were both built by the Bureau of Reclamation to compensate for construction of the Trinity Dam and the Folsom and Nimbus Dams, respectively. Additionally, Iron Gate and Mokelumne are funded by power companies and the Feather River Hatchery is supported by the California Department of Water Resources.

HATCHERY TRENDS

Hatchery Numbers

Since the first Pacific coast hatchery was built in 1872, rearing of salmon and steelhead trout has become a big business, both in efforts and dollars expended and benefits derived. In the late 1800's and early 1900's, many

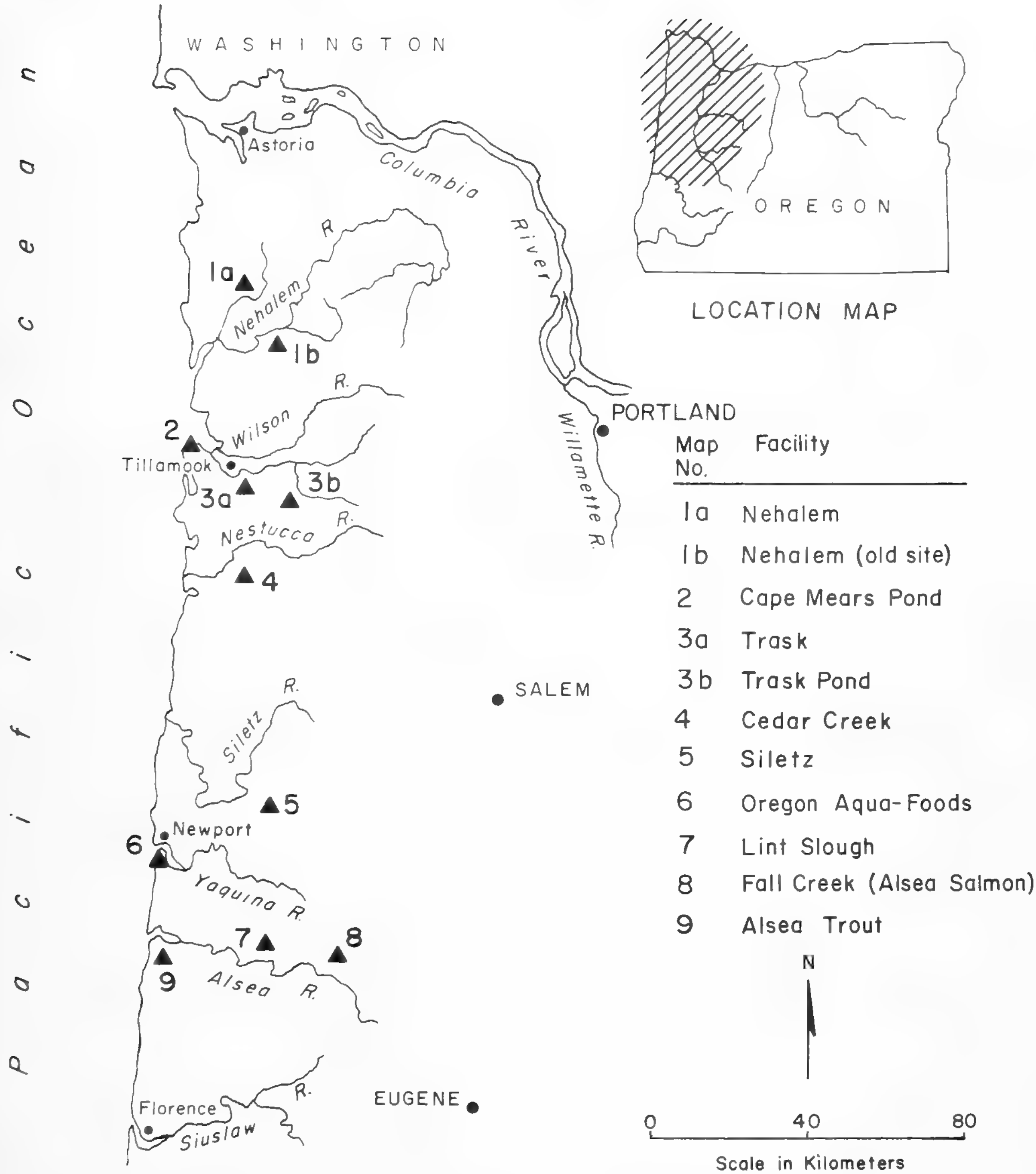
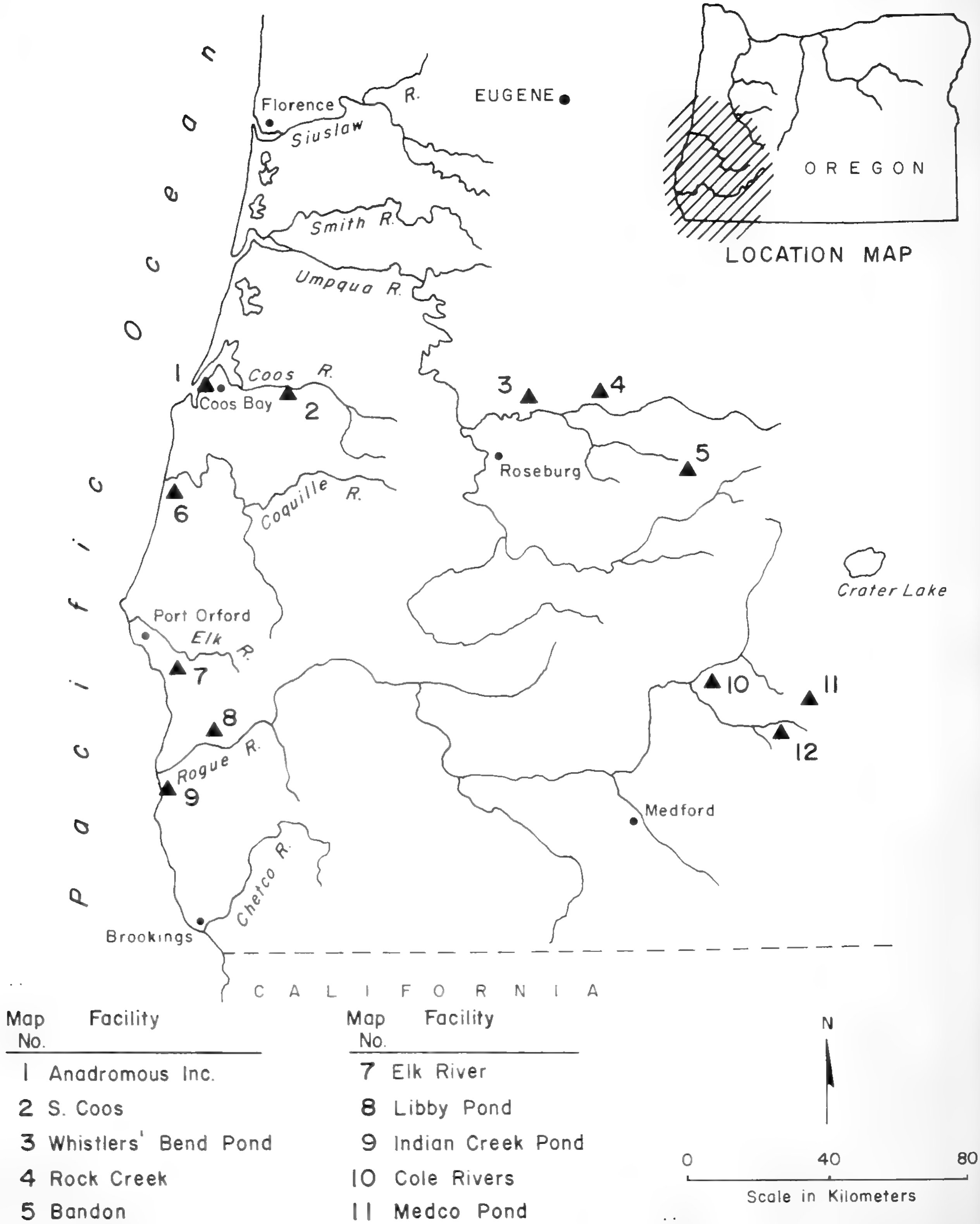


Figure 9.—Map of locations of northern Oregon coastal salmonid rearing facilities, 1960-76.

State, Federal, and local government agencies and private enterprises rushed to build hatcheries. Though many of these early efforts ended in failure for various reasons, there were 72 hatcheries and rearing ponds on the coast in 1929. The total releases from all early hatcheries through 1928 were in excess of 12 billion fry and 1 billion fingerlings and yearlings (Cobb 1931).

Between 1929 and the early 1940's, there was a decline in the number of active hatcheries due in part to the Depression and World War II. All but 3 of the 18 U.S. Bureau of Fisheries (now U.S. Fish and Wildlife Service) hatcheries were closed, replaced, or turned over for State operation. The Alaskan, Canadian, and California facilities in production in 1929 were also closed, or in a few cases, converted to trout culture. Only the State hatcheries of Washington and Oregon did not decline significantly in number. Many of those built in these two States prior to 1929 are currently in production. Additionally, new facilities built in the Washington coastal region in the 1930's are still in operation today.



Map No.	Facility	Map No.	Facility
1	Anadromous Inc.	7	Elk River
2	S. Coos	8	Libby Pond
3	Whistlers' Bend Pond	9	Indian Creek Pond
4	Rock Creek	10	Cole Rivers
5	Bandon	11	Medco Pond
6	Hemlock Meadows	12	Butte Falls

Figure 10.—Map of locations of southern Oregon coastal salmonid rearing facilities, 1960-76.

Table 22.—Anadromous fish rearing facilities—Oregon coastal, 1960-76.

Facility	General location	Operating agency[1,3]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[3]
Hatcheries						
Alsea	Philomath	ODFW (OGC)	sh, src (fc, co)	Yes	1937	Oregon
Anadromous Inc.	Coos Bay	Private	co	Yes	1975	Private
Bandon	Bandon	ODFW (OGC)	sh, src (fc, co)	Yes	1924	Oregon
Butte Falls	Butte Falls	ODFW (OGC)	sc, sh	No	1916	Oregon
Cedar Creek	Hebo	ODFW (OGC)	fc, sc, sh, src (co)	Yes	1935	Oregon
Cole Rivers	McLeod	ODFW (OGC)	sc, sh	Yes	1972	Corps
Elk River	Port Orford	ODFW (FCO)	fc (co, sh)	Yes	1969	Oregon, Fed
Fall Creek	Alsea	ODFW (FCO)	fc, co (sc)	Yes	1952	Oregon
Nehalem	Nehalem	ODFW (FCO)	fc, co, sh (sc, ch)	Yes	[4]1968	Oregon
Oregon Aqua Foods	Newport	Private	fc, sc, co	Yes	1972	Private
Rock Creek	Idleyld Park	ODFW (OGC)	sc, co, sh (fc)	Yes	1922	Oregon
Siletz River	Nashville	ODFW (FCO)	co (fc, sc)	Yes	1937	Oregon
South Coos	Coos Bay	ODFW (FCO)	co	No	1900	Oregon
Trask River	Tillamook	ODFW (FCO)	fc, sc, co (ch)	Yes	1914	Oregon
Rearing ponds						
Cape Mears	Tillamook	ODFW (OGC)	fc	No	1967	Oregon
Hemlock Meadows	Roseburg	ODFW (OGC)	sh	No	1964	Oregon
Indian Creek	Shady Cove	ODFW (OGC)	co	No	1969	Oregon
Libby	Gold Beach	ODFW (OGC)	fc	No	1965	Oregon
Lint Slough	Waldport	ODFW (OGC)	fc, co	No	1963	Oregon
Medco	Prospect	ODFW (OGC)	sh	No	1962	Oregon
Whistlers Bend	Roseburg	ODFW (OGC)	fc	No	1967	Oregon

[1]Current agency with premerger agency in parentheses.
[2]fc = fall chinook salmon, sc = spring chinook salmon, co = coho salmon, sh = steelhead trout, src = sea-run cutthroat trout, ch = chum salmon.
[3]ODFW = Oregon Department of Fish and Wildlife, FCO = Fish Commission of Oregon, OGC = Oregon Game Commission, Oregon = State of Oregon General Fund, Corps = U.S. Army Corps of Engineers, Fed = Federal Fund 89-304.
[4]Hatchery moved to this location in 1968. It was constructed on the original site in 1918.

Table 23.—Migrant releases of chinook and coho salmon and steelhead and sea-run cutthroat trout—Oregon coastal[1] (in thousands).

Release year	Fall chinook		Spring chinook		Coho		Winter steelhead		Summer steelhead		Sea-run cutthroat	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	304.5	1.0	98.4	13.9	1,001.7	68.0	216.3	16.7	79.2	8.5	154.2	41.5
1961	358.1	2.6	137.2	15.6	1,390.0	89.2	263.5	28.8	173.4	31.5	173.5	50.0
1962	340.7	1.1	251.7	42.2	2,810.7	167.8	294.1	33.2	368.3	32.3	280.4	74.1
1963	677.2	7.5	212.4	35.7	2,773.6	171.7	299.6	36.8	292.2	23.8	126.9	45.3
1964	359.5	1.9	330.8	39.6	1,960.6	121.2	511.0	60.8	334.9	28.0	173.5	53.4
1965	77.8	0.9	190.4	23.8	2,172.3	129.0	573.1	57.4	268.4	27.0	114.2	35.9
1966	806.5	9.2	138.6	14.9	2,105.0	138.7	617.1	90.4	205.9	22.6	163.5	51.1
1967	890.7	10.7	265.3	39.9	2,432.8	156.8	606.5	79.2	299.2	43.9	200.0	65.5
1968	2,706.7	42.6	259.7	39.9	3,229.0	193.8	869.0	127.2	337.6	53.5	152.7	45.2
1969	1,599.1	61.7	175.6	27.4	3,407.9	235.8	935.6	136.3	477.2	73.3	131.2	45.5
1970	2,880.5	107.5	417.8	56.1	3,303.3	219.2	1,213.1	173.4	529.5	90.6	195.8	60.8
1971	2,138.8	96.4	412.5	57.8	3,834.9	261.3	1,292.5	206.3	457.6	74.5	192.8	53.9
1972	1,669.2	103.6	378.4	57.2	3,528.3	244.1	1,378.5	211.4	460.6	71.7	206.3	55.0
1973	2,143.4	97.5	408.7	64.9	3,926.6	266.2	1,285.3	183.5	445.8	81.6	244.0	70.8
1974	2,631.9	162.4	534.5	83.3	4,287.7	273.5	1,187.4	159.0	421.6	73.0	204.3	61.2
1975	1,924.6	120.1	657.7	106.3	4,196.4	307.8	1,277.3	196.5	384.7	77.3	106.0	51.5
1976	1,902.2	166.4	417.3	57.5	5,217.7	349.2	1,279.3	206.8	317.9	53.3	220.1	64.2
Total	23,411.4	993.1	5,287.0	776.0	51,578.5	3,393.3	14,099.2	2,003.7	5,854.0	866.4	3,129.4	924.9

[1]Derived from Wahle et al. (1975) prior to 1974 and Oregon Department of Fish and Wildlife hatchery release reports.
[2]1 lb = 0.454 kg.

In the late 1940's salmon and steelhead trout populations along the Pacific coast began to decline because of increased fishing pressure, loss of habitat, and fish passage problems at newly constructed hydroelectric projects. This decline stimulated increased hatchery production efforts. The Lower Columbia River Development Program, of the then Bureau of Commercial Fisheries, funded the construction of a number of hatcheries, including Willard, Kalama Falls, Abernathy, and Klickitat, and the renovation of other facilities already in operation. Several new hatcheries were built in California including the Coleman NFH constructed by the U.S. Bureau of Reclamation for the USFWS to replace two facilities inundated by the filling of Shasta Lake.

Table 24.—Anadromous fish rearing facilities—California, 1960-76.

Facility	General location	Operating agency[1]	Species reared during year span[2]	Anadromous releases in 1976	Year anadromous operation began	Funding agency[1]
Hatcheries						
Coleman	Anderson	USFWS	fc, sh (co)	Yes	1942	USFWS
Crystal Lake	Burney	CDFG	sh (co)	Yes	1948	CDFG
Darrah Springs	Paynes Creek	CDFG	co (fc)	Yes	1954	CDFG
Feather River	Oroville	CDFG	fc, sc, sh	Yes	1967	CDWR
Iron Gate	Hornbrook	CDFG	fc, sc, co, sh	Yes	1966	CDFG, PP&L
Mad River	Blue Lake	CDFG	fc, co, sh	Yes	1971	CDFG, NMFS
Merced rearing facility	Snelling	CDFG	fc, co	Yes	1973	CDFG
Mokelumne	Clements	CDFG	fc, sh	Yes	1964	EBMUD
Nimbus	Rancho Cordova	CDFG	fc, sh	Yes	1955	BR
Prairie Creek	Orick	Humbolt County	fc, co, sh, src	Yes	1928	Humbolt County
Trinity	Lewiston	CDFG	fc, sc, co, sh	Yes	1963	BR
Ponds						
Cochran Creek	Eureka	Fish Action Council Humbolt County	fc, co	Yes	1968	CDFG
Pacific Lumber Co.	Scotia	Pacific Lumber Co., CDFG	sh	No	1972	Pacific Lumber Co.
Talmadge	Talmadge	Sports Club, CDFG	sh	Yes	1972	Mendocino County

[1]USFWS = U.S. Fish and Wildlife Service, CDFG = California Department of Fish and Game, CDWR = California Department of Water Resources, PP&L = Pacific Power and Light, NMFS = National Marine Fisheries Service (Anadromous Fish Act), EBMUD = East Bay Municipal Utility District, BR = Bureau of Reclamation.

[2]fc = fall chinook salmon, sc = spring chinook salmon, co = coho salmon, sh = steelhead trout, src = sea-run cutthroat trout.

As water-use projects continued to block access to anadromous salmonid spawning and rearing areas, it was necessary to build hatcheries to compensate for the resulting loss of fish. Some of these hatcheries include Trinity River and Iron Gate in California, Chelan PUD and the two Cowlitz hatcheries in Washington, and Round Butte in Oregon.

The 1960's saw the re-entry of Alaska and British Columbia into the salmonid propagation field. Again, this was necessitated by decline in fish stocks and the decreases in catches in those two areas. Idaho was also forced into the hatchery salmon and steelhead trout program because of the adverse effects of dams on the Columbia and Snake Rivers.

In 1960 there were 72 hatcheries, pens, and saltwater net pens producing salmon and steelhead trout on the coast (Fig. 12). This was approximately the same number as in 1929. The number increased to a maximum of 154 in 1976, over a twofold gain. In all, 192 facilities reared anadromous fish for at least 1 yr on the Pacific coast during the 17-yr span ending in 1976.

Species Reared

One of the major trends in hatchery production of salmonids has been the shift in emphasis placed on rearing different species of salmon and anadromous trout. Prior to 1929, of the over 12 billion fry and 1 billion fingerlings and yearlings released, almost half were sockeye salmon. In 1910 alone there were almost 400 million sockeye salmon fry released (Cobb 1931).

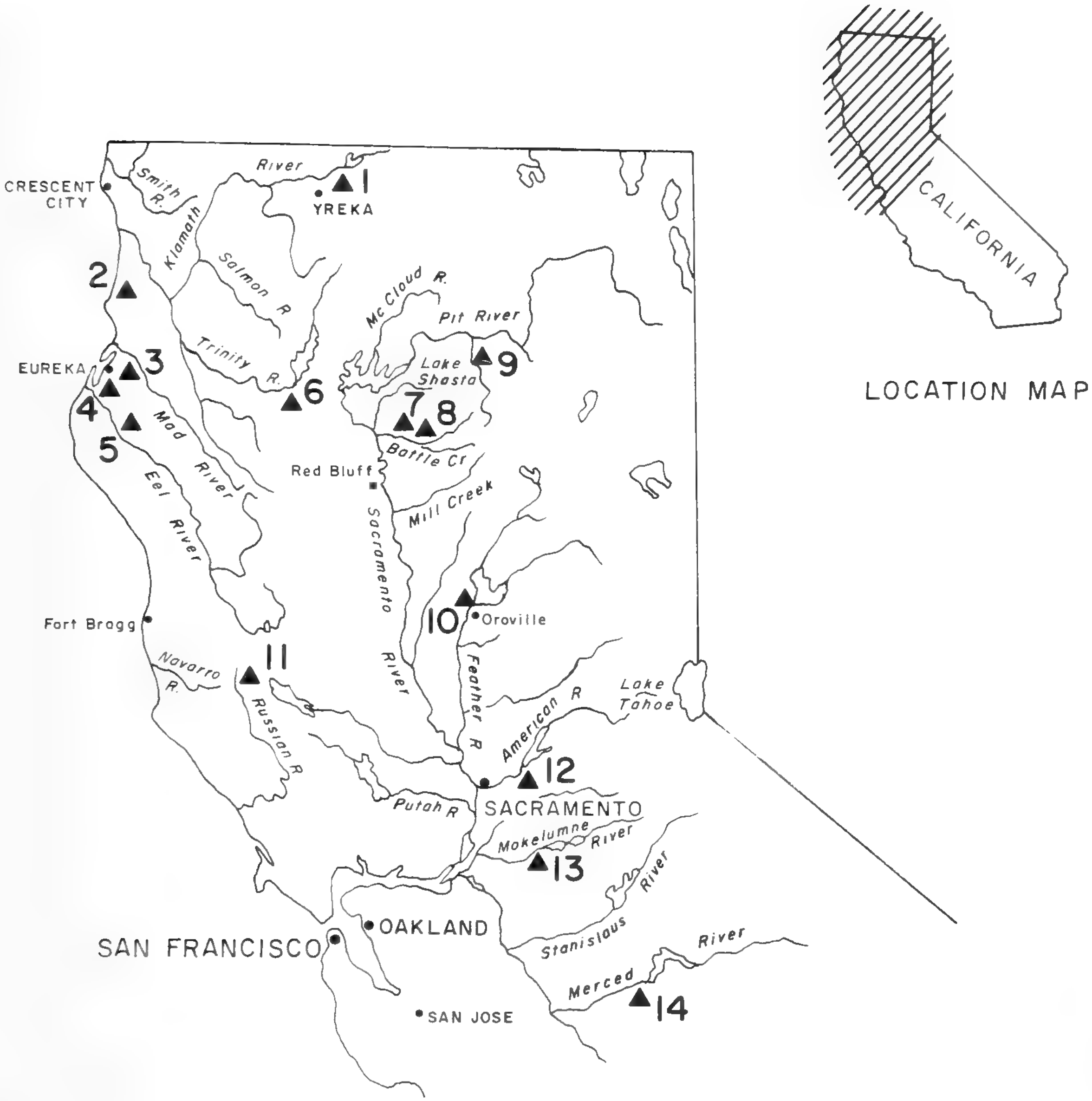
With the closing of large Alaska and British Columbia sockeye salmon stations in the 1920's and 1930's species emphasis changed. For the 17 yr since 1960, the major species reared have been chinook salmon, coho salmon, and steelhead trout (Fig. 13). The sockeye salmon releases had declined to only 3 million in 1960 with most of these coming from Leavenworth NFH on the upper Columbia River in Washington. Since 1967, when Leavenworth terminated its sockeye salmon program, only two releases of this species have been made totaling 27,000 fish.

Rearing Trends

One of the major changes in hatchery operations has been the switch from releasing unfed fry to releasing salmon and steelhead trout after a period of rearing. In the late 1800's and early 1900's, the standard hatchery practice was to release fish soon after the eggs hatched, when the yolk sac had been absorbed. The small number that were retained and fed were kept as curiosities. Although no difficulty was experienced raising these fish, the added expense of fish food as well as the inadequate rearing space at the hatcheries precluded general adoption of rearing programs.

As previously stated, a few fish culturists, including R. D. Hume from Oregon, disagreed with the practice of releasing unfed fry. It was their belief that unfed fry were ill equipped to survive competition with wild fish and predators and the increased survival and contribution obtained from releasing larger fish would outweigh the additional expense of rearing. Over the years this has proven to be true and today almost all anadromous fish are fed for a period of time before they are released.

The early efforts of rearing fish depended on diet based on ground meat and fish products. Liver, spleen, and salmon carcasses were common ingredients, supplemented with various grains and meals. These diets were not very efficient and were messy and time consuming to



Map No.	Facility	Map No.	Facility
1	Iron Gate	8	Darrah Springs
2	Prairie Creek	9	Crystal Lake
3	Mad River	10	Feather River
4	Cochran Creek	11	Talmadge Pond
5	Pacific Lumber Co. Pond	12	Nimbus
6	Trinity River	13	Mokelumne Facility
7	Coleman	14	Merced River

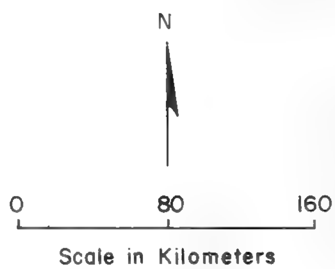


Figure 11.—Map of locations of northern California salmonid rearing facilities, 1960-76.

Table 25.—Migrant releases of chinook and coho salmon and steelhead and sea-run cutthroat trout—California[1] (in thousands).

Release year	Fall chinook		Spring chinook		Coho		Winter steelhead		Summer steelhead		Sea-run cutthroat	
	Number	Pounds[2]	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds	Number	Pounds
1960	5,386.6	125.5	0.0	0.0	0.0	0.0	315.1	16.4	0.0	0.0	0.0	0.0
1961	34,085.5	226.6	0.0	0.0	58.0	5.9	518.1	49.7	0.0	0.0	0.0	0.0
1962	7,293.3	140.7	0.0	0.0	364.0	32.0	187.3	18.6	0.0	0.0	1.9	0.4
1963	19,862.4	205.5	0.0	0.0	498.9	43.9	72.3	10.4	0.0	0.0	0.0	0.0
1964	10,161.7	148.7	300.0	10.4	499.3	43.9	1,163.1	146.3	0.0	0.0	2.7	0.9
1965	6,529.8	161.8	224.5	12.8	1,097.4	81.8	736.7	74.6	0.0	0.0	6.8	1.1
1966	11,015.7	171.6	0.0	0.0	747.2	86.2	2,436.2	327.1	0.0	0.0	10.7	2.6
1967	7,748.4	123.9	0.0	0.0	1,264.6	87.9	2,027.0	281.3	0.0	0.0	7.6	2.0
1968	14,157.1	163.0	528.6	41.3	1,821.0	130.1	2,129.7	314.3	0.0	0.0	5.3	1.3
1969	17,442.9	193.7	673.4	57.4	1,448.1	123.1	1,818.8	274.8	0.0	0.0	3.1	1.3
1970	16,808.6	302.9	120.8	14.8	1,152.1	93.0	2,169.8	318.5	18.7	2.2	55.0	3.8
1971	34,206.1	475.3	569.9	66.5	1,245.5	112.1	3,618.9	399.3	133.6	18.5	0.0	0.0
1972	37,275.7	494.3	247.3	24.8	1,664.5	153.3	4,340.6	527.9	212.2	26.9	0.8	0.1
1973	21,707.1	387.6	507.6	64.5	1,161.7	79.3	2,916.7	344.4	37.1	3.8	1.0	0.6
1974	22,667.0	418.4	482.9	47.2	802.8	54.4	3,081.1	348.7	141.6	27.2	0.0	0.0
1975	27,837.6	456.6	303.2	32.9	1,771.1	151.0	2,524.3	298.8	0.0	0.0	6.1	0.8
1976	24,444.4	471.2	888.5	115.8	1,046.6	90.4	2,948.5	416.2	77.8	12.6	4.3	1.2
Total	318,629.9	4,667.3	4,846.7	488.4	16,642.8	1,368.3	33,004.2	4,167.3	621.0	91.2	105.3	16.1

[1]Derived from Wahel et al. (1975) prior to 1974, U.S. Fish and Wildlife Service hatchery annual reports, and California hatchery records.

[2]1 lb = 0.454 kg.

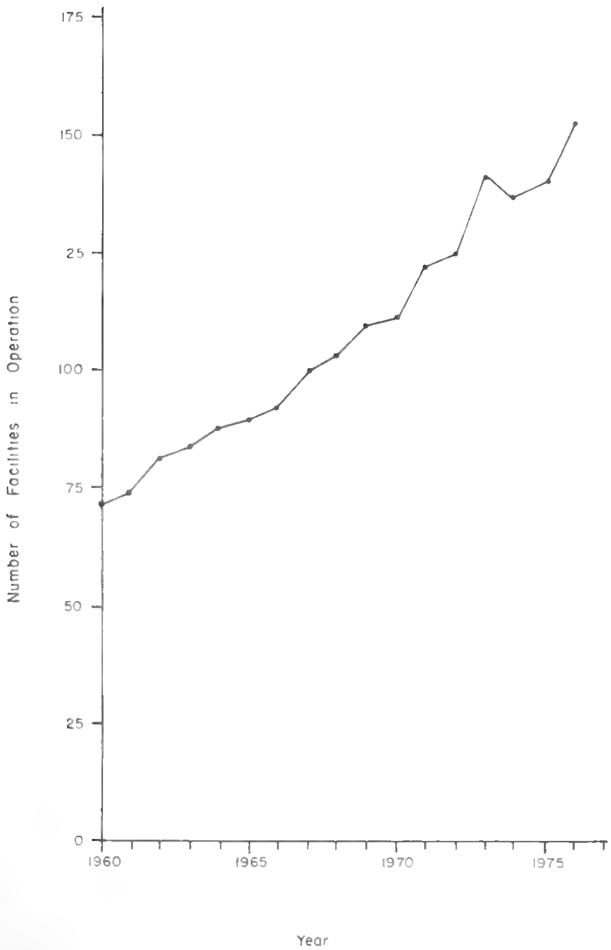


Figure 12.—Number of Pacific coast salmonid rearing facilities releasing anadromous salmonids by year, 1960-76.

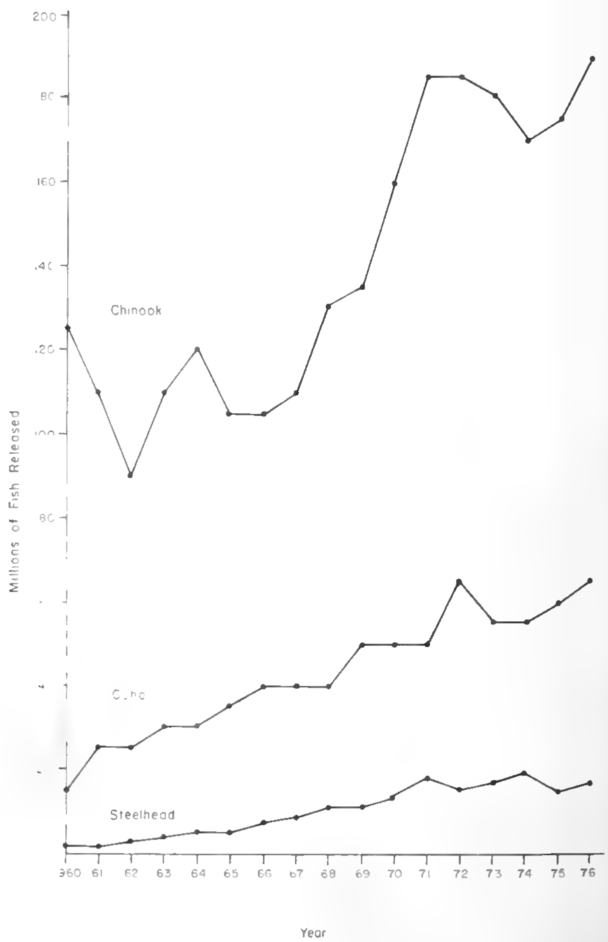


Figure 13.—Numbers of Pacific coast releases of chinook and coho salmon and steelhead trout (in millions).

prepare. In the 1950's, conversion ratios as low as 5.6 lb (25 kg) of food fed per pound (0.45 kg) of weight gained were reported from the ground-meat base diets used at several FCO hatcheries. At most hatcheries today, less than 2 lb (0.91 kg) of food are required for a 1 lb (0.45 kg) gain in weight. Another disadvantage of the meat diets was the spread of bacteria and viral diseases, to young fish from diets that included salmon carcasses. Although the diets did have disadvantages, they still allowed larger fish to be reared.

Several developments in the late 1950's had important effects on rearing practices. Improved pasteurization methods were developed to treat salmon viscera, an important component of many meat based diets. This process was used to kill disease-causing organisms that would otherwise have affected the young fish. Commercial, dry, pelletized trout diets received much attention experimentally as a salmon diet. Few of the standard trout feeds showed promise and all required meat diets to be used while the fish started feeding.

In 1959, after many years of experimentation, the FCO began feeding Oregon moist pellets (OMP) to fish at 16 of their salmon hatcheries. The OMP diet, developed jointly by the FCO and Oregon State University scientists with funds supplied by the U.S. Bureau of Commercial Fisheries (now National Marine Fisheries Service), was a breakthrough in the area of hatchery nutrition. This easily fed diet does not require any preparation at the hatchery and is readily accepted by the fish. It consists of a combination of cereals, fish meals, fish oils, dried skim milk, and vitamin supplements. Fish fed this diet have shown, in almost all cases, better survival and contribution to the fishery than fish fed old ground meat type diets (Hublou et al. 1959, Hublou 1963). Development of the OMP has opened the way for other types of diets including the Abernathy dry pellet developed at Abernathy Salmon Cultural Development Center. These new diets have made hatcheries biologically and economically feasible ventures.

Size at Time of Release

One of the most interesting trends of hatchery production over the last 17 yr has been the change in release size of migrant coho, spring chinook, and fall chinook salmon. Until the early 1960's hatcheries emphasized numbers of fish liberated. It was common for a hatchery to take more eggs than could be reared to migrant size. As fish grew and crowding occurred, fish in excess of hatchery capacities were released. Out of an egg-take of over 13 million fall chinook salmon eggs in 1959, Spring Creek NFH produced only 7.8 million migrants in May of 1960. The other 5.8 million were thinned out 3 mo earlier (Wahle et al. 1975). The average size for all species of migrant salmon released from Pacific coast rearing facilities in 1960 was 88 fish/lb (5.2 g/fish) (Fig. 14a). Fall chinook salmon, reared for 5 or 6 mo, averaged 211 fish/lb (2.29 g/fish) (Fig. 14b). Spring chinook and coho salmon, reared for an average of 20 mo, both averaged 33 fish/lb (13.8 g/fish) (Fig. 14c,d).

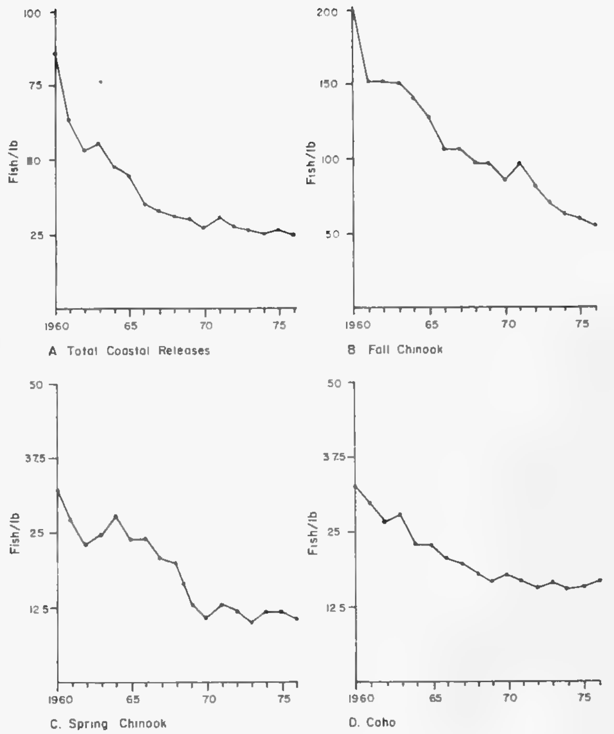


Figure 14.—Average size of various species of Pacific coast anadromous salmonid releases (all species combined), 1960-76. (1 lb equals 0.454 kg.)

In the early 1960's, a trend developed away from maximizing numbers at hatcheries. Instead, the philosophy of raising less fish to a larger size began to gain acceptance among the fish rearing agencies. Marking experiments showed that these larger fish had better survival and contribution to the fisheries (Senn and Noble 1968; Johnson 1970; Wallis[7]; Senn et al.[8]; Washington Department of Fisheries[9]). Numbers of migrant fish released actually declined slightly from 1960 to 1962 (Fig. 15) even though the number of facilities increased (Fig. 12). While migrant numbers held fairly constant from 1960 to 1976, the number of migrant pounds increased almost six times (Fig. 15). In 1976, fall chinook salmon smolts averaged 59 fish/lb (7.7 g/fish) (Fig. 14b). Spring chinook and coho salmon showed similar size change, going from approximately 32 fish/lb (4.2 g/fish) to 11 fish/lb (41.2 g/fish) and from 33 fish/lb (13.6) to 17 fish/lb (26.7 g/fish), respectively (Fig. 14c,d). During this time, the average size for all species combined went from 88 fish/lb (5.2 g/fish) to 26 fish/lb (17.5 g/fish) (Fig. 14a).

[7]Wallis, J. 1968. Recommended time, size and age for release of hatchery-reared salmon and steelhead trout. Fish. Comm. Oreg., Clackamas, Proc. Rep., 61 p.

[8]Senn, H. G., R. C. Hager, and C. W. Hopley, Jr. 1975. The effects of experimentally varying the size and time of release of hatchery-reared coho salmon. Unpubl. manuscr., 14 p. Washington Department of Fisheries, Olympia, Wash.

[9]Washington Department of Fisheries. 1977. 1972-brood Toutle River coho time/size at release study. Unpubl. manuscr., 16 p. Washington Department of Fisheries, Olympia, Wash.

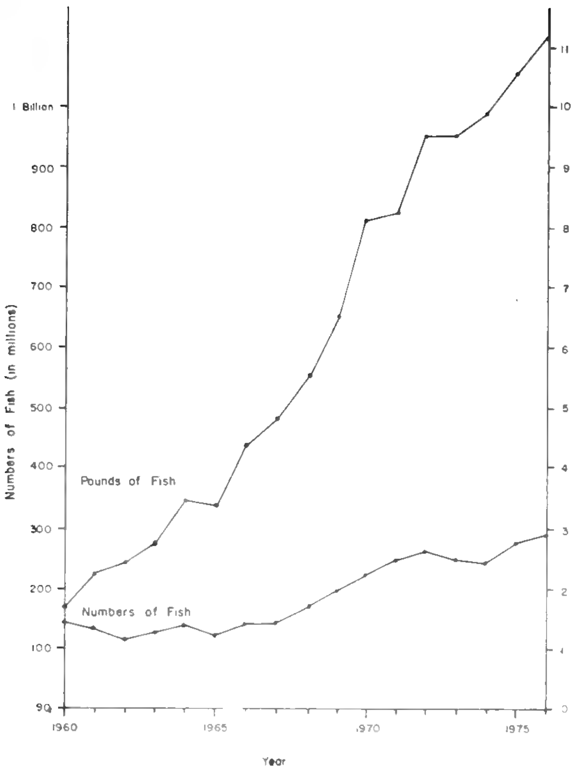


Figure 15.—Total Pacific coast migrant anadromous salmonid releases (all species combined), 1960-76. (1 lb equals 0.454 kg.)

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Appendix Table 1.—Pacific coast anadromous fish rearing facilities.

Facility name	Region
Aberdeen State Fish Hatchery 4203 Central Park Drive Aberdeen, WA 98520	Washington coastal and Puget Sound
Abernathy Salmon Cultural Development Center 1440 Abernathy Road Longview, WA 98632	Columbia Basin-Washington
Alder Creek Rearing Pond c/o Beaver Creek State Fish Hatchery Route 1, Box 274A Cathlamet, WA 98612	Columbia Basin-Washington
Alsea Fish Hatchery Star Route 2, Box 52 Philomath, OR 97370	Oregon coastal
Anadromous Inc. Route 2, Box 2012 Deer Island, OR 97054	Oregon coastal
Arlington Trout Hatchery Route 3, Box 107 Arlington, WA 98223	Washington coastal and Puget Sound
Aumsville Pond 8743 Bishop Rd S.E. Aumsville, OR 97325	Columbia Basin-Oregon
Bandon Fish Hatchery Route 1, Box 195 Bandon, OR 97411	Oregon coastal
Barnaby Rearing Pond P.O. Box 102 Rockport, WA 98283	Washington coastal and Puget Sound
Bay Center Mariculture Box 303 Bay Center, WA 98527	Washington coastal and Puget Sound
Beaver Creek Trout Hatchery Route 1, Box 274A Cathlamet, WA 98612	Columbia Basin-Washington
Bellingham Fish Hatchery Whatcom Falls Park Bellingham, WA 98225	Washington coastal and Puget Sound
Big Creek Fish Hatchery Route 4, Box 594 Astoria, OR 97103	Columbia Basin-Oregon
Big Qualicum Hatchery RR # 3 Qualicum Beach, British Columbia	British Columbia
Big White Salmon Rearing Pond c/o Spring Creek National Fish Hatchery Underwood, WA 98651	Columbia Basin-Washington
Blue Slough Rearing Pond (Closed) c/o Washington Dept. of Game 600 N. Capitol Way Olympia, WA 98504	Washington coastal and Puget Sound
Bonneville Fish Hatchery P.O. Box 262 Bonneville, OR 97008	Columbia Basin-Oregon
Bowman's Bay Rearing Ponds (Closed) c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Butte Falls Fish Hatchery 580 Fish Lake Road Butte Falls, OR 97522	Oregon coastal
Cape Mears (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Oregon coastal
Capilano Hatchery 4500 Capilano Park Road North Vancouver, British Columbia	British Columbia
Carson National Fish Hatchery Carson, WA 98610	Columbia Basin-Washington
Cascade Fish Hatchery Star Route, Box 526 Bonneville, OR 97008	Columbia Basin-Oregon
Cedar Creek Fish Hatchery Route 1, Box 9 Hebo, OR 97122	Oregon coastal
Chambers Creek Trout Hatchery c/o South Tacoma Hatchery 7723 Phillips County Road, S.W. Tacoma, WA 98498	Washington coastal and Puget Sound
Chelan PUD Trout Fish Hatchery Star Route Chelan, WA 98816	Columbia Basin-Washington
Cochran Creek Rearing Pond c/o Humbolt Fish Action Council P.O. Box 154 Eureka, CA 95501	California

Coleman National Fish Hatchery Route 1, Box 2105 Anderson, CA 96007	California
Cole Rivers Fish Hatchery Laurelhurst Road Trail, OR 97541	Oregon coastal
Columbia Basin State Fish Hatchery Route 2, Box 333C Moses Lake, WA 98837	Columbia Basin-Washington
Coos River State Hatchery (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Oregon coastal
Cowlitz Salmon Hatchery 2284 Spencer Road Salkum, WA 98582	Columbia Basin-Washington
Cowlitz Trout Hatchery Salkum, WA 98582	Columbia Basin-Washington
Crystal Lake Hatchery P.O. Box 1088 Petersburg, AK 99833	Alaska
Crystal Lake Hatchery Route 2, Box 1113 Burney, CA 96013	California
Darrah Springs Hatchery P.O. Box 8 Paynes Creek, CA 96075	California
Decker Flats Rearing Pond P.O. Box 1196 Salmon, ID 83467	Columbia Basin-Idaho
Deschutes Rearing Pond c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Dexter Rearing Pond General Delivery Lowell, OR 97456	Columbia Basin-Oregon
Domsea Farms Aquaculture Salt water-P.O. Box 372 Manchester, WA 98353 Fresh water-510 Washington Bremerton, WA 98310	Washington coastal and Puget Sound
Dungeness Salmon Hatchery Route 6, Box 983 Sequim, WA 98383	Washington coastal and Puget Sound
Dworshak National Fish Hatchery P.O. Box 251 Ahsahka, ID 83520	Columbia Basin-Idaho
Eagle Hatchery Eagle, ID 83616	Columbia Basin-Idaho
Eagle Creek National Fish Hatchery Route 1, Box 610 Estacada, OR 97023	Columbia Basin-Oregon
Elk River Fish Hatchery Star Route, Box 150 Port Orford, OR 97465	Oregon coastal
Elokomin Salmon Hatchery Route 1, Box 300 Cathlamet, WA 98612	Columbia Basin-Washington
Entiat National Fish Hatchery Star Route, Box 410 Entiat, WA 98822	Columbia Basin-Washington
Fall Creek Hatchery (Alsea Salmon) Route 2, Box 47 Alsea, OR 97324	Oregon coastal
Falls River Fish Hatchery 15055 S. Century Drive Bend, OR 97701	Columbia Basin-Oregon
Feather River Hatchery 5 Table Mt. Blvd. Oroville, CA 95965	California
Fire Lake Hatchery P.O. Box 488 Eagle River, AK 99577	Alaska
Garrison Spring Salmon Hatchery P.O. Box 94141 Fort Steilacoom, WA 98494	Washington coastal and Puget Sound
George Adams Hatchery Rt. 5, Box 125 Shelton, WA 98584	Washington coastal and Puget Sound
Gnat Creek Fish Hatchery Star Route 2 Clatskanie, OR 97016	Columbia Basin-Oregon
Goldendale Trout Hatchery Route 2, Box 111 Goldendale, WA 98620	Columbia Basin-Washington
Gorst Creek Pond c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Grays River Salmon Hatchery P.O. Box 768 Grays River, WA 98621	Columbia Basin-Washington
Green River Salmon Hatchery Route 1, Box 740 Auburn, WA 98002	Washington coastal and Puget Sound
Green River Rearing Pond P.O. Box 96 Palmer, WA 98048	Washington coastal and Puget Sound
Hagerman State Fish Hatchery Hagerman, ID 83332	Columbia Basin-Idaho
Halibut Cove Lagoon c/o F.R.E.D. Division P.O. Box 234 Homer, AK 99603	Alaska
Harrison Rearing Pond c/o Barnaby Rearing Pond P.O. Box 102 Rockport, WA 98283	Washington coastal and Puget Sound
Hayden Creek Hatchery P.O. Box 25 Lemhi, ID 83465	Columbia Basin-Idaho

Hemlock Meadows Rearing Pond (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Oregon coastal
Hood Canal Salmon Hatchery P.O. Box 6 Hoodsport, WA 98548	Washington coastal and Puget Sound
Hood River State Trout Hatchery (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Columbia Basin-Oregon
Indian Creek Rearing Pond (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Oregon coastal
Iron Gate Hatchery Copco Star Route Hornbrook, CA 96044	California
Issaquah Salmon Hatchery P.O. Box 465 Issaquah, WA 98027	Washington coastal and Puget Sound
Kalama Falls Salmon Hatchery 3900 Kalama River Road Kalama, WA 98625	Columbia Basin-Washington
Klaskanine Fish Hatchery Route 1, Box 764 Astoria, OR 97103	Columbia Basin-Oregon
Klickitat Salmon Hatchery Route 2, Box 90 Glenwood, WA 98619	Columbia Basin-Washington
Kooskia National Fish Hatchery Route 1, Box 98-A Kooskia, ID 83539	Columbia Basin-Idaho
Leaburg Fish Hatchery 90701 Fish Hatchery Road Leaburg, OR 97401	Columbia Basin-Oregon
Leavenworth National Fish Hatchery Route 1, Box 123-A Leavenworth, WA 98826	Columbia Basin-Washington
Lewis River Salmon Hatchery 4404 Lewis River Road Woodland, WA 98674	Columbia Basin- Washington
Libby Rearing Pond (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Oregon coastal
Lint Slough Rearing Pond c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Oregon coastal
Little Clam Bay Rearing Pond c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Little Port Walter Research Station c/o Auke Bay NMFS Fisheries Laboratory P.O. Box 155 Auke Bay, AK 99821	Alaska
Little White Salmon National Fish Hatchery P.O. Box 17 Cook, WA 98605	Columbia Basin-Washington
Lower Kalama Salmon Hatchery 1404 Kalama River Road Kalama, WA 98625	Columbia Basin-Washington
Lummi Indian Net Pens c/o Lummi Indian Tribal Enterprises Mr. Jim Ellis P.O. Box 309 Marietta, WA 98268	Washington coastal and Puget Sound
MacKay Hatchery MacKay, ID 83251	Columbia Basin-Idaho
Mad River Hatchery Route 1, Box 184 Arcata, CA 95521	California
Marion Forks Fish Hatchery Star Route, Box 71 Idanha, OR 97350	Columbia Basin-Oregon
McCall Hatchery P.O. Box 1021 McCall, ID 83638	Columbia Basin-Idaho
McKenzie Fish Hatchery 43863 Greer Drive Leaburg, OR 97401	Columbia Basin-Oregon
Medco Rearing Pond (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Oregon coastal
Mendenhall Rearing Pond c/o Alaska Dept. of Fish and Game 210 Ferry Way Juneau, AK 99801 ATTN: Mr. Bethers	Alaska
Merced River Rearing Facility P.O. Box 94 Snelling, CA 95369	California
Metolius Hatchery (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Columbia Basin-Oregon
Minter Creek Salmon Hatchery Route 4, Box 4595 Gig Harbor, WA 98335	Washington coastal and Puget Sound
Mokelumne Rearing Facility P.O. Box 158 Clements, CA 95227	California

Mossyrock Trout Hatchery P.O. Box 108 Mossyrock, WA 98564	Columbia Basin-Washington
Mullen Hatchery P.O. Box 448 Mullen, ID 83846	Columbia Basin-Idaho
Naches Trout Hatchery Rural Route 1 Naches, WA 98937	Columbia Basin-Washington
Nehalem Fish Hatchery Route 1, Box 292 Nehalem, OR 97131	Oregon coastal
Nelson Bridge Rearing Pond c/o Naches State Fish Hatchery Rural Route 1 Naches, WA 98937	Columbia Basin-Washington
Nemah Salmon Hatchery Star Route South Bend, WA 98586	Washington coastal and Puget Sound
Niagara Springs Hatchery P.O. Box 128 Wendell, ID 83355	Columbia Basin-Idaho
Nile Springs c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Columbia Basin-Washington
Nimbus Hatchery 2001 Nimbus Road Rancho Cordova, CA 95670	California
Nooksack Salmon Hatchery Glacier Star Route Deming, WA 98244	Washington coastal and Puget Sound
Northwest Steelheaders' Rearing Ponds c/o N.W. Steelheaders Council 3634 Walker Road Tacoma, WA 98443	Washington coastal and Puget Sound
Oakridge Fish Hatchery 76389 Fish Hatchery Pt. Oakridge, OR 97463	Columbia Basin-Oregon
Oak Springs Fish Hatchery Route 1, Box 134 Maupin, OR 97037	Columbia Basin-Oregon
Olympic Rearing Channel 420 Laird Port Angeles, WA 98362	Washington coastal and Puget Sound
Oregon Aqua Foods 88700 Marcola Road Springfield, OR 97477	Oregon coastal
Oxbow Hatchery P.O. Box 85 Oxbow, OR 97840	Columbia Basin-Idaho
OxBow Fish Hatchery Star Route, Box 750 Cascade Locks, OR 97014	Columbia Basin-Oregon
Pacific Lumber Co. Rearing Ponds c/o Pacific Lumber Council Scotia, CA 95565	California
Pahsimeroi Hatchery P.O. Box 84 Ellis, ID 83235	Columbia Basin-Idaho
Percival Cove Rearing Pond c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Prairie Creek Hatchery Orick, CA 95555	California
Priest Rapids Salmon Rearing Facility P.O. Box 937 Mattawa, WA 99344	Columbia Basin-Washington
Puntledge Rearing Facility c/o Big Qualicum Hatchery RR # 3 Qualicum Beach, British Columbia	British Columbia
Puyallup Salmon Hatchery Route 1, Box 97 Orting, WA 98360	Washington coastal and Puget Sound
Puyallup Trout Hatchery 1416 14th Street Puyallup, WA 98371	Washington coastal and Puget Sound
Quilcene National Fish Hatchery Quilcene, WA 98376	Washington coastal and Puget Sound
Quinault National Fish Hatchery P.O. Box 80 Neilton, WA 98556	Washington coastal and Puget Sound
Rapid River Hatchery (Circle "C" Hatchery) Riggins, ID 83549	Columbia Basin-Washington
Ringold Salmon Rearing Pond Star Route Mesa, WA 99343	Columbia Basin-Washington
Ringold Trout Rearing Pond Star Route Mesa, WA 99343	Columbia Basin-Washington
Roaring River Fish Hatchery 42255 Fish Hatchery Drive Scio, OR 97374	Columbia Basin-Oregon
Robertson Creek Rearing Facility c/o Environment Canada Fisheries and Marine Service 1090 Pender St. Vancouver, British Columbia V6E 2Pl	British Columbia
Rock Creek Fish Hatchery Toketee Route, Box 12 Idleyld Park, OR 97447	Oregon coastal
Rock Reach Salmon Rearing Facility 601 N. Jenifer Lane E. Wenatchee, WA 98801	Columbia Basin-Washington
Rosewall Rearing Facility c/o Pacific Biological Station P.O. Box 100 Nanaimo, British Columbia	British Columbia

Round Butte Fish Hatchery P.O. Box 513 Madras, OR 97741	Columbia Basin-Oregon
Salem Rearing Pond c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTN: Mr. Jefferies	Columbia Basin-Oregon
Salt Creek Rearing Pond (Closed) c/o Washington Dept. of Game 600 N. Capitol Way Olympia, WA 98504	Washington coastal and Puget Sound
Samish Salmon Hatchery P.O. Box 555 Old Highway 99 Burlington, WA 98233	Washington coastal and Puget Sound
Sandpoint Hatchery Route 1 Sagle, ID 83860	Columbia Basin-Washington
Sandy River Fish Hatchery 39800 S.E. Fish Hatchery Road Sandy, OR 97055	Columbia Basin-Oregon
Seward Park Hatchery Seward Park Seattle, WA 98118	Washington coastal and Puget Sound
Shelton Trout Hatchery Route 5, Box 251 Shelton, WA 98584	Washington coastal and Puget Sound
Siletz Fish Hatchery Nashville Route, Box 125 Blodgett, OR 97326	Oregon coastal
Simpson Salmon Hatchery Route 1, Box 140 Elma, WA 93541	Washington coastal and Puget Sound
Skagit Salmon Hatchery Cascade Route Marblemount, WA 98267	Washington coastal and Puget Sound
Skamania Trout Hatchery Route 2, Box 464 Washougal, WA 98611	Columbia Basin-Washington
Skykomish Rearing Ponds Route 2, Box 395 1/2 Sultan, WA 98294	Washington coastal and Puget Sound
Skykomish Salmon Hatchery Route 2, Box 423 Sultan, WA 98294	Washington coastal and Puget Sound
Soleduck Salmon Hatchery P.O. Box 8 Beaver, WA 98305	Washington coastal and Puget Sound
South Santiam Fish Hatchery 43182 N. River Road Sweet Home, OR 97386	Columbia Basin-Oregon
South Sound Net Pens c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
South Tacoma Trout Hatchery 7723 Phillips County Road, S.W. Tacoma, WA 98498	Washington coastal and Puget Sound
Speelyai Salmon Hatchery 11001 Lewis River Road Ariel, WA 98603	Columbia Basin—Washington
Spring Creek National Fish Hatchery Underwood, WA 98651	Columbia Basin—Washington
Squaxin Island Mariculture 33324 Pacific Highway Auburn, WA 98002	Washington coastal and Puget Sound
Starrigavan Net Pens P.O. Box 499 Sitka, AK 99835	Alaska
Stayton Rearing Pond c/o Aumsville Rearing Pond 8743 Bishop Road S.E. Aumsville, OR 97325	Columbia Basin-Oregon
Steilacoom Net Pens (Closed) c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Swofford Rearing Pond 1182 Spencer Road Winlock, WA 98596	Columbia Basin-Washington
Talmadge Rearing Pond c/o Mendocino County Offices Ukiah, CA 95482	California
Tokul Creek Trout Hatchery Route 1 Fall City, WA 98024	Washington coastal and Puget Sound
Toutle River Salmon Hatchery 1500 Cook Road Toutle, WA 98649	Columbia Basin-Washington
Trask River Fish Hatchery 15020 Chance Road Tillamook, OR 97141	Oregon coastal
Trinity River Hatchery P.O. Box 162 Lewiston, CA 96052	California
Tucannon Trout Hatchery Route 1, Box 32 Pomeroy, WA 99347	Columbia Basin-Washington
Tulalip Rearing Facility c/o Mr. Wayne Williams 3901 Totem Beach Road Marysville, WA 98270	Washington coastal and Puget Sound
Vancouver Trout Hatchery 12208 Evergreen Highway S.E. Vancouver, WA 98660	Columbia Basin-Washington
Wahkeena Rearing Pond c/o OxBow State Salmon Hatchery Star Route, Box 750 Cascade Locks, OR 97014	Columbia Basin-Oregon

Wallowa Fish Hatchery Route 1, Box 278 Enterprise, OR 97828	Columbia Basin-Oregon
Washburn Island Rearing Facility (Closed) c/o Washington Dept. of Game 600 N. Capitol Way Olympia, WA 98504	Columbia Basin-Washington
Washougal Salmon Hatchery Route 2, Box 443 Washougal, WA 98671	Columbia Basin-Washington
Wells Salmon Rearing Facility Box 3, Azwell Route Pateros, WA 98846	Columbia Basin-Washington
Wells Trout Hatchery Box 2, Azwell Route Pateros, WA 98846	Columbia Basin—Washington
Westport Boat Basin Rearing Facility c/o Washington Dept. of Fisheries Rm 115, Gen. Admin. Bldg. Olympia, WA 98504	Washington coastal and Puget Sound
Whidby Island Rearing Facility c/o Whidby Salmon Association P.O. Box 175 Clinton, WA 98236	Washington coastal and Puget Sound
Whistler's Bend Rearing Pond (Closed) c/o Oregon Dept. of Fish and Wildlife P.O. Box 3503 Portland, OR 97208 ATTEN: Mr. Jefferies	Oregon coastal
Whitehorse Rearing Pond Route 3, Box 229 Arlington, WA 98223	Washington coastal and Puget Sound
Willapa Salmon Hatchery Route 1, Box 192 Raymond, WA 98577	Washington coastal and Puget Sound
Willard National Fish Hatchery Star Route Cook, WA 98605	Columbia Basin-Washington
Winthrop National Fish Hatchery P.O. Box 218 Winthrop, WA 98862	Columbia Basin-Washington
Wizard Falls Fish Hatchery Camp Sherman, OR 97730	Columbia Basin-Oregon
Yakima Trout Hatchery 2306 S. 16th Avenue Yakima, WA 98902	Columbia Basin-Washington

Appendix Table 2.—Agencies operating fish rearing facilities on the Pacific coast.

Agency	Address	Contact	Phone
Alaska Department of Fish and Game	F.R.E.D. 333 Raspberry Road Anchorage, AK 99502	Nikki Newcome	907-344-0541
California Department of Fish and Game	1001 Jedsmith Drive Sacramento, CA 95819	Patrick O'Brien	916-445-0111
Environment Canada-Fisheries and Marine Service	1090 West Pender St. Vancouver 1, B.C. V6E 2P1	Ted Perry	604-666-6966
Humboldt County, California	C/o Prairie Creek Hatchery Orick, CA 95555	Steven Sanders	707-488-2253
Idaho Department of Fish and Game	600 South Walnut P.O. Box 25 Boise, ID 83707	Walt Bethke	208-964-3791
National Marine Fisheries Service (Alaska)	Auke Bay Research Station Box 155 Auke Bay, AK 99821	William Heard	907-789-7231
Oregon Department of Fish and Wildlife	P.O. Box 3503 Portland, OR 97208	Ernie Jefferies	503-229-5675
U.S. Fish and Wildlife Service	Suite 1692 Lloyd 500 Building 500 N.E. Multnomah St. Portland, OR 97232	Paul Handy	503-231-6216
Washington Department of Fisheries	Room 115, General Admin. Bldg. Olympia, WA 98501	Harry Senn	206-753-1872
Washington Department of Game	600 N. Capitol Way Olympia, WA 98504	James Gearhart	206-753-5713

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NOAA Technical Report NMFS SSRF- 737

Movements of Pelagic Dolphins (*Stenella* Spp.) in the Eastern Tropical Pacific as Indicated by Results of Tagging, With Summary of Tagging Operations, 1969-76

W. F. Perrin, W. E. Evans, and
D. B. Holts

September 1979

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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721. National Marine Fisheries Service survey of trace elements in the fishery resource. By R. A. Hall, E. G. Zook, and G. M. Meaburn. March 1978, iii + 313 p., 5 tables, 3 app. figs., 1 app. table.

NOAA Technical Report NMFS SSRF- 737

Movements of Pelagic Dolphins (*Stenella* Spp.) in the Eastern Tropical Pacific as Indicated by Results of Tagging, With Summary of Tagging Operations, 1969-76

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U.S. DEPARTMENT OF COMMERCE
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CONTENTS

Figures

Tables

Movements of Pelagic Dolphins (*Stenella* Spp.) in the Eastern Tropical Pacific as Indicated by Results of Tagging, With Summary of Tagging Operations, 1969-76

W. F. PERRIN[1], W. E. EVANS[2], and D. B. HOLTS[1]

ABSTRACT

Through 1976, 3,712 small cetaceans were tagged in the course of research cruises operating out of the Southwest Fisheries Center. These included 2,996 spotted dolphins, *Stenella attenuata;* 324 spinner dolphins, *S. longirostis;* 193 common dolphins, *Delphinus delphis;* and 113 bottlenose dolphins, *Tursiops truncatus.* Others tagged in small numbers included Pacific whitesided dolphins, *Lagenorhynchus obliquidens;* striped dolphins, *Stenella coeruleoalba;* and a short-finned pilot whale, *Globicephala macrorhynchus.* Several types of tags were used. Tags have been recovered from 97 spotted dolphins and 7 spinner dolphins. Time at liberty ranged from less than 2 h to more than 4 yr. Net distance traveled ranged from 7 to 582 n.mi. Average short-term movement in the spotted dolphin is 30-50 n.mi./day; range is 200-300 n.mi. in diameter, and seasonal onshore-offshore migrations may exist.

INTRODUCTION

Populations of pelagic dolphins are important to the purse seine fishery for yellowfin tuna in the eastern tropical Pacific and are affected by the fishery.[3] Adequate assessment of the impacts of the fishery on the dolphin populations requires knowledge of such aspects of life history as home range and seasonal migration. For this reason, we began a program of tagging dolphins in 1969. The tagging program was specifically designed to examine movements, but the tagging itself was largely opportunistic. In addition, research projects with other objectives but involving tagging have also yielded information on movements. The main purpose of this report is to summarize and to report the results of analyses of data on movements of spotted dolphins, *Stenella attenuata,* and spinner dolphins, *S. longirostris,* yielded by tag returns through 1976. A secondary purpose is to summarize and document all dolphin tagging operations carried out in conjunction with dolphin/tuna research at the Southwest Fisheries Center, La Jolla, Calif., from 1969 through 1976. This is necessary because of the possibility that tagged dolphins released by us may be recovered by other investigators not familiar with our program. We suspended field work in our tagging program in 1976, pending development of better tags and design of a plan for large-scale tagging aimed at estimating population sizes. The results of the expanded program will be the subject of future reports.

Many small marine odontocetes are thought to undergo migrations of varying scale in time and distance. Most published conclusions about movements have been based on sightings or strandings and have to do with season of the year or sea surface temperature. Fraser (1934) noted a possible intrusion of elements of the warm-temperate Atlantic cetacean fauna (including *Delphinus delphis*) into the North Sea during a year of anomalous sea-surface warming. Sightings and correlated oceanographic data suggest that the distributions of dolphins (*Lissodelphis peroni, Lagenorhynchus cruciger, Lagenorhynchus obscurus,* and *Delphinus delphis*) off the east coast of New Zealand are "closely associated with certain temperature ranges and consequently with specific water masses and convergence regions," causing different animals to be seen in summer than in winter (Gaskin 1968). Similarly, Kasuya (1971) found, on the basis of aerial sightings, that warm-water delphinids, including *Stenella attenuata,* in Japanese waters migrate north in the summer season as far as Hokkaido; whereas cold-water forms, such as *Phocoenoides dalli* and *Lissodelphis borealis,* migrate south in the winter. The northern extent of the distribution of the warm-water forms may vary seasonally as much as 13° of latitude (780 n. mi.) (Miyazaki et al. 1974). Evans (1975) demonstrated the existence of similar seasonal migrations by the common dolphin, *D. delphis,* off the coasts of southern California and Baja California. Several other similar studies have been carried out, and this review is not exhaustive.

Very little information has been available on home range of pelagic dolphins. As Norris (1967) noted, some dolphins seem quite sedentary. He found that herds of spinner dolphins, *Stenella longirostris,* are consistently found off limited stretches of coast; five such home ranges have been tentatively recognized off Oahu, Hawaii. On the other hand, some other dolphins are very

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[3]Report of the Workshop on Stock Assessment of Porpoises Involved in the Eastern Pacific Yellowfin Tuna Fishery. Unpubl. Manuscr., 109 p. SWFC Admin. Rep. No. LJ-76-29, Nat. Mar. Fish. Serv., La Jolla, CA 92038.

mobile. Herds of common dolphins off southern California and Baja California may move as far as 120 km in a 24-h period, following underwater escarpments (Evans 1971, 1974).

Preliminary results of our tagging program through early 1974 have been previously published (Perrin 1975). Time at liberty for tagged spotted dolphins ranged from 1.7 h to 502 days and minimum distance traveled from 13 to 532 km.[4] The tentative conclusion was that these data indicate a great deal of east-west and north-south movement within the eastern portion of the range of the offshore race of *S. attenuata*. Tag returns for *S. longirostris* showed less net movement.

[4]A maximum value for minimum distance traveled of 2,415 km was given in Perrin (1975). Subsequently, additional information has been acquired concerning the recapture of that tag, and the data are now considered to be unreliable and are not included in the analysis below.

MATERIALS AND METHODS

During the course of research on the dolphin/tuna problem, 3,712 small cetaceans were tagged (Table 1), including 2,996 spotted dolphins (Fig. 1) and 324 spinner dolphins (Fig. 2). One of us (Evans) carried out other dolphin-tagging operations during the period 1969-76, but these did not involve *Stenella* spp. and will be described in another report. Several types of tags and tag legends were used:

1. *Spaghetti tag with plastic dart.* This tag was described and figured by Nishiwaki et al. (1966). The

Table 1.—Dolphins and small whales tagged, 1969-76. Radiotags included.

Year	*Stenella attenuata*	*Stenella longirostris*	*Delphinus delphis*	*Tursiops truncatus*	Other	Unidentified	Total
1969	207	11	0	0	0	0	218
1970	618	94	10	0	0	[1]46	768
1971	147	18	50	12	[2]1	[3]15	243
1972	306	41	28	19	[2]7	0	401
1973	203	35	56	8	[4]2	1	305
1974	1,048	70	23	72	[2]7	1	1,221
1975	336	46	26	2	[5]4	[3]2	416
1976	131	9	0	0	0	0	140
Total	2,996	324	193	113	21	65	3,712

[1]Probability is high that these were either spotted dolphins, *Stenella attenuata*, or spinner dolphins, *S. longirostris*.

[2]Pacific white-sided dolphin, *Lagenorhynchus obliquidens*.

[3]Spotted or spinner dolphins.

[4]Striped dolphin, *Stenella coeruleoalba*.

[5]Two striped dolphins and two short-finned pilot whales, *Globicephala macrorhynchus*.

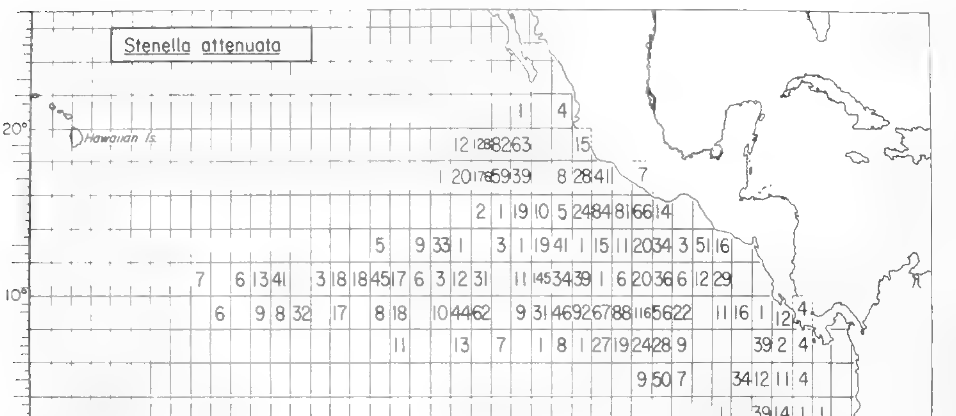


Figure 1.—Number of releases of tagged spotted dolphins, *Stenella attenuata*, by 2-degree area, 1969-76. Releases given in Table 1 for which precise localities are not available are not included.

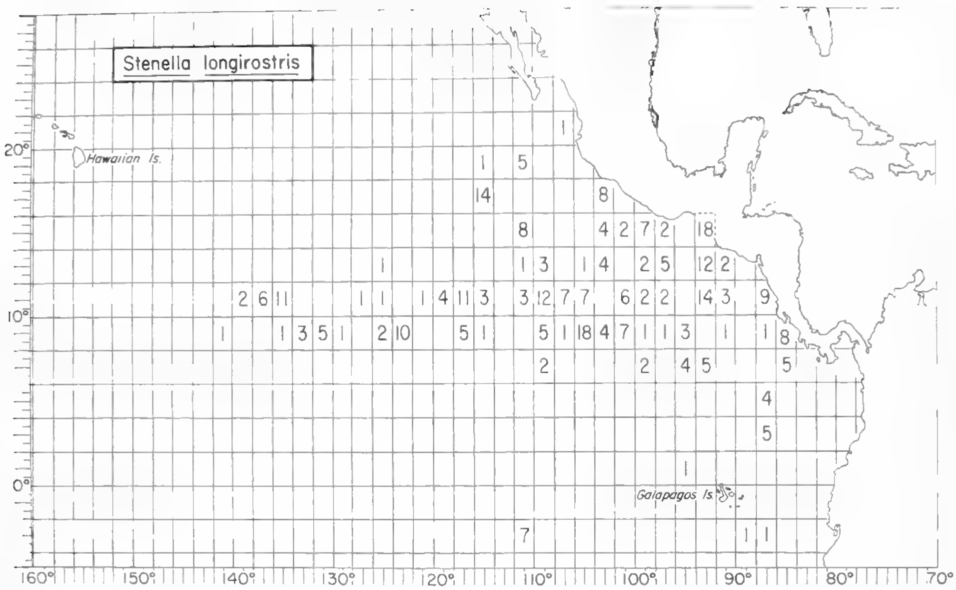


Figure 2.—Number of releases of tagged spinner dolphins, *Stenella longirostris*, by 2-degree area, 1969-76. Two dolphins given in Table 1 for which precise localities are not available are not included.

tags released in 1969 and 1970 were yellow and bore one of two legends (in addition to serial number):

a. RETURN TUNA COMM SAN DIEGO or
b. REWARD BU COMM FISHERIES SAN DIEGO.

2. *Spaghetti tag with steel dart.* This type of tag was developed for use on large pelagic fishes (Mather 1963) and was first used on cetaceans by Sergeant and Brodie (1969). It has been modified from its original design by addition of a clear plastic sleeve to protect the legend (Evans et al.1972). It is manufactured by Floy Tag and Manufacturing, Inc., Seattle, Wash. Four versions of the tag were used in the operations described here:

   a. 15-cm long, orange, with legend:
      REWARD U.S. BUR COMM FISH LA JOLLA, CALIF(CF)
   b. 12-cm long, yellow, with legend:
      REWARD NATL MARINE FISH SERVICE LA JOLLA, CAL
   c. 32-cm long, yellow, with legend:
      NUC-502 SAN DIEGO, CAL. 92132 REWARD
   d. 30-cm long, orange, with legend:
      NATIONAL MARINE FISHERIES SERVICE LA JOLLA, CA U.S.A. REWARD.

3. *Spaghetti tag with steel dart/braided.* These tags were designed at sea for use in underwater observations of tagged dolphins during the research cruise of the *Elizabeth C. J.* in 1976 (see following section on Chronological Account of Tagging Operations, 1969-76). Three-strand braids of spaghetti tubing of various colors were linked together in unique color/length combinations and fastened to steel-dart tags from which all but 1 in of tubing (bearing the serial number) has been removed. Six-inch lengths of ½-in wide flexible, bright orange plastic streamers were added to the ends of some of the tags to further increase visibility.

4. *Plastic deer ear tag.* This tag ("jumbo rototag") was described and figured by Norris and Pryor (1970). Tag and applicators are manufactured by Dalton, Henley, United Kingdom.

   a. Tags released in 1971 were yellow and bore the legend:
      DEVUELVA OF. DE PESCA PREMIO. 150 PESOS BU COMM FISH SAN DIEGO CON CABEZA
   b. Tags released in 1972 were yellow, with the legend:
      $15 DOLLAR REWARD FOR RETURN WITH HEAD BU COM FISH SAN DIEGO
   c. Tags released in 1973 were white and bore no legend other than the serial number.

5. *Radiotag.* Martin et al. (1971) and Evans (1971, 1974) described and figured the radiotags used.

CHRONOLOGICAL ACCOUNT OF TAGGING OPERATIONS, 1969-76

1. In 1969 and 1970, the Inter-American Tropical Tuna Commission (IATTC) conducted tuna-tagging operations on three cruises on the chartered tuna seiners, the *Connie Jean* and the *Anne M.* At NMFS' request, tuna tags (spaghetti tag with plastic dart—see discussion of tag types above) were also placed in dol-

phins captured with tuna (see Bayliff 1973 for description of tagging operations). Nine hundred and forty-nine dolphins were thusly tagged (Table 2).

2. In 1970, a crewman on the seiner *Conquest* volunteered to tag dolphins during fishing operations. He tagged 37 dolphins (probably spotted and spinner dolphins) with plastic-dart spaghetti tags.

3. Beginning in 1971, scientific observers from NMFS each year have accompanied some tuna seiners to the "porpoise-fishing" grounds. Through 1975, these observers tagged dolphins on an opportunity basis. The observers tagged 105 dolphins on 3 cruises in 1971, 316 on 9 cruises in 1972, 204 on 16 cruises in 1973, 1,221 on 25 cruises in 1974, and 416 on 22 cruises in 1975 (Table 3). Two short-finned pilot whales,

Table 2.—Tags released from commercial seiners, 1969-76. Releases by NUMFS observers aboard nonchartered seiners are detailed in Table 3. Tag type PD = plastic-dart spaghetti tag, MD = metal-dart spaghetti tag (see Table 3), DE = deer ear tag, and RX = radio-transmitter tag. Letters a, b, and c refer to tag type subcategories defined in text.

			Tagged							
Vessel	Cruise number	Cruise period	Spotted dolphin	Spinner dolphin	Common dolphin	Bottlenosed dolphin	Other	Unidentified	Total	Tag type
Connie Jean	1055	Oct-Nov 69	207	11	0	0	0	0	218	PD (a)
Anne M	1057	Jun-Aug 70	≥278	≥46	10	—	—	9	343	PD (61a, 278b)
Anne M	1058	Sep-Nov 70	340	48	0	0	0	0	388	PD (b)
Conquest	—	Mar-Apr 70	—	—	—	—	—	37	37	PD (b)
Queen Mary	13	Nov-Dec 71	≥105	—	0	0	0	[1]15	120	MD (107b, 24c)
			15	0	0	0	0	0	15	DE (a)
			3	0	0	0	0	0	3	RX
Independence	26	Sep-Oct 72	1	4	18	0	[2]1	0	24	MD (a)
			61	0	0	0	0	0	61	DE (b)
Trinidad	52	Oct-Nov 73	12	1	7	0	0	0	20	MD (a)
John F. Kennedy	53	Nov-Dec 73	59	0	0	0	0	0	59	MD (a)
			22	0	0	0	0	0	22	DE (c)[3]
Elizabeth C J	208	Oct-Dec 76	124	8	0	0	0	0	132	MD[4]
			7	1	0	0	0	0	8	RX
Total			1,234	119	35	0	1	61	1,450	

[1]Spotted or spinner.
[2]Pacific white-sided dolphin, *Lagenorhynchus obliquidens*.
[3]With 2-in disc.
[4]With braided tubing.

Table 3.—Tag releases (steel-dart spaghetti tags) by NMFS observers aboard commercial tuna seiners, 1971-75. Tag types defined in text.

		Tagged								
Cruise number	Year	Spotted dolphin	Spinner dolphin	Common dolphin	Bottlenose dolphin	Other	Unidentified	Totals		Tag type
6	1971	0	0	23	0	[1]1	0	24		(a)
8		8	18	17	11	0	0	54		(a)
9		16	0	10	1	0	0	27	105	(10c, 95a)
14	1972	18	0	0	0	0	0	18		(a)
15		43	0	2	0	0	0	45		(a)
16		22	21	0	0	0	0	43		(a)
17		6	0	2	9	[1]6	0	23		(a)
20		16	0	0	0	0	0	16		(a)
21		54	1	0	1	0	0	56		(a)
22		32	13	0	0	0	0	45		(a)
23		15	0	0	0	0	0	15		(a)
24		38	2	6	9	0	0	55	316	(a)
29	1973	2	4	7	0	0	0	13		(a)
30		12	5	0	0	0	1	18		(a)
31		1	0	0	0	0	0	1		(a)
32		1	0	0	0	0	0	1		(a)
33		1	0	0	0	0	0	1		(a)
34		9	0	0	0	0	0	9		(a)
38		4	1	0	0	0	0	5		(a)
39		1	0	0	0	0	0	1		(a)
40		1	0	0	0	0	0	1		(a)
41		12	10	6	0	0	0	28		(a)
43		5	1	4	0	0	0	10		(a)
44		11	1	4	0	[2]2	0	18		(a)
45		23	0	8	0	0	0	31		(a)
47		7	0	4	0	0	0	11		(a)
48		9	12	16	8	0	0	45		(a)

Table 3.—Continued.

Cruise number	Year	Tagged: Spotted dolphin	Spinner dolphin	Common dolphin	Bottlenose dolphin	Other	Unidentified	Totals		Tag type
49		11	0	0	0	0	0	11	204	(a)
54	1974	0	3	0	0	0	0	3		(a)
55		3	0	0	0	0	0	3		(b)
57		16	3	0	0	0	0	19		(a)
58		47	3	0	9	0	0	59		(a)
59		24	8	2	4	0	0	38		(a)
61		51	8	4	17	[1]3	0	83		(b)
65		17	0	4	0	0	0	21		(a)
66		29	0	0	0	0	0	29		(a)
67		0	1	0	0	0	0	1		(a)
68		20	1	7	0	0	0	28		(b)
71		2	5	0	0	0	0	7		(a)
72		1	0	0	0	0	0	1		(b)
73		3	2	0	0	0	0	5		(a)
74		34	1	0	0	0	1	36		(b)
75		2	0	0	0	0	0	2		(a)
76		1	1	0	0	0	0	2		(a)
78		8	0	0	0	0	0	8		(b)
80		10	0	0	0	0	0	10		(a)
81		2	0	0	8	0	0	10		(b)
82		34	0	0	0	0	0	34		(a)
87		91	5	6	32	[1]4	0	138		(b)
90		5	7	0	0	0	0	12		(a)
91		623	14	0	2	0	0	639		(a)
94		5	2	0	0	0	0	7		(a)
96		20	6	0	0	0	0	26	1,221	(a)
99	1975	1	0	0	0	0	0	1		(a)
100		16	0	0	1	0	0	17		(d)
102		43	2	0	0	[2]1	0	46		(d)
104		42	4	0	0	0	[3]2	48		(d)
105		18	2	0	0	0	0	20		(d)
106		45	3	0	1	0	0	49		(d)
110		3	0	0	0	[2]1	0	4		(d)
112		42	8	0	0	0	0	50		(d)
113		27	10	0	0	0	0	37		(d)
114		1	0	0	0	0	0	1		(d)
115		6	1	0	0	0	0	7		(b)
116		2	1	0	0	0	0	3		(d)
117		1	0	0	0	0	0	1		(d)
118		0	2	0	0	0	0	2		(d)
119		15	5	0	0	0	0	20		(d)
120		1	0	0	0	0	0	1		(d)
121		43	0	0	0	0	0	43		(d)
123		8	1	2	0	[4]2	0	13		(d)
124		1	0	0	0	0	0	1		(d)
125		5	0	0	0	0	0	5		(d)
129		16	7	24	0	0	0	47	416	(d)
	Total	1,762	205	158	113	20	4	2,262		

[1]Pacific white-sided dolphin, *Lagenorhynchus obliquidens*.
[2]Striped dolphin, *Stenella coeruleoalba*.
[3]Spotted dolphin or spinner dolphin.
[4]Short-finned pilot whale, *Globicephala macrorhynchus*.

Globicephala macrorhynchus, were also tagged in 1975. Before application, the tag heads were sprayed with Topazone, a topical antibiotic. The tags were applied in several different ways:

a. from the bow (when animals rode the bow wave), with a quick-release head (Beckett 1968) mounted on a long wooden pole or with a crossbow (as described by Kasuya and Oguro 1972, but using a rubber stop on the crossbow bolt rather than a brass stop);
b. from a skiff at the corkine of the seine during the dolphin-rescue maneuver called "backing-down" (see Perrin 1969 for details of fishing operation), using short (40 cm) wooden wands, with permanently mounted tag pins, as applicators; and
c. on the work-deck, when live dolphins were extricated from the net or the catch and then thrown overboard, using short applicators.

4. In late 1971, NMFS chartered the tuna seiner *Queen Mary* for a dolphin/tuna research cruise on the fishing

grounds. Three tagging operations were carried out on the cruise.

a. Radiotags were attached to spotted dolphins, to monitor herd movements, herd integrity, and recruitment of associated yellowfin tuna to the herd. The technique has been described by Evans (1971, 1974). Five dolphins were radiotagged and followed.
b. Fifteen spotted dolphins were measured, sexed, and injected with lead acetate and tagged with plastic deer ear tags placed in the dorsal fin. The animals were pulled into a small skiff for examination and tagging. Technique of application was described by Norris and Pryor (1970). The purpose of the injection of lead acetate was to lay down a time check in the hard tissues, so that growth rates in teeth and bone could be calibrated through examination of recaptured animals. The technique was developed by Nishiwaki and Yagi (1953). The tagged animals were also injected with an antibiotic to combat sepsis. Results of this experiment will be analyzed when tags are returned (none returned with sufficient data to date).
c. One hundred and twenty dolphins were also tagged with steel-dart spaghetti tags.

5. In late 1972, NMFS chartered the seiner *Independence* for a dolphin/tuna cruise. Sixty-one spotted dolphins were injected with lead acetate and tagged with plastic deer ear tags. Tagging was accomplished through use of an aluminum chute supported by two skiffs at the corkline of the seine (Fig. 3). In addition, 24 dolphins were tagged with steel-dart spaghetti tags.

6. Also in 1973, the seiner *Trinidad* was chartered by NMFS for technological research on dolphin rescue methods and equipment. During the cruise, 20 dolphins were tagged with steel-dart spaghetti tags.

7. In late 1973, NMFS chartered the seiner *John F. Kennedy*. The main purpose of the cruise was to conduct research on dolphin-rescue methods, but some tagging was also carried out. Twenty-two spotted dolphins in a single herd were tagged with white deer ear tags, inserted in the dorsal fin. A 2-in diameter thin red plastic disc was placed on the tag post on each side of the fin to increase visibility of the tag in the water. The objective was to tag dolphins in several herds, using a different color for each herd, and then to study herd structure and integrity through observation of tagged animals in the seine in subsequent hauls in the same area. Rough weather, however, prevented further use of the tagging chute (described above) and completion of the scheduled tagging. In addition to the 22 dolphins tagged with ear tags, 59 spotted dolphins were tagged with steel-dart spaghetti tags.

8. In late 1976, NMFS chartered the seiner *Elizabeth C. J.* for a combined dolphin/tuna behavioral research and gear research cruise sponsored by several governmental and private organizations. Two types of tags were used to mark dolphin schools so that they could be followed and recaptured and the tagged dolphins observed in the net. Radiotags were placed on seven spotted dolphins and one spinner dolphin. The radiotags failed after only a few hours, but two were subsequently recovered (the recoveries are treated below like other tag returns; the radio-transmitted data will be presented elsewhere). In addition, 124 spotted dolphins and 8 spinner dolphins were tagged with steel-dart spaghetti tags modified for greater underwater visibility (see 3. *Spaghetti tag with steel dart/braided* above).

ACCOUNT OF RADIOTRACKING EXPERIMENT

Transmitters were placed on one adult male (animal A) and two adult females (animals B and C) captured in a tuna seine on 21 November 1971. The object of the experiment was to track the school and set the net on what was assumed to be the same herd five times, at 24-h intervals and at about 1000. The initial set was in the afternoon, and the tagged animals were not released until almost sunset. The chronology of events (Fig. 4) may be summarized as follows:

After the release of the tagged animals it became increasingly obvious that the behavior of the male was quite different from that of the females. At first all animals appeared to stay on the same relative heading. After sunset the females began to move away from the male and the decision was made to stay with the male. After 6 h of tracking the females were separated from the male by an estimated 12 n.mi. and their transmitted signals were extremely weak. It was assumed the transmitter on at least one of the two animals (B and C) had failed.

The vessel followed the male (A) until 1040 on 22 November when the first recapture set was made (set 2). Net distance traveled between initial release and this recapture was 59 n.mi., in about 16 h. One of the females (C) rejoined the male (A) at 0800 but separated from him again at 0930 prior to the net set. An additional long-range transmitter was placed on another male (D) during set 2. Also, a long-life, short-range transmitter was placed on another female (E). After release, A and D stayed together and were rejoined by one of the females from the first set (C). Female B was not seen again following her separation from A and C after initial release in set 2. A, D, E, and C were followed until 1036 (set 3) on 23 November. Net distance traveled in 24 h was 28 n.mi. During this period, the males (A and D) were separated by some distance (3 n.mi.) from the school containing the females (C and E). The set (3) was made on the portion of the school containing the males A and D. They evaded capture by passing between the boat and the net skiff be-

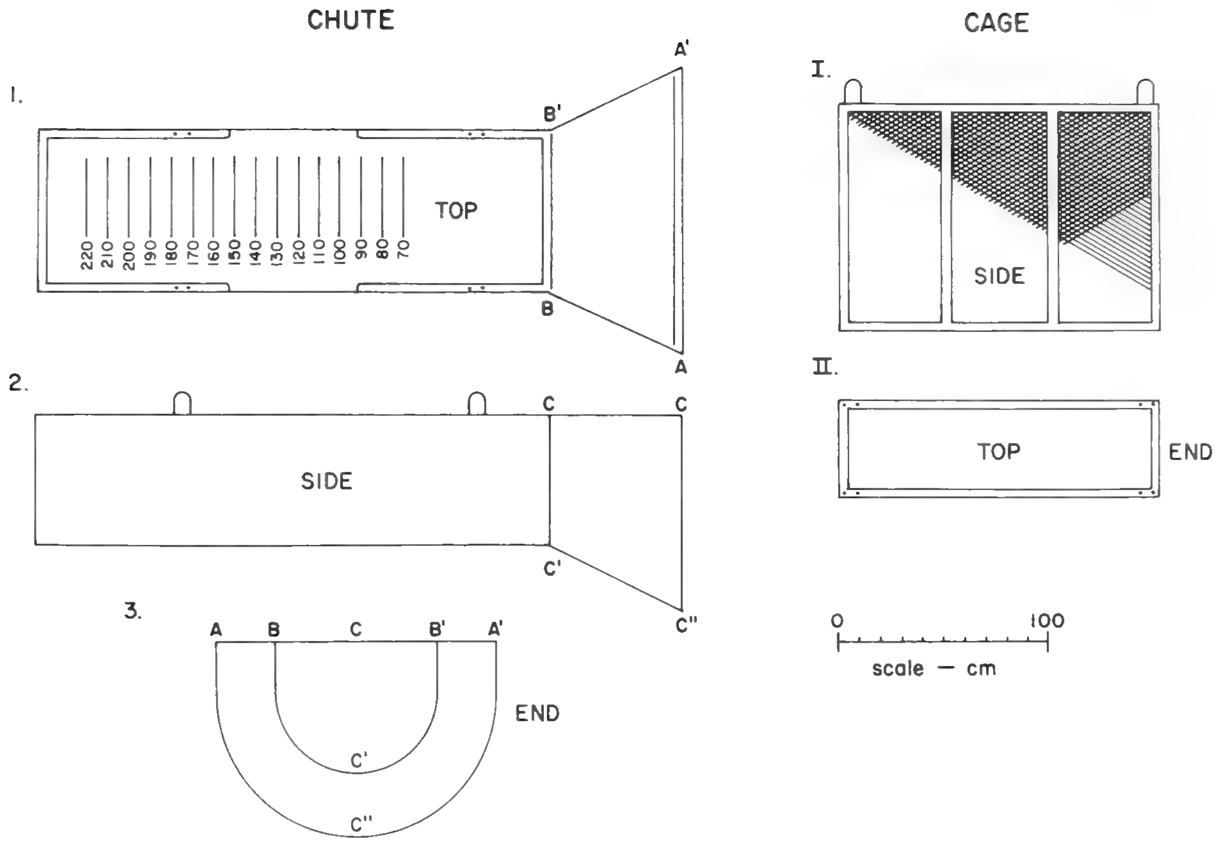
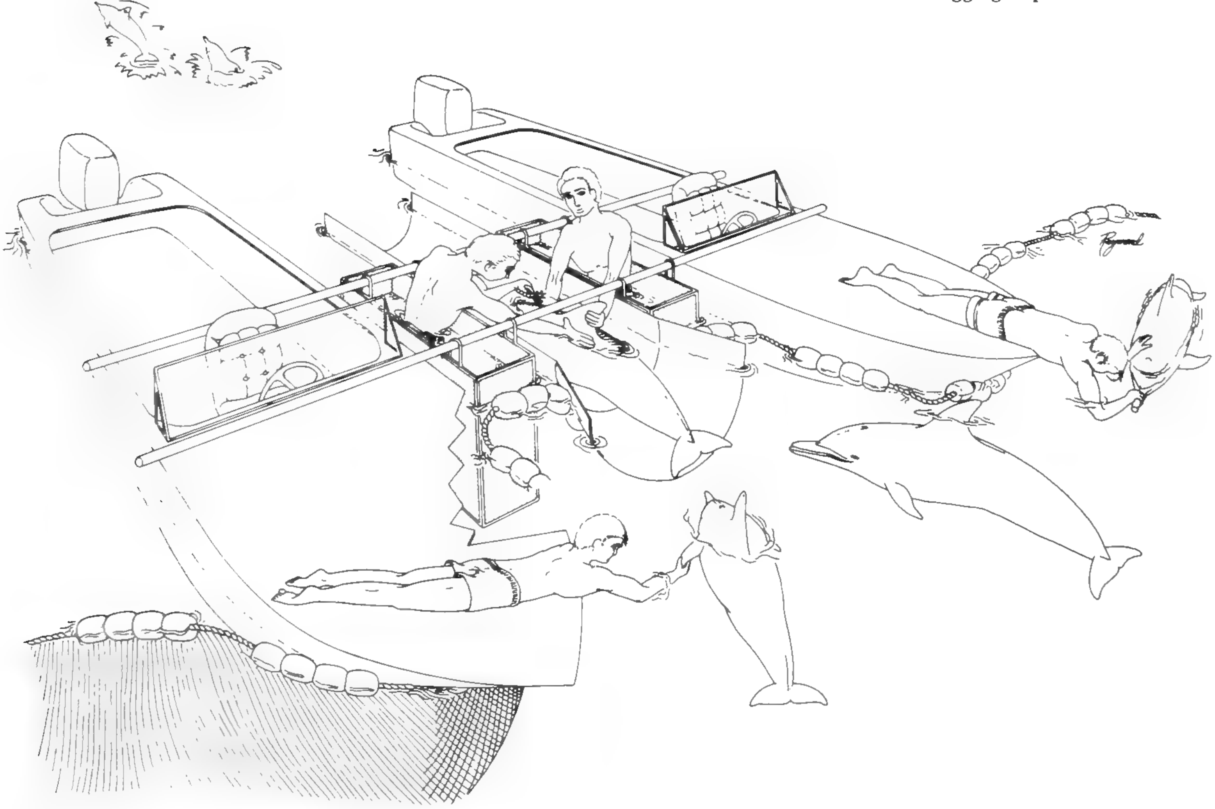


Figure 3.—Chute system used for tagging dolphins in the tuna seine.



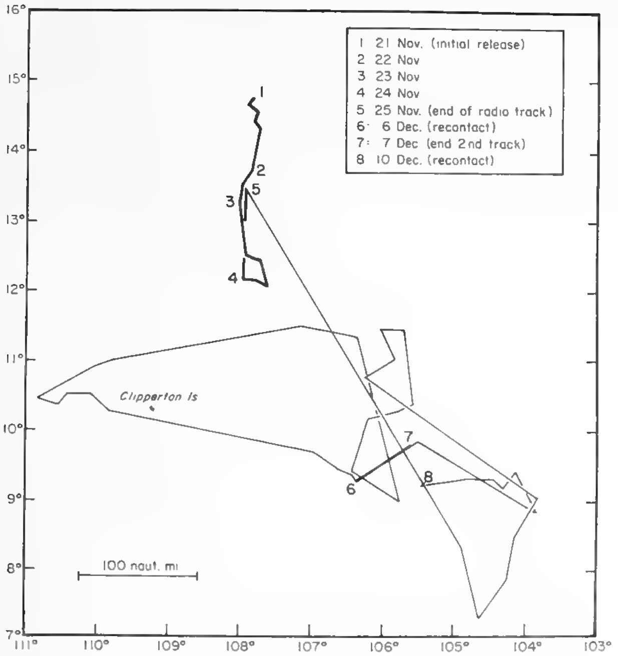


Figure 4.—Cruise track of chartered purse seiner *Queen Mary* while tracking movement of school of radiotagged spotted dolphins, *Stenella attenuata*, in November-December 1971. Heavy lines represent portions of the cruise track when radio contact was maintained with the school. The lines represent movements of the vessel, not necessarily the exact route of the radio-tagged animals.

fore completion of the net circle. After the set, A and D were followed until 2200 when they separated. Male D was followed, with a faint signal in the background from A, until 1020 on 24 November (set 5). Net distance traveled in this 24-h period was 69 n.mi., but actual distance traveled was about 110 n.mi. (Fig. 4). At this time, A and D had reconverged, but the set was made on the portion of the school containing D. Animal D again eluded capture in the seine. A and D rejoined after the set and were followed until 0700 on 25 November when the track was terminated because of an approaching storm. Net distance traveled during this 22-h period was approximately 75 n.mi. The school had doubled back and was heading north on almost exactly the same path it had followed south 3 days before. Total net distance traveled during the 110 h of the 5-day radiotrack was only about 75 n.mi., about one-fourth of the actual distance traveled. Maximum distance between any two points on the track was about 160 n.mi.

On 6 December, 11 days and approximately 285 n.mi. distance from termination of the first track, signals from both of the males (A and D) were picked up at 1255 and followed until 0750 on 7 December when strong signals were received from A in a school of <30 spotted dolphins. The school was chased to allow close approach and a good estimate of size, but no net set was made, and the school was not further followed. Net distance traveled during this 19-h second radiotrack was about 75 n.mi. Three days later, on 10 December, at 0925, signals were again received from A and D, and, this time, also from the female C, which had not been heard from since separating from the males on 23 November. The males and females were again segregated within the school. The school was not set on or followed after this recontact, and the research cruise ended shortly thereafter. Net distance traveled by the school between initial release and last contact (19 days) was 357 n.mi. (19 n.mi./day, south-southeast).

RESULTS AND DISCUSSION

Of 3,712 tags released from 1969 through 1976, 104 had been returned as of 1 January 1977 (Tables 3, 4). Tags were recovered only from spotted dolphins (97) and spinner dolphins (7). Time at liberty ranged from 1 h and 40 min to 1,478 days for *S. attenuata* and from 15 h and 48 min to 776 days for *S. longirostris*. Minimum distance traveled (distance between release and recovery locations) ranged from 7 to 582 n.mi. for *S. attenuata* (Fig. 5) and 12 to 275 n.mi. for *S. longirostris* (Fig. 6). Details of returns are presented in Tables 4, 5. Returns are sufficient for the spotted dolphin to allow some analyses based on these and on the results of radiotagging.

Short-Term Movements

Twenty-six tagged spotted dolphins were recaptured within 2 days (48 h) after release (Fig. 7). Longer term recoveries were not included in the analysis because of the increasing potential for bias caused by the animals doubling back on themselves (see results of radiotagging experiment above). A linear regression line fitted to the data has a slope indicating an average movement rate of about 1.2 n.mi./h (about 30 n.mi./day).

The results of the radiotagging experiment indicate daily movement rates of similar scale (Fig. 4), yielding estimates of net daily travel rate ranging from 5 to 89 n.mi. and an average of 54 n.mi./day (Table 6), as compared with the estimate of about 30 n.mi./day based on short-term tag returns. The former can be assumed to be less affected by the "doubling back" factor.

Long-Term Movements

A plot of minimum distance traveled on time at liberty for all tag returns shows maximum movement of 500 to 600 n.mi. (Fig. 8). The data may have a periodic component. Average minimum distance traveled is 100 n.mi. for 10- to 50-day returns ($n = 21$) and 274 n.mi. for 50- to 200-day returns ($n = 12$) but only 93 n.mi. for 200- to 400-day returns ($n = 15$). A major question in interpreting these results is that of recovery effort. Tags are recovered during the fishing operation. Was there significantly more fishing effort in areas <200 n.mi. from areas in which tags were released 200 to 400 days earlier than in areas more than 200 n.mi. from areas of release? In other words, could the data reflect periodic fishing effort rather than periodic movement of dolphins? In an attempt to settle this question, we examined, for each of the 50- to 200-day returns (12) and each of the 200- to

Table 4.—Tag return data for spotted dolphin, *Stenella attenuata*, 1969-76. Recovered radiotags included. Tag type codes defined in text.

	Release				Recapture			Days at liberty	Minimum distance traveled	Direction net movement		Tag	Tag
		Cruise	Position			Position							
	Date	number	lat. N	long. W	Date	lat. N	long. W	(or h)	(n.mi.)	°T	bearing	type	number
1	1 Nov 69	1055	14°17′	98°58′	1970	—	—	60	—	—	—	PD (a)	T3154
2	2 Nov 69	1055	13°49′	99°20′	25 Feb 70	15°39′	101°09′	114	152	316	NW	PD (a)	T3160
3	4 Nov 69	1055	15°03′	101°42′	3 Mar 70	15°10′	100°41′	119	59	83	E	PD (a)	T3193
4	17 Nov 69	1055	10°28′	107°40′	3 Apr 70	7°58′	98°10′	137	582	104	ESE	PD (a)	A1171
5	18 Nov 69	1055	10°58′	107°34′	19 Nov 69	10°41′	107°08′	(24 h)	31	124	SE	PD (a)	A1181
6	18 Nov 69	1055	11°09′	107°20′	5 Mar 70	13°20′	100°15′	107	435	72	ENE	PD (a)	A1199
7	11 Sep 70	—	9°46′	140°50′	3 Dec 70	9°32′	134°15′	83	390	92	E	MD (b)	P1019
8	24 Nov 71	13	12°11′	107°57′	11 Jan 72	11°37′	105°03′	48	174	101	E	MD (c)	01667
9	7 Dec 71	13	9°49′	105°29′	12 Jan 72	10°40′	106°31′	36	67	320	NW	MD (c)	00769
10	8 Dec 71	13	10°15′	104°32′	9 Dec 72	9°16′	104°26′	(15 h)	59	174	S	MD (a)	00013
11	9 Dec 71	13	9°17′	104°48′	10 Feb 72	9°16′	98°40′	63	363	90	E	MD (a)	00096
12	9 Dec 71	13	9°17′	104°48′	10 Feb 72	9°16′	98°40′	63	363	90	E	MD (a)	00099
13	11 Dec 71	26	9°21′	105°50′	12 Jan 72	10°40′	106°13′	32	82	344	NNW	DE (b)	116
14	11 Dec 71	26	9°21′	105°50′	8 Jan 72	8°50′	104°40′	28	76	144	ESE	DE (b)	118
15	13 Jan 72	14	7°10′	102°30′	1973	—	—	—	—	—	—	MD (a)	00609
16	21 Jan 72	17	10°30′	99°50′	10 Feb 72	9°50′	97°10′	20	162	104	ESE	MD (a)	00591
17	30 Jan 72	16	6°15′	98°58′	31 Jan 72	6°07′	99°36′	(21 h)	40	252	WSW	MD (a)	00434
18	24 Feb 72	16	14°54′	99°34′	4 Mar 72	14°40′	100°55′	9	80	260	W	MD (a)	00457
19	25 Feb 72	21	9°45′	98°35′	28 Mar 72	10°35′	100°55′	32	147	290	WNW	MD (a)	00475
20	27 Mar 72	22	9°28′	98°21′	11 Apr 72	13°16′	96°22′	15	256	27	NNE	MD (a)	00111
21	8 Aug 72	26	12°30′	109°23′	21 Feb 74	12°55′	99°41′	501	568	86	E	DE (b)	011
22	23 Oct 72	26	10°28′	104°03′	15 Nov 76	—	—	1478	—	—	—	DE —	039
23	27 Mar 73	45	9°53′	96°17′	—	—	—	—	—	—	—	MD (a)	01425
24	6 Feb 74	61	17°37′	112°41′	3 Aug 74	19°20′	113°25′	179	111	338	NNW	MD (b)	02959
25	9 Feb 74	61	17°24′	102°24′	9 Feb 74	17°29′	102°19′	(2 h)	7	44	NE	MD (b)	02986
26	18 Feb 74	59	11°05′	90°38′	29 Jan 75	12°45′	91°43′	345	119	328	NNW	MD (a)	01457
27	18 Feb 74	59	9°37′	91°26′	6 Mar 74	11°20′	91°23′	16	103	2	N	MD (a)	01461
28	18 Feb 74	59	9°37′	91°26′	6 Mar 74	11°40′	91°50′	16	125	349	N	MD (a)	01469
29	20 Feb 74	58	14°46′	102°09′	20 Feb 74	14°39′	102°11′	(2 h)	7	188	S	MD (a)	00837
30	25 Feb 74	66	14°15′	102°20′	27 Feb 74	14°38′	102°38′	(54 h)	32	328	NNW	MD (a)	00073
31	4 Apr 74	82	5°10′	89°10′	4 Mar 75	4°22′	87°02′	334	136	111	ENE	MD (a)	00059
32	19 Jun 74	91	18°16′	115°51′	7 Mar 75	16°32′	113°30′	260	170	127	SE	MD (b)	02101
33	20 Jun 74	91	18°00′	114°50′	30 Jun 74	18°09′	115°49′	10	57	279	W	MD (b)	02699
34	21 Jun 74	91	17°54′	114°02′	22 Jun 74	17°57′	113°38′	(14 h)	23	82	E	MD (b)	02085
35	21 Jun 74	91	17°20′	114°23′	30 Jun 74	18°09′	115°17′	9	71	314	NW	MD (b)	02691
36	21 Jun 74	91	17°20′	114°23′	1 Jul 74	18°19′	114°23′	10	39	356	N	MD (b)	02694
37	22 Jun 74	91	18°27′	113°19′	13 Dec 74	20°07′	112°15′	174	117	31	NNE	MD (b)	02032
38	22 Jun 74	91	18°27′	113°91′	20 Apr 75	17°23′	114°09′	302	80	217	SW	MD (b)	02037
39	22 Jun 74	91	18°20′	113°17′	1 Jul 74	18°19′	114°23′	9	63	269	W	MD (b)	02042
40	22 Jun 74	91	18°20′	113°17′	—	—	—	—	—	—	—	MD (b)	02047
41	22 Jun 74	91	17°57′	113°38′	25 Jun 74	17°10′	115°00′	3	91	239	WSW	MD (b)	02071
42	23 Jun 74	91	18°00′	113°00′	24 Jun 74	17°53′	113°06′	(14 h)	9	219	SW	MD (a)	00395
43	23 Jun 74	91	18°00′	113°00′	15 Apr 75	18°17′	113°36′	296	38	297	WNW	MD (a)	00398
44	23 Jun 74	91	18°00′	113°00′	8 Aug 74	18°12′	114°45′	46	101	277	W	MD (b)	02029
45	26 Jun 74	91	17°50′	116°00′	20 Apr 75	17°23′	114°09′	298	109	104	ESE	MD (a)	00376
46	28 Jun 74	91	17°45′	115°00′	3 May 75	18°12′	114°20′	315	47	55	NE	MD (a)	00667
47	28 Jun 74	91	17°45′	115°00′	30 Jun 74	18°09′	115°49′	(45 h)	52	297	WNW	MD (a)	01037
48	28 Jun 74	91	17°45′	115°00′	29 Jun 74	17°57′	115°22′	(18 h)	24	300	WNW	MD (a)	01039
49	29 Jun 74	91	18°07′	115°08′	5 Aug 74	19°08′	116°00′	37	70	330	NNW	MD (a)	01016
50	29 Jun 74	91	17°57′	115°22′	30 Jun 74	18°09′	115°49′	(25 h)	28	295	WNW	MD (a)	01056
51	30 Jun 74	91	18°09′	115°49′	5 Aug 74	18°05′	114°10′	36	94	92	E	MD (a)	01023
52	30 Jun 74	91	18°09′	115°49′	5 Aug 74	19°08′	116°00′	36	60	350	N	MD (a)	01028
53	1 Jul 74	91	18°19′	114°23′	2 Jul 74	18°35′	114°40′	(17 h)	23	315	NW	MD (a)	01043
54	1 Jul 74	91	18°19′	114°23′	2 Jul 74	18°35′	114°40′	(17 h)	23	315	NW	MD (a)	01050
55	1 Jul 74	91	18°19′	114°23′	2 Jul 74	18°35′	114°40′	(17 h)	23	315	NW	MD (a)	01093
56	1 Jul 74	91	18°19′	114°23′	2 Jul 74	18°35′	114°40′	(17 h)	23	315	NW	MD (a)	01094
57	1 Jul 74	91	17°58′	114°36′	4 Aug 74	19°00′	114°26′	34	63	9	N	MD (a)	01077
58	1 Jul 74	91	17°58′	114°36′	4 Aug 74	19°00′	114°26′	34	63	9	N	MD (a)	01084
59	1 Jul 74	91	17°58′	114°36′	7 Jul 74	16°50′	114°15′	6	71	164	SSE	MD (a)	01079
60	2 Jul 74	91	18°35′	114°40′	5 Jul 74	18°18′	114°12′	3	32	123	ESE	MD (a)	01069
61	2 Jul 74	91	18°12′	114°26′	4 Aug 74	19°00′	114°23′	33	48	3	N	MD (b)	02013
62	2 Jul 74	91	18°12′	114°23′	3 Aug 74	19°20′	113°25′	32	87	39	NE	MD (b)	02018
63	5 Jul 74	91	18°23′	114°46′	9 May 75	18°12′	114°20′	308	27	114	ESE	MD (b)	02060
64	5 Jul 74	91	18°18′	114°12′	20 Apr 75	17°23′	114°09′	289	55	117	S	MD (b)	02117
65	5 Jul 74	91	18°18′	114°12′	3 Aug 74	19°20′	113°25′	29	76	36	NE	MD (b)	02118
66	31 Jul 74	91	18°28′	111°00′	16 Nov 74	20°05′	109°39′	108	124	38	NE	MD (b)	02534
67	1 Aug 74	91	19°40′	110°12′	24 Mar 75	16°00′	109°40′	235	222	172	S	MD (b)	02745

Table 4.—Continued.

	Release				Recapture			Days at liberty	Minimum distance traveled	Direction net movement		Tag	Tag
	Date	Cruise number	Position lat. N	Position long. W	Date	Position lat. N	Position long. W	(or h)	(n.mi.)	°T	bearing	type	number
68	3 Aug 74	91	19°20′	113°25′	20 Apr 75	17°23′	114°09′	259	124	200	SSW	MD (b)	02618
69	4 Aug 74	91	19°00′	114°26′	14 Apr 75	17°07′	113°33′	252	123	156	SSE	MD (b)	02622
70	4 Aug 74	91	19°00′	114°26′	20 Apr 75	17°23′	114°09′	258	98	171	S	MD (b)	02646
71	8 Aug 74	91	18°12′	114°45′	22 May 75	17°20′	114°55′	287	53	190	S	MD (b)	02152
72	9 Aug 74	91	18°40′	113°55′	10 Apr 75	17°10′	114°15′	244	92	192	SSW	MD (b)	02155
73	17 Aug 74	91	11°15′	109°05′	18 Aug 75	11°34′	108°16′	(19 h)	52	68	ENE	MD (b)	02275
74	17 Aug 74	91	10°54′	109°13′	18 Aug 75	11°34′	108°16′	(25 h)	71	52	NE	MD (b)	02784
75	17 Aug 74	91	10°54′	109°13′	17 Aug 75	11°15′	109°05′	(5 h)	22	20	NNE	MD (b)	02786
76	17 Aug 74	91	10°54′	109°13′	17 Aug 75	11°15′	109°05′	(5 h)	22	20	NNE	MD (b)	02792
77	17 Aug 74	91	10°54′	109°13′	17 Aug 75	11°15′	109°05′	(5 h)	22	20	NNE	MD (b)	02799
78	7 Jan 75	99	20°14′	110°32′	13 Jan 75	19°35′	110°20′	6	41	164	SSE	MD (a)	01321
79	21 Jan 75	100	13°35′	100°35′	30 Mar 75	12°59′	103°00′	68	146	256	WSW	MD (d)	04509
80	30 Jan 75	102	14°47′	99°09′	3 May 75	15°31′	109°00′	93	572	276	W	MD (d)	04227
81	31 Jan 75	112	13°08′	91°50′	1 Feb 75	13°12′	91°38′	(16 h)	12	71	ENE	MD (d)	04366
82	31 Jan 75	112	13°08′	91°50′	1 Feb 75	13°12′	91°38′	(16 h)	12	71	ENE	MD (d)	04391
83	31 Jan 75	112	13°08′	91°50′	18 Feb 75	12°23′	91°38′	18	47	165	SSE	MD (d)	04377
84	18 Feb 75	112	9°25′	95°15′	5 Aug 75	9°13′	99°18′	168	240	267	W	MD (d)	04389
85	19 Feb 75	113	9°20′	95°43′	21 Feb 75	9°08′	96°55′	2	72	261	W	MD (d)	04407
86	21 Feb 75	113	9°01′	97°57′	23 Feb 75	8°32′	98°28′	2	42	227	SW	MD (d)	04413
87	21 Feb 75	113	9°01′	97°57′	23 Feb 75	8°32′	98°28′	2	42	227	SW	MD (d)	04414
88	22 Feb 75	119	12°10′	92°10′	2 Mar 75	12°48′	92°37′	8	46	325	NW	MD (d)	04963
89	14 Apr 75	121	17°07′	113°33′	21 Apr 75	17°29′	114°11′	7	42	301	NNW	MD (d)	04264
90	14 Apr 75	121	17°07′	113°33′	21 Apr 75	17°29′	114°11′	14	54	152	WNW	MD (d)	04266
91	21 Apr 75	105	14°48′	109°15′	5 May 75	14°00′	108°49′	14	54	152	SSE	MD (d)	04467
92	21 Apr 75	105	14°48′	109°15′	5 May 75	14°00′	108°49′	14	54	152	SSE	MD (d)	04468
93	24 Oct 76	208	9°33′	104°46′	26 Oct 76	9°11′	105°01′	(15 h)	26	214	SW	MD[1] —	05194
94	25 Oct 76	208	9°33′	104°46′	26 Oct 76	9°11′	105°01′	(15 h)	26	214	SW	MD[1] —	05200
95	25 Oct 76	208	9°33′	104°46′	26 Oct 76	9°11′	105°01′	(15 h)	26	214	SW	MD[1] —	05217
96	25 Oct 76	208	9°33′	104°46′	26 Oct 76	9°11′	105°01′	(15 h)	26	214	SW	RX —	—
97	25 Oct 76	208	9°33′	104°46′	26 Oct 76	9°11′	105°01′	(15 h)	26	214	SW	RX —	—

[1]With braided tubing.

Table 5.—Tag return data for spinner dolphin, *Stenella longirostris*, 1969-76. Tag type codes defined in text.

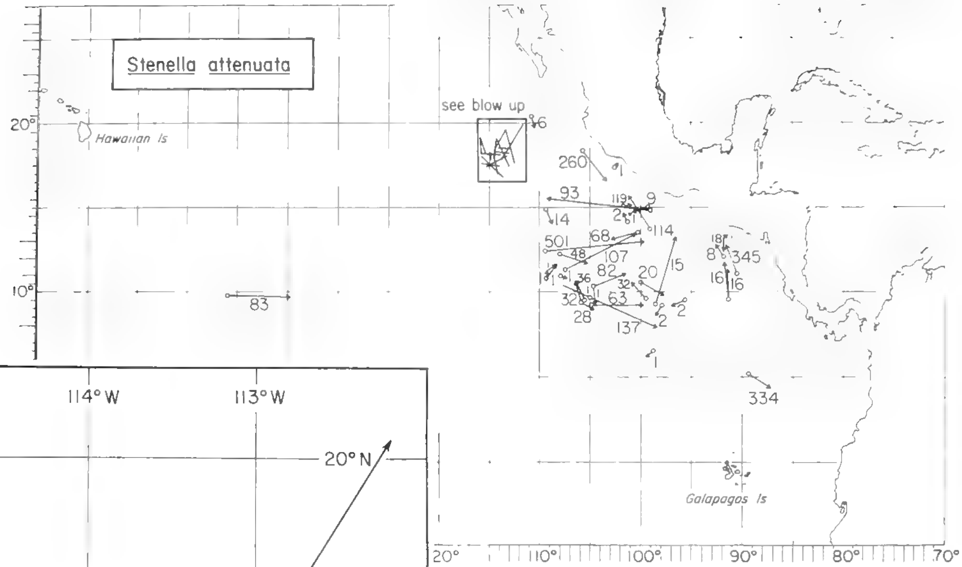
	Release				Recapture			Days at liberty	Minimum distance traveled	Direction of net movement		Tag	Tag
	Date	Cruise number	Position lat. N	Position long. W	Date	Position lat. N	Position long. W	(or h)	(n.mi.)	°T	bearing	type	number
1	18 Aug 70	26	10°47′	127°48′	17 Sep 71	11°17′	123°09′	395	275	83	E	PD (a)	A6242
2	23 Nov 71	13	13°20′	108°00′	8 Jan 74	11°44′	105°32′	776	172	124	SE	MD (a)	01116
3	8 Dec 71	13	10°15′	104°32′	28 Feb 72	11°01′	101°15′	82	199	76	ENE	MD (a)	00741
4	8 Dec 71	13	10°15′	104°32′	28 Feb 72	11°01′	101°15′	82	199	76	ENE	MD (a)	00016
5	10 Jan 72	16	9°04′	105°01′	6 Feb 72	9°35′	108°10′	37	189	280	W	MD (a)	00413
6	31 Jan 75	112	13°08′	91°50′	1 Feb 75	13°12′	91°38′	(16 h)	12	71	ENE	MD (d)	04363
7	13 Apr 75	105	6°38′	93°21′	16 Apr 75	6°54′	94°43′	3	83	281	W	MD (d)	04464

Table 6.—Net distance traveled and net travel rates for radiotrack segments <50 h long.

Track segment (Fig. 4)	Duration (h)	Minimum distance (n.mi.)	N.mi. h	N.mi. day
1-2 (set)	16	59	3.7	89
2-3 (set)	24	28	1.2	29
3-4 (set)	24	69	2.9	70
4-5	22	75	3.4	82
1-3 (set)	40	70	1.8	43
2-4 (set)	48	80	1.7	41
3-5	46	10	0.2	5
6-7 (chase)	19	60	3.2	77
Average	—	—	2.3	54

400-day returns (15), the logged take of yellowfin tuna[5] within a radius of 250 n.mi. and a radius of 250 to 600 n.mi. during the period after 50 days following release and before capture, or after 200 days and before recapture, respectively (Table 7) (catch of yellowfin tuna is the closest correlate of actual tag recapture effort (i.e., number of dolphins captured) for which data of sufficient geographical and temporal precision are available). For both groups of tag returns, the catch of yellowfin tuna in each instance was greater in the 250- to 600-

[5]Unpublished data furnished by J. Joseph, Inter-American Tropical Tuna Commission, P.O. Box 271, La Jolla, CA 92038.



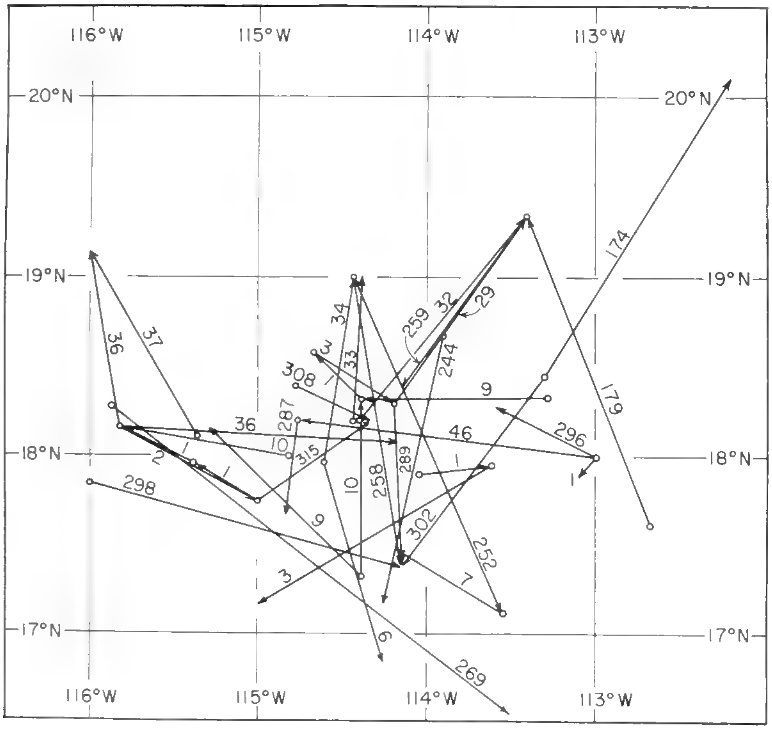
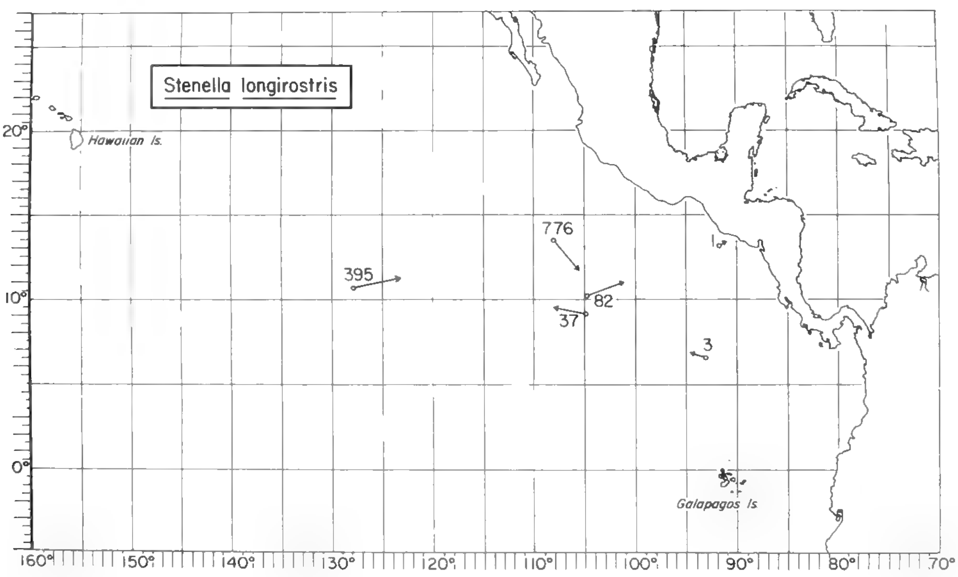


Figure 5.—(Top) Minimum distance and net direction of travel, with days at liberty, of spotted dolphins, *Stenella attenuata,* tagged 1969-76 and recaptured before 1 January 1977. Returns from radio transmitters not included. (Bottom) Blow up of inset.

Figure 6.—Minimum distance and net direction of travel, with days at liberty, of spinner dolphins, *Stenella longirostris,* tagged 1969-76 and recaptured before 1 January 1977.



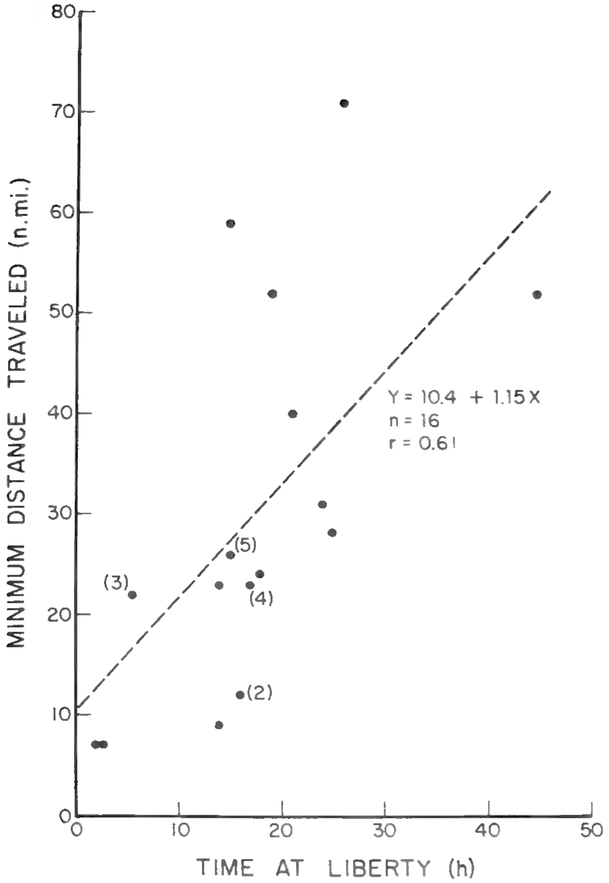


Figure 7.—Movement of tagged spotted dolphins, *Stenella attenuata*, recaptured within 48 h of release. When more than one dolphin was tagged and recovered from the same school at the same time, the number is indicated in parentheses. Dashed line is linear regression line fitted to unweighted data points.

n.mi. area than in the 250-n.mi. area. This result shows that the pattern in Figure 8 of apparent annual migration or dispersal of at least some of the tagged animals is real and not an artifact of the distribution of recapture effort.

The net direction of movements of <300 n.mi. was essentially random, but movements >300 n.mi. had a very strong east-west component (Fig. 9). This apparent predominance of longitudinal movement in long-distance returns is probably not due to chance. If it is assumed that the distribution of deviations in Figure 8 would be random, given that neither longitudinal nor latitudinal movement predominate, the probability that all seven of the over 300 n.mi. net movements would have deviations of <20° is described by a binomial probability distribution. If $n = 7$ and $P = 90$, then the probability is 2.6×10^{-5}. The data, therefore, show that, if seasonal migration or dispersal does indeed exist, it is primarily onshore-offshore. The time-of-year data for the few tag returns indicating movements >300 n.mi. indicate that movement may be generally onshore (E) in fall and winter and offshore (W) in late spring and summer (Table 8). This hypothesis must be considered as highly tentative, however, pending availability of more data.

In summary, home range at any particular season is roughly circular, on the order of 200 to 300 n.mi. in diameter, and may move seasonally several hundred miles onshore (possibly in fall and winter) and offshore (possibly in spring and summer). Average short-term net movement is on the order of 30 to 50 n.mi./day.

Table 7.—Estimated catch of yellowfin tuna within 250 n.mi. and within 250-600 n.mi. of point of tag release for 12 tagged dolphins recovered between 50 and 200 days after release and traveling up to 582 mi (average 174 mi) and 15 tagged dolphins recovered between 200 and 400 days after release and traveling <223 mi (average 93 mi). Catches for the first group are between 50 days after release and before recapture and for the second group between 200 days and recapture.

Tag returns		Estimated yellowfin tuna catch: Within 250 n.mi. (short tons)	Within 250-600 n.mi. (short tons)
Group 1			
(50-200 days):	1.	886	14,041
	2.	9,363	25,908
	3.	4,858	35,508
	4.	4,728	30,119
	5.	76	657
	6.	2,065	11,906
	7.	2,365	4,562
	8.	745	1,529
	9.	516	1,501
	10.	1,202	7,885
	11.	1,436	4,497
	12.	4,737	6,605
Group 2			
(200-400 days):	1.	5,108	6,224
	2.	2,396	26,142
	3.	470	6,325
	4.	4,656	14,737
	5.	4,523	16,180
	6.	3,277	12,389
	7.	3,893	14,452
	8.	3,893	13,126
	9.	4,485	13,573
	10.	1,955	3,177
	11.	3,051	6,746
	12.	952	3,611
	13.	3,214	6,377
	14.	5,390	13,312
	15.	759	3,944

Table 8.—Time of year at liberty and net direction of movement for seven tagged spotted dolphins, *Stenella attenuata*, traveling more than 300 n.mi. before recapture.

At liberty	Net movement: Direction	Distance (n.mi.)
1. Jan-May	W	572
2. Aug-Feb	E	568
3. Sept	E	390
4. Nov-Mar	ENE	435
5. Nov-Apr	ESE	582
6.[1] Dec-Feb	E	363

[1]Two dolphins.

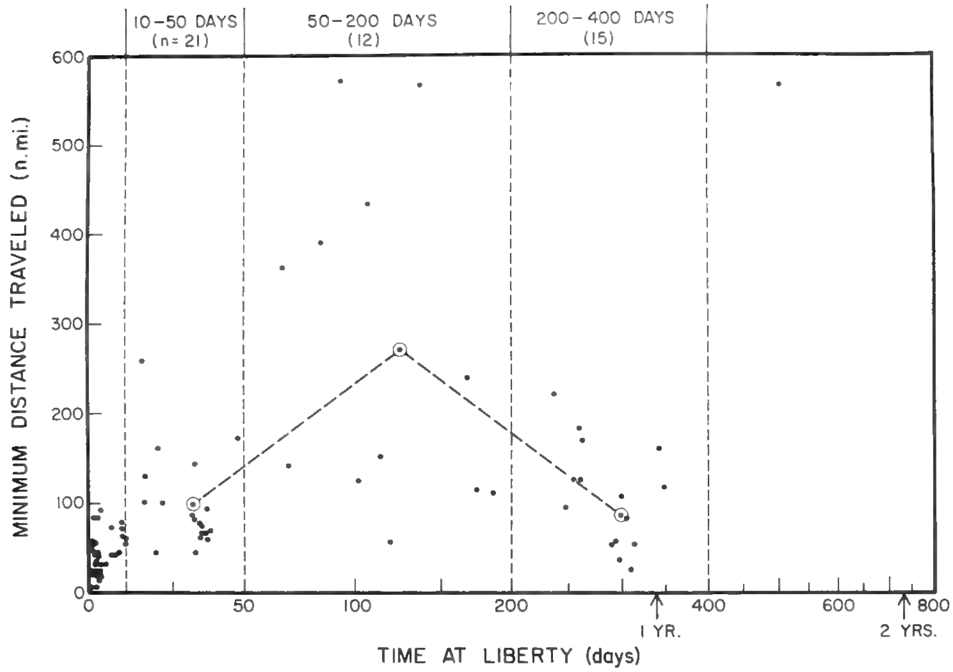


Figure 8.—Plot of minimum distance traveled on time at liberty (logarithmic scale) for tagged and recaptured spotted dolphins, *Stenella attenuata*. Circled means are for 10- to 50-, 50- to 200-, and 200- to 400- day returns.

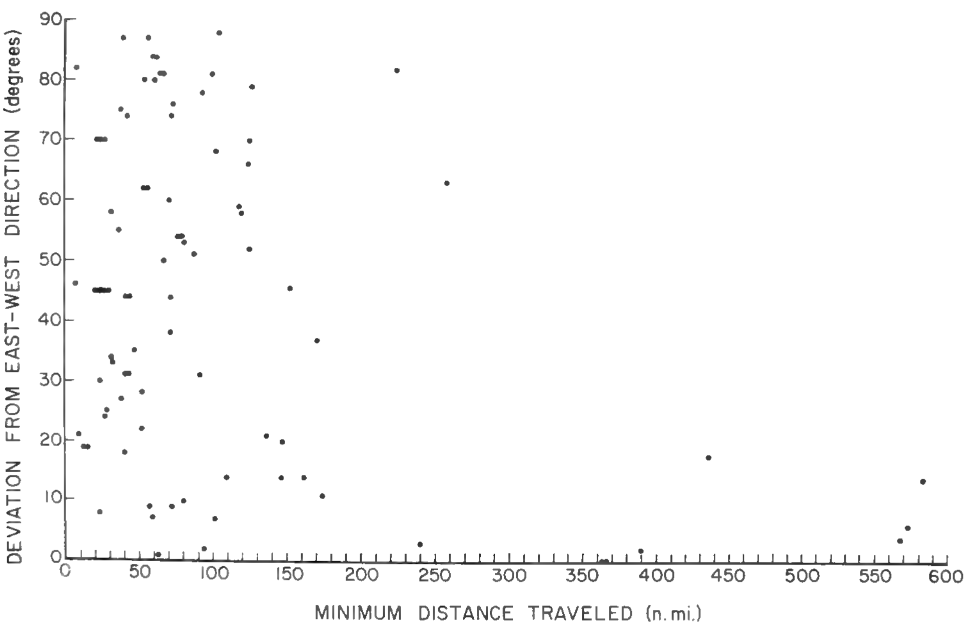


Figure 9.—Deviation from E-W direction of net movement plotted on minimum distance traveled for tagged and recaptured spotted dolphins, *Stenella attenuata*.

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