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Title: Relationships Between Oceanographic Factors and the Distribution of Juvenile Coho Salmon (*Oncorhynchus kisutch*) Off Oregon and Washington, 1982-1983

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Dr. William G. Pearcy

Juvenile coho salmon (101-400 mm) were sampled by purse seine off the Pacific Coast from Waatch Point, Washington to Four Mile Creek, Oregon, out to 30 mi offshore, during the months of May, June, and September in 1982 and 1983. Sea surface temperature, surface salinity,

surface chlorophyll-a concentration, and Secchi depth were measured at each station. Sea surface temperatures were higher in 1983 than in 1982, while surface chlorophyll-a concentrations and surface salinities were lower. Catch data were not highly correlated with any of the four physical parameters measured.

Strong northerly winds and strong upwelling tended to disperse juvenile coho offshore and south. Fish were found closer inshore during periods of weak winds and weak upwelling. In both years the center of distribution of the fish appeared to shift northward as the summer progressed. Larger fish, in general, were found farther north and offshore throughout the year.

Relationships Between Oceanographic Factors and the Distribution of Juvenile Coho Salmon
(*Oncorhynchus kisutch*)
Off Oregon and Washington, 1982-1983

by

Alton W. Chung

A THESIS

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I've got a dream when the darkness is over
We'll be lying in the rings of the sun,
But it's only a dream and tonight is for real;
You'll never know what it means,
But you'll know how it feels;
It's gonna be over
Before you know it's begun
It's all we really got...tonight!
Stop you're crying, hold on!
Tonight! Before you know it, it's gone!
Tonight! Tonight is what it means to be young!
Let the revels begin
Let the fires be started
We're dancing for the restless
And the broken hearted.
Say a prayer in the darkness for the magic to come;
For no matter what it seems,
Tonight is what it means to be young.

--Fire, Inc. from
The Streets of Fire

"So long, and thanks for the fish...."

--Douglas Adams from
The Hitchhike's Guide
to the Galaxy

APPROVED:

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Typed by Alton W. Chung for Alton W. Chung

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RELATIONSHIPS BETWEEN OCEANOGRAPHIC FACTORS AND THE DISTRIBUTION OF JUVENILE COHO SALMON (*Oncorhynchus kisutch*) OFF OREGON AND WASHINGTON, 1982-1983

INTRODUCTION

Compared to other phases of their life cycle, little is know about the ecology of juvenile coho salmon (*Oncorhynchus kisutch*) during their first few months in the ocean. Hartt (1978), Walters *et al* (1978), and Healey (1980) identified these months as a critical period during which the success of the year class may be determined. During the spring and early summer juvenile coho salmon are distributed in a narrow belt along the coast from Oregon and Washington to the eastern Aleutian Islands (Hartt and Dell, 1978; Fisher, Pearcy, and Chung, 1983; Fisher, Pearcy, and Chung, 1984; Fisher and Pearcy, 1985).

Distributions of salmon have been correlated with several environmental factors. Godfey et al (1975) found that coho salmon usually occurred above the thermocline in the upper 10 m of the water column and that juvenile coho were most frequently caught in waters with temperatures between 8 and 12^{o} C (range 3 to 16^{o} C). According to the California Department of Fish and Game (1968), 69.8% (22,465 of 32,183) of the coho salmon caught in the 1966-1967 troll fishery were taken in waters with sea surface temperatures between 10.6 - 11.7^{o} C. Brett (1952) determined that juvenile coho cannot tolerate temperatures above 25^{o} C or below 0^{o} C and prefer waters between 12 - 14^{o} C. Favorite (1963), however, determined that surface temperature and salinity were not good indicators of the presence or absence of salmon in the Gulf of Alaska, but suggested that shallow thermoclines might concentrate prey organisms nearer to the surface. Healey (1980) suggested that juvenile coho salmon distributions in Georgia Strait, British Columbia are related to the distribution of their food resources.

Juvenile coho salmon (101 - 400 mm) were sampled by purse seine off the Pacific coast from Waatch Point, Washington to Four Mile Creek, Oregon, out to 30 mi offshore during the months of May, June, and September in 1982 and 1983. Transect positions were selected to bracket the Columbia River and Yaquina Bay, the major points of ocean entrance of coho salmon into the study area. The months of May and June were selected for sampling as the peak of juvenile coho out-migration usually occurs at this time. The month of September was chosen as a sampling period so that growth rates and changes in the distributional pattern of juvenile coho could be monitored. The years 1982 and 1983 were selected to examine the differences between a relatively "normal" upwelling and an abnormal El Nino year.

This paper addresses the relationships between the ocean environment and the distribution and abundance of juvenile coho salmon off the coast of Washington and Oregon during May, June, and September of 1982 and 1983. Distribution of juvenile coho are compared with contour maps of sea surface temperatures (SST's), surface salinities, surface chlorophyll-a concentrations, and Secchi depth. A general mechanism for coho nearshore dispersal is proposed.

Physical Oceanography of the Study Site

The California Current is a slow, southward-flowing current located between 300 and 800 km off the Oregon coast. Inshore of this permanent feature, the direction of circulation varies with season. During spring and summer, the northerly winds induce upwelling along the coast, offshore advection, and generally southward flow. During the fall and winter, the winds reverse. The California Undercurrent surfaces and becomes the northward-flowing Davidson Current (Petersen and Miller, 1974; Hickey, 1979).

The hydrography of the study area is influenced by upwelling and the Columbia River plume. Upwelling is the process by which cold, nutrient-rich water from below 30 m is brought to the surface along the coast. Upwelling off Oregon seems to be governed by simple Ekman dynamics: the mean offshore transport in the upper layers is about equal to the mean offshore Ekman transport computed from the wind stress (Halpern, 1973; Smith, 1974; Huyer, 1982). During the spring and summer, the local winds blow from the north (northerly winds), transporting the upper 15-20 m of the water column offshore. The resulting "vacuum" along the coast is filled by colder, nutrient-rich water rising from below 30 m. Intense upwelling is not a continuous process during the summer, but occurs rather as discrete, sporadic events. If the northerly winds blow consistently for a day or two, upwelling will occur. If the winds relax or change direction, upwelling ceases (Halpern, 1973; Petersen and Miller, 1974). Upwelling is more pronounced off southern

Oregon in May and June when the northerly winds are relatively strong. It lessens in September when the winds reverse and begin blowing from the south. A convenient measure of the strength of the northerly winds is the Bakun Upwelling Index (Bakun, 1973).

The Columbia River plume is another major feature of the hydrography off Oregon and Washington. The nearshore edge of the Columbia River plume is contained in the surface Ekman layer. The low salinity water of the plume is advected offshore and southward during the summer regime of northerly winds and along the coast of Washington during the winter regime of southerly wind stress (Huyer, 1982). Discharge from the Columbia River is at its peak in June (Small and Curl, 1972) when it accounts for more than 90% of the fresh water entering the ocean in the region between the Straits of Juan de Fuca and San Francisco Bay (Barnes et al , 1972). Off central Oregon, the offshore boundary of upwelling normally coincides with the location of the nearshore edge of the Columbia River plume (Huyer, 1982). Strong salinity gradients and fronts form when newly upwelled water comes in contact with waters of the plume. Very strong winds cause intense surface mixing and blur such gradients. When the northerly winds are weak, the Columbia River plume is much more dispersed and covers a large portion of the region. In previous studies the 32

0/00 and 32.5 0/00 salinity isopleths were used to define the horizontal and vertical extent of the plume (Anderson, 1972; Barnes et al , 1972; Small and Curl, 1972). During the summer off Oregon a shallow pycnocline associated with the Columbia River plume (sigma-t less than 24.75) and a deeper, permanent pycnocline (sigma-t = 25.5-26.0) is associated with a permanent halocline (32.5-33.8 0/00) which extends across the eastern subarctic Pacific Ocean (Smith, 1974; Huyer, 1982). During the upwelling season all isopycnals below 15 m sloped up towards the coast. During upwelling events, the isopycnals often reached the surface, but when the northerly winds reversed, they sloped downward in the region from the shore to about 10 km (Huyer, 1974; Petersen and Miller, 1974).

The Columbia River also acts as a point source for some nutrients. Nutrient depletion with increasing distance from the Columbia River mouth is probably the major factor controling chlorophyll-a concentration off northern Oregon and southern Washington (Small and Curl, 1972). During the summer the Columbia River is the dominant contributor of dissolved silicates in the region. Because of photosynthetic depletion during the summer, the river contributes virtually no nitrates (Conomos et al , 1972). Most of the phosphate and nearly all the nitrates consumed by phytoplankton originate from water below the thermocline (Conomos *et al*, 1972). Upwelling brings nutrient-rich subsurface ocean water into the lighted surface layers where conditions are best for phytoplankton growth. Surface ocean waters are usually impoverished of nutrients, thus photosynthetic activity in the surface layers during summer is largely dependent upon upwelling (Conomos *et al*, 1972).

Anderson (1972) determined that the difference in productivity between plume water and ambient ocean water is apparently due to the earlier stabilization of the water column and the shallower mixed layer of the plume. This allows the phytoplankton to develop earlier and at a higher rate than in the surrounding water. As a result productivity is limited by nutrients earlier in the plume than adjoining waters (Anderson, 1972). Beginning in June, the plume usually develops in a southerly direction and the slightly higher chlorophyll-a values can be used to delineate its seaward border. Chlorophyll-a concentrations in nearshore waters usually depend upon whether the water was recently upwelled or has been at the surface long enough to develop a large phytoplankton population. In this way chloropyll-a concentrations do not reflect the immediate hydrographic or chemical environment, but rather might be indicative of the prehistory of the water from which the sample was taken (Small and Curl, 1972).

Standing stocks of phytoplankton fuel the food web and affect the stocks of food resources utilized by juvenile coho.

Phytoplankton standing stocks also influence, and are influenced by, water clarity. The other three major agents which are thought to scatter and absorb light in the sea are the water itself, dissolved organic material, and non-absorbing, suspended particles such as zooplankton, silts, and clays (Mueller, 1973). During summer in areas where low-salinity Columbia River plume water mixes with oceanic water, the major sources of suspended particles are the river, phytoplankton, and particles resuspended from the bottom. Biogenous material, primarily phytoplankton and detritus, however, constitutes the bulk of the particles found in the ocean. In addition, fine clay-like particles (less than 4 microns) are held above the halocline (32.5 0/00 isohaline) because their settling velocities are the same as the vertical water movement caused by the vertical salt flux and upwelling (Conomos and Gross, 1972). Reduced water clarity results in a reduction in the amount of light phytoplankton receive and light is one of the factors which influences phytoplankton growth. Extinction of light is affected by scattering and absorption of light by particles including phytoplankton. Small and Curl (1972) found large light attenuation coefficients (shallow Secchi depths) in the Columbia River plume in summer. Smaller light attenuation coefficients (deeper Secchi depths) were found in oceanic water which had low chlorophyll-a concentrations. The amount of absorbing and light scattering substances in the water was found to decrease as a power function of distance from shore.

The major change in the physical oceanography of the study site was the arrival of the El Nino in October 1982 (Huyer and Smith, in press). The arrival of the intruding warm, nutrient-depleted water from the south was evidenced by a rise in sea level which progressed northward along the coast. The anomalously warm water extended as much as 200 to 250 km offshore and subsurface anomalies at a depth of 100 m were as large as those at the surface. The maximum temperature anomaly off Washington in 1983 was about 1.6^{o} C. In the last forty years, there have only been two large El Nino events (1940 and 1957- 58) which have markedly affected the waters as far north in the eastern Pacific (Fluharty, 1984).

METHODS

Sampling Gear

The *Pacific Warwind*, a 28 m (92 ft.) commercial purse seiner was chartered for all six cruises. A herring purse seine of 32 mm (1.25 inch) stretch measured mesh and approximately 495 m long was used to collect salmon and associated nekton. All sets were round hauls, where the net was laid out in a circle by seiner and skiff. Each set sampled an area of approximately 19,000 square meters.

In 1982 a depth gauge attached to the bottom of the seine indicated that the net fished to a depth of 67 m. The net was shortened in 1983 and fished only to a depth of 49 m.

Sampling Area

Sets were made at stations generally 9.3 km (5 nautical miles hereafter abbreviated as mi.), apart along transect lines extending from 48° 20' N to 44° 00' N during May 19 - June 2, 1982; 48° 20' N to 44° 20' N during May 16 - 27, 1983; 47° 20' N to 44° 20' N during June 7 - 22, 1982; 48° 20' N to 43° 00' N during June 9 - 27, 1983; 47° 20' N to 44° 20' N during September 4 - 14, 1982; and 48° 20' N to 43° 28' N during September 15 - 24, 1983 (See Figure 1). Sampling was conducted from as close to the coast as the seine could safely be set (the 55 m contour in 1982 and the 37 m contour in 1983), to 37 km (20 nautical miles), or until juvenile salmon were no longer caught. Transects were generally sampled from north to south on all cruises.

Sixty-two good sets were made in May 1982, 55 in May 1983, 56 in June 1982, 58 in June 1983, 38 in September 1982, and 52 in September 1983.

Environmental Data

Surface water samples were taken at each purse seine station. Temperatures were measured and additional water samples were obtained with an NIO bottle at 1 m from which chlorophyll-a and phaeophytin concentrations and salinity were determined.

Known volumes of sea water (500 ml in 1982 and 140 ml in 1983) were filtered through a 0.3 um (pore size) glass fiber filter (Gelman A/E). The pigments were extracted from the filtrate with 10 ml of 90% acetone, and the fluorescence measured with a Model-10 Turner Designs Fluorometer. The salinities of water samples were determined with a Guildline Autosal (Model 8400) salinometer.

Salinity and temperature profiles of the water column were obtained at selected stations in 1982 and at most stations in 1983 with a self-contained Applied Microsystems CTD-12 (conductivity, temperature, depth recorder).

Water clarity was measured with a 30 cm Secchi disk. Ambient light intensity was measured at deck level with a Spectra Lumicon light meter.

Processing the Catch at Sea

The purse seine catch was dip netted from the seine bunt, lifted aboard in the bunt, or brailed aboard. Juvenile salmonids were anesthesized in a seawater solution of Tricaine Methanesulfonate (MS-222), identified, and measured to the nearest millimeter (F.L.). They were then checked for adipose fin clips, individually wrapped in plastic bags (along with a label identifying set number, species, and length), and frozen.

Analysis of Catch Data

To quantify juvenile salmon distributions, the study area was divided into the following sections: all sets greater than 12.5 miles from the coast were considered offshore; all sets less than or equal to 12.5 miles from the coast were considered inshore; all sets made north of and along the Grays Harbor transect were referred to as Washington sets; sets between and along the Willapa Bay and Nehalem Beach transects were grouped as Columbia River sets; and all sets south of and along the Cape Lookout transect were called Oregon sets (Figure 1).

RESULTS

Environmental Data

May 19 to June 2, 1982

Upwelling was very strong in May, 1982--45 cubic meters per second per 100 m of coastline (hereafter referred to as Bakun Units) above the 1948-67 monthly mean for May (Bakun, 1973) (Table 1). The Daily Bakun Upwelling Index (DBUI) indicates that the winds were favorable for upwelling during the entire May cruise and that a major upwelling event occurred on May 25th (Figure 2).

The strong upwelling during May resulted in low surface temperatures (9 - 10^{o} C) as far offshore as 10 mi off Washington and up to 20 mi off Oregon and relatively saline water (greater than or equal to 33 0/00) 5 mi off Nehalem Beach and as far offshore as 15 mi off Yachats (Figures 3 and 4). Sea surface temperatures usually increased with distance from shore. The boundaries of the Columbia River plume (less than 31 0/00) were not as well defined by salinity gradients during this period (Figure 4). Surface mixing and upwelling induced by strong winds presumably mixed the surface waters and reduced any severe gradients, but areas of low salinity surface water (less than 30 0/00), remnants of the plume, were found off the northern Oregon coast.

Chlorophyll concentrations in the area were highly variable and patchy in distribution. High surface chlorophyll-a concentrations greater than 15 ug/liter were found 5 miles off the coast south of Cape Lookout to Yachats and extended out to 15 miles off Yachats (Figure 5). These high chlorophyll values were correlated with the high surface salinities (32 to 33 0/00) found in this area. High chlorophyll concentrations (greater than or equal to 10 ug/liter) were recorded in 32 0/00 salinity water 15 to 20 mi off Willapa Bay and Warrenton, in 31 0/00 water 10 mi off the Quinault River and Destruction Island; and in 31 0/00 south of the Straits of Juan de Fuca 15 miles off Waatch Point (Figures 4 and 5). The higher concentrations off Waatch Point were probably due to the influence of the waters from the Straits of Juan de Fuca.

The patterns of Secchi depth and chlorophyll-a contours were generally similar (Figures 5 and 6). Shallow Secchi depths off northern Washington (Waatch Point) and southern Oregon (south of Cape Lookout) corresponded to high chlorophyll-a concentrations. The area of deep Secchi depths off Sea Lion Rock was an area of low chlorophyll concentrations (less than 3 ug/l). The tongue of shallow Secchi depths off the Columbia River, probably caused by particulates entrained in Columbia River plume, did not correspond to a similar feature on the chlorophyll contour map.

Sigma-t cross-sections along the Nehalem Beach and Cape Lookout transects depict isopycnals sloping up towards the coastline. The Columbia River plume (Figure 4) is clearly evident in the Nehalem cross-section as a lens of low density water beginning at 10 mi and extending offshore (Figure 7a). The presence of the 25.0 isopycnal at the surface 10 mi off Cape Lookout indicates active upwelling (Figure 7b).

June 7 - 22, 1982

Upwelling was slightly higher than the long-term monthly mean during June 1982 (11 Bakun Units above the monthly mean for June, Table 1). The DBUI's were positive and favorable for upwelling over the entire period of the June cruise (Figure 8).

A tongue of cold (9 - 10^{o} C), upwelled water extended seaward from the coast at least 20 mi off Yaquina Head (Figure 9). A tongue of relatively warm (11 - 13^{o} C), low salinity (28 - 31 0/00) water (Figure 10) originating from the Columbia River mixed with the cooler coastal waters at the boundaries of the plume and resulted in a strong latitudinal temperature-salinity gradient between the Nehalem Beach and Cape Lookout transects. This front extended diagonally southwest to about 10 mi off Wecoma Beach and continued seaward almost perpendicular to the coast. Salinity south of the front exceeded 33 0/00, while salinity north of the front was 30 0/00.

The core of the plume (28 0/00) extended from Warrenton to Hug Point out to 15 mi offshore. The northern front began between the Breakers and Warrenton transects and extended seaward along the Warrenton transect. The gradient across this front was as much as 5 0/00 (31 0/00 to 26 0/00).

High surface chlorophyll-a concentrations were recorded along the Yachats transect out to 15 mi (greater than 15 ug/l at 5 mi). Other areas of high concentrations were 4 mi off Nehalem Beach (greater than 10 ug/l), 10 mi off Ocean Park (greater than 5 ug/l), and 15 mi off the Quinault River (greater than 6 ug/l). Low concentrations (less than 2 ug/l) were found along both the Yaquina Head and Wecoma Beach transects and coastwide beyond 17 mi (Figure 11). The presence of high salinity water (greater than 33 0/00) off southern Oregon (Figure 10) suggests that the high chlorophyll concentrations found there (Figure 11) were probably due to upwelling. Close inshore off Nehalem Beach, surface concentrations were higher than surrounding waters probably due to nutrient input from the Columbia River plume. High concentrations offshore off central Washington (Willapa Bay) could be due to input from the Straits of Juan de Fuca.

The contour plot of Secchi depths generally resembled the pattern of surface chlorophyll-a distribution. The band of high concentration off Yachats appeared as a low-transparency tongue extending from the coast. A tongue of low-transparency water extending seaward from Nehalem Beach (5 mi) to 15 mi off Cape Lookout corresponded to a peak in chlorophyll (greter than 10 ug/l). High chlorophylls (greater than 10 ug/l) and high salinities (greater than 33 0/00) also coincided with shallow Secchi depths (less than 4 m) off southern Oregon (Yachats) (Figures 10, 11, and 12). Areas of low concentrations corresponded to areas of relatively deep Secchi depths, e.g., greater than or equal to 10 m off the Yaquina Head transect (Figure 12). Moderate chlorophyll concentrations (3 - 4 ug/l) corresponded to 3 - 6 m Secchi depths in the core of the Columbia River plume suggesting that phytoplankton stock enhancement by plume water was also occurring at this time. A finger of low transparency water (Secchi depths of 3 - 6 m) extended along the Cape Lookout transect.

The sigma-t cross-section of the Cape Lookout transect shows the isopycnals sloping up to the shore with the 24.0 isopycnal surfacing at 10 mi (Figure 13). Upwelling was probably related to the high chlorophyll and shallow Secchi depths found 5 mi offshore.

September 4 - 14, 1982

The DBUI for early September indicates that this was a period of transition between upwelling and downwelling (Figure 14). Upwelling in September 1982 was slightly below the monthly mean for September--12 Bakun Units (Table 1), and sea surface temperatures were high (15-16° C, Figure 15). The coldest water was found close inshore (less than 3 mi) off Yachats (12.4° C). Temperatures, in general, were warmer off Washington than Oregon.

The core of the Columbia River plume was well-defined as a band of low salinity water stretching seaward between the Willapa Bay and Hug Point transects to at least 20 mi. The salinity across both the northern and southern front increased from 26 to 31 0/00. Newly upwelled, high salinity water (greater than 33 0/00) was found close inshore (3 mi) off Yachats (Figure 16).

The highest chlorophyll concentrations, 5 to 9 ug/l (Figures 16 and 17) were found within the Columbia River plume. The relatively low winds reduced surface mixing during September and probably confined most of the river borne nutrients in a small area around the plume. Areas of moderate chloropyll-a concentrations, in general, were inshore (less than or equal to 12.5 mi from the coast): 4 ug/l 10 mi off the Quinault River; 5 ug/l 10 mi off Willapa Bay; 4 ug/l 2.5 mi off Seaside; and 4 ug/l off Cape Lookout. The remainder of the stations recorded concentrations less than 3 ug/l (Figure 17).

The contour plot of Secchi depths (Figure 18) was again similar to the plots of surface chlorophyll-a concentration and surface salinity. The Columbia River plume was depicted as a tongue of low transparency water extending from the coast between the Willapa Bay and Hug Point transects to at least 20 mi. The shallowest Secchi depth recorded was found 10 mi off the Quinault River. River input of nutrients and particulates contributed to the low transparency of the water. Secchi depths, in general, increased with distance from shore.

The sigma-t cross-section along the Cape Disappointment transect demonstrates how dependent the density structure of the water column is on wind stress (Figure 19a). From September 2 - 4 the winds blew from the south and did not favor upwelling. Three days prior to sampling the winds reversed and became upwelling favorable. The deeper isopycnals (greater than 20 m) still sloped down towards the coast. The shallower isopycnals, however, sloped up to the shore, especially within 10 mi of the coast. The shallow isopycnals apparently responded quickly to daily changes in the local wind stress whereas the deeper isopycnals took longer to respond and may reflect wind patterns which persist for several days (Petersen and Miller, 1974). The Columbia River plume appears as a low density lens of water about 10 - 15 m thick extending from the shore to at least 20 mi.

Summary of 1982

Strong northerly winds in May (Figure 2) advected nearshore surface water offshore and induced strong upwelling which caused colder, more saline water (Figures 3 and 4) to rise from depth along the coast (Figure 7). The surfacing of the dense, nutrient-rich water sparked localized phytoplankton blooms (Figure 5). The increased phytoplankton populations and particulate matter from the Columbia River decreased water clarity (Figure 6). The high winds also induced a large amount of surface mixing and diminished large salinity fronts around the Columbia River plume (Figure 4).

Northerly winds were also strong in June though not as strong as they were in May (Figures 2 and 8). Cold (less than 9^{o} C), high salinity water (greater than 33 0/00) was present at the surface south of Cape Lookout, indicating that upwelling was occurring (Figures 9 and 10). Surface chlorophyll-a concentrations (Figure 11) in the cold, newly-upwelled water, south of Cape Lookout to Yaquina Head were very low (less than 2 ug/l). In the slightly warmer (11^{o} C) water off Yachats, surface chlorophyll-a concentrations were relatively high. This is consistent with the findings of Small and Curl (1972) in that there is a lag between the time newly-upwelled water reaches the surface and when local phytoplankton populations bloom.

The surface waters were not as well-mixed in June as in May. As a result, the warmer, less saline Columbia River plume formed a 15 - 20 m thick, low-density lens over the more dense ocean water and sharp horizontal salinity gradients or fronts formed at the boundaries of the Columbia River plume (Figure 10). Secchi depth tended to be lower in the plume due to river borne particulates which reduced water clarity and nutrients which sparked phytoplankton growth. Chlorophyll-a concentrations in plume water were higher inshore and decreased with distance from shore.

The June sigma-t cross-section along the Cape Lookout transect differed from those of May. In May, the 24.0 isopycnal surfaced at 15 mi and the 25.0 surfaced at 10 mi (Figure 7b). In June, the 23.0 isopycnal surfaced at about 18 mi and the 24.0 surfaced at 10 mi (Figure 13a). This difference can be attributed to a reduction in the northerly winds. In May, lower density water was advected further offshore and water of higher density from depth was found closer inshore. In June, the winds were not as strong and lower density water found offshore in May was observed closer inshore.

The upwelling winds in September were below average for that time of year and less than half of what they were in June. The freshening of the northerly winds towards the end of the cruise resulted in upwelling along the Yachats transect where lower temperatures and higher salinities were noted close inshore. Due to the reduced winds there was little surface mixing. Salinity gradients were strong and the Columbia River plume extended far offshore along the Cape Disappointment transect as a tongue of 25 0/00 salinity water (Figure 16). The high chlorophyll-a concentrations and low Secchi depths were also recorded along this transect (Figures 17 and 18). These localized phytoplankton blooms could be related to nutrient and particulate input from the Columbia River plume.

According to monthly means of the Bakun Index, 1948 to 1967 (Table 1), upwelling winds begin to build up in May, peak in July, and taper off in September. In 1982 the winds were at their strongest in May and consistently declined in strength through September.

May 16 to May 22, 1983

Upwelling was about average for the month of May (Table 1), however, it was less than half of what it was in

1982. The DBUI was positive during the sampling period (Figure 2). Sea surface temperatures were a few degrees warmer in 1983 compared with 1982. Cold 10 - 11° C water was noted as far as 20 mi offshore off southern Oregon (Yachats) and northern Washington (Waatch Point). Relatively warm water (13 to 15° C) originating from the Columbia River was widespread over the northern Oregon and southern Washington coasts (Figures 3 and 4). Solar heating of the shallow plume water resulted in the warm sea surface temperatures between the Seaside and Yaquina Head transects (Figure 3). A temperature gradient of 2 - 3° C occurred between the Yachats and Yaquina Head transects.

In contrast to 1982, well-developed salinity gradients defining the boundaries of the Columbia River plume extended seaward from the coast (Figure 4). The southern front coincided with the temperature gradient between the Yachats and Yaquina Head transects. Northward across this gradient the salinity dropped from greater than 32 0/00 to 29 0/00. The northern front lay between the Cape Disappointment and Seaside transects where the salinity dropped from 30 0/00 to 26 0/00. Water with salinity greater than or equal to 31 0/00 was found inshore off northern Washington (Waatch Point and Sea Lion Rock).

Surface chlorophyll-a concentrations, in general, were lower in 1983 than in 1982. High concentrations (greater than or equal to 7 ug/l) were found along the Yachats transect out to 20 mi, south of the front formed by the Columbia River plume. Other areas of high concentration were 10 mi off Destruction Island (greater than 8 ug/l), 5 and 10 mi off Sea Lion Rock (greater than 10 and 7 ug/l, respectively), and 15 mi off Waatch Point (greater than 8 ug/l). In contrast to 1982, most of the stations from the Quinault River south to Yaquina Head had surface chlorophyll-a concentrations less than 1 ug/l (Figure 5).

As in May 1982, the major features of the contour map of Secchi depths were also reflected in the map of chlorophyll-a concentration. Low Secchi depths recorded off southern Oregon (Yachats and Yaquina Head) and northern Washington (Waatch Point and Sea Lion Rock) appeared as areas of high chlorophyll concentrations. A tongue of shallow Secchi depths which extended from the Columbia River to about 10 mi offshore, however, did not correspond to any feature on the chlorophyll contour map. These lower Secchi depths were probably the result of the advection of entrained particles from the Columbia River (Figures 5 and 6).

The winds had been upwelling favorable for over two weeks prior to the sampling of the Nehalem Beach, Cape

Lookout, and Yachats transects. As a result, sigma-t cross-sections made along these transects depicted isopycnals sloping up to the shore indicating that upwelling was occurring (Figures 7a and 7b). The Columbia River plume (sigma-t less than 24.0), which was advected south by the winds and covered much of the study area as far south as Yaquina Head, appeared at the surface as a low-density lens 15 - 20 m deep.

The density structure in 1983 differed from that of 1982. The 25.5 isopycnal surfaced within 6 mi of the coast along the Nehalem Beach transect in 1982, but was below 30 m in 1983. The 25.5 isopycnal off Cape Lookout in 1983 was approximately 15 m deeper than in 1982 (Figure 7b). The 25.0 isopycnal surfaced at 10 mi in 1982, but was found below 30 m in 1983.

June 9 - 27, 1983

Upwelling in June was 19 Bakun units--less than half the normal monthly mean of 48 units (Table 1). The northerly winds during the cruise were less than half of what they were in 1982 (Figure 8). With reduced mixing in the surface layer, the SST's increased due to summer heating (Figure 9). The warm Columbia River water covered a large proportion of the region from northern Washington to central Oregon. Sea surface temperatures were high (16^{o} C) especially inshore off Nehalem Beach and beyond 15 mi off Oregon. Lowest temperatures were found less than 5 mi off Coos Bay and along the Waatch Point and Sea Lion Rock transects. A north-south thermal gradient was found off northern Washington.

The core of the Columbia River plume (less than or equal to 26 0/00) extended from Grays Harbor to Nehalem Beach to 15 mi offshore (Figure 10). The northern plume front extended seaward from the Quinault River to 10 mi, then parallel to the coast to Cape Disappointment, and continued out to 15 mi. The salinity drop across the front was as much as 6 0/00 (31 0/00 to 25 0/00). The southern front stretched from Wecoma Beach (2 mi) to Nehalem Beach (10 mi) and out to 20 mi. The sharpest change in salinity across this front was 4 0/00 (30 0/00 to 26 0/00). Upwelling, as indicated by high salinity water, was weak and only apparent close inshore off southern Oregon. The surface salinity off northern Washington out to 20 mi was about 31 0/00. The contour plot for salinity of June 1983 resembled that of September 1982 in that both depict the Columbia River plume extending seaward almost perpendicular to the coast.

Since there was little input of nutrients from below the depressed thermocline, phytoplankton standing stocks at the surface were dramatically reduced. Surface chlorophyll-a concentrations, in general, were low, often below 1 ug/l, especially off Oregon. Concentrations were a little higher off Washington (greater than 1 ug/l). Areas of relatively high chlorophyll-a concentrations (greater than or equal to 5 ug/l) were all located north of the Columbia River: the 12.5 and 12 mi stations located between the Cape Disappointment and Willapa Bay transects (5 ug/l); 5 mi off Willapa Bay (5 ug/l); 15 mi off Destruction Island (5 ug/l); and 5 mi off Sea Lion Rock (6 ug/l). Concentrations greater than 1 ug/l off Oregon were recorded off Four Mile Creek (5 and 2 mi) and Yaquina Head (3 mi, Figure 11).

Secchi depths were shallower north of the Columbia River reflecting the higher chlorophyll-a concentrations off Washington. The minor chlorophyll-a peaks off Four Mile Creek and Yaquina Head appear as areas of shallow Secchi depths. In general, Secchi depths were deeper off Oregon than off Washington (Figure 12).

The northerly winds were weak for several days prior to the sampling of the Destruction Island transect (Figure 20a). As a result, though the deeper isopycnals sloped up to the coast, none surfaced. The flat 24.0 isopycnal suggests that little upwelling was occurring and that the upper 10 - 15 m of the water column were well-mixed. Upwelling was also weak prior to the sampling of the Nehalem Beach transect (Figure 20b). The flat shallow isopycnals (less than 20 m) indicate that the less dense and stratified Columbia River plume overlays the denser, ocean water.

September 15 - 24, 1983

The northerly winds in September 1983 were stronger than in 1982--25 B.U., higher than the normal monthly mean of 16 (Table 1). The DBUI for the sampling period depicts weak winds and fluctuations in wind intensity and direction (Figure 14). The winds increased between 12 - 20 September.

Sea surface temperatures of 11 - 13° C were found close inshore (less than 10 mi) especially south of Nehalem Beach (Figure 15). A tongue of 13° C water extended 7 mi offshore bracketing the mouth of the Columbia River. Water temperatures were higher off Washington (14 - 16° C).

Low salinity plume water (27 0/00) was found close inshore near the mouth of the Columbia River, but the intense salinity fronts of June were absent (Figure 16). This and the fact that the salinity of the water from Cape Lookout north to Destruction Island only ranged from 30 - 31 0/00 suggest that the surface layer over most of the study area was well-mixed. Higher salinity water (32 - 33 0/00) indicative of upwelling was found south of Cape Lookout. Water with high salinity (32 0/00) was also found close inshore off Waatch Point.

Surface chlorophyll concentrations were patchy, but much higher than in June. The highest chlorophyll-a concentrations (up to 9 ug/l) were recorded in a band stretching seaward between the Seaside and Nestucca Bay transects (Figure 17). This band of high chlorophyll concentration was observed north of the 32 0/00 isohaline in waters which had been mixed with waters of the plume (Figure 16). This is consistent with the findings of Small and Curl (1972) in that phytoplankton populations take time to develop in newly-upwelled waters. High concentrations were also noted close inshore (less than or equal to 2 mi) between Nehalem Beach and the Siuslaw River (4 - 9 ug/l). Chlorophyll concentrations tended to be lower (usually greater than or equal to 3 ug/l) off central and northern Washington.

As in 1982, the contour plot of Secchi depths (Figure 18) often corresponded to the general features of the contour plot of chlorophyll-a concentrations (Figure 17). The shallowest Secchi depths (3 - 4 m) were recorded close inshore (less than or equal to 7 mi) from Nestucca Bay north to Cape Disappointment. Deep Secchi depths (greater than or equal to 9 m) off Yachats, the Siuslaw River, and Coos Bay correlated with low chlorophyll-a concentrations (less than or equal to 2 ug/l). Deep Secchi depths (7 - 8 m) also correlated with low chlorophyll-a concentrations (less than or equal to 1 ug/l) inshore (less than or equal to 10 mi) off Waatch Point, Sea Lion Rock, and Destruction Island.

The northerly winds were relatively strong for over a week prior to the sampling of the Nehalem Beach transect (Figure 19b). The sigma-t cross-sections shows isopycnals sloping up to the shore indicating upwelling. The 23.0 isopycnal surfaced within 5 mi of the coast and the 25.5 isopycnal was within 15 m of the surface. The unusually thick mixed layer (sigma-t less than 25.5) present in other months of 1983 was absent off Nehalem Beach.

Summary of 1983 Environmental Conditions:

Upwelling in 1983 was not as intense as in May, 1982. Surface mixing was less and as a result, salinity fronts formed around the Columbia River plume (Figure 4). In the area of the Columbia River plume, sea surface temperatures were high (13 - 14^{o} C) and surface chlorophyll-a concentrations were very low (less than or equal to 2 ug/l) (Figures 3 and 5). The sigma-t cross-sections off Nehalem Beach, Cape Lookout, and Yachats transects showed the isopycnals slanting up towards the coast (Figures 7a, 7b, and 13b).

According to a plot of the DBUI (Figure 8), upwelling during the June 1983 cruise was consistently lower than during the June 1982 cruise. As a result, upwelling-induced surface advection and surface mixing were lower. Sea surface temperatures were higher and salinity gradients were extreme around the Columbia River plume.

Sigma-t diagrams for June show that high density water was close to the surface, but that the shallowest isopycnals were flat. This indicated that the upper water column was stratified and stable and that the cold, high salinity, nutrient-rich water was not getting through the cap of warm, low salinity, nutrient-depleted surface waters. As a result, surface chlorophyll-a concentrations were often low (less than 1.0 ug/l).

The DBUI for September 1983 fluctuated greatly compared with 1982 (Figure 14), but the monthly average was higher in 1983. The increased northerly winds induced greater surface advection, upwelling, and surface mixing. The sigma-t cross-section along the Nehalem Beach transect suggested that the winds were mixing the waters of the Columbia River plume with denser, upwelled, ocean water in the surface layers. This resulted in lower surface temperatures, higher surface salinities, and higher chlorophyll-a concentrations relative to September 1982.

In 1983 the upwelling winds increased as usual in May, but then declined in June and July. The seasonal peak was reached in August, though the monthly mean for September was higher than average. The sudden relaxation of the upwelling winds in June and July caused the low-density Columbia River plume to spread out and blanket the high density deep water. This and the El Nino intrusion lead to a stratified water column with warm, low salinity water sitting above colder, higher salinity, nutrient-rich water (Fluharty, 1984). When the northerly winds advected the surface waters offshore, deep water beneath rose to replace it along the coast and local phytoplankton blooms resulted. These conditions persisted through the month of September.

Fish Catch Data

May 19 to June 2, 1982

In May 1982, 529 juvenile coho were caught in 62 sets. Juvenile coho were found predominantly south of Nehalem Beach as far as 20 mi offshore. Large catches were also made within 10 mi of the coast (closer inshore especially less than or equal to 5 miles) off Cape Lookout and Wecoma Beach in recently upwelled water having temperatures of 8 - 9^{o} C and salinities greater than or equal to 32 0/00 (Figures 3 and 4). This was also an area of relatively high surface chlorophyll concentrations. Sets north of the Columbia River off southern Washington had smaller catches and lower frequency of occurrence of juvenile coho (10 mi offshore, Table 3).

To facilitate the comparison of the distributions of juvenile coho salmon, the study area was divided into two inshore-offshore regions: offshore = greater than 12.5 mi from the coast, and inshore = less than or equal to 12.5 mi from the coast; and three north-south regions: Washington = Grays Harbor and north; Columbia River = between the Willapa Bay and Nehalem Beach transects; and Oregon = south of Cape Lookout (Figure 1). Juvenile coho enter the ocean off Oregon and Washington from many coastal streams. The major points of ocean entrance for juvenile coho in the study area are the Columbia River and Yaquina Bay. Many state and federal hatcheries release yearling (age I) smolts into the Columbia River, and Oregon Aqua-Foods, Inc. (OAF), a private salmon ranching company, releases accelerated (age 0) coho into Yaquina Bay. Accelerated or 0-age coho are reared in the hatchery in warm water and do not spend a year in fresh water. During the study, OAF released as many as 20 million accelerated coho smolts per year into Yaquina Bay. Estimates of the number of yearling (age I) and accelerated (age 0) coho per set were determined from scale analysis (Fisher, pers. comm.). The average catch per set (CPS), and the average size of individuals per set were computed for each of the six regions (Table 2).

In May 1982, juvenile coho were most abundant inshore off Oregon (CPS = 36). A large catch of 329 individuals, many from the Columbia River based on coded-wire tag information, was made 5 mi off Wecoma Beach. Omitting this set, the CPS was still high at 11 individuals per set. The next highest CPS was found greater than 12.5 mi off Oregon (CPS = 4). Catch per set in the Columbia River and Washington regions was comparatively low, and more fish were caught off Oregon than the other four regions combined. Few accelerated, 0-age coho were caught in May (29 of 529 individuals). Most of those found inshore off Oregon tended to be larger than the yearlings caught in the same area (170 mm vs 160 mm). Yearlings were about the same size coastwide (142 mm - 160 mm).

June 7 - 22, 1982

In June, 825 juvenile coho were caught in 56 sets. Juvenile coho were widely dispersed in 1982. Coho were found in the core of the plume and along the Cape Lookout transect, but large catches were also made north of the plume off the Willapa Bay and Ocean Park transects. Few coho were found close inshore (less than or equal to 5 mi) south of Cape Lookout (Figure 10). The highest concentrations of juvenile coho were found inshore off Washington (CPS = 26) and the lowest concentration of fish was found greater than 12.5 mi off Washington (CPS = 3, Table 2). Larger fish were found off Oregon (181 - 185 mm). Zero-age coho from OAF appeared with greater frequency in June than May making up as much as 14% of the catch inshore off the Columbia River. Most accelerated fish were found greater than 12.5 mi off Oregon and inshore off the Columbia River. No 0-age coho were found off Washington, though large 0-age coho (larger than 200 mm) were found offshore in the Columbia River region. There was a trend for fish caught off Oregon to be larger than those caught off the Columbia River or Washington. Some juveniles appeared to congregate along the salinity fronts of the Columbia River plume (Figure 10).

September 4 - 14, 1982

Three hundred eighty-four juveniles were caught in 38 sets in September. Large catches of coho were recorded in the plume core off Cape Disappointment from 5 to 15 mi offshore (Figure 16). Large catches were also noted north of the core of the plume from Willapa Bay to the Quinault River 10 to 15 mi offshore. Few coho were found off Oregon greater than 10 mi offshore.

Fish appeared to have aggregated close inshore off Oregon and the Columbia River region in September (Figure 16). The largest concentrations of fish were found inshore off the Columbia River (CPS = 20) and Washington (CPS = 17). In contrast to June, larger fish were found farther north suggesting that fish migrate north as they grow throughout the summer (Table 2). Smaller, zero-age coho made up a large percentage of the catch off Oregon (75%) and the Columbia River (62%). Few fish were found in any other region.

Coded-wire tag recovery data and scale analysis indicate that juvenile coho released from the OAF facility at Yaquina Bay were found in large concentrations close inshore (in general, less than or equal to 7 mi) south of the Seaside transect along the southern front as shown in Figure 16.

Summary of the Catch Data 1982

In May, the largest concentrations of fish were found off Oregon. Catches were low off Washington and inshore off the Columbia River. The largest fish were also found off Oregon and 0-age coho made up a small percentage of the catch. In June, fish tended to be more widely distributed. The largest concentrations were found inshore off Washington and the larger fish were found off Oregon. Although no 0-age coho were found off Washington, they did make up a sizeable percentage of the catch inshore off the Columbia River (14%) and offshore off Oregon (12%). Coho distribution shifted farther to the north in September. Most fish were found inshore, while few were found offshore. Large concentrations of fish were found off the Columbia River and Washington. In contrast to June, larger fish were found off Washington. Smaller, 0-age coho made up an ever larger percentage of the catches inshore off Oregon (75%) and the Columbia River (62%). In 1982, the center of the distribution appeared to shift from south to north throughout the summer. Larger fish also appeared to be south in May and north in September. The percent contribution of 0-age coho increased throughout the season and in September they made up the majority of the catch off Oregon and the Columbia River. On the whole, 0-age coho tended to be smaller than age I coho (yearlings) throughout the season.

May 16 to May 22, 1983

In May 1983, 178 juvenile coho were caught in 55 sets. Juvenile coho were found out to 25 mi, along the oceanic edge of the southern front of the Columbia River plume, but were most abundant in plume water (less than or equal to 29 0/00) close inshore (less than or equal to 10 mi) south of Seaside. As in 1982, sets off Washington, in general, had small catches and low frequency of occurrence of juvenile coho (Figure 4 and Table 3).

Unlike May 1982, the largest concentrations of coho were found inshore off the Columbia River (CPS = 8).

Catches were also high off Oregon (inshore CPS = 4 and offshore CPS = 3) and lowest offshore off Washington (CPS = less than 1). As in September 1982, there was a trend for smaller fish to be found off Oregon and larger fish to be found off Washington. OAF 0-age coho made up a small percentage of the catch (up to 12% inshore off Washington). As in 1982, 0-age and yearling fish in May 1983 were of similar lengths.

June 9 - 27, 1983

In June, 202 juveniles were caught in 58 sets. Catches of juvenile coho were highest north of the Columbia River plume, off the Washington coast from Willapa Bay to Sea Lion Rock up to 15 mi offshore. Smaller catches were recorded along the southern front of the plume. Several large catches were made far to the south off Coos Bay and Four Mile Creek. These fish were released from Anadromous, Inc., a private salmon ranching company with release facilities located at Coos Bay (coded-wire tag information). Few coho were caught between Coos Bay and Nehalem Beach off Oregon (Figure 10).

Most individuals were found inshore and north of the Columbia River, a distributional pattern similar to that of

September 1982. In June, CPS varied more with latitude than with distance from shore (Table 2). The highest CPS were found off the Columbia River (inshore CPS = 6 and offshore CPS = 6) and the lowest CPS were recorded off Oregon (inshore CPS = 2 and offshore CPS = 2). More fish were found off Washington in June than in May (inshore CPS = 3 and offshore CPS = 3). The smallest fish were found off Oregon, while large fish were caught offshore off the Columbia River. Off the Columbia River and Oregon, yearling and 0-age coho were about the same size. No 0-age coho were caught inshore off Washington and those which were caught offshore off Washington were larger than yearlings caught in the same sets. OAF 0-age coho comprised over 10% of the catch in all the offshore areas. Inshore off the Columbia River, 0-age coho made up 28% of the catch.

September 15 - 24, 1983

In September 1983, 194 juveniles were caught in 52 sets. Large catches of juvenile coho were made off Waatch Point as far offshore as 25 mi. Few fish were captured in the large area between northern Washington and central Oregon. South of the Columbia River large catches were confined to within 5 mi offshore from Nehalem Beach to the

Siuslaw River (Figure 10). Most of those caught inshore south of the Columbia River were probably released by OAF from their Yaquina Bay release site (coded-wire tag information).

The distribution of fish shifted farther north in September (Table 2). Large catches were made off Washington (inshore CPS = 11 and offshore CPS = 7). Off Oregon and the Columbia River, no juvenile coho were caught offshore and very few were caught inshore (Oregon CPS = 2 and Columbia River CPS = 2). In general, larger fish were found farther north and offshore. OAF 0-age coho made up a large percentage of the catch inshore (as much as 76% off the Columbia River) and were smaller than the yearlings.

Summary of Fish Catch Data 1983:

In May, catches were largest off Oregon and inshore off the Columbia River. Large fish were found farther to the north than smaller fish. OAF 0-age coho made modest contributions to the catch and were found predominantly inshore. There was a shift in the distribution of coho northward in June. Larger numbers of fish were found off the Columbia River and more were found off Washington than Oregon. Estimates of CPS were almost identical both inshore and offshore suggesting that fish distributions were related to latitude more than distance from shore. As in 1982, larger fish were found to the north. OAF 0-age coho were found offshore over the entire coast, but made their largest contribution to the catch inshore off the Columbia River. In September, the distribution of fish again shifted farther to the north. Large catches were made off Washington. Smaller catches were made south of Washington inshore and no juvenile coho were recorded offshore. Larger fish were found to the north offshore and OAF 0-age coho made up large percentages of the catch inshore over the entire coast.

Pattullo-Denner Diagrams

A Pattullo-Denner (1965) diagram is a plot of surface temperature versus surface salinity from which the processes which affect the temperature and salinity characteristics of sea water can be identified. According to year-round, coastal measurements collected over the entire Oregon coast, the most frequently observed "water type" has a salinity of between 33 and 33.5 0/00 and a temperature of between 10 and 11° C (Pattullo and

Denner, 1965). Vectors defining areas of influence of specific processes are constructed from this modal water type. Symbols representing the catch per set of juvenile coho salmon were plotted on these T-S fields to relate distributions of fish to major processes. Because Pattullo and Denner did not include information from offshore stations, their vector labelled "rainfall and runoff" also corresponds to Columbia River plume water in more offshore areas.

The Pattullo diagram for May 1982 (Figure 21a) shows that most of the sets were made in waters affected by Columbia River discharge. Intense surface mixing caused the salinities to center between 31.5 and 32 0/00. The Pattullo diagram for June (Figure 22a) shows that temperatures were warmer due in part to summer heating and that surface waters were not as mixed as in May. Most high catches were made in waters influenced by the plume. Large catches were made in the core of the plume (26 0/00 and 12.5^{o} C) and in waters with salinities between 30.5 and 31.5 0/00. The distribution pattern of the fish suggests that juvenile coho may congregate along the salinity fronts bordering the plume (Figure 10) possibly because of concentrations of zooplankton. Sets made in colder, more saline water did not yield many fish.

The Pattullo diagram for September 1982 (Figure 23a) shows a general elevation in temperatures due to reduced surface mixing and summer heating. The fact that fewer sets were made in lower salinity water (less than 30.5 0/00) in September than in June suggests that the plume was not as dispersed in September. Though catches were smaller than in previous months, the frequency of occurrence of juvenile coho in September was higher (Table 3) suggesting that fish were more widely dispersed than in other months. Most of the juveniles caught south of the Columbia River were 0-age coho released from OAF at Yaquina Bay (Table 2).

The Pattullo diagram for May 1983 (Figure 21b) indicates that temperatures were higher and that surface salinities varied over a greater range than in May 1982 due to reduced surface mixing and upwelling, and the intrusion of El Nino waters.

In contrast to June 1982, the June 1983 Pattullo diagram indicates that few sets were made in higher salinity water (greater than 32 0/00), though wide ranges of salinities were apparent in both years (Figures 22a and 22b). The June 1983 Pattullo diagram resembles the plot for September 1982 with respect to the range of temperatures observed. Reduced upwelling and surface mixing resulted in a stable, stratified water column (Figure 20b). The already warm, less dense Columbia River plume water overlay the warm, oceanic, El Nino water and became even warmer due to summer heating.

The Pattullo diagram for September 1983 indicates that surface salinities were greater than 30 0/00 suggesting that surface mixing was greater in 1983 than 1982 (Figure 23a and 23b). The frequency of occurrence of juvenile coho salmon in September 1983 was the lowest of all six cruises (Table 3).

The Relationship Between Environmental and Catch Data

To explore the relationship between catches of juvenile coho salmon and selected environmental factors, catch was plotted against sea surface temperatures, surface salinities, surface chlorophyll-a concentrations, and Secchi depths for each of the cruises in 1982 and 1983.

Sea Surface Temperature

In May 1982, catches were made in waters with temperatures between 9.4 and 12.3° C. High catches (greater than 10 fish per set) were all between 9.7 and 12.3° C, with one large catch (329 fish) at 10.6° C (Figure 24a). In June 1982, the highest catches were between 11.1 and 12.7° C and showed a trend to decrease with increasing temperature (Figure 24b). Catches were low above 13° C and below 11° C. In September, temperatures were warmer and no sets were made in waters less than 12° C (Figure 24c). Highest catches in this month were between 14.1 and 15.8° C. Catches were low above 16.5° C.

In 1983, due to the influence of the poorer upwelling winds and warm El Nino conditions, water temperatures were considerably higher than in 1982. In May, catches ranged from 11.1 to 14.6° C with highest catches between 11.9 and 14.1° C, several degrees warmer than the high catches of May 1982 (Figure 25a). Few sets were made in temperatures below 11° C. This trend for juvenile coho to be found in warm water was even more pronounced in June 1983 when most high catches were made between 14.7 and 16.3° C (Figure 25b) and in September 1983 when the highest catches were between 14.1 and 14.9° C (Figure 25c).

These plots of catch of juvenile coho and sea surface temperature usually suggest a parabolic relationship with low catches at the highest and lowest temperatures and highest catches at intermediate temperatures. The position of maximum catches, however, varies among months within a year and between years. Peak catches were found at 10.6° C, 12.1° C, and 14.1° C in May, June, and September 1982, respectively, and 14.1° C, 15.4° C, and 14.6° C in May, June, and September 1983. These shifts in the temperature of maximum catch suggest that distributions are influenced more by changing oceanographic conditions than by a narrow, fixed, and preferred optimal temperature of juvenile coho salmon. For example, the temperatures of high catches in May 1982, when upwelling was intense, were not even observed in surface waters in 1983.

Surface Salinity

Relationships between catch and salinity were also variable among cruises and were influenced mainly by upwelling and the Columbia River plume. In May, 1982 sets were made in waters with surface salinities of 14.6 0/00 to 33.2 0/00. Catches were only made in waters above 27 0/00 and tended to increase with increasing salinity up to 33 0/00 (Figure 26a). High catches were made in recently upwelled water with high salinities (greater than or equal to 33 0/00) off Oregon (Figure 4). A parabolic relationship was indicated in June with peak catches occurring at intermediate salinities (30 - 32 0/00), in waters influenced more by the Columbia River plume than upwelling (Figure 26b). Several sets were made in newly upwelled, cold (8 - 9^{o} C), high salinity water (greater than 33 0/00) though few fish were taken. In September, large catches were made in low salinity (less than 26 0/00), plume-affected waters, but peak catches were between 31 0/00 and 32 0/00 (Figure 26c).

Reduced overall upwelling and the upwelling of intermediate density El Nino water (Fluharty, 1984) could account for the lower salinties observed in 1983 than 1982 (less than 33 0/00 as opposed to greater than or equal to 33 0/00). The relationship between catch and surface salinity in May 1983 also appeared to be parabolic with a peak at 29.4 0/00 (Figure 27a). In June, catches were made between 18.1 0/00 and 32.9 0/00 with the highest catches between 31.0 0/00 and 31.5 0/00 in plume-affected waters. A secondary peak at 26 0/00 represented those sets made in the core of the plume. No sets were made in waters greater than 33 0/00 (Figure 27b). Surface waters were more mixed in September than in June. Highest catches were made between 31.5 0/00 and 32 0/00 and no sets were made in waters below 30 0/00 or above 33 0/00 (Figure 27c).

These plots of catch of juvenile coho and surface salinity suggest a parabolic relationship, with catch declining at the lowest and highest salinities. Peak catches were found at 32.4, 31.1, and 31.8 0/00 in May, June, and September 1982 and 29.4, 31.4, and 31.5 0/00 in May, June, and September 1983. Large catches in low-salinity plume water, particularly early in May and June, as in 1983, may be related to out-migration of juvenile coho from the Columbia River. Juvenile coho distributions are not governed by rigid salinity requirements. As long as salinities occur within their tolerance range, juvenile coho appear to adapt to changing oceanographic conditions.

Surface Chlorophyll-a Concentration

Surface chlorophyll concentrations are especially variable in areas affected by upwelling (Small and Curl, 1972). In May 1982, catches were made in waters with chlorophyll concentrations of 0.6 to 21.3 ug/l with the largest catch occurring at 15 ug/l. There was a slight trend for catches to increase with increasing chlorophyll concentration (Figure 28a). This trend was reversed in June when catches were largest (greater than 30 fish) at lower concentration (less than 3 ug/l) and declined with increasing concentrations (Figure 28b). In September, catches were made in waters with concentrations from 0.8 to 9.3 ug/l with the largest catch (98 fish) at 4.1 ug/l. Larger catches (greater than 20 fish) were associated with higher concentrations (greater than 4 ug/l, Figure 28c).

The reduced upwelling and El Nino conditions of 1983 probably contributed to the lower chlorophyll concentrations observed in May and June. The highest concentrations in 1983 (about 12 ug/l) were half of what they were in 1982. In May, the larger catches (greater than 10 fish) occurred in waters with less than 2 ug/l. There was also a trend for catches to decline with increasing concentration (Figure 29a). This trend for the largest catches to occur in waters with less than 2 ug/l was also observed in June (Figure 29b) and September (Figure 29c).

These plots indicated that the relationship between catch of juvenile coho and surface chlorophyll-a concentration varied from month to month in 1982, but were more consistent in 1983. Peak catches were made at 15.0, 3.1, and 4.1 ug/l in May, June, and September 1982, and at 0.1, 0.4, and 0.8 ug/l in May, June, and September 1983. These variable relationships suggest that surface chlorophyll concentrations probably do not, in and of themselves, govern juvenile coho distributions.

Secchi Depths

In May 1982, catches were made in waters with Secchi depths between 1 and 10 m, with the highest catches (greater than 10 fish) occurring between 3 and 3.5 m. There was a slight trend for catch to decline with increasing Secchi depths (Figure 30a). In June, catches occurred between 2.5 and 12 m with the largest catches at 6 m. The majority of the larger catches (greater than or equal to 30 fish) were made in waters with Secchi depths between 3 and 7 m (Figure 30b). In September, the larger catches (greater than 20 fish) were made between 3.5 and 5 m and there was a trend for catch to decline with increasing Secchi depth (Figure 30c).

Trends shown in the plots of Secchi depth versus catch of juvenile coho were much more variable in 1983 than in 1982. In May, the size of the catch tended to increase with Secchi depth with the largest catch (38 fish) occurring at 10 m (Figure 31a). In June, catches were made between 1 and 13 m and peaks of large catches were made at both 4.5 and 10 m (Figure 31b). The plot for June 1982 showed a single peak at 6 m (Figure 30b). In September, catches occurred between 3.5 and 10.5 m with the largest catch (68 fish) occurring at 8 m (Figure 31c).

The relationship between Secchi depth and catch of juvenile coho differed between years in that catches declined with increasing Secchi depth in 1982, but increased with Secchi depth in 1983. Peak catches were made at 3.5, 6, and 4.5 m in May, June, and September in 1982, and 10, 4.5 and 10, and 8 m in May, June, and September in 1983. This suggests a variable relationship between juvenile coho distributions and Secchi depths.

Correlation Matrices and Multiple Regression Equations

In an attempt to quantify the relationships between catches of juvenile coho and selected oceanographic factors, correlation matrices and multiple regression equations were calculated for each cruise. In addition to the four factors described above, the Daily Bakun Upwelling

Index (DBUI) was included in the calculations as a measure of northerly wind stress.

In May 1982, chlorophyll-a concentration (correlation coefficient = 0.26), Secchi depth (-0.14), and DBUI (-0.14) were most highly correlated with juvenile salmon catch, but the three variables which explained the most variation in the catch data (R^2 = 0.08) were chlorophyll, temperature, and DBUI (Table 4). In June, DBUI (0.25) and Secchi depth (-0.23) were most correlated with catch, but the regression equation had an R^2 of only 0.11 (Table 4). September was the only cruise of which over 25% of the variation in the catch data could be explained by the variables measured. Chlorophyll-a (0.52), Secchi depth (-0.48), and DBUI (-0.31) were most correlated with catch and a regression using chlorophyl, DBUI, and salinity had an R^2 of 0.52 (Table 4).

As in 1982, correlation coefficients and R^2 were generally low. In May, chlorophyll (-0.16), DBUI (-0.16), and temperature (0.14) were most correlated with salmon catch, yet chlorophyll, DBUI, and Secchi depth had an R^2 of only 0.08 (Table 4). In June, Secchi depth (-0.34), DBUI (-0.27), and salinity (-0.22) had an R^2 of 0.22 (Table 4). DBUI (0.23) and chlorophyll (-0.21) were the most correlated with salmon catch in September, yet DBUI and salinity had an R^2 of only 0.07 (Table 4).

Pooling the data for each year and for both years resulted in correlation coefficients less than or equal to 0.25 and R^2 less than or equal to 0.05. Chlorophyll and Secchi depth explained the largest amount of variation in the catch data (Table 4). In general, low correlation coefficients and R^2 were determined for each cruise, year, and for both years combined. Plots of estimates of catch from each equation (Y-hat) versus the residuals indicated that simple data transformations would not significantly improve the regression model. This suggests that ocean conditions were variable between months and years and that the distribution and abundance of juvenile coho salmon were probably influenced by oceanographic factors other than those measured.

DISCUSSION

The El Nino arrived off Oregon in October 1982 (Huyer and Smith, 1984) as an enormous wedge of warm water. Compounding the problem of below normal upwelling, this wedge of intermediate density (sigma-t approximately 24.0 - 25.5) rode above the permanent thermocline and below the less dense waters of the Columbia River plume and blocked the cold, nutrient-rich water, associated with the thermocline, from rising to the surface (Fluharty, 1984). Off Yachats in May 1983 (Figure 13) the 25.0 isopycnal surfaced at 3 mi and the 25.5 isopycnal was within 15 m of the surface in the region from 10 mi to the shore. The 24.5 isopycnal surfaced at 22 mi and high surface chlorophyll concentrations (greater than 6 ug/l) were found inshore of 20 mi. Low concentrations (less than 1 ug/l) were found at 25 mi suggest that the 24.5 sigma-t water at the surface was El Nino water. The deepening of the upper mixed layer and the depression of the thermocline (the 25.5 isopycnal) is apparent in the sigma-t cross-sections off Nehalem Beach and Cape Lookout in May (Figures 7a and 7b) and Nehalem Beach (Figure 20b) and Cape Lookout (Figure 13a) in June.

The northerly winds were weak in the summer of 1983, about half of that observed in May and June of 1982. Reduced winds resulted in reduced surface mixing and exchange between the warm surface layer and the cooler layers at depth. The warm surface layer became even warmer as the season progressed due to solar heating. These factors resulted in a stable and stratified water column with a deeper than normal surface mixed layer. The flat, shallow isopycnals were especially apparent off Nehalem Beach in June 1983 (Figure 20b).

Though weak northerly winds resulted in reduced upwelling in the summer of 1983 much of the water from the level of entrainment (30 - 60 m; Huyer, 1982) was warm and relatively poor in nutrients in comparison with water below the thermocline. As a result, the standing stocks of phytoplankton were lower in surface waters (Figures 5, 11, and 17), the waters were transparent (deep Secchi depths) close inshore, especially off southern Oregon (Figure 18), and primary productivity was generally depressed. Miller et al (in prep.) found that surface chlorophyll concentrations off Newport, Oregon in 1983 were about half of what they were during the summer of 1982. They also observed subsurface chlorophyll maxima, features typical of non-upwelling, oceanic conditions. Thus the upwelling that did occur off Oregon and Washington in 1983 was less effective than normal in bringing nutrients to the surface and stimulating productivity.

In comparison with hydrographic data collected from 1962 - 1968, Huyer and Smith (in press) found that the waters off Newport, Oregon in July 1983 showed strong stratification over the continental shelf, very warm temperatures, and very low salinities much nearer to shore than normal. These features are consistent with the weak coastal upwelling that occurred in June and July. The low salinities (less than 30 0/00) and high surface temperatures (greater than 18^{o} C) found at 50 km off Newport indicated that the Columbia River plume was much nearer to shore than usual due to the decrease in offshore Ekman transport.

The food web off Oregon was undoubtedly affected by the reduced primary productivity in 1983. The number of herbivores and, therefore, the number of carnivores, such as juvenile coho salmon, that could be supported, was presumably reduced. The fact that no juvenile coho were found in poor condition in 1983 and growth rates were generally similar to earlier years (Fisher and Pearcy, unpublished) suggests that those individuals which could not successfully compete for the limited food supply were probably removed from the population by predators. Although approximately the same number of smolts were released into the Oregon Production Index area in both years, over three times as many juvenile coho were caught in 1982 as in 1983. A total of 90,200 jacks returned to the Columbia River and the coastal streams in 1982, but only 37,400 jacks returned in 1983. This was the lowest jack return since records were kept in 1969. Apparently coho smolts that entered the El Nino affected waters in the spring of 1983 experienced unusually high mortality (Johnson, 1984).

Standing stocks of phytoplankton were also affected by the 1957-58 El Nino. Off the Washington coast the standing crop was estimated to be an order of magnitude lower in 1958 than in 1957 (Aron, 1962). It was also a disasterous year for salmon production off Oregon. Despite relatively strong upwelling, the coho salmon entering the ocean in 1957 produced the fewest adult salmon since 1917. The low adult abundance of 1957 was probably due to unfavorable oceanic conditions brought about by the 1957 El Nino (Nickelson, 1983).

The weak offshore flow during the summer of 1983 also affected the distribution of ichthyoplankton off Oregon. Brodeur et al (1984) found increased occurrences and higher abundances inshore of taxa usually found at distances greater than 37 km in other years. Many of the dominant taxa usually found inshore, like osmerids, were present in reduced numbers. The dominant species of larval fish collected by Brodeur et al (1984) was the northern anchovy. Larval anchovy are usually found offshore in the relatively warm, stable waters of the Columbia River plume (Richardson, 1980). The reduced upwelling and the intrusion of the warm El Nino waters apparently created a broad spawning habitat for anchovy in 1983 that included nearshore waters normally affected by upwelling.

Petersen and Miller (1974) found similar changes in the distributional patterns of zooplankton off Newport when comparing samples collected during the years of varying upwelling intensity. The samples from 1971, a year of reduced upwelling, showed that offshore species had high frequencies of occurrence and abundance and that there was a general reduction in the density and number of more neritic species.

The weak upwelling winds and the unusual El Nino conditions of the summer of 1983 changed the distributional patterns of juvenile coho salmon compared to 1982. In 1982 the winds were about double what they normally are during May and were average for the rest of the season. The winds were about average during May in 1983, fell far below normal during June, and were above normal during September. When the northerly winds were strong as in May 1982, upwelling was strong and surface waters, including the Columbia River plume, were advected offshore and south (Figure 4). Juvenile coho, a large percentage of which are released from Washington and Oregon hatcheries into the Columbia River, were found relatively far offshore and south of the Columbia River off central Oregon. The winds moderated in June. Upwelling and advection continued though surface mixing was reduced. The Columbia River plume was not advected as far south as it was in May and the distribution of juvenile coho shifted north. Most were found offshore in plume water off northern Oregon and southern Washington (Figure 10).

The winds during May 1983 were about half of what they were in 1982. Upwelling and advection still occurred and the Columbia River plume was advected south, though surface mixing was not as intense as it was in 1982. Juvenile coho were found closer inshore and not as far south as in 1982 (Figure 4). With little upwelling, surface advection, or mixing, the Columbia River plume dispered over a large area and extended almost perpendicular to the coast (Figure 10).

There was a dramatic shift in the distribution of juvenile coho in June 1983. They were found farther to the north of the Columbia River than in June 1982 and their distributional pattern resembled that of September 1982 (Figures 10 and 16). The strength of the northerly winds and sea surface temperatures for both months were comparable (Table 1 and Figures 28b and 29a). As in September 1982, the Columbia River plume was almost perpendicular to the coast in June 1983 which is indicative of reduced surface mixing and advection. The Bakun Upwelling Index for September 1982 was 16 as compared with 19 for June 1983. Few fish were collected in the study area in September 1983. The winds were stronger than average; surface mixing was high as indicated by the absence of an extended Columbia River plume; and upwelling was occurring off southern Oregon, yet the fish disappeared.

In general, the center of juvenile coho distribution shifted northward throughout the summer of 1983. Toward the end of the season, larger fish were found farther north and yearlying (age I) coho were generally larger than OAF 0-age coho. OAF 0-age coho made up ever larger proportions of the total catch as the summer progressed, especially south of Cape Lookout.

The largest difference in catches between years occurred in June when the difference in sea surface temperatures (SST's) was the greatest. Yet even though the SST's in September 1983 were lower than September 1982, the catches in 1983 were still much lower. Miller et al (1983) sampled the southern Washington and northern Oregon coast for salmon in May, June, and September of 1980. In May, they observed SST's of between 11.1 and 13.2° C and caught 858 juvenile coho. In July, the SST's ranged from 14.2 to 16.2° C and their catch of juvenile coho dropped to 56 individuals. In September, the SST's ranged from 10.6 to 14.7° C and their catch of juvenile coho was 241 individuals. They attributed the low catch of the July cruise to rapid migration of salmon out of the sampling area and the high water temperatures.

The distribution of juvenile coho off Washington and Oregon in 1982 and 1983 did not appear to be rigidly governed by either sea surface temperature, surface salinity, surface chlorophyll-a concentration, or Secchi depth. Temperature and salinity, if taken to extremes, can be lethal to juvenile coho. Brett (1952) demonstrated that juvenile coho prefer waters of between 12 and 14° C, but have a wide temperature tolerance range (0 - 25°

C). Though temperature and salinity may be important, distributions of juvenile coho are probably affected more by oceanographic processes that influence advection, food concentrations, and migratory behavior.

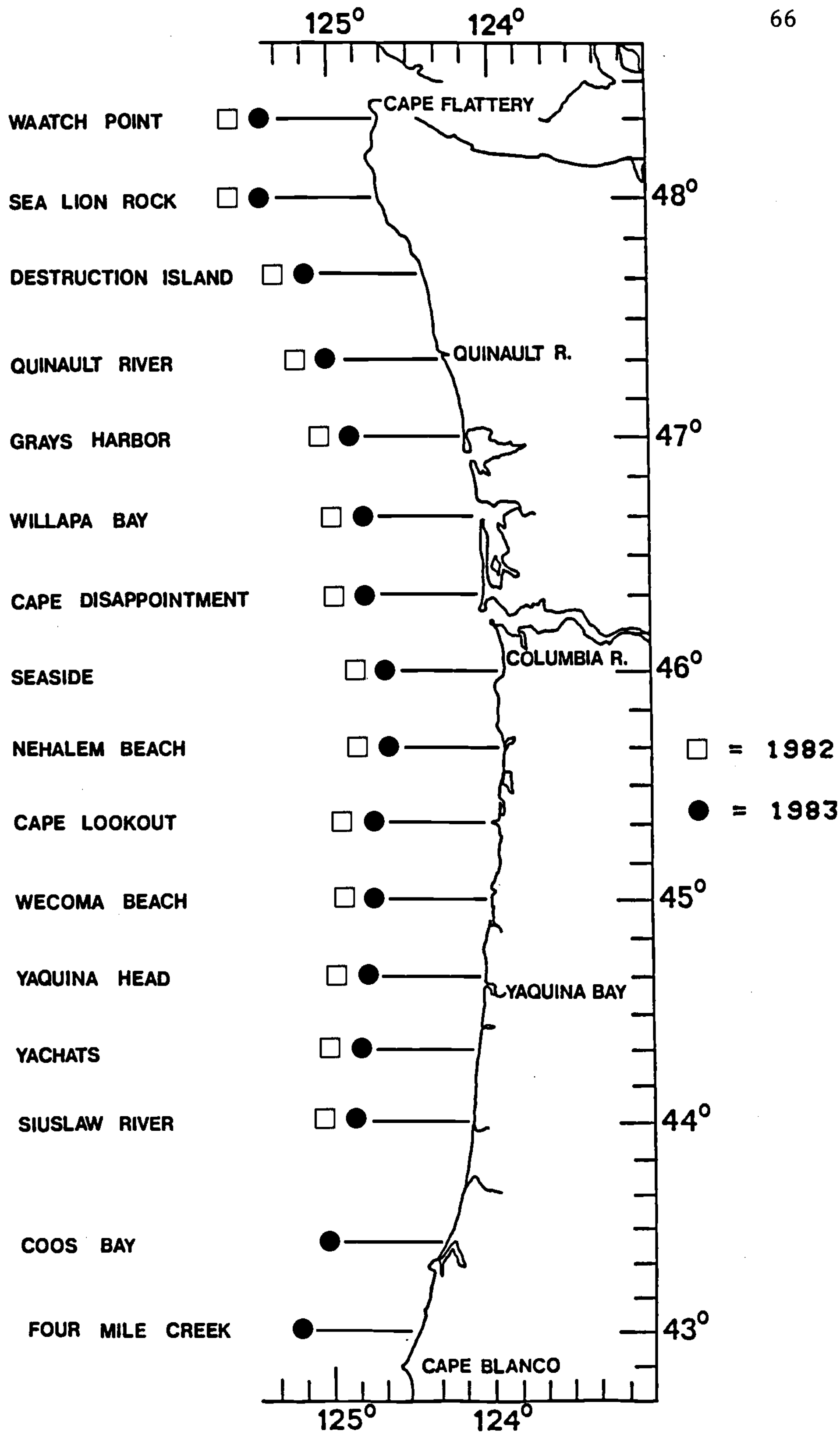


Figure 1. Map of the Coast of Washington and Oregon.

Figure 2. Daily Bakun Upwelling Index (DBUI) for May 1982 (squares) and 1983 (filled circles). Arrows indicate beginning and ending dates of respective cruises.

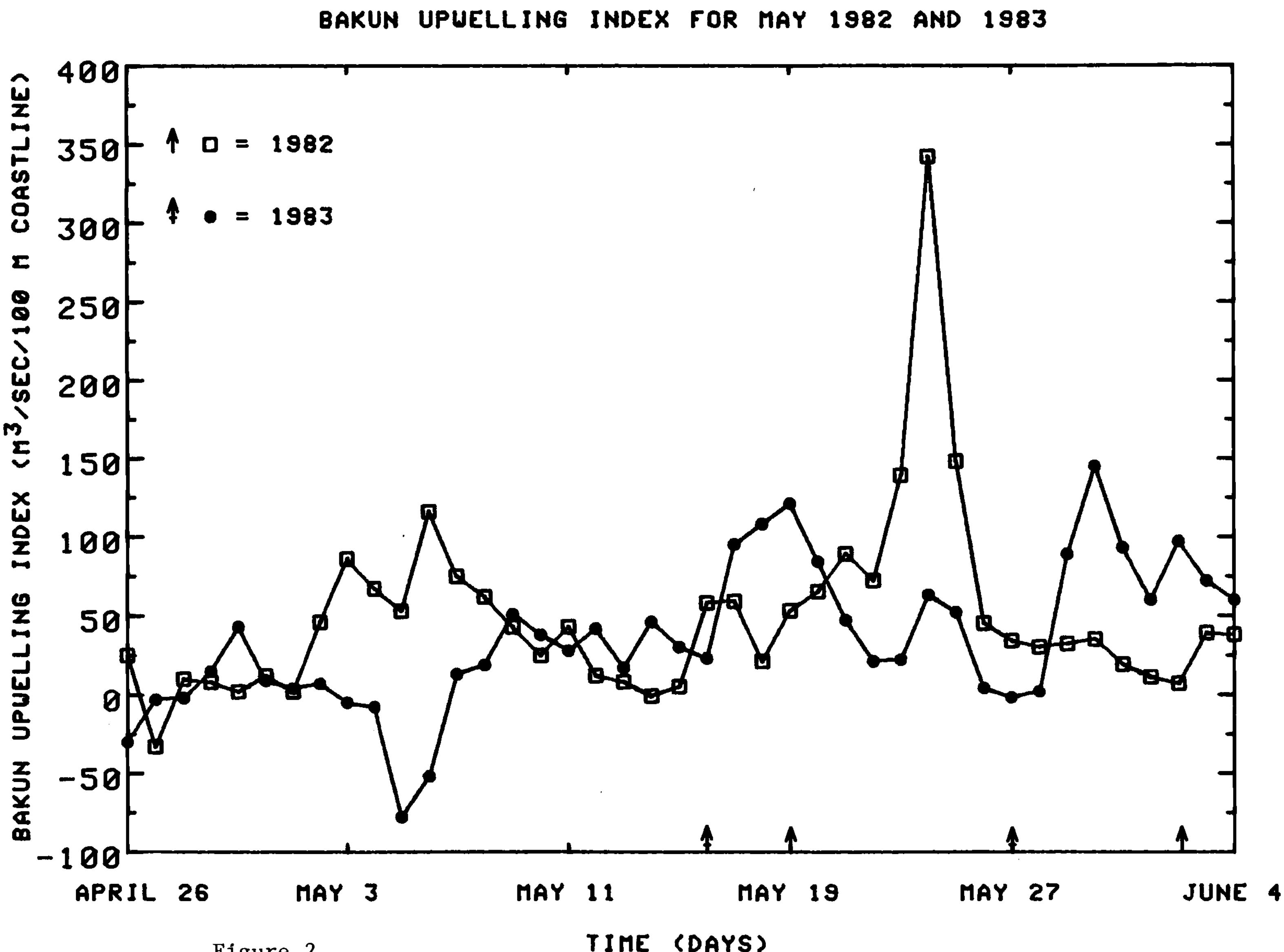
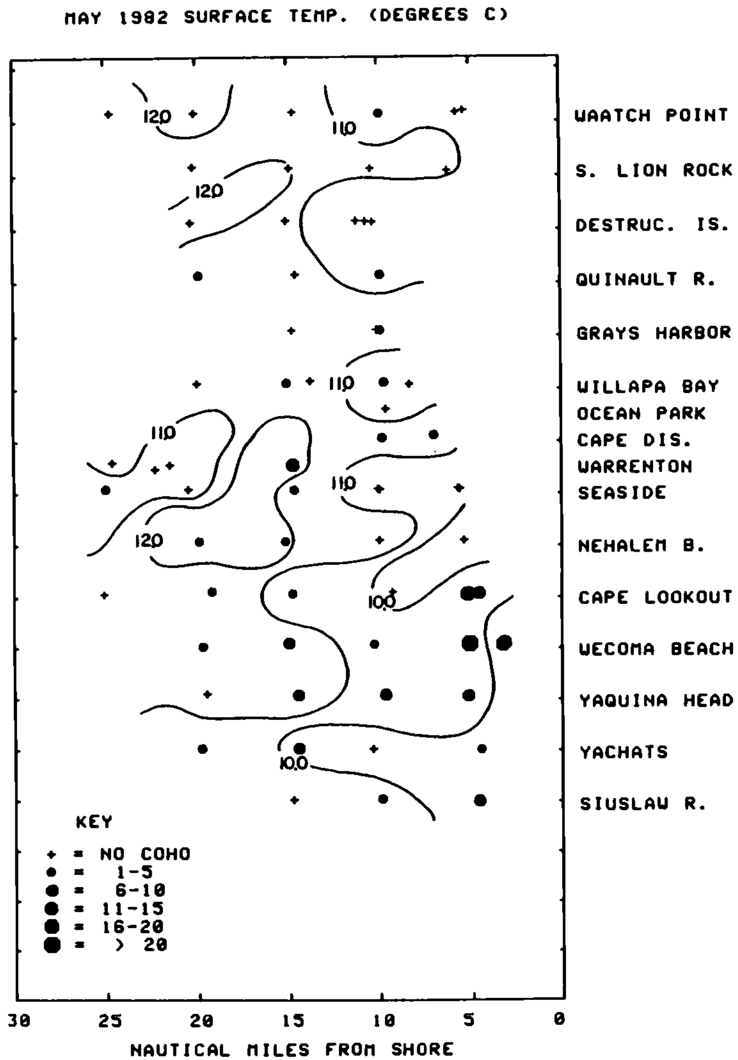

BAKUN UPWELLING INDEX FOR MAY 1982 AND 1983
BAKUN UPWELLING INDEX (M3/SEC/100 M COASTLINE)
400
350
300
250
200
150
100
50
0
-50
-100
□ = 1982
● = 1983
APRIL 26
MAY 3
MAY 11
MAY 19
MAY 27
JUNE 4
TIME (DAYS)

Figure 2.



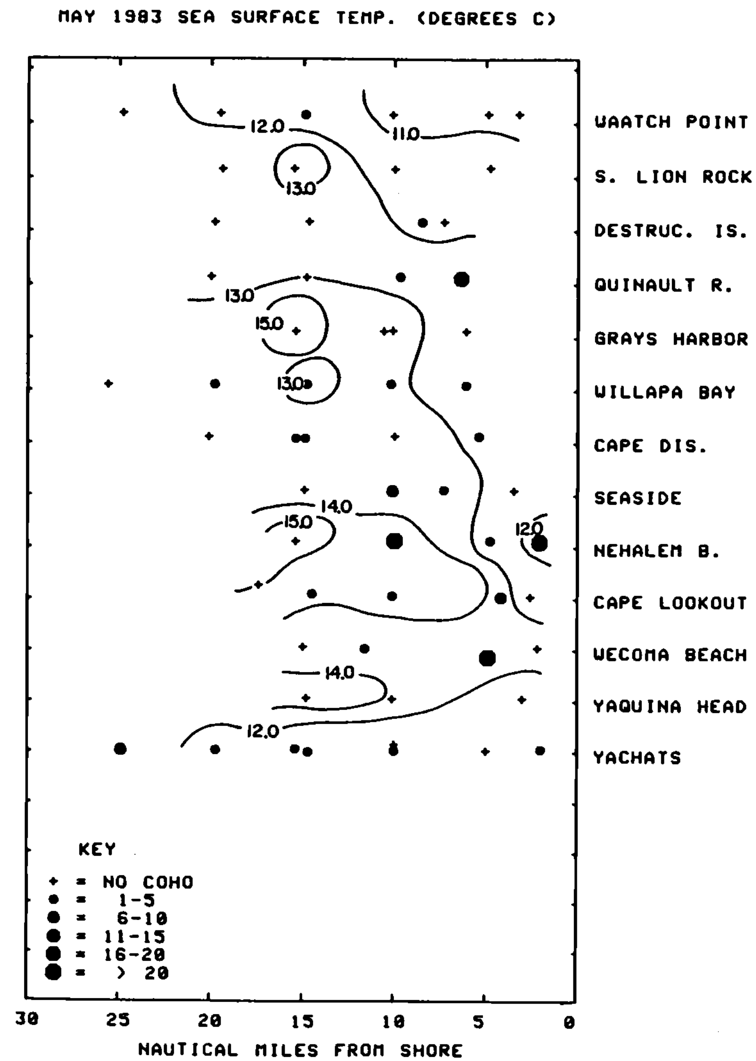


Figure 3. Sea Surface Temperatures (SST's) for May 1982 and 1983.

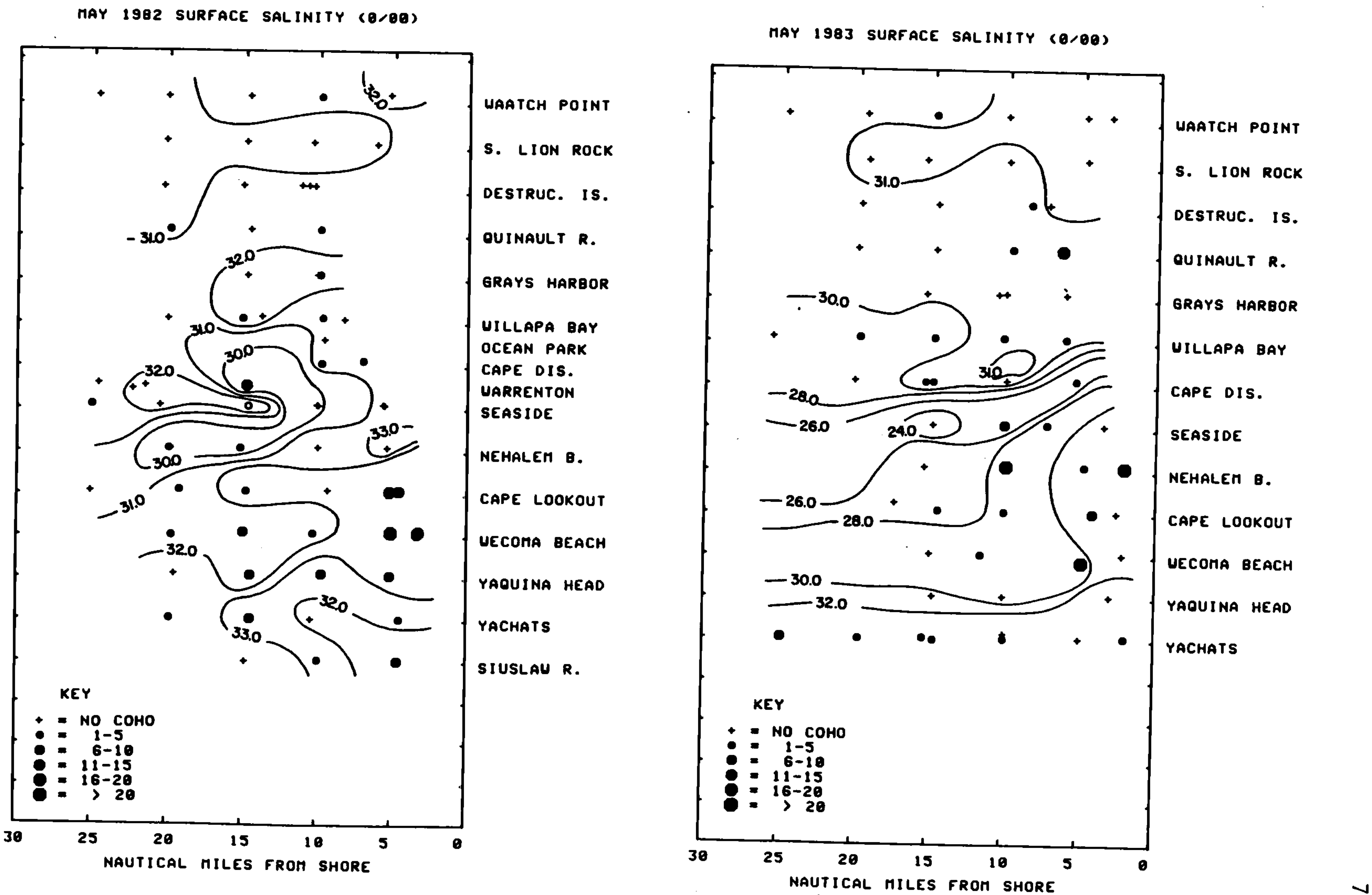


Figure 4. Surface Salinities for May 1982 and 1983.

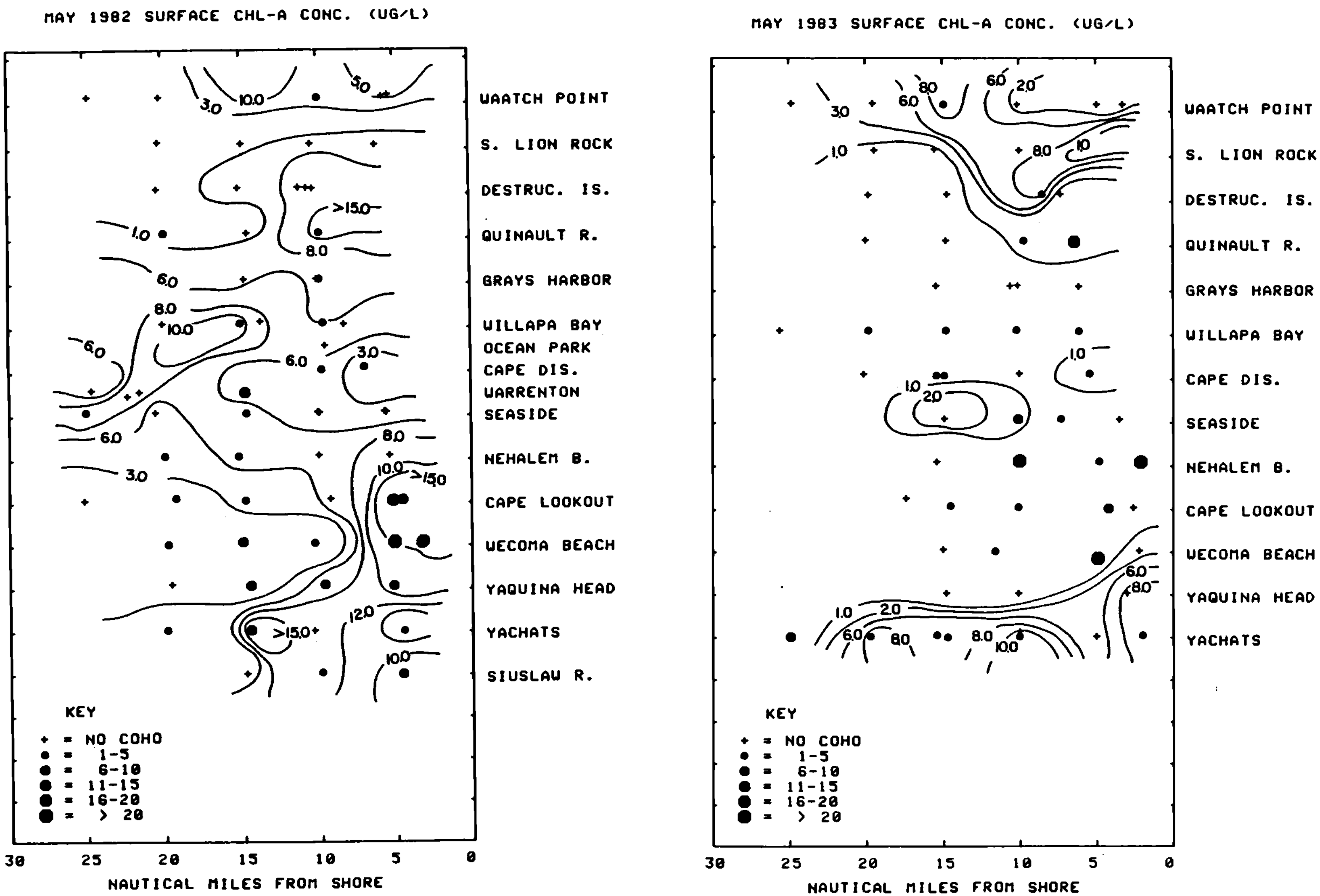


Figure 5. Surface Chlorophyll-a Concentrations for May 1982 and 1983.

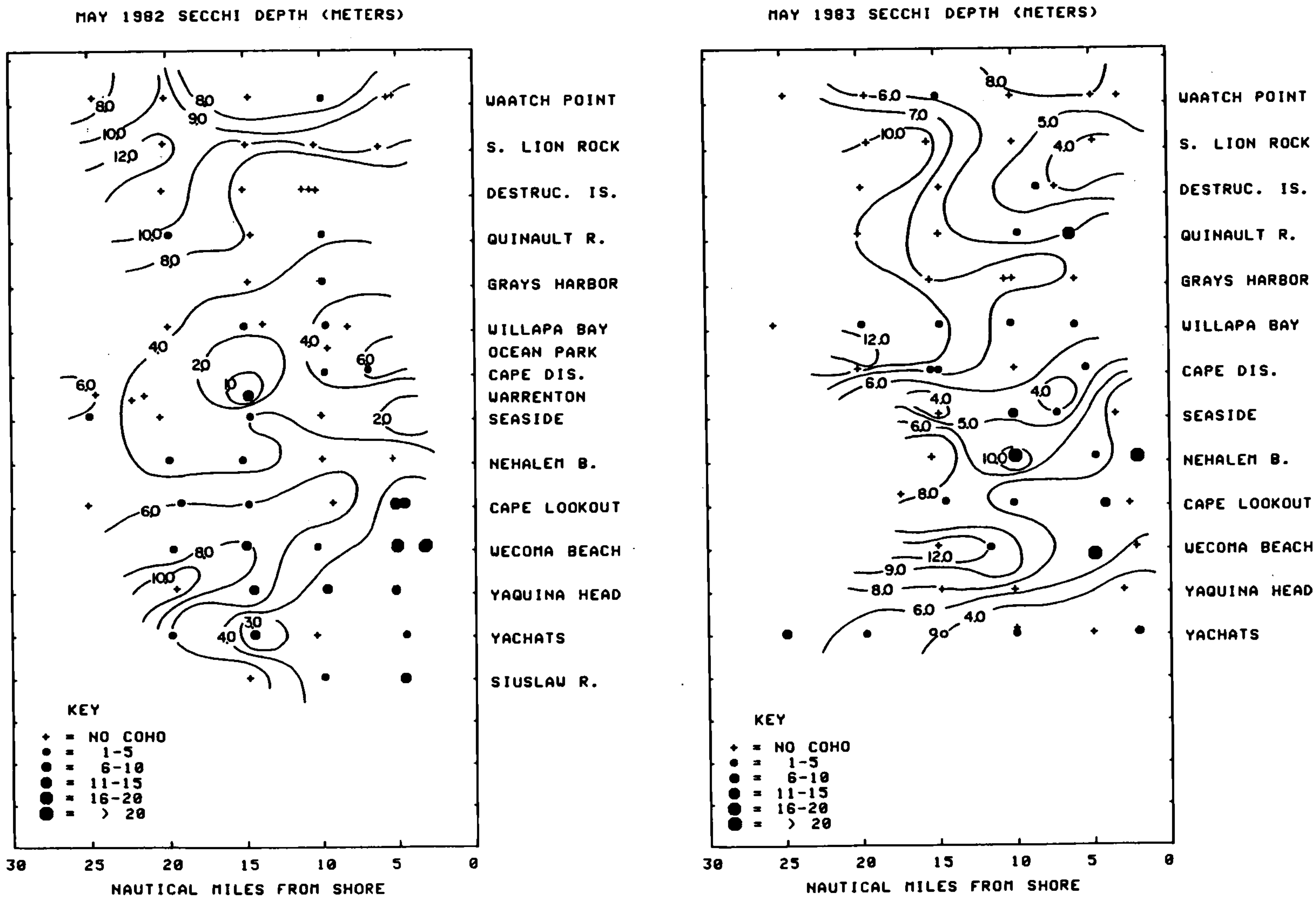


Figure 6. Secchi Depth for May 1982 and 1983.

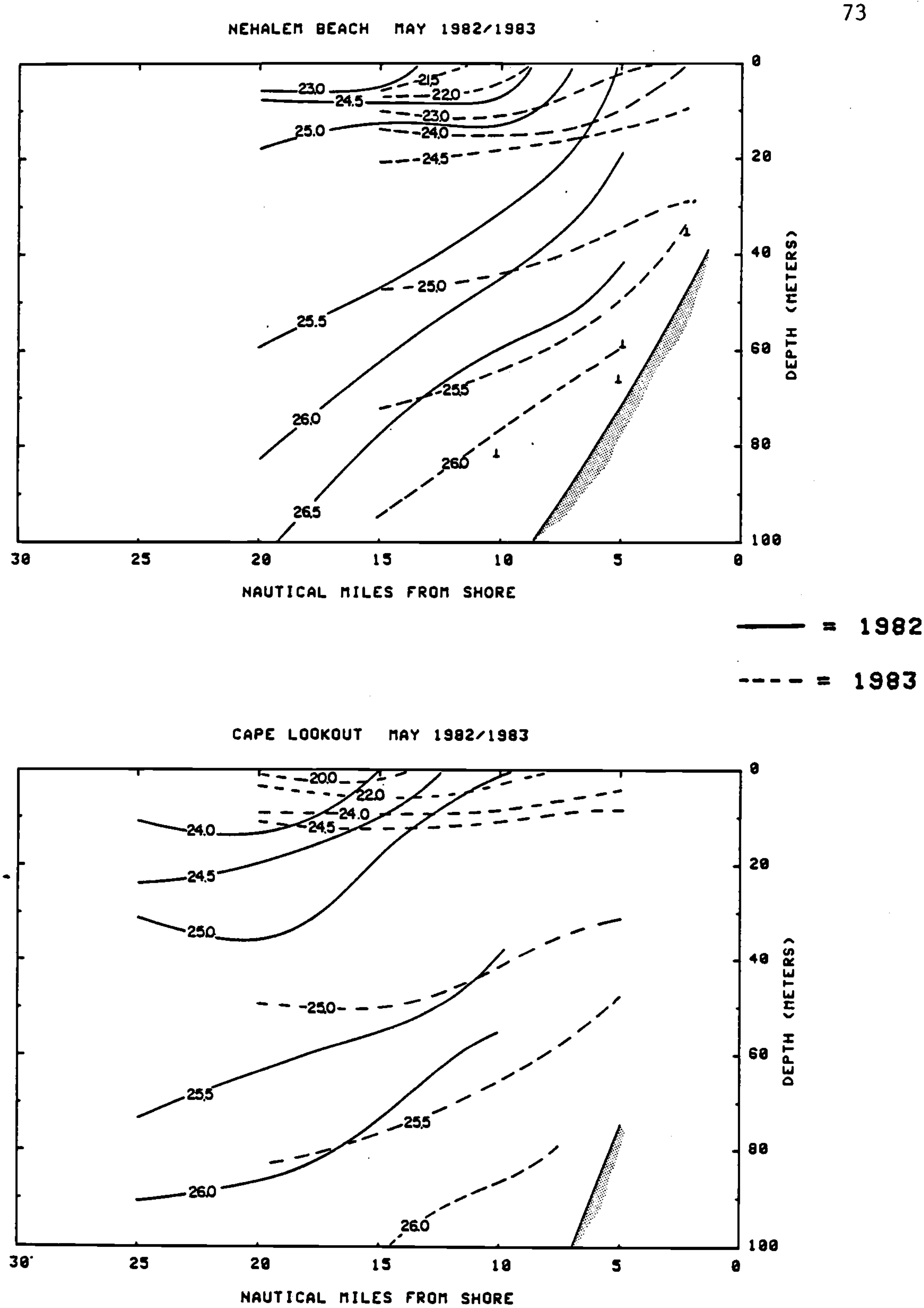


Figure 7. Sigma-t Cross-sections for Nehalem Beach May 30, 1982 and May 23, 1983, and Cape Lookout May 30-31, 1982 and May 23-24, 1983.

Figure 8. Daily Bakun Upwelling Index (DBUI) for June 1982 (squares) and 1983 (filled circles). Arrows indicate beginning and ending dates of respective cruises.

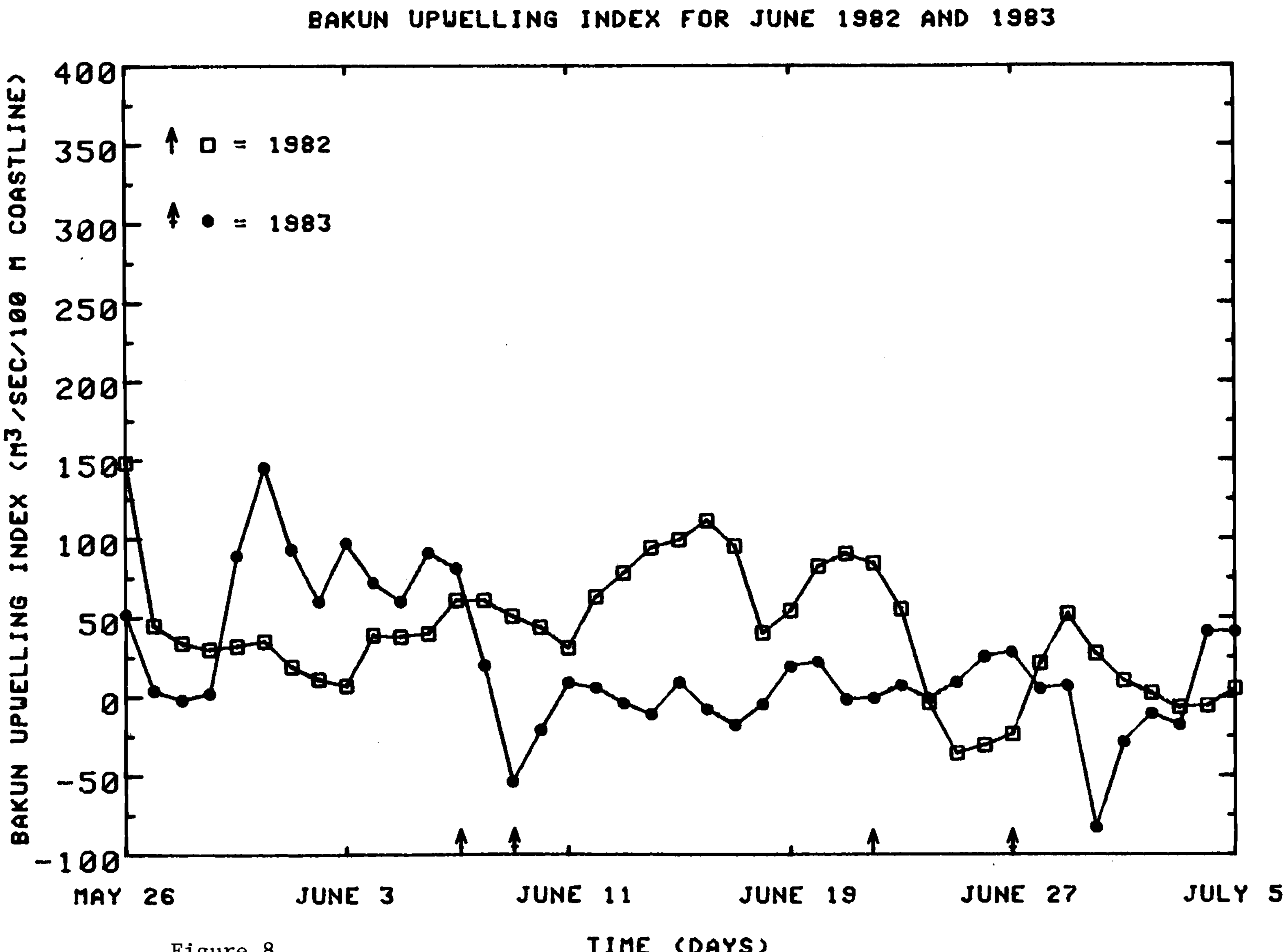

BAKUN UPWELLING INDEX FOR JUNE 1982 AND 1983
BAKUN UPWELLING INDEX (M3/SEC/100 M COASTLINE)
□ = 1982
● = 1983
400
350
300
250
200
150
100
50
0
-50
-100
MAY 26
JUNE 3
JUNE 11
JUNE 19
JUNE 27
JULY 5
TIME (DAYS)

Figure 8.

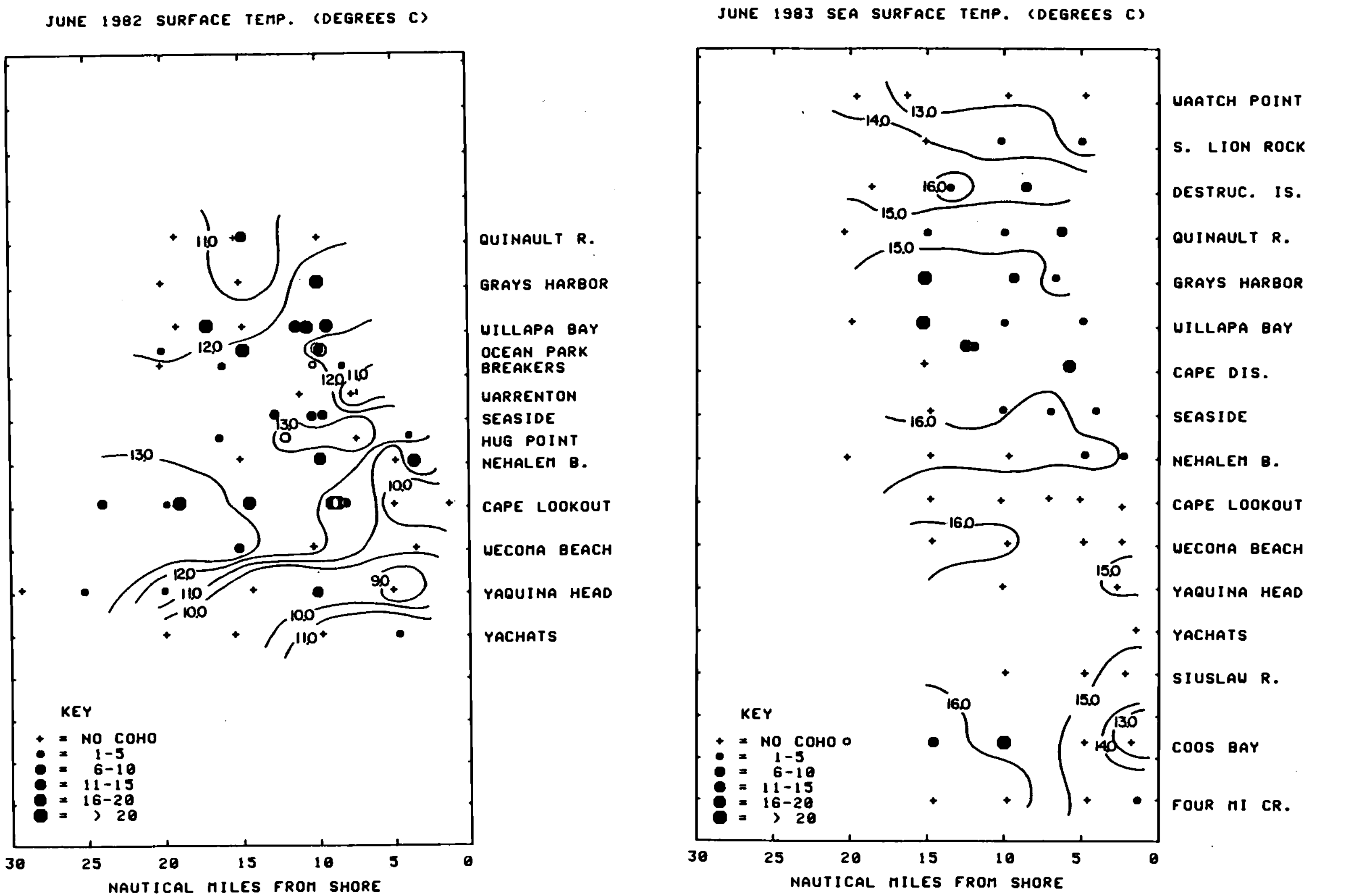


Figure 9. Sea Surface Temperatures (SST's) for June 1982 and 1983.

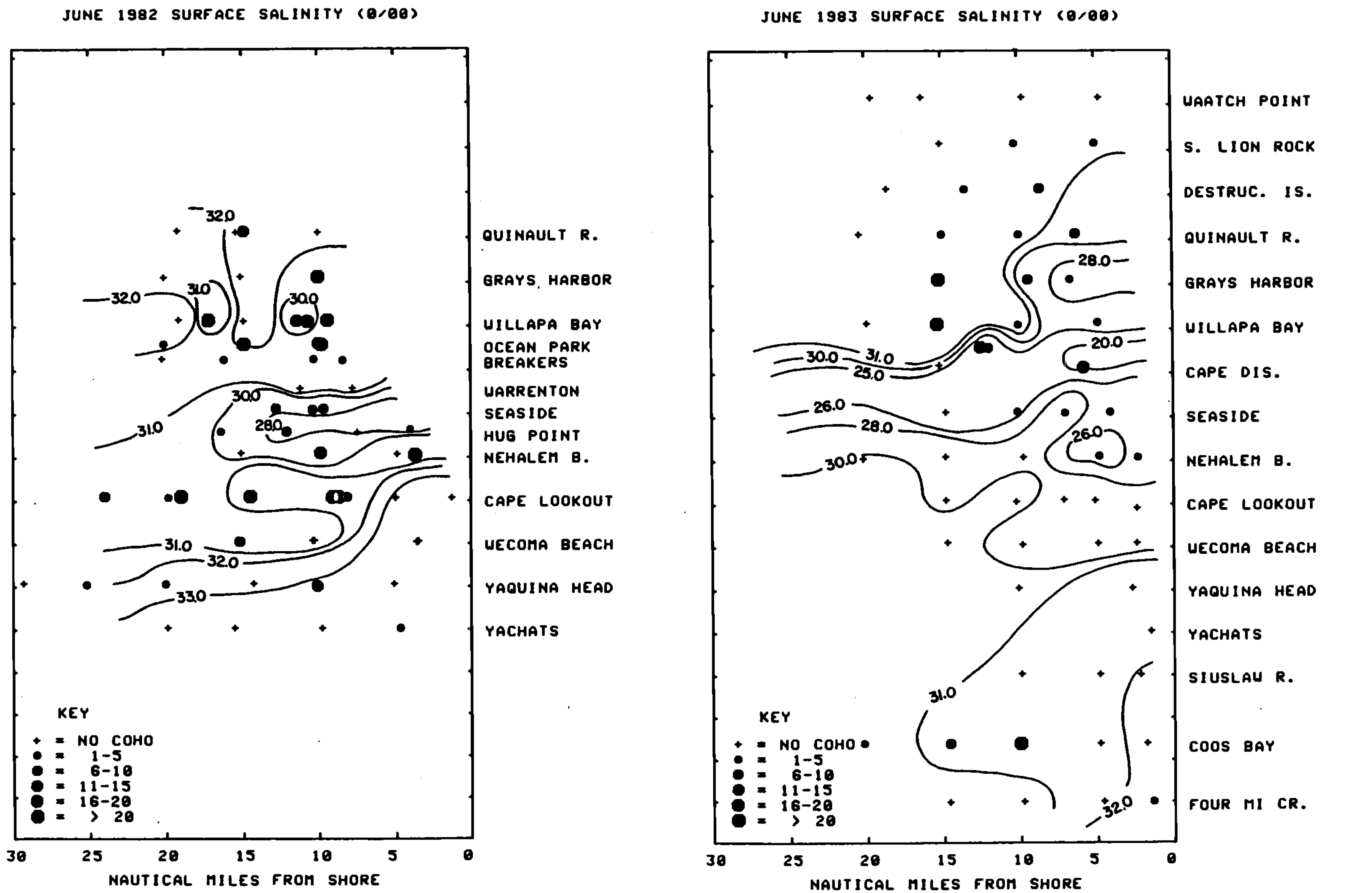


Figure 10. Surface Salinity for June 1982 and 1983.

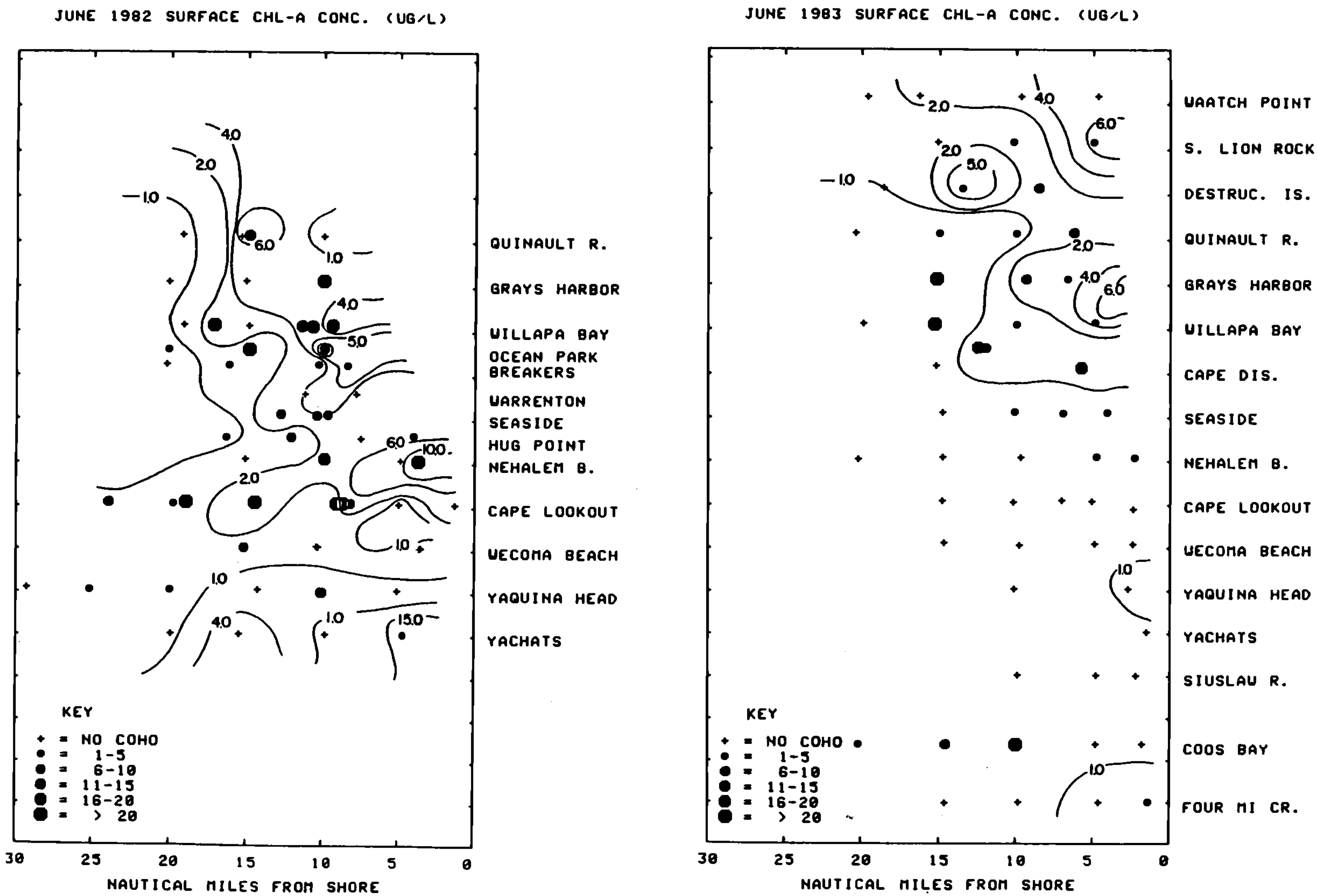


Figure 11. Surface Chlorophyll-a Concentration for June 1982 and 1983.

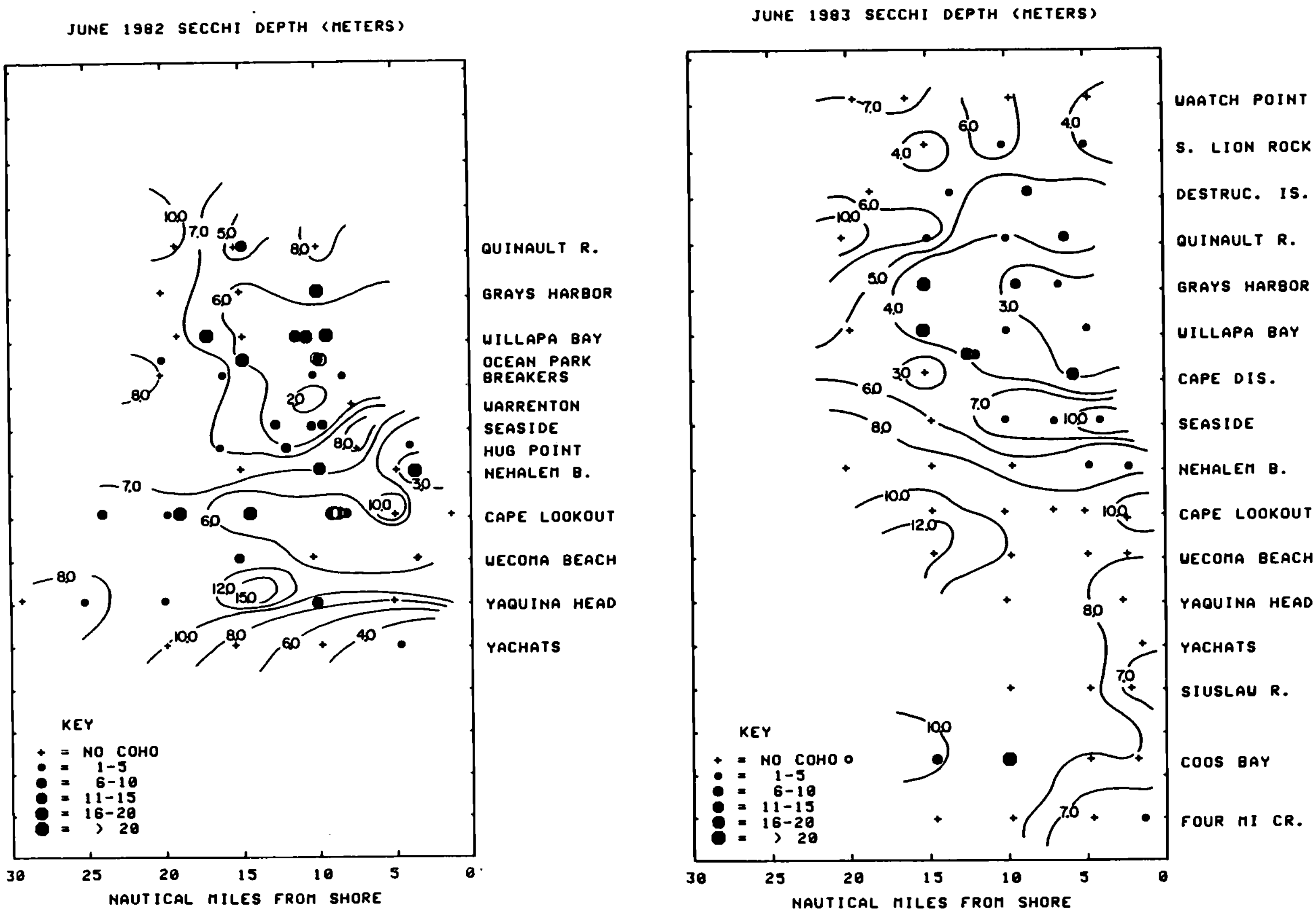


Figure 12. Secchi Depth for June 1982 and 1983.

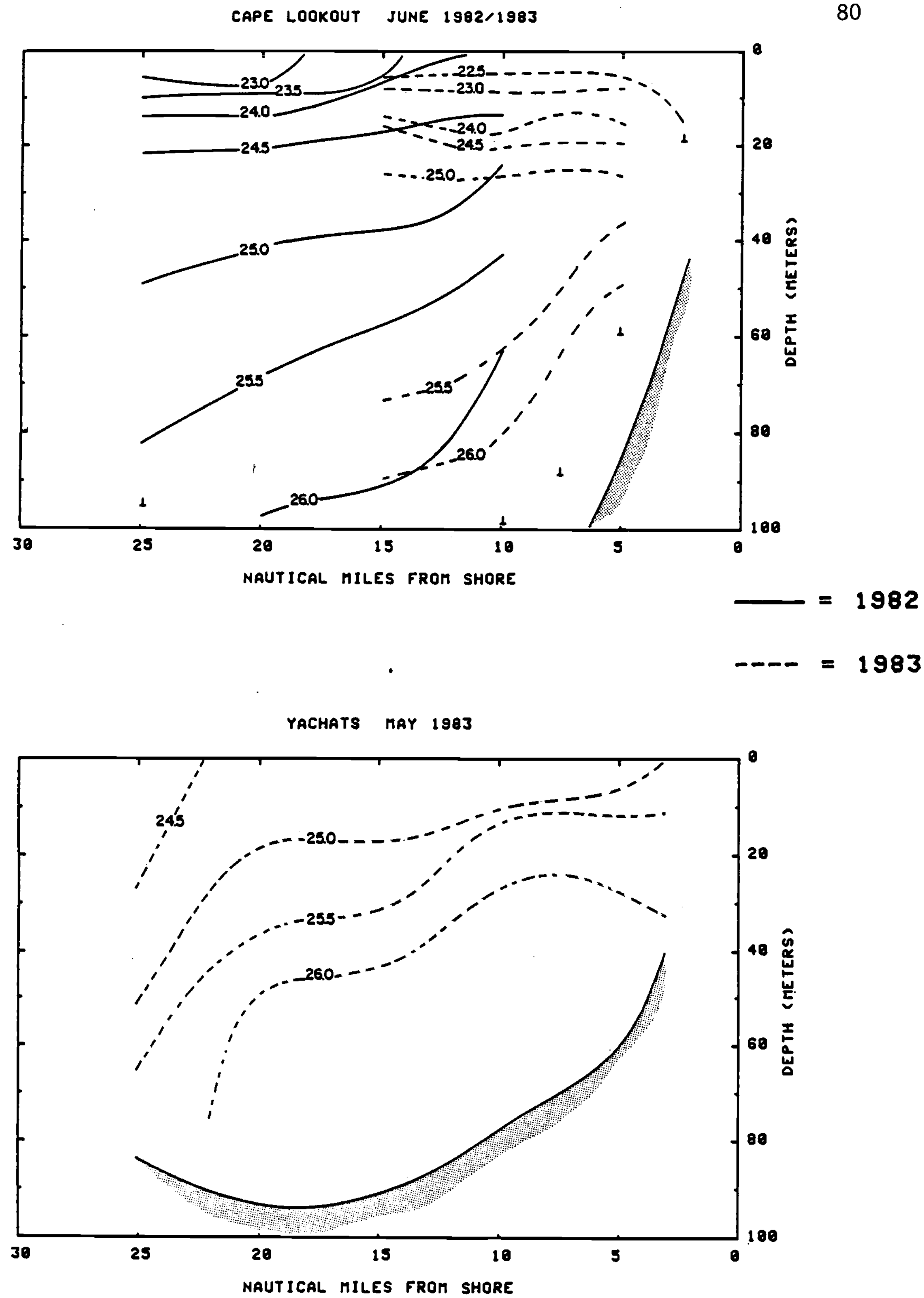


Figure 13. Sigma-t Cross-sections for Cape Lookout June 21-22, 1982 and June 24, 1983, and Yachats May 26-27, 1983.

Figure 14. Daily Bakun Upwelling Index (DBUI) for September 1982 (squares) and 1983 (filled circles). Arrows indicate beginning and ending dates of respective cruises.

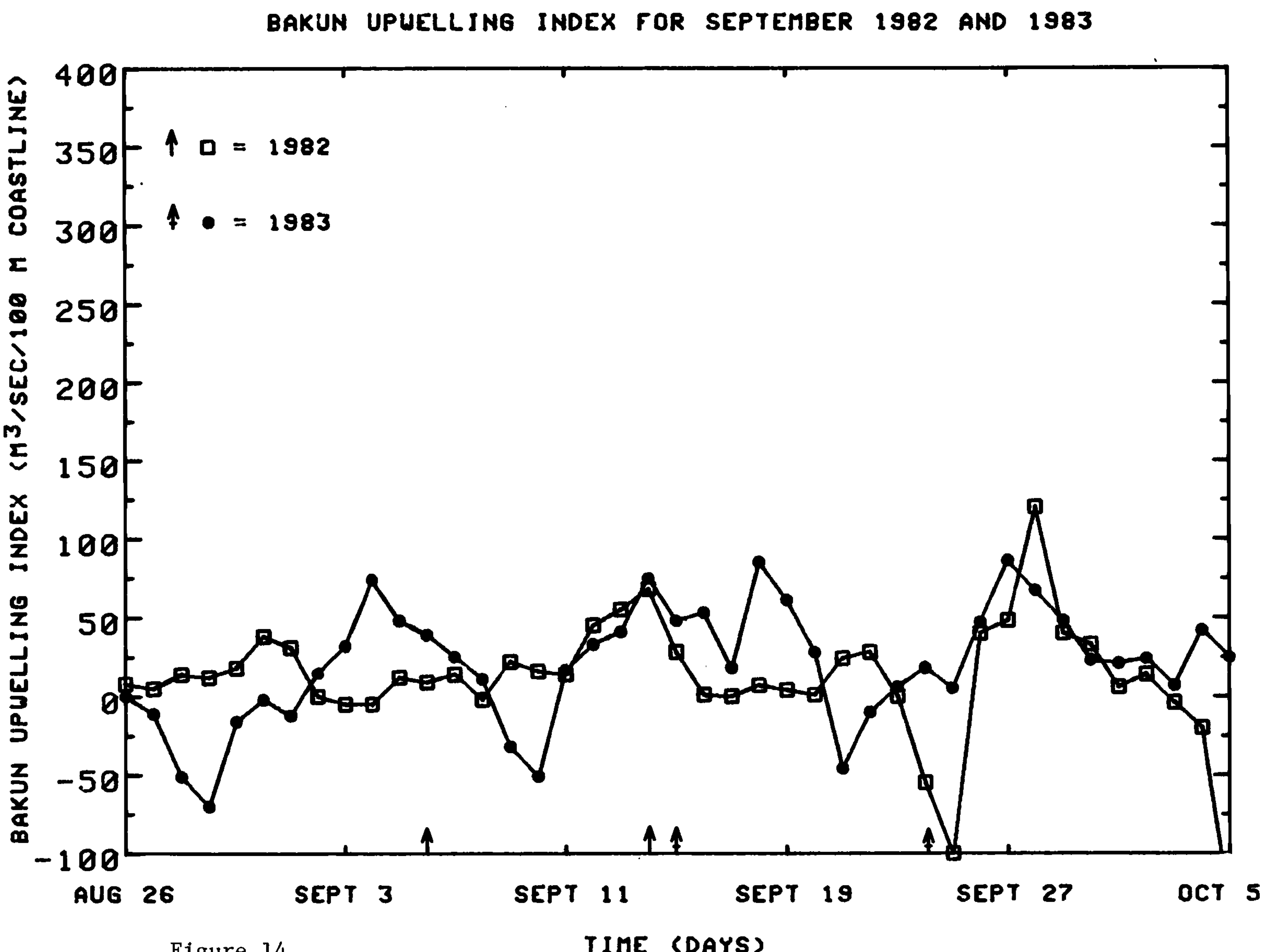

BAKUN UPWELLING INDEX FOR SEPTEMBER 1982 AND 1983
BAKUN UPWELLING INDEX (M3/SEC/100 M COASTLINE)
400
350
300
250
200
150
100
50
0
-50
-100
□ = 1982
● = 1983
AUG 26
SEPT 3
SEPT 11
SEPT 19
SEPT 27
OCT 5
TIME (DAYS)

Figure 14.

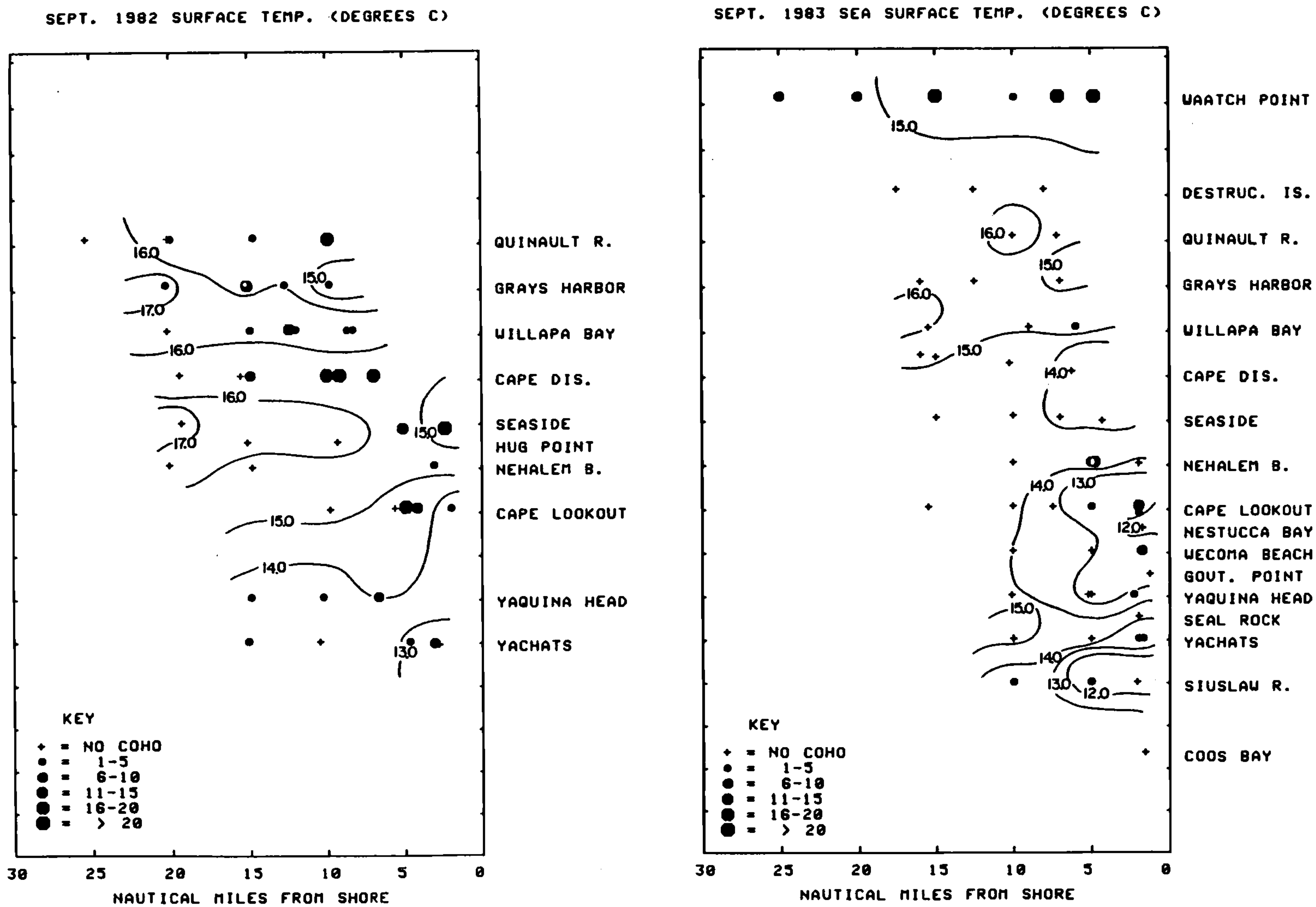


Figure 15. Sea Surface Temperatures (SST's) for September 1982 and 1983.

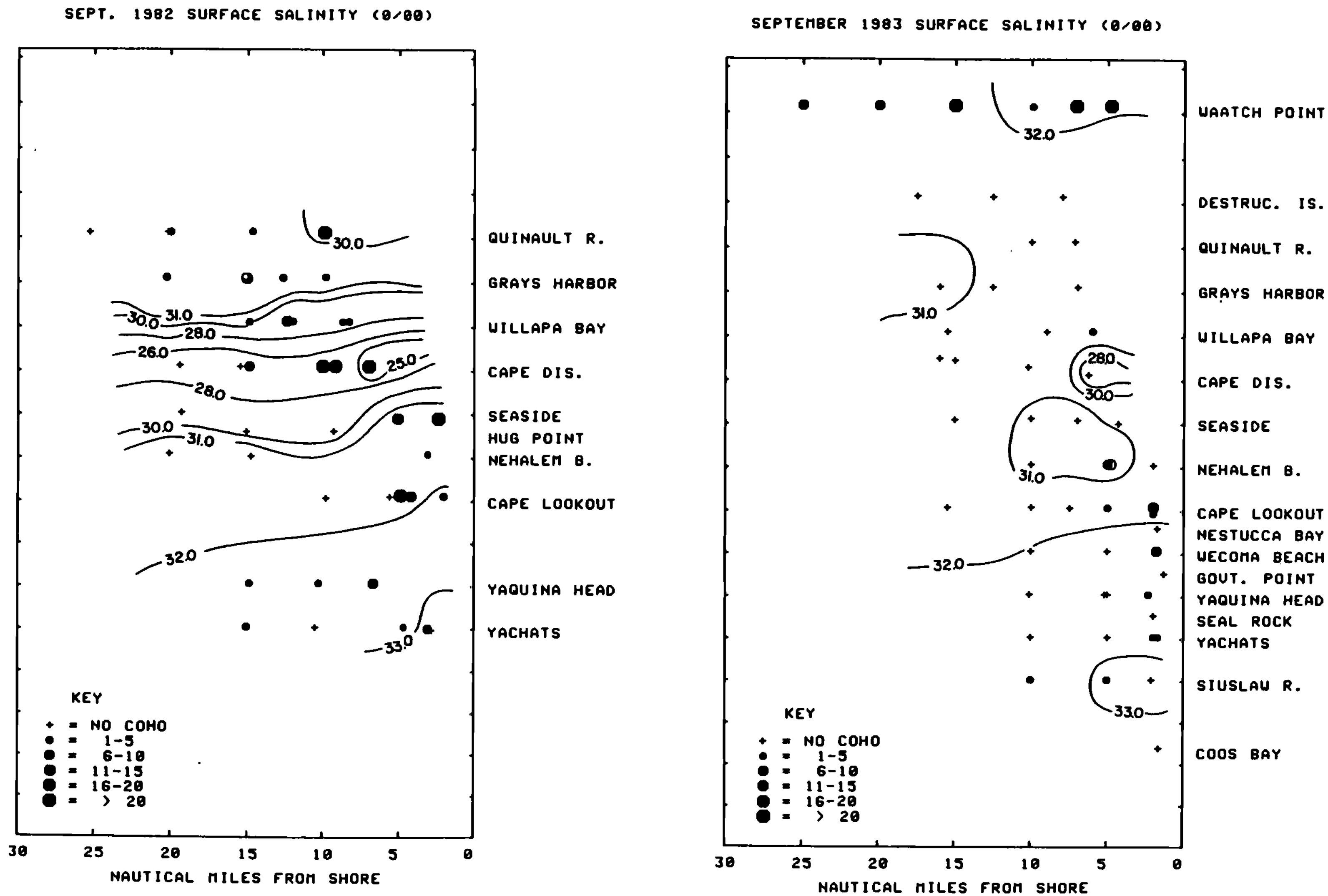


Figure 16. Surface Salinity for September 1982 and 1983.

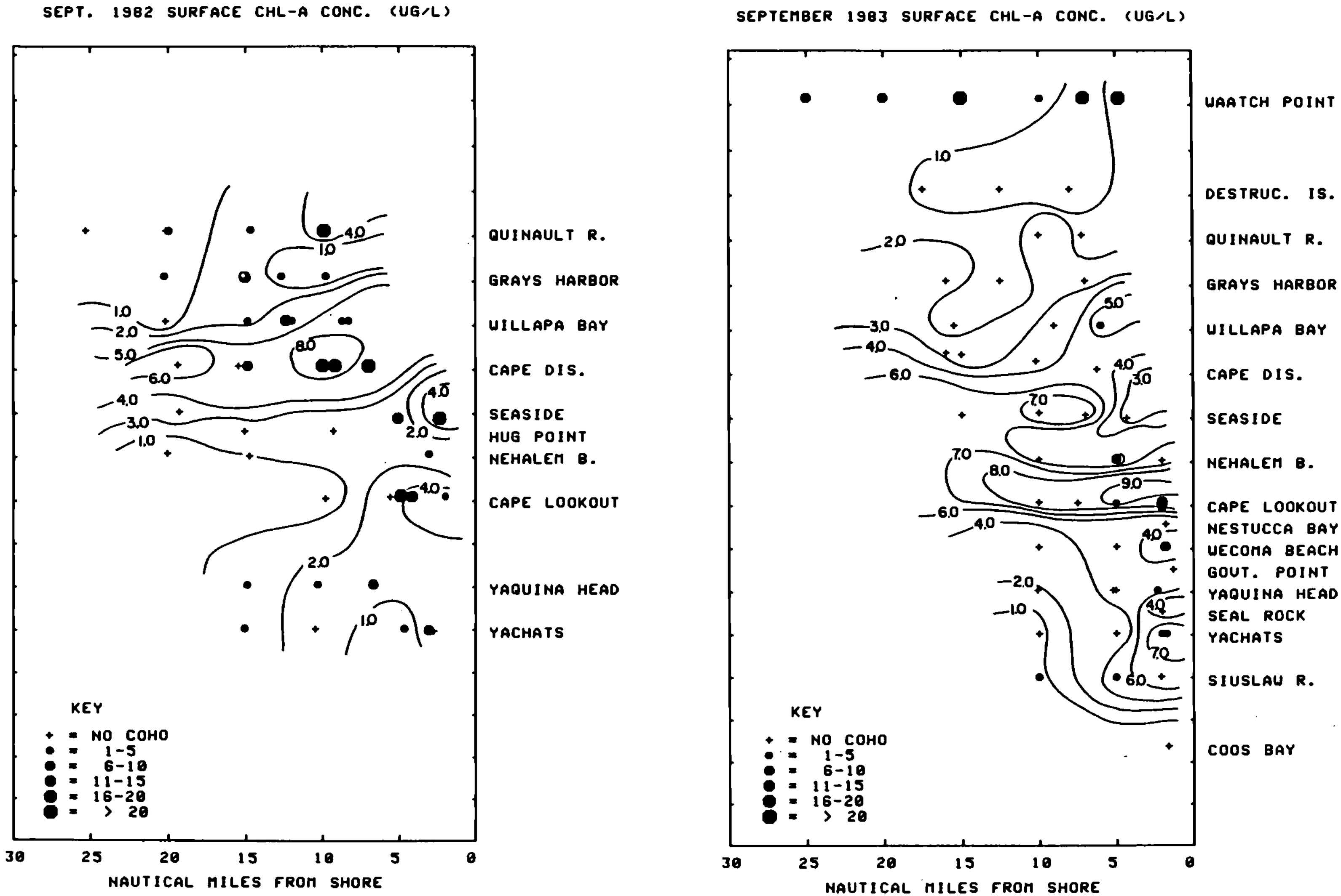


Figure 17. Surface Chlorophyll-a Concentrations for September 1982 and 1983.

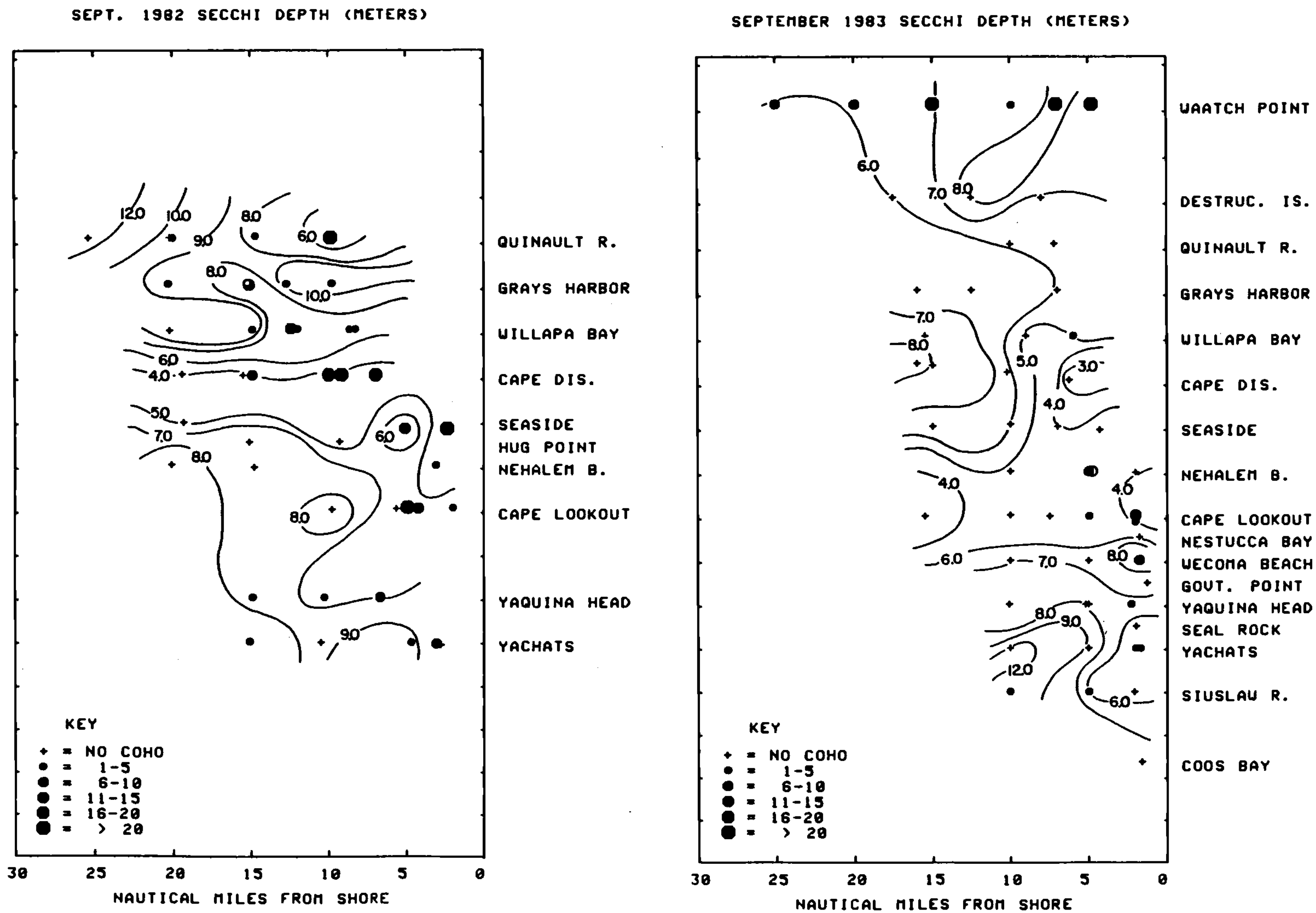


Figure 18. Secchi Depth for September 1982 and 1983.

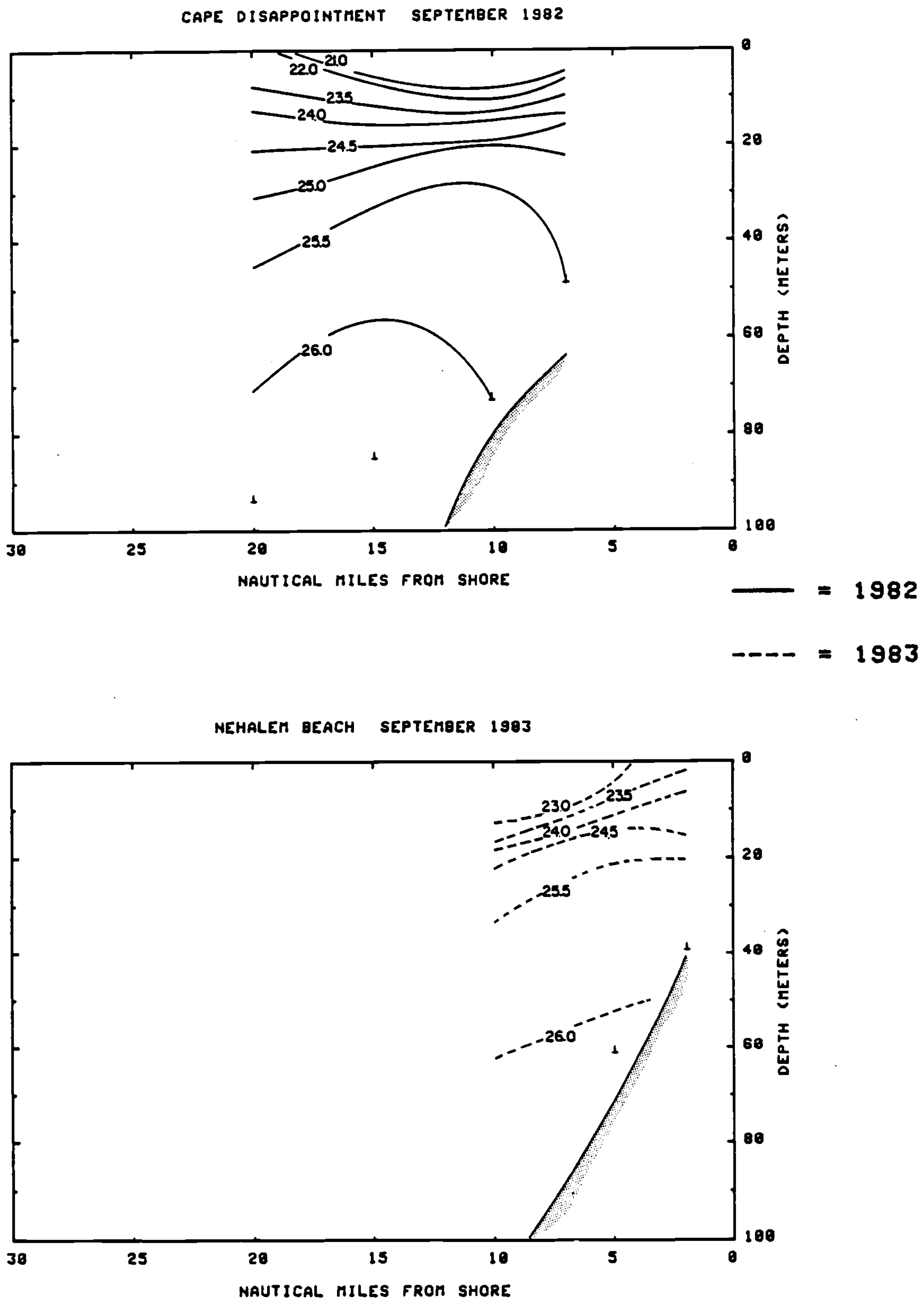
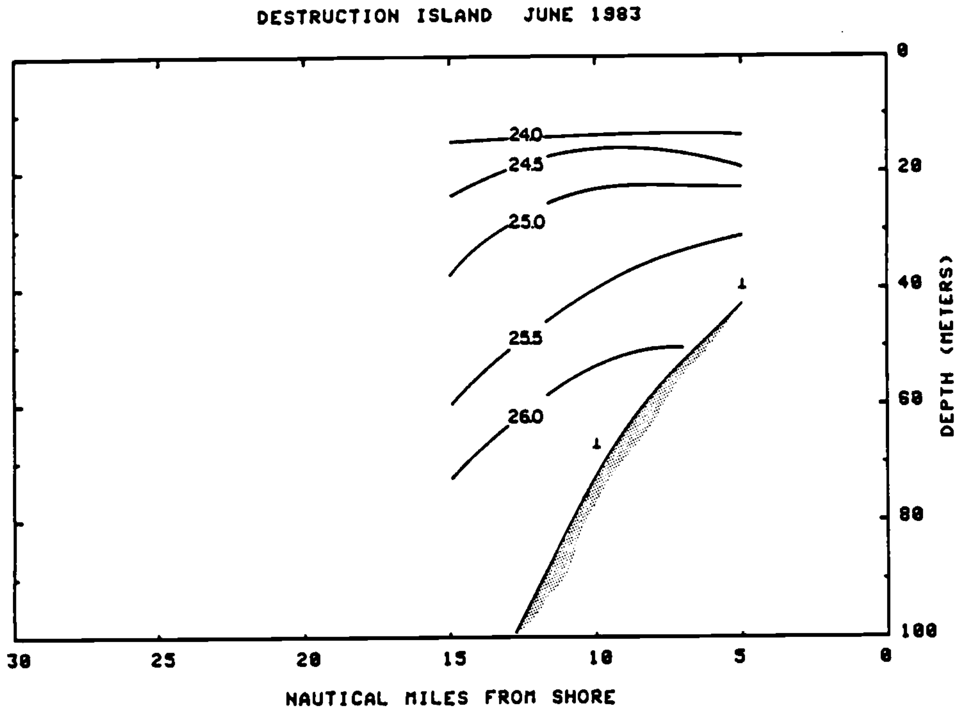


Figure 19. Sigma-t Cross-sections for Cape Disappointment September 6-7, 1982, and Nehalem Beach September 20, 1983.



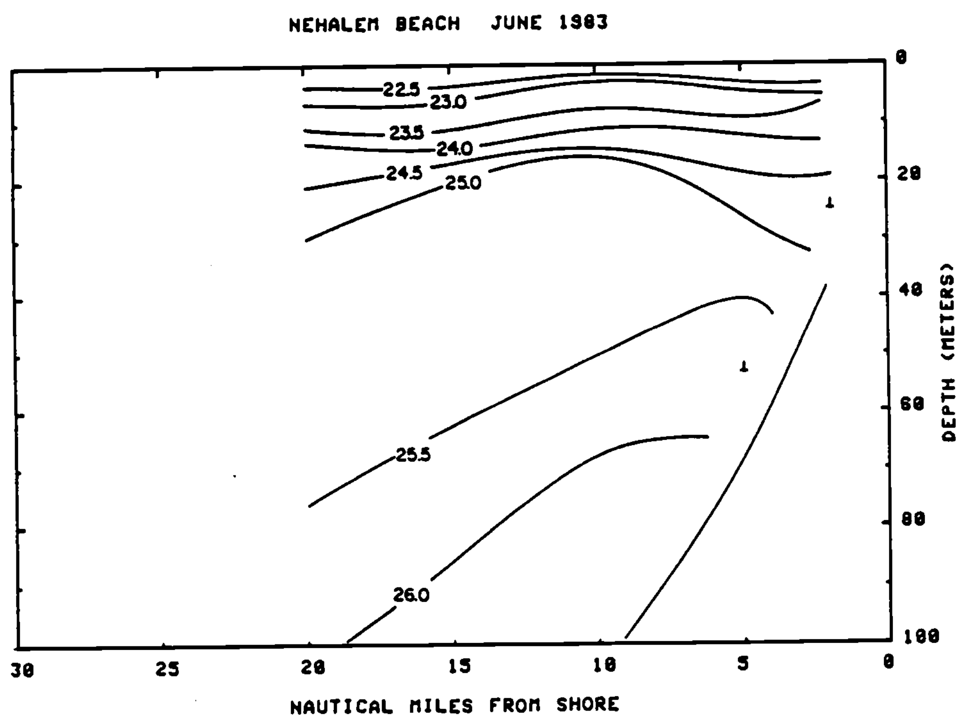


Figure 20. Sigma-t Cross-sections for Destruction Island June 15, 1983, and Nehalem Beach June 23, 1983.

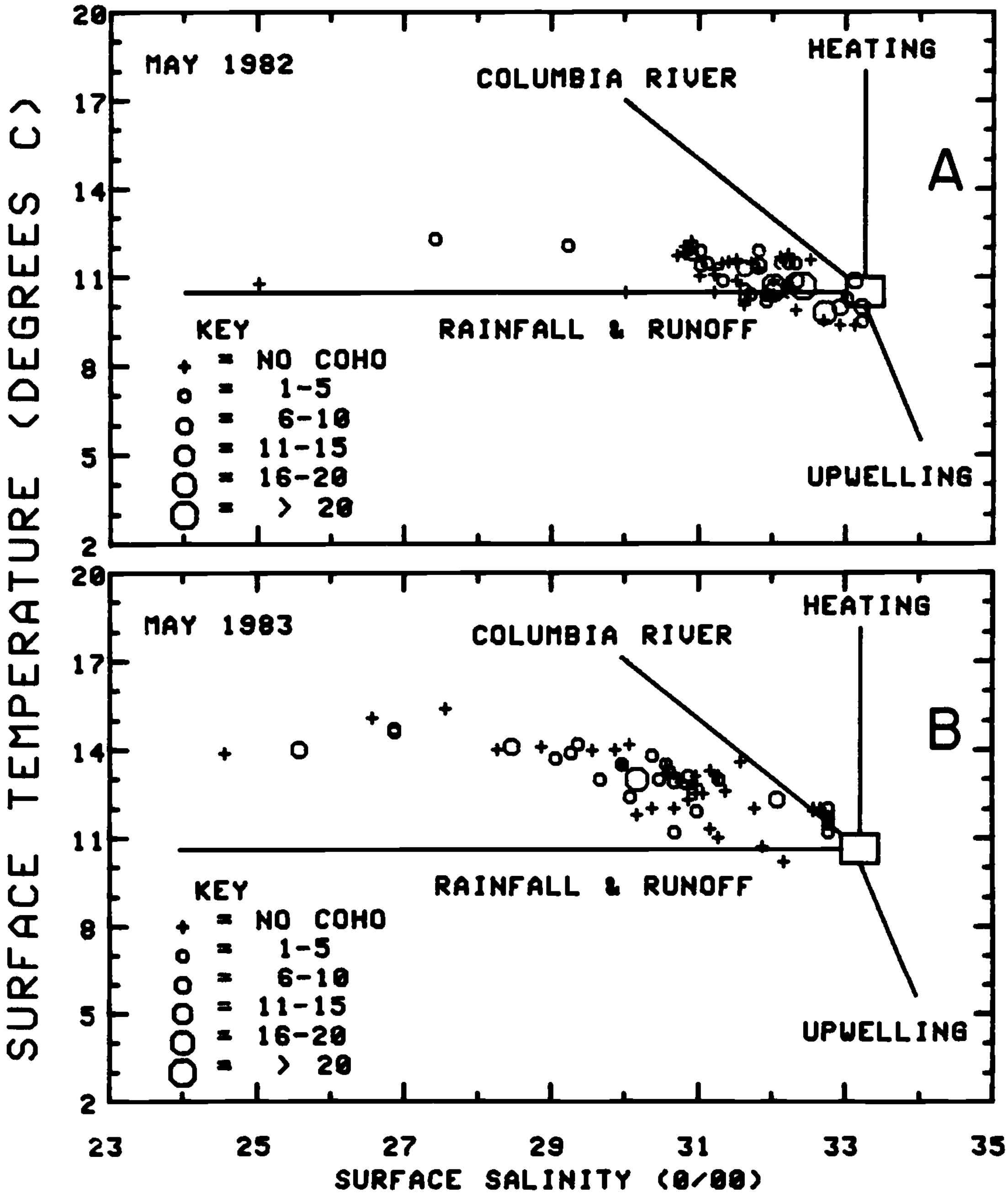


Figure 21. Pattullo-Denner Diagram for May 1982 and 1983.

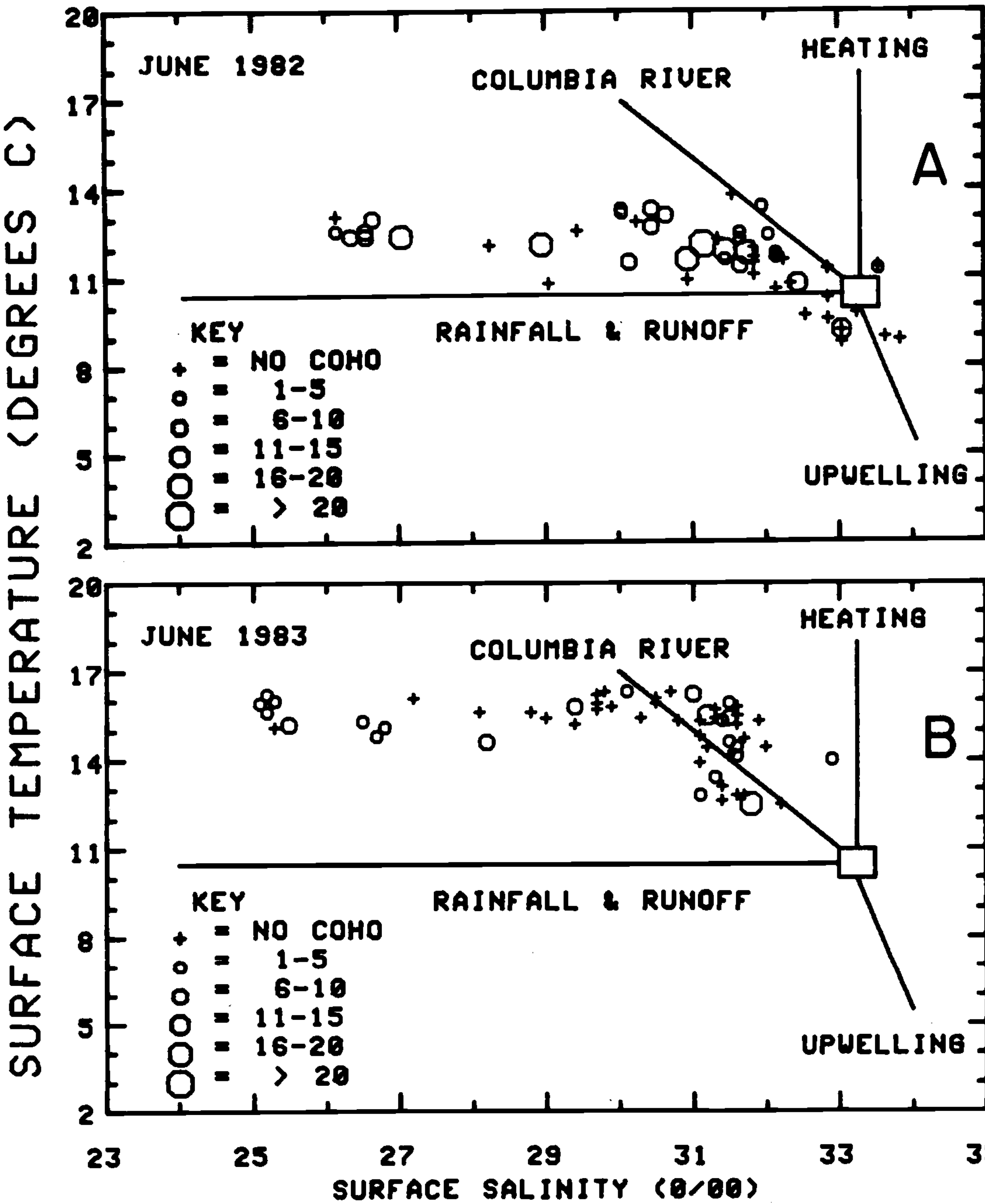


Figure 22. Pattullo-Denner Diagram for June 1982 and 1983.

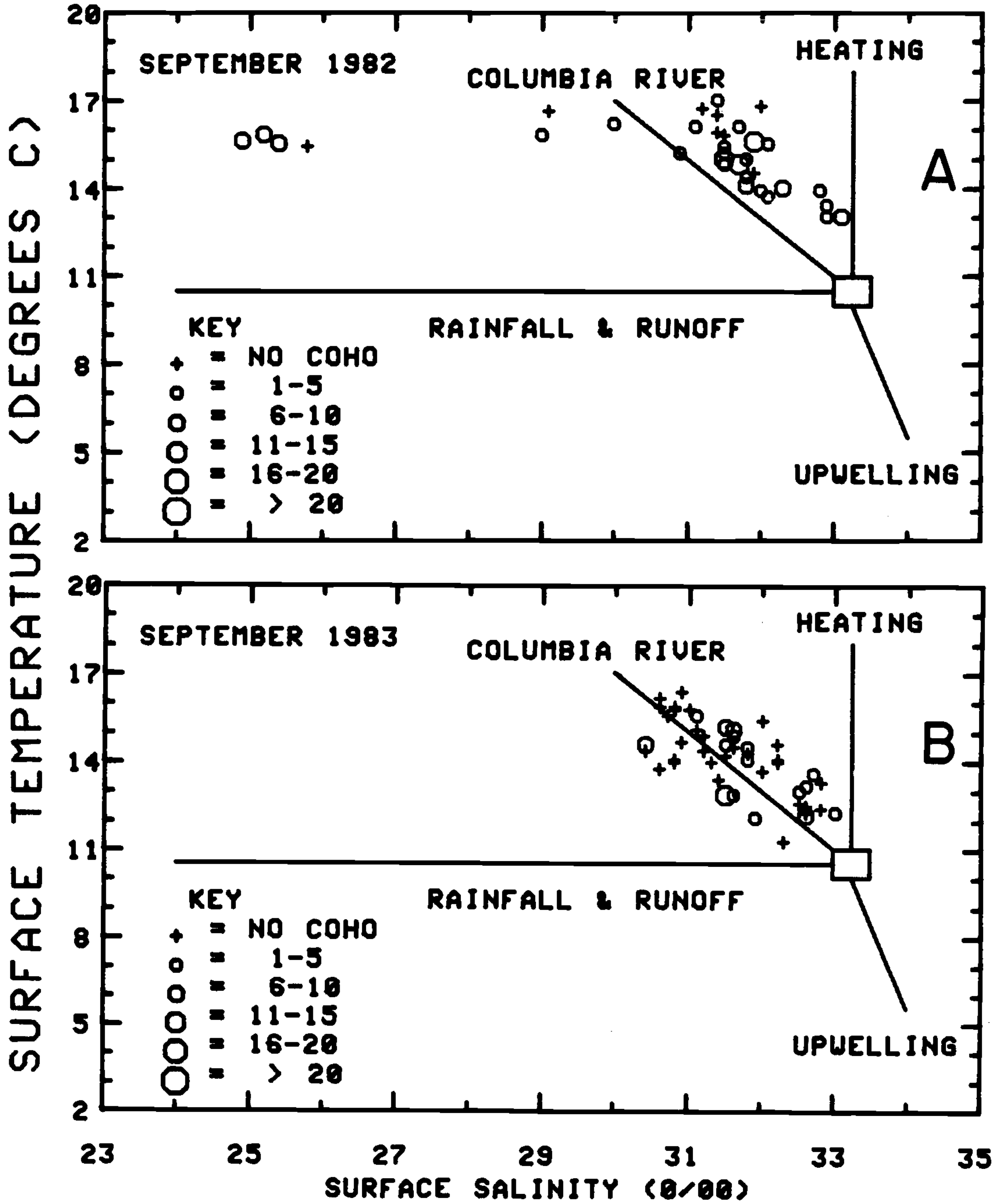


Figure 23. Pattullo-Denner Diagram for September 1982 and 1983.

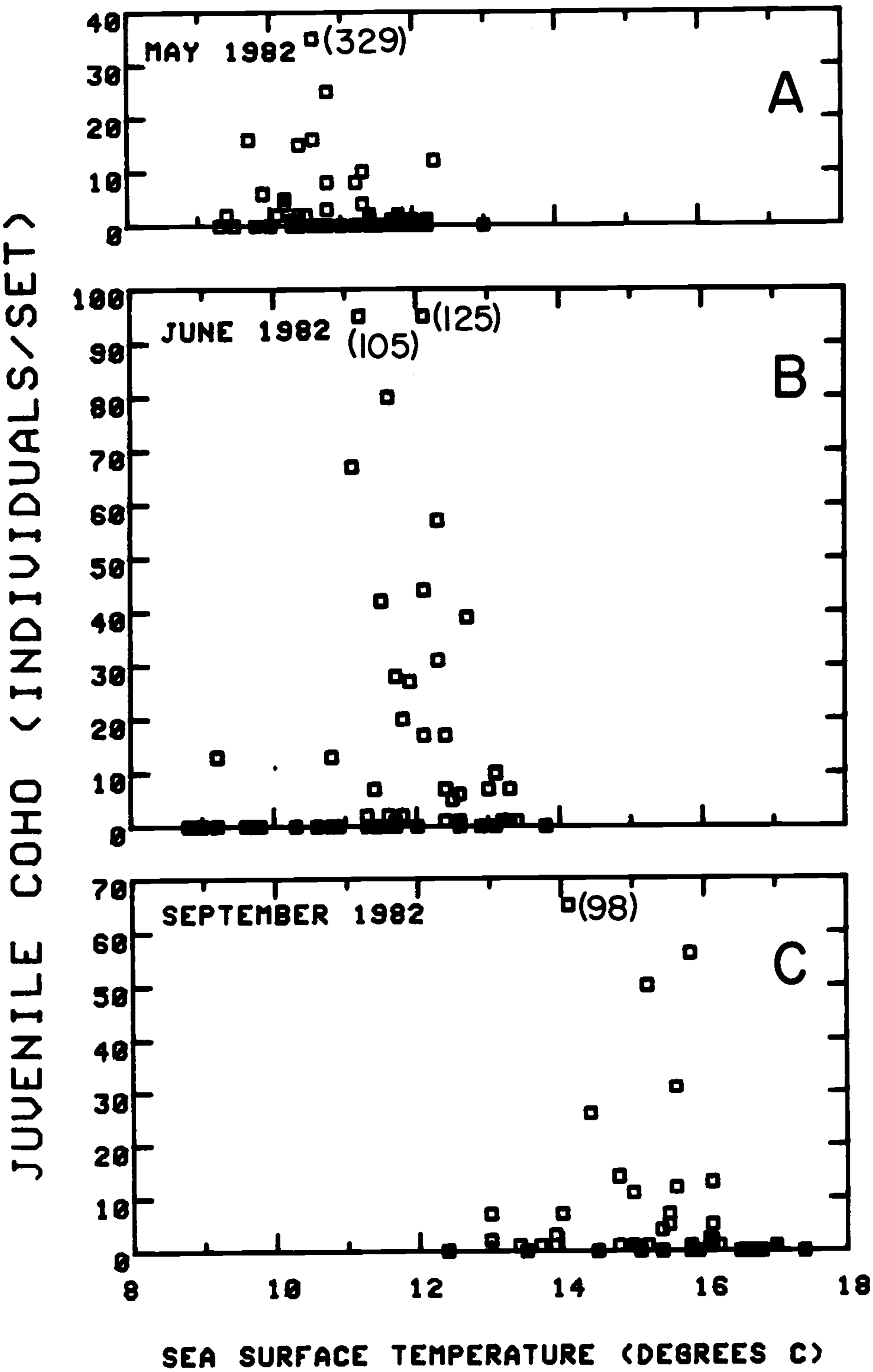


Figure 24. Catch per Set versus Sea Surface Temperature (SST) for May, June, and September 1982.

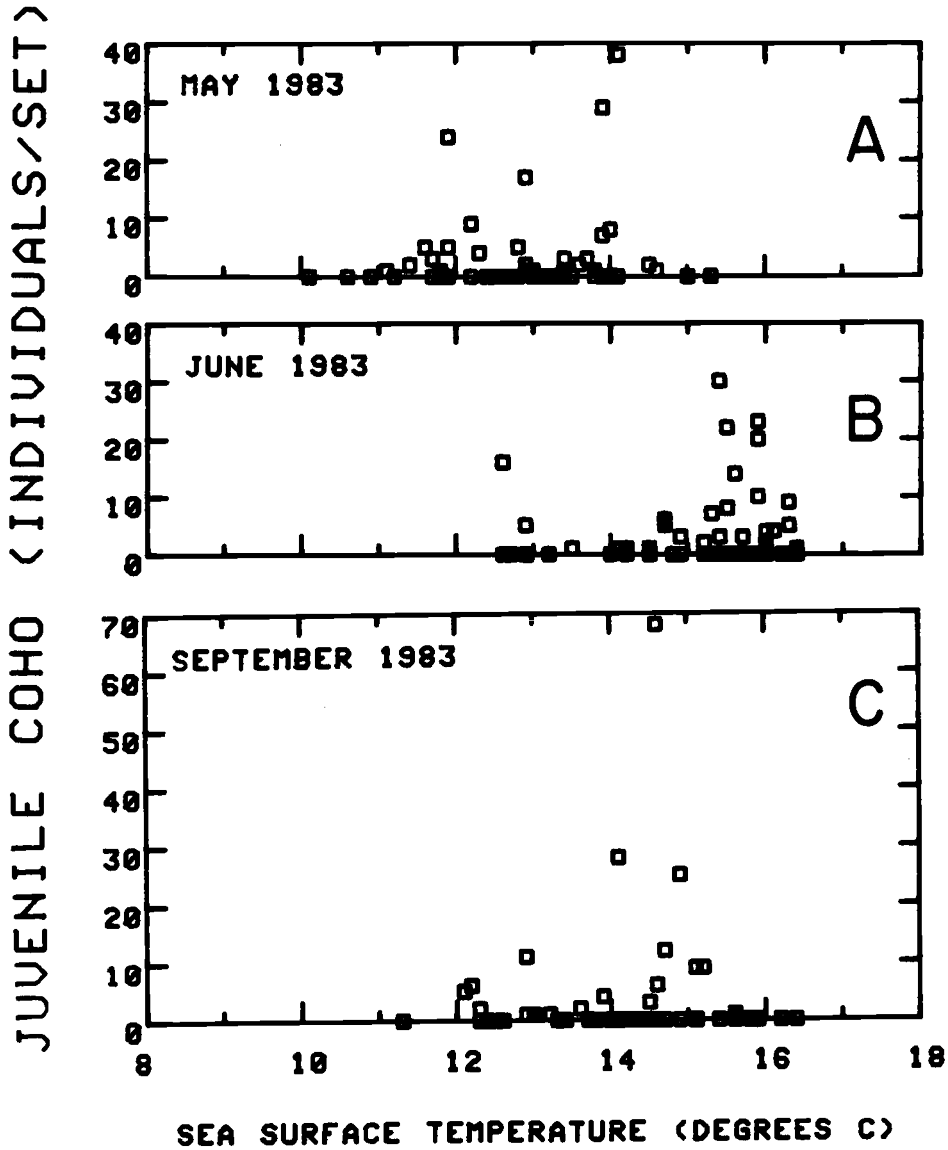


Figure 25. Catch per Set versus Sea Surface Temperature (SST) for May, June, and September 1983.

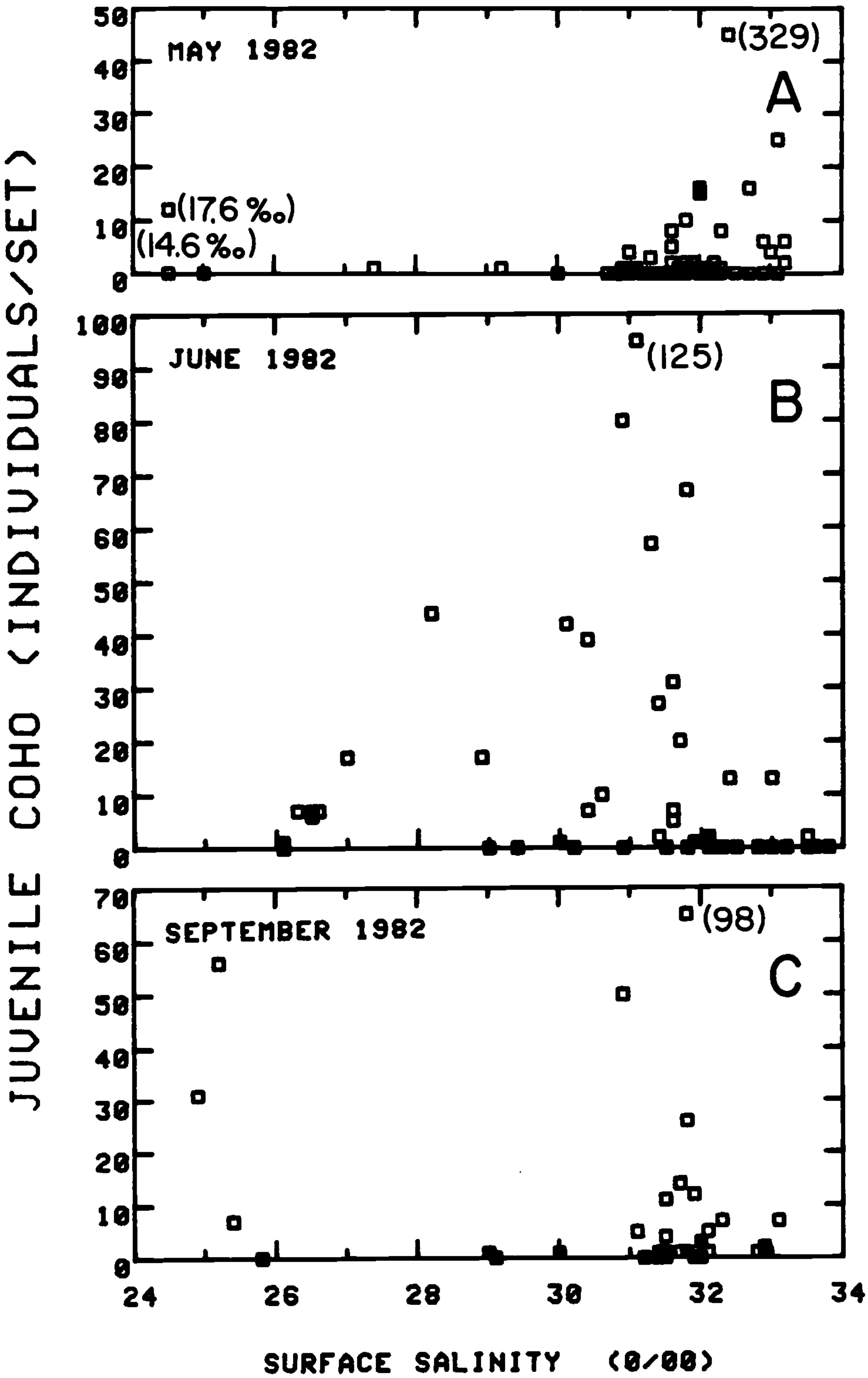


Figure 26. Catch per Set versus Surface Salinity for May, June, and September 1982.

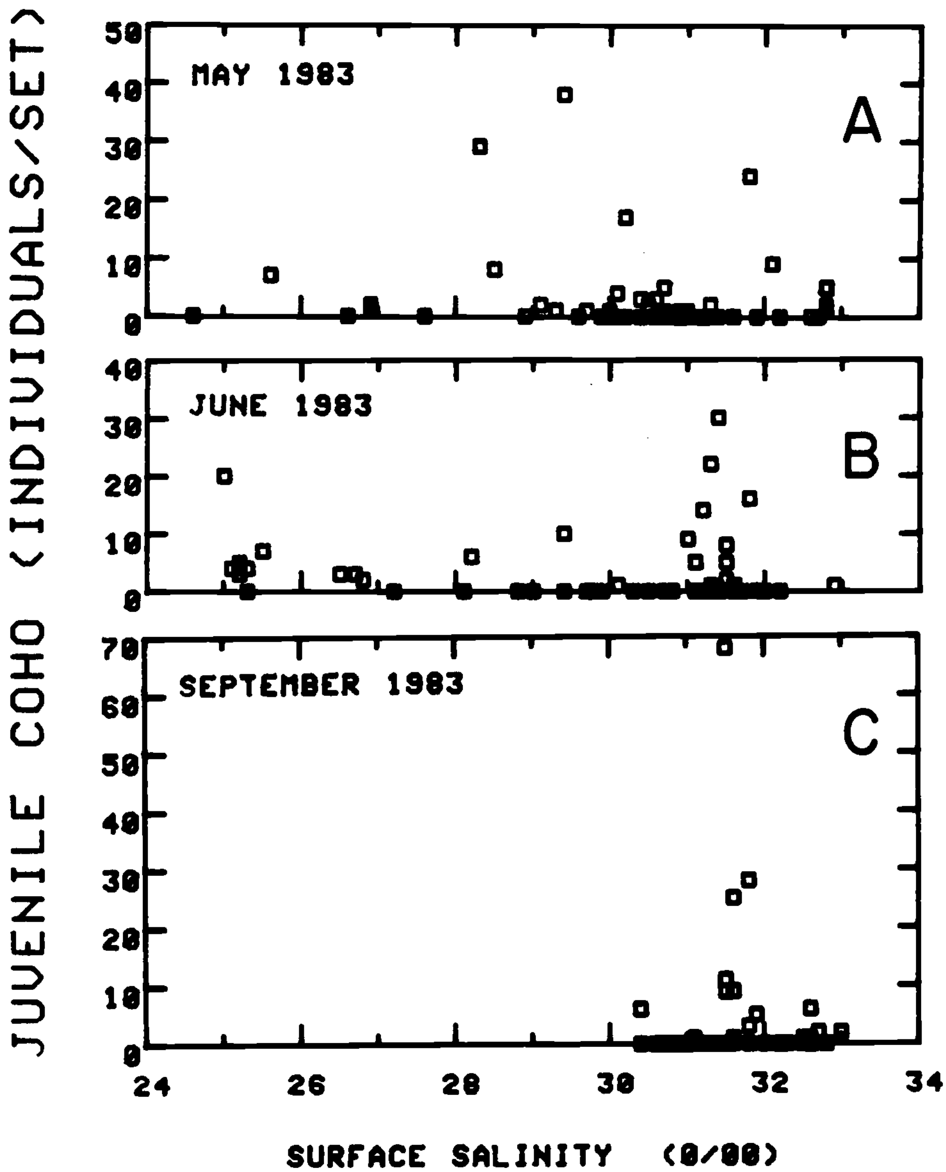


Figure 27. Catch per Set versus Surface Salinity for May, June, and September 1983.

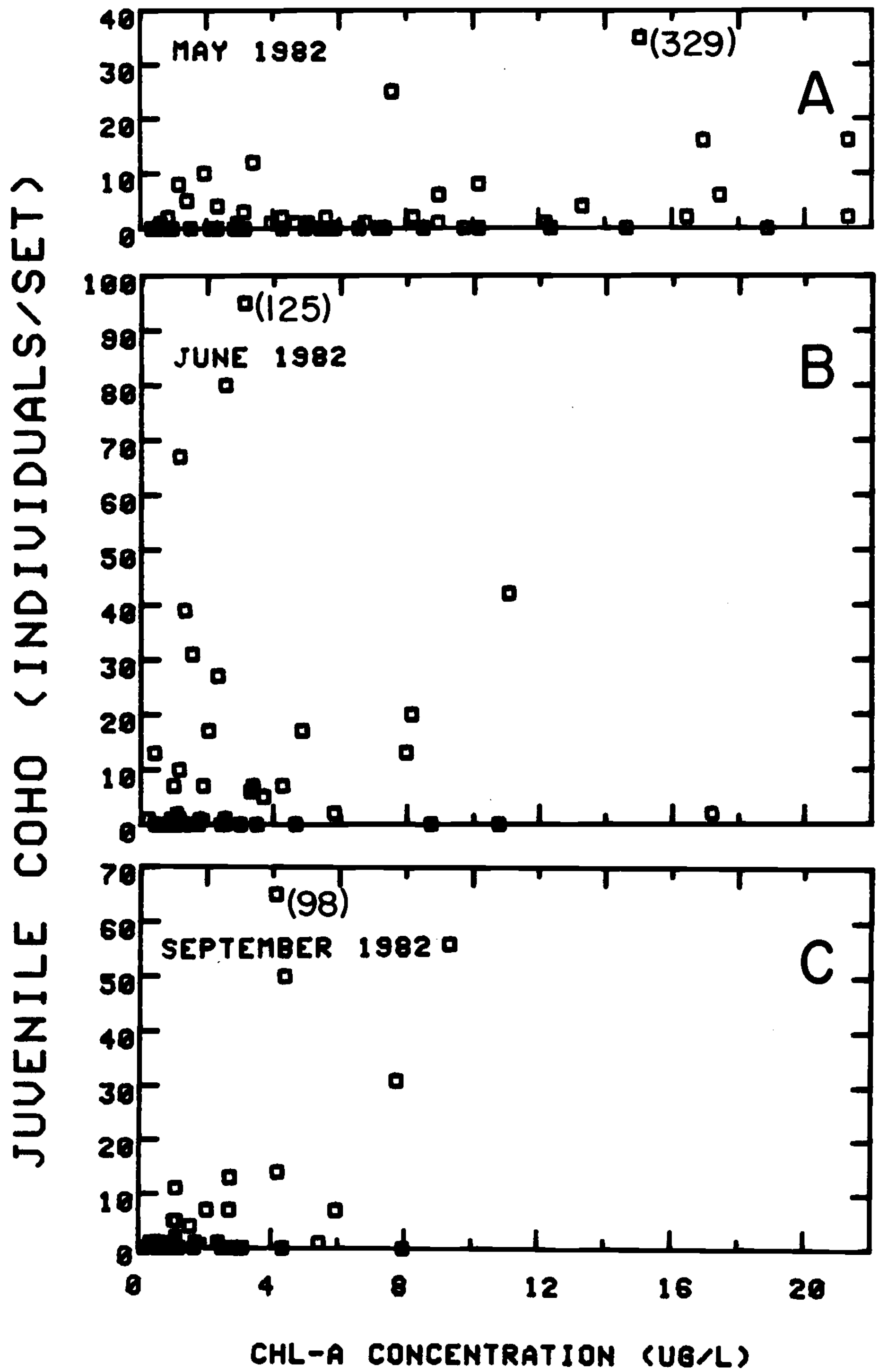


Figure 28. Catch per Set versus Surface Chlorophyll-a Concentrations for May, June, and September 1982.

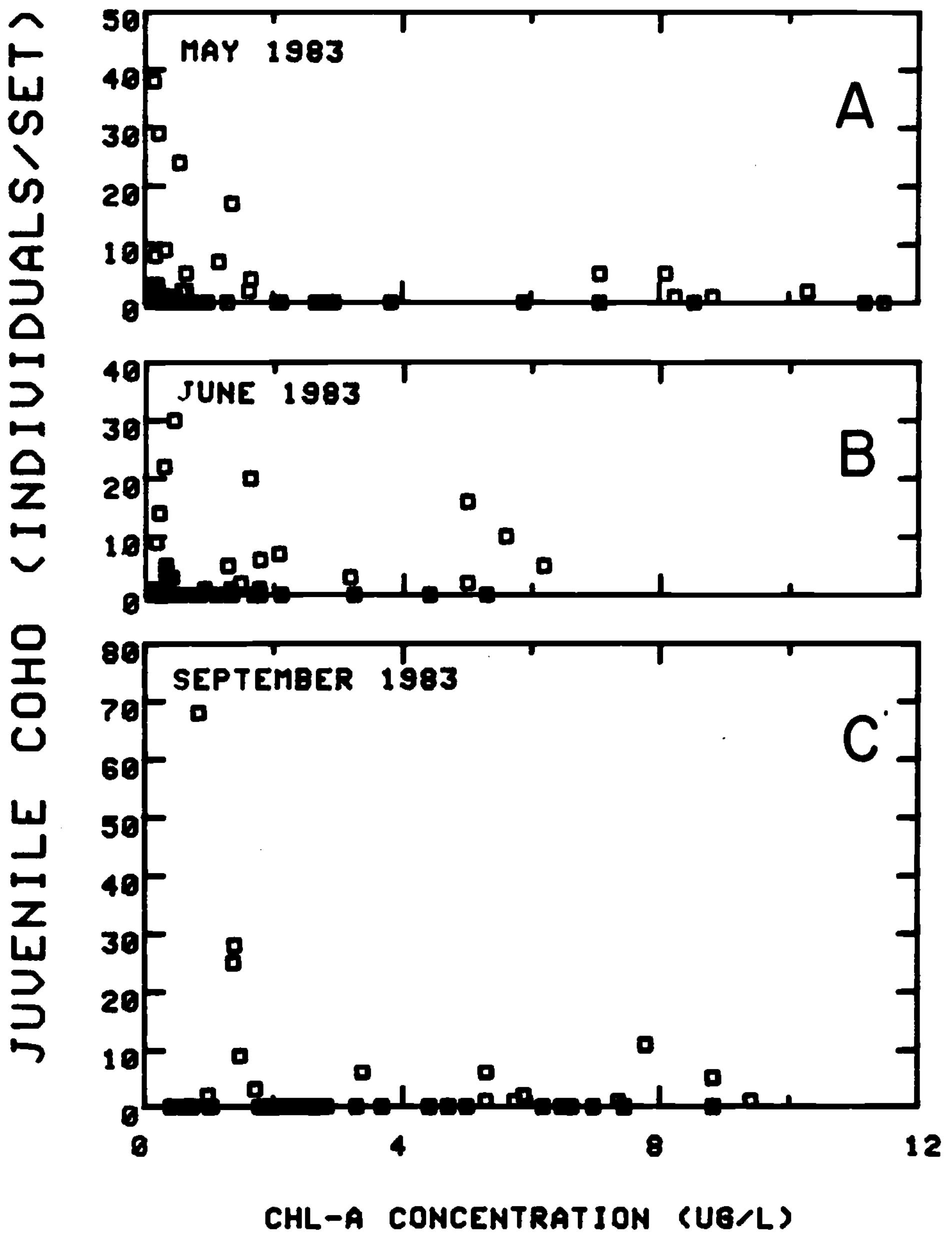


Figure 29. Catch per Set versus Surface Chlorophyll-a Concentrations for May, June, and September 1983.

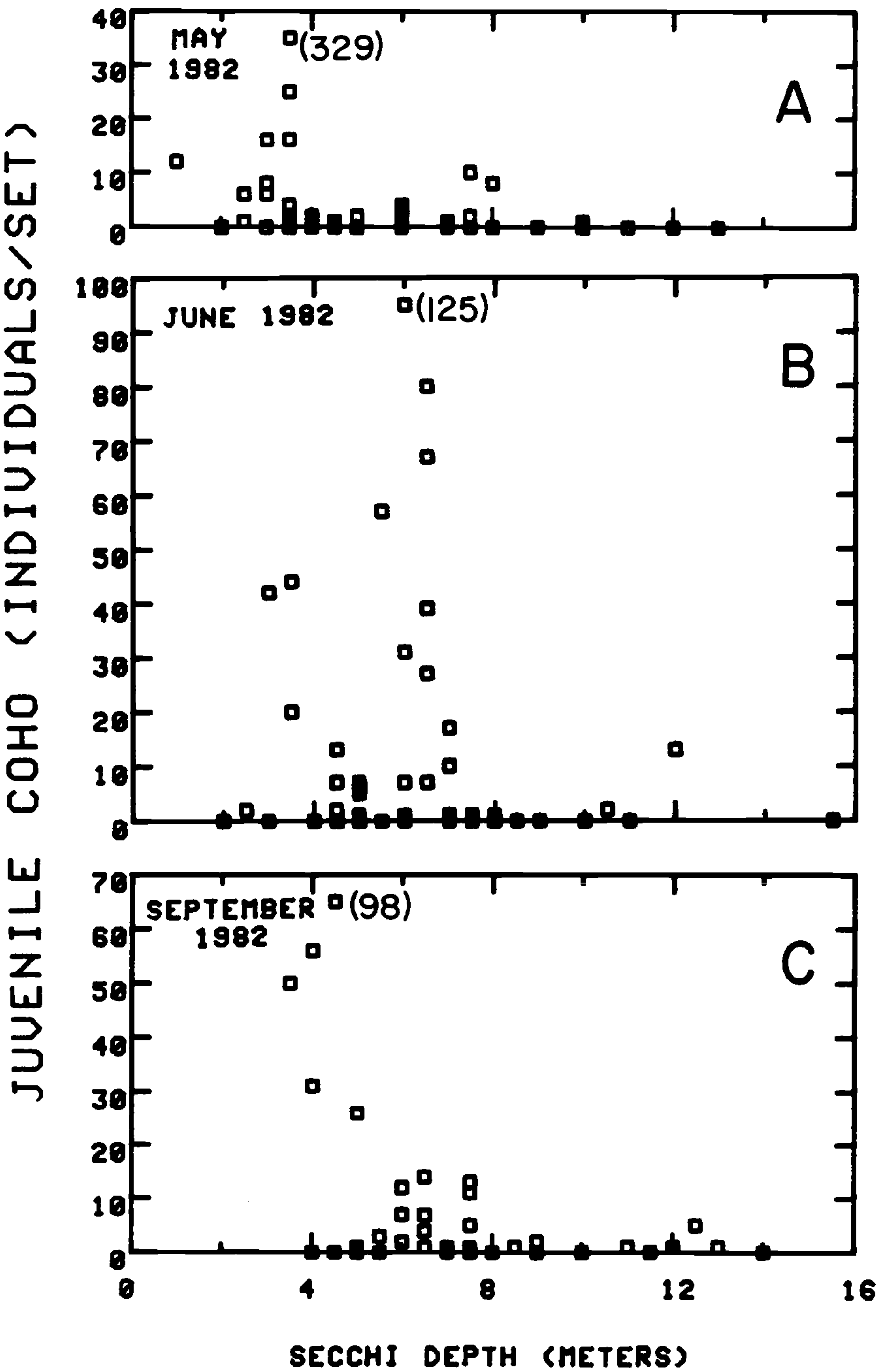


Figure 30. Catch per Set versus Secchi Depth for May, June, and September 1982.

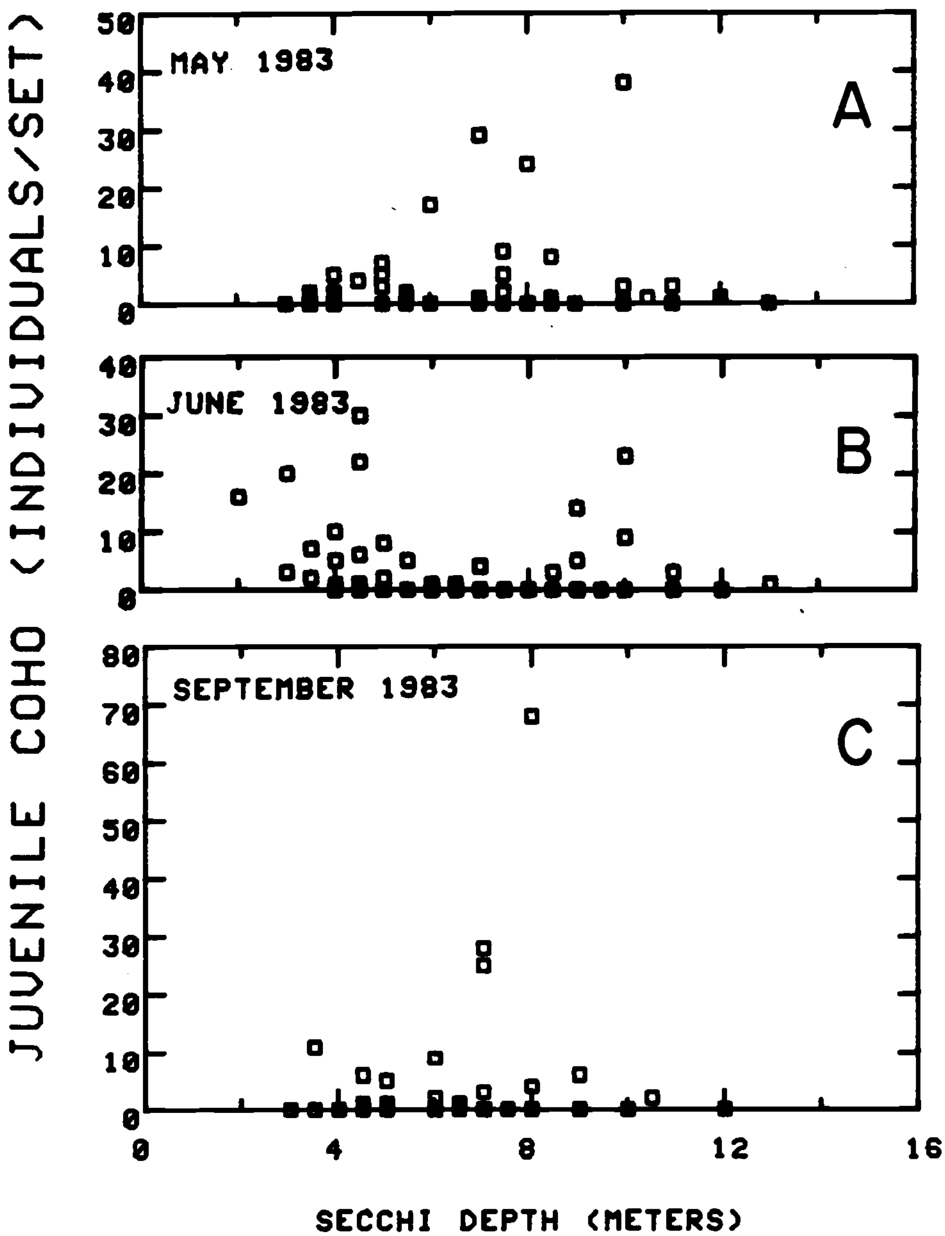


Figure 31. Catch per Set versus Secchi Depth for May, June, and September 1983.

Table 1. Monthly Mean Coastal Upwelling Indices for 1982 and 1983 at 45° N, 125° W and the long term means for 1948-1967 (Bakun, 1973). (All readings in cubic meters per second per 100 m of coastline). From NOAA/NMPS Pacific Environmental Group--Monterey, Cal.).

Month	1982	1983	1948-1967
May	79	35	34
June	59	19	48
July	51	18	74
August	38	35	50
September	12	25	16

Table 2. Catch per Set for Washington, the Columbia River, and Oregon.

MAY 1982

	OREGON	COLUMBIA RIVER	WASHINGTON
TOTAL CATCH			
INSHORE	35.9/SET	0.4/SET	0.6/SET
	(161 MM) N = 467 SETS = 13	(152 MM) N = 4 SETS = 11	(157 MM) N = 4 SETS = 7
OFFSHORE	3.9/SET	1.6/SET	0.1/SET
	(156 MM) N = 35 SETS = 9	(142 MM) N = 18 SETS = 11	(143 MM) N = 1 SETS = 11
0-AGE vs YEARLINGS			
INSHORE	YR = 94%	YR = 100%	YR = 50%
	(160 MM) N = 441	(152 MM) N = 4	(152 MM) N = 1
	ZERO = 3%	ZERO = 7%	ZERO = 0%
	(171 MM) N = 26	---- N = 0	(162 MM) N = 0
OFFSHORE	YR = 97%	YR = 93%	YR = 100%
	(157 MM) N = 32	(142 MM) N = 14	(143 MM) N = 1
	ZERO = 3%	ZERO = 7%	ZERO = 0%
	(135 MM) N = 1	(147 MM) N = 1	---- N = 0

Table 2. (cont.)

JUNE 1982

	OREGON	COLUMBIA RIVER	WASHINGTON
TOTAL CATCH			
INSHORE	14.9/SET	13.5/SET	26.3/SET
	(185 MM) N = 194 SETS = 13	(149 MM) N = 230 SETS = 17	(145 MM) N = 79 SETS = 3
OFFSHORE	16.3/SET	14.3/SET	3.3/SET
	(181 MM) N = 195 SETS = 12	(146 MM) N = 114 SETS = 8	(143 MM) N = 13 SETS = 4
0-AGE vs YEARLINGS			
INSHORE	YR = 98%	YR = 86%	YR = 100%
	(186 MM) N = 191	(149 MM) N = 191	(145 MM) N = 79
	ZERO = 2%	ZERO = 14%	ZERO = 0%
	(141 MM) N = 3	(148 MM) N = 31	---- N = 0
OFFSHORE	YR = 88%	YR = 98%	YR = 100%
	(186 MM) N = 159	(145 MM) N = 112	(143 MM) N = 13
	ZERO = 12%	ZERO = 2%	ZERO = 0%
	(144 MM) N = 22	(224 MM) N = 2	---- N = 0

Table 2. (cont.)

SEPTEMBER 1982

	OREGON	COLUMBIA RIVER	WASHINGTON
TOTAL CATCH			
INSHORE	6.0/SET	20.4/SET	17.3/SET
	(195 MM) N = 60 SETS = 10	(237 MM) N = 224 SETS = 11	(298 MM) N = 52 SETS = 3
OFFSHORE	1.0/SET	1.7/SET	5.5/SET
	(218 MM) N =2 SETS = 2	(274 MM) N = 12 SETS = 7	(277 MM) N = 22 SETS = 4
0-AGE vs YEARLINGS			
INSHORE	YR = 25%	YR = 38%	YR = 90%
	(230 MM) N = 15	(295 MM) N = 84	(298 MM) N = 47
	ZERO = 75%	ZERO = 62%	ZERO = 10%
	(183 MM) N = 45	(202 MM) N = 140	(301 MM) N = 5
OFFSHORE	YR = 50 %	YR = 73%	YR = 74%
	(211 MM) N = 1	(295 MM) N = 9	(301 MM) N = 16
	ZERO = 50%	ZERO = 27%	ZERO = 26%
	(225 MM) N = 1	(217 MM) N = 3	(216 MM) N = 6

Table 2. (cont.)

MAY 1983

	OREGON	COLUMBIA RIVER	WASHINGTON
TOTAL CATCH			
INSHORE	4.2/SET	8.3/SET	2.0/SET
	(157 MM) N = 42 SETS = 10	(160 MM) N = 83 SETS = 10	(185 MM) N = 20 SETS = 10
OFFSHORE	3.4/SET	1.1/SET	0.1/SET
	(161 MM) N = 24 SETS = 7	(174 MM) N = 8 SETS = 7	(297 MM) N = 1 SETS = 9
0-AGE vs YEARLINGS			
INSHORE	YR = 91%	YR = 93%	YR = 88%
	(157 MM) N = 38	(160 MM) N = 77	(181 MM) N = 18
	ZERO = 9%	ZERO = 7%	ZERO = 12%
	(159 MM) N = 4	(160 MM) N = 6	(209 MM) N = 2
OFFSHORE	YR = 94%	YR = 100%	YR = 0%
	(163 MM) N = 20	(174 MM) N = 8	---- N = 0
	ZERO = 6%	ZERO = 0%	ZERO = 0%
	(132 MM) N = 1	---- N = 0	---- N = 0

Table 2. (cont.)

JUNE 1983

	OREGON	COLUMBIA RIVER	WASHINGTON
TOTAL CATCH			
INSHORE	2.0/SET	6.6/SET	3.3/SET
	(155 MM) N = 39 SETS = 20	(187 MM) N = 72 SETS = 11	(189 MM) N = 33 SETS = 10
OFFSHORE	2.0/SET	6.0/SET	3.3/SET
	(156 MM) N = 10 SETS = 5	(202 MM) N = 30 SETS = 5	(168 MM) N = 23 SETS = 7
0-AGE vs YEARLINGS			
INSHORE	YR = 94%	YR = 72%	YR = 100%
	(156 MM) N = 36	(185 MM) N = 52	(189 MM) N = 33
	ZERO = 6%	ZERO = 28%	ZERO = 0%
	(156 MM) N = 2	(191 MM) N = 20	---- N = 0
OFFSHORE	YR = 89%	YR = 88%	YR = 86%
	(157 MM) N =9	(204 MM) N = 26	(161 MM) N = 20
	ZERO = 11%	ZERO = 12%	ZERO = 14%
	(152 MM) N = 1	(193 MM) N = 4	(216 MM) N = 3

Table 2. (cont.)

SEPTEMBER 1983

	OREGON	COLUMBIA RIVER	WASHINGTON
TOTAL CATCH			
INSHORE	1.5/SET	1.73/SET	11.0/SET
	(212 MM) N = 34 SETS = 22	(243 MM) N = 19 SETS = 11	(291 MM) N = 99 SETS = 6
OFFSHORE	0.0/SET	0.0/SET	7.17/SET
	---- N = 0 SETS = 1	---- N = 0 SETS = 2	(312 MM) N = 43 SETS = 6
0-AGE vs YEARLINGS			
INSHORE	YR = 24%	YR = 24%	YR = 65%
	(240 MM) N = 8	(323 MM) N = 5	(297 MM) N = 71
	ZERO = 76%	ZERO = 76%	ZERO = 35%
	(203 MM) N = 25	(218 MM) N = 15	(274 MM) N = 25
OFFSHORE	YR = 0%	YR = 0%	YR = 94%
	---- N = 0	---- N = 0	(311 MM) N = 40
	ZERO = 0%	ZERO = 0%	ZERO = 6%
	---- N = 0	---- N = 0	(330 MM) N = 3

Table 3. Frequency of Occurrence of Juvenile Coho Salmon, 1982 and 1983.

	MAY	JUNE	SEPTEMBER
1982			
Sets with Juv. Coho	30	35	28
Total Number of Sets	62	56	38
Freq. of Occurrence	0.48	0.63	0.74
1983			
Sets with Juv. Coho	27	27	18
Total Number of Sets	55	58	52
Freq. of Occurrence	0.49	0.47	0.35

Table 4. Correlation Matices and Regression Equations.

MAY 1982

	TEMP	SALINITY	CHL-A	SECCHI	SALMON
DBUI	.3918	-.1090	-.2837	.0719	-.1364
TEMP		-.4428	-.5839	.3323	-.0848
SALINITY			.2879	.1763	.0605
CHL-A				-.6418	.2562
SECCHI					-.1415

$$SALMON = -80.94 + (2.49)*(CHL\text{-}A) + (7.32)*(TEMP)^2 + (-0.16)*(DBUI)^3$$

$R^2 = 0.08$

JUNE 1982

	TEMP	SALINITY	CHL-A	SECCHI	SALMON
DBUI	-.0623	-.2359	-.0363	-.0928	.2527
TEMP		-.5823	-.0165	-.3800	.0916
SALINITY			.0659	.2933	-.0499
CHL-A				-.6581	.0559
SECCHI					-.2300

$$SALMON = 8.87 + (0.244)*(DBUI) + (-1.96)*(SECCHI)^2$$

$R^2 = 0.11$

Table 4. (cont.)

SEPTEMBER 1982

	TEMP	SALINITY	CHL-A	SECCHI	SALMON
DBUI	-.6972	.3965	-.1151	-.0688	-.3067
TEMP		-.4043	-.0811	.2355	-.1318
SALINITY			-.7926	.4310	-.2653
CHL-A				-.7058	.5215
SECCHI					-.4761

$$SALMON = -257.42 + (9.97)*(CHL\text{-}A) + (-0.44)*(DBUI)^2 + (8.24)*(SALINITY)^3$$

$R^2 = 0.52$

MAY 1983

	TEMP	SALINITY	CHL-A	SECCHI	SALMON
DBUI	.1301	-.0084	-.2774	.1268	-.1565
TEMP		-.7417	-.6393	.4711	.1447
SALINITY			.4609	-.2003	-.1079
CHL-A				-.7057	-.1617
SECCHI					.0584

$$SALMON = 10.23 + (-0.71)*(CHL\text{-}A) + (-0.05)*(DBUI)^2 + (-0.41)*(SECCHI)^3$$

$R^2 = 0.08$

Table 4. (cont.)

JUNE 1983

	TEMP	SALINITY	CHL-A	SECCHI	SALMON
DBUI	.3707	.1085	-.3382	.3031	-.2675
TEMP		-.3973	-.4914	.3976	.0701
SALINITY			.0366	.0406	-.2185
CHL-A				-.6095	.1195
SECCHI					-.3366

$$SALMON = -17.23 + (-0.92)*(SECCHI) + (1.83)*(TEMP)^2 + (-0.11)*(DBUI)^3$$

$R^2 = 0.22$

SEPTEMBER 1983

	TEMP	SALINITY	CHL-A	SECCHI	SALMON
DBUI	.5204	-.4194	-.5037	.0774	.2280
TEMP		-.6958	-.5665	.1191	.0062
SALINITY			.0788	.4062	.0401
CHL-A				-.6092	-.2141
SECCHI					.1068

$$SALMON = -76.57 + (0.14)*(DBUI) + (2.45)*(SALINITY)^2$$

$R^2 = 0.07$

Table 4. (cont.)

1982

	TEMP	SALINITY	CHL-A	SECCHI	SALMON
DBUI	-.2837	-.0207	-.1890	-.0198	-.0493
TEMP		-.3116	-.3395	.2054	-.0018
SALINITY			.0990	.2417	-.0153
CHL-A				-.6593	.2051
SECCHI					-.1897

$$SALMON = -3.62 + (1.25)*(CHL\text{-}A) + (-1.12)*(SECCHI)^2 + (1.29)*(TEMP)^3$$

$R^2 = 0.05$

1983

	TEMP	SALINITY	CHL-A	SECCHI	SALMON
DBUI	-.1947	.0187	-.2039	.1738	-.0230
TEMP		-.4109	-.4785	.2072	.0539
SALINITY			.3087	-.0382	-.0876
CHL-A				-.6010	-.1096
SECCHI					-.0460

$$SALMON = 9.10 + (-0.65)*(CHL\text{-}A) + (-0.61)*(SECCHI)^2$$

$R^2 = 0.03$

Table 4. (cont.)

1982-1983

	TEMP	SALINITY	CHL-A	SECCHI	SALMON
DBUI	-.3356	.0438	-.1070	.0603	-.0062
TEMP		-.3804	-.4432	.2095	-.0599
SALINITY			.2087	.0925	-.0056
CHL-A				-.6240	.1763
SECCHI					-.1491

$$SALMON = 7.55 + (0.85)*(CHL\text{-}A) + (-0.58)*(SECCHI)^2$$

$R^2 = 0.03$

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