*Pilot SST mapping flights
helped locate coastal coho salmon
stocks 92.7 percent of the
time in 42°-56°F water.*

A System for Monitoring the Location
of Harvestable Coho Salmon Stocks

DAVID J. WRIGHT, BRUCE M. WOODWORTH,
and JAMES J. O'BRIEN

ABSTRACT—During the summer of 1973, a pilot program was undertaken to test a system for monitoring the location of environmental factors favorable to coho salmon (Oncorhynchus kisutch) fishing and advising fishers of these locations. The operational system was successfully tested and proved to be effective, in both a subjective and statistical sense. The pilot program was operated off the Oregon coast from Cape Lookout south to Seal Rock from 15 June to 16 August. Primary users of the system were commercial and recreational fishers, including sport charter boat operators, with access to the ports of Newport and Depoe Bay. In the northern part of the test area, the "through-the-surf" dory fishery at Pacific City participated. In the study area, the coho salmon is a significant economic factor and was estimated to have an average impact on the order of $8,000,000 per year. This impact is estimated to be about equally divided between the commercial and sport fisheries. The coho salmon project involved the use of an aircraft mounted radiation thermometer to produce a daily sea surface temperature map over a finite offshore coastal area. Using the sea surface temperature map, along with other meteorological and oceanographic inputs, a daily forecast was produced to predict the location of environmental factors favorable to coho salmon. This paper describes the details of the system and presents an initial evaluation of system effectiveness.

FACTORS WHICH LED TO THE PILOT STUDY

The scientific basis for the system was a result of Coastal Upwelling Experiment-Phase I (CUE-I) held off the central Oregon coast during the summer of 1972. During CUE-I, a large-scale physical oceanographic experiment, a research aircraft from the National Center for Atmospheric Research, Boulder, Colo., was used to map sea surface temperature (SST) with a remote sensing precision radiation thermometer. This mapping effort, coupled with a reasonably comprehensive understanding of the offshore circulation pattern and the effect of the rapidly changing wind field (O'Brien and Tamura, 1972), indicated a predic-tive capability was possible for the three-dimensional temperature field in the offshore area.

It has been hypothesized that the coho or silver salmon, *Oncorhynchus kisutch*, prefer a rather narrow tem-perature range, as do other species of fish. For coho salmon this range is esti-mated to be between 52° and 56°F (God-frey, 1965; and Fisher, 1972). A predic-tive capability for the area wherein these temperatures would occur was thought to be of significant value to the coho salmon fishery.

The overall objective of the coho salmon project was to study the applica-tion of remote sensing techniques for the benefit of the central Oregon offshore coho salmon fishery. Substan-tively, this overall objective included the development and testing of the op-erational system and the forecast dis-tribution system. To determine its economic value the pilot program also provided for a complete analysis of sys-tem effectiveness.

In designing the system, the previous experience of those involved in using SST maps to assist fishers was taken into account. This included reviews in techniques used in the tuna and menha-den fisheries (Douglas and Gorenbein, 1968; Hynd, 1968; Pearcy and Mueller, 1970; and Pearcy, 1971). In both fisheries, however, the application of these techniques is limited. In the tuna fishery, for example, SST fields are re-corded and transmitted, but with little or no interpretation; in the menhaden fishery, aircraft overflights are used merely as an improved visual scouting method. The coho salmon forecast sys-tem, therefore, appears to provide a significant development in fish fore-casting techniques. As far as can be de-termined, it is the first system to bring so many factors to bear on the problem of forecasting the location of those ele-ments which would indicate harvestable fish stocks. Specifically, the factors were a detailed knowledge of the envi-ronment, including knowledge of the

David J. Wright is with the School of Oceanography, Oregon State University, Corvallis, OR 97331; Bruce M. Woodworth is with the School of Business, Oregon State University, Corvallis, OR 97331; and James J. O'Brien is with the Departments of Meteorology and Oceanography, Florida State University, Tallahassee, FL 32306.

three-dimensional offshore shelf circulation pattern gained through the CUE-I experiments, and standard meteorological forecasting coupled with the principle of continuity. During the test period, 41 forecasts were issued, of which 38 did locate favorable conditions for an accuracy rate of 92.7 percent.

THE OPERATIONAL FORECAST SYSTEM

Organization and the data flowpath for the operational phase is diagrammed and shown in Figure 1. The personnel organization used during the pilot program is indicated.

A Cessna 182 Skylane[1] was used for the daily SST mapping flight. This high-winged, single-engine aircraft was equipped for remote SST measurement with a narrow-band (10-12 μm) Precision Filter Radiometer (Barnes Engineering Co.; Model PRT-6 on loan from NASA-Ames Research Laboratory, Moffett Field, Calif.). For offshore navigation, the aircraft was equipped with a very-high frequency omnidirectional radio range receiver (VOR) with distance measuring equipment (DME). A 23-channel citizen's band (CB) radio was installed to allow direct communication with offshore trollers. During offshore flights, the aircraft crew wore inflatable life vests and carried a complete rescue and survival kit.

The daily flight would characteristically begin at 1100 hours, after development of a flight plan and a ground calibration of the PRT-6. A typical flight path is shown in Figure 2, which the aircraft flew at an altitude of 500 feet and an average speed of about 120 mph. During the flight the PRT-6 output, in recorder chart form, was annotated with navigational reference points and other observations appropriate to the evaluation effort, such as location of waterfronts, color changes, birds, fish, and fishing boat concentrations. Navigational reference points in the primary area off Newport and Depoe Bay were determined using a range and bearing from the Newport VOR transmitter. All such reference points were within the 30-mile range of the Newport facility. In the northern area, reference

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.
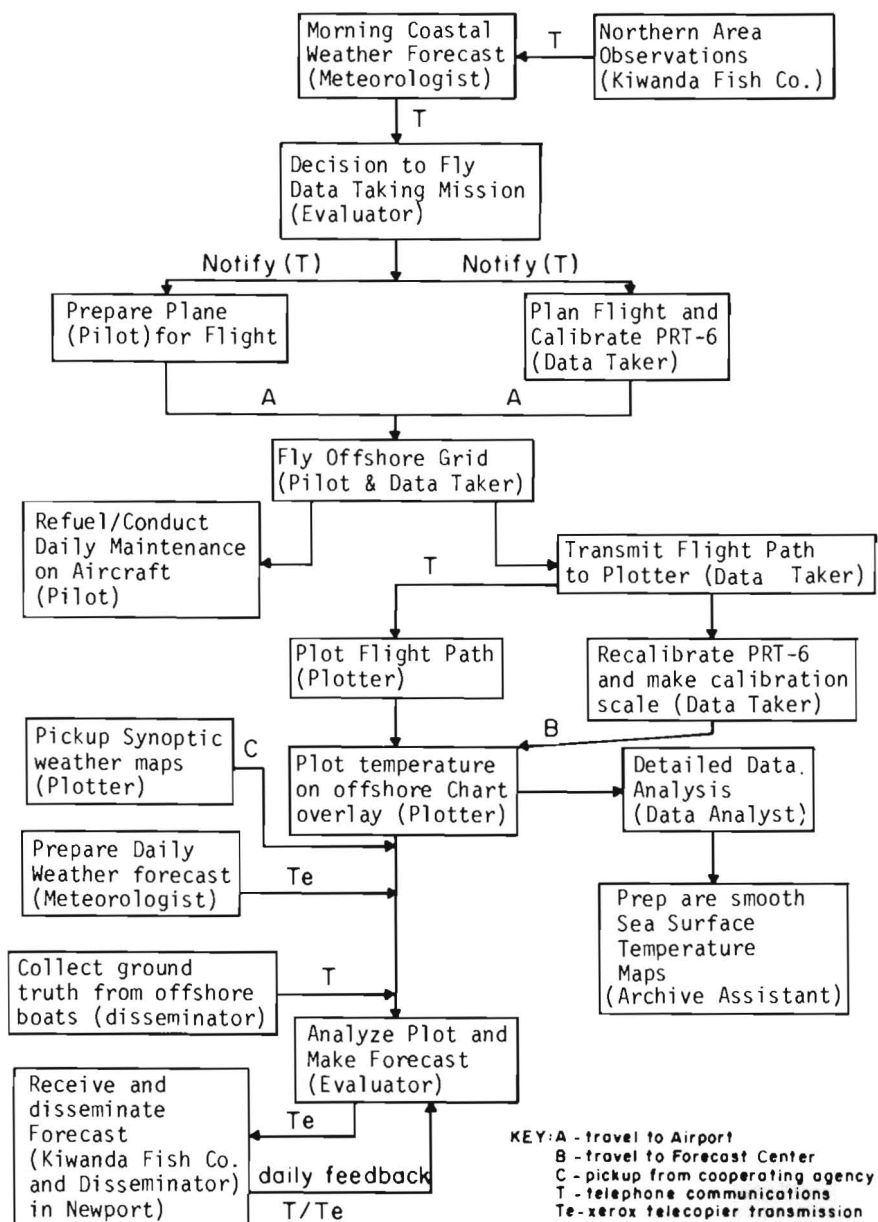

Figure 1.—Data flow for coho forecast.

points were determined using the Newport facility coupled with visual sightings of prominent landmarks.

Upon completion of the flight the PRT-6 was again calibrated to determine in-flight instrument response drift, if any. Using this data, a calibration chart was constructed. Then the temperature data were transferred directly to a plot of the aircraft track over the study area. The calibration was checked using sea surface "ground truth" temperatures provided daily by offshore charter boats and commercial fishing vessels.

From the above, a near "real-time" (immediate analysis) SST map was prepared (Fig. 3), which formed the basis for the forecast. In addition to the SST, the forecast required a historical knowledge of the wind field and SST patterns over the past several days, a general knowledge of the three-dimensional offshore circulation, and a forecast of the wind field expected to be present in the study area (Fig. 4). Taking these factors into account, and assuming the principle of continuity, the forecast was prepared.
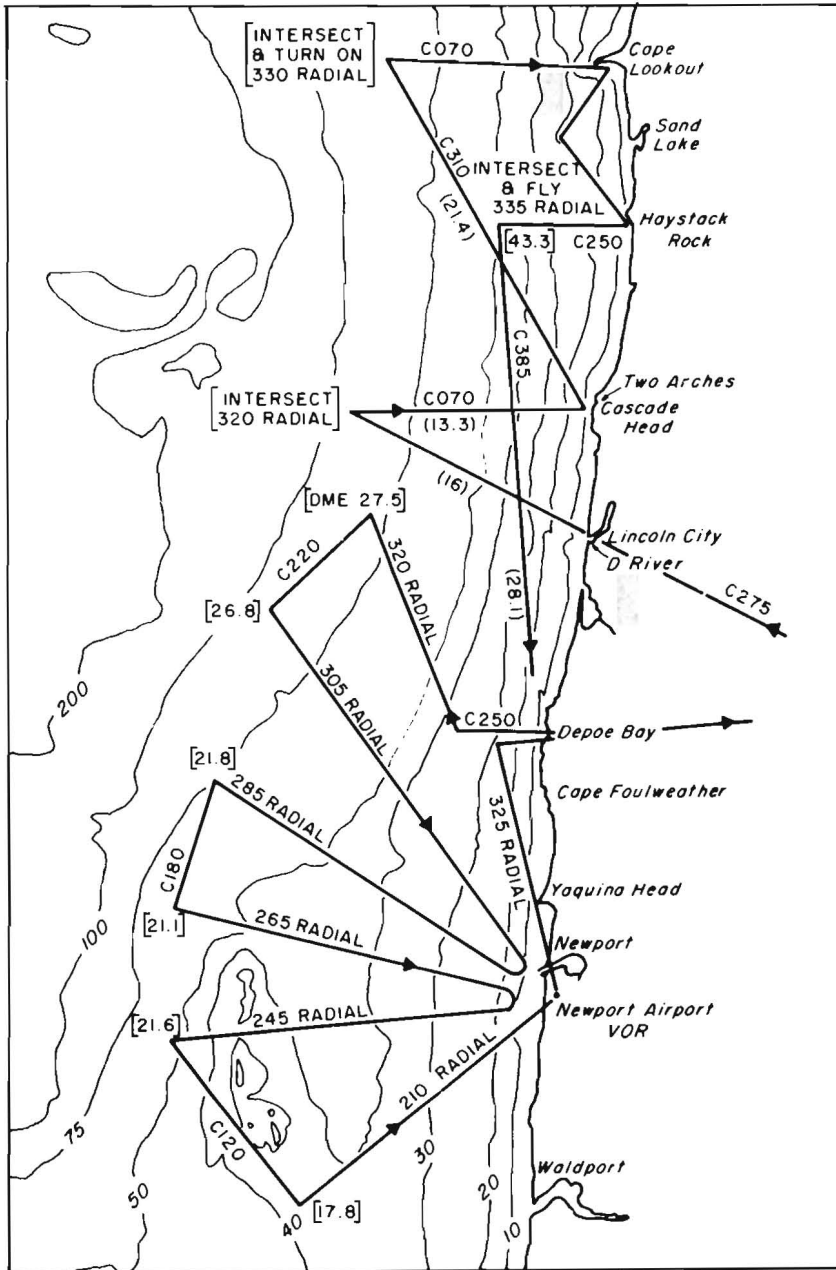
The forecast consisted simply of a

Figure 2.—Typical offshore grid for SST mapping flight.

FEEDBACK TO THE SYSTEM

Communication with the user was important for three purposes: 1) as the system was being developed, constructive operational criticism was desired; 2) daily feedback of offshore "ground-truth" temperatures was required to check the accuracy of the airborne measurements; and 3) data were required in order to evaluate the system.

During the project, the telephone was used frequently by fishing boat operators to make comments on the system but, by far, most operational criticism was received through the forecast disseminator or from the data sheets issued to cooperating fishing boat operators. Figure 7 shows the data sheet used in the study. It was designed to provide the data necessary for a statistical and subjective evaluation of the system with a minimum of inconvenience for cooperators. The sheets were submitted anonymously at about weekly intervals.

SYSTEM EVALUATION

The evaluation of the coho prediction system was conducted from two points of view. One was strictly subjective in nature and the second was statistical. The subjective evaluation was based on the comments and observations made by the people involved in, or affected by, the system. It should be noted that these comments plus the data used in the statistical evaluation came primarily from the smaller boats. Since it is expected that the small fishing boat operators, with the least experience, would be more likely to use the forecast, it is felt the statistics are biased in favor of the system. If the experienced fisher using the larger trip boats had submitted data sheets, much better catch rates from the areas recommended by the forecast could be expected. The most significant conclusion to be drawn from these comments is that the system, as designed, was being utilized by fishers even though it was experimental; furthermore, most of those involved expressed the hope that it would be continued in the future.

For more detailed evaluations, participants were asked for daily comments to be recorded on the data collection sheets (Fig. 7). The comment most frequently made was that the forecast was useful in that it gave an indication of
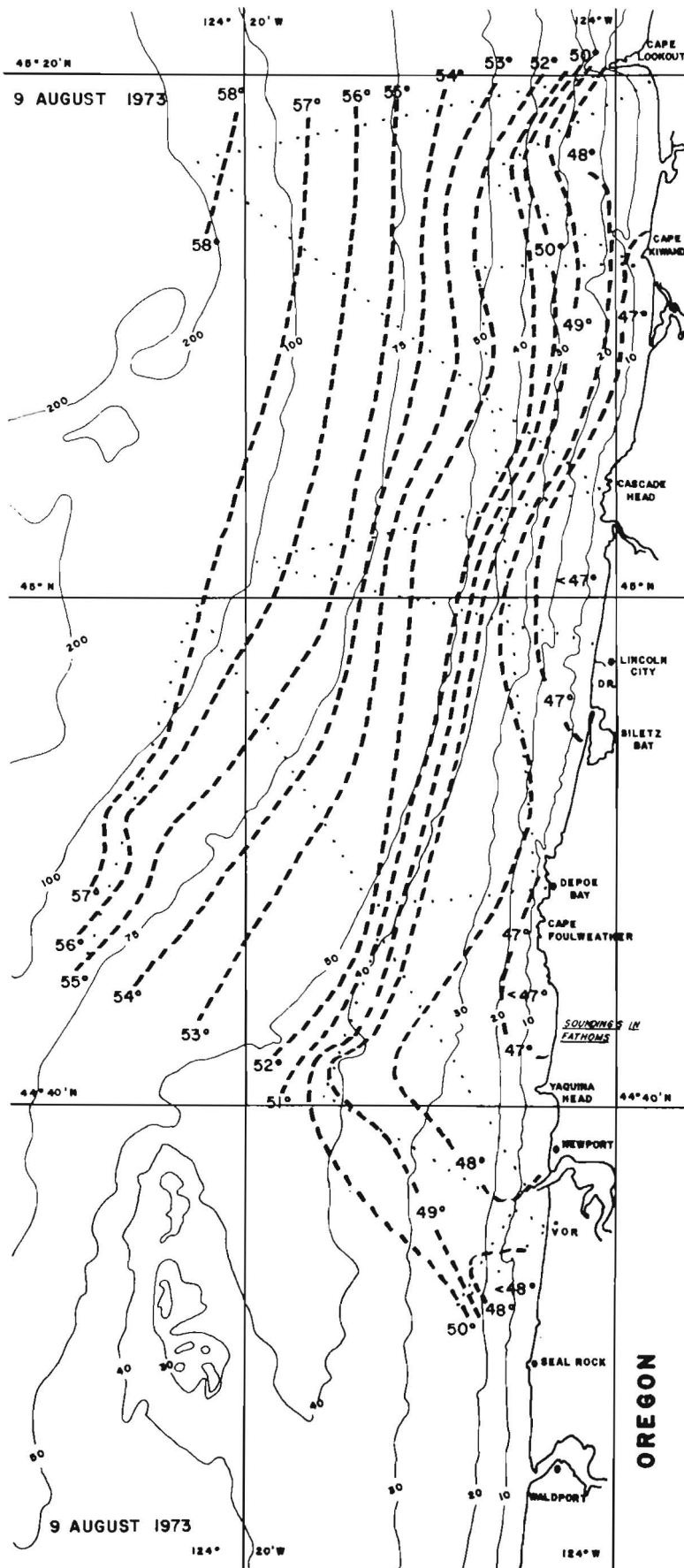
copy of the SST field mapped on the day the forecast was issued and a word description of observations, projected conditions, and fishing recommendations. The SST map was superimposed over a chart showing rate 1L0 loran lines of position and bottom contours in fathoms. Use of a single 1L0 loran line and depth is the two point navigation system in common usage in the area. Figure 5 shows a typical forecast issued during the program.

Rapid dissemination of the forecast was effected by telecopying it to user location on the coast at Newport and Pacific City. From Newport the forecast was recorded for commercial radio broadcast, passed to a CB radio operator for transmission to offshore trollers, posted at public waterfront locations, and distributed to charter boat operators in both Newport and Depoe Bay. Figure 6 outlines the distribution system in its final form. Using this system the forecast would be disseminated typically by about 1900 hours.

Figure 3.—SST map for 9 August 1973.

9 AUGUST 1973

where to begin fishing and thereby saved transit or search time. Another frequent comment concerned the distance offshore of the forecast areas. During the 1973 season, the 52° to 56°F band of water quite often was located 2 to 3 hours transit time from port. Many participants stated that without the forecast they would not have traveled as far as they did.

There were, of course, unfavorable comments. Some were made by people who were merely skeptical of the capabilities of the system. On the other hand, some fishers were firmly opposed to it. It is interesting to note that none of the unfavorable comments were directed at the operational capabilities of the system. In fact, it seems that most of the resistance was based on the belief that the system would be successful. There was a feeling that such a system would benefit the less efficient at the expense of those with good fishing skills since more people would be harvesting a given school of fish.

A number of people were against the system due to the potential hazard associated with a large number of boats concentrated in a small area. Many experiences were related showing the danger in such situations, particularly when compounded by fog. The system, however, did not pinpoint any specific spots of water. The smallest area in any forecast was 60 square miles which was approximately 4 percent of the total area covered by the system.

The statistical evaluation of the system was based on data collected from 41 participants. The basic data were the time spent fishing and the total poundage of coho salmon caught. For comparative purposes, some of the participants were specifically asked not to use the forecast but still submit data sheets. The primary point of comparison was the individual catch rate on a pounds-per-hour basis. The hypothesis for evaluation was that the system would locate bodies of water having relatively higher concentrations of coho salmon than surrounding water and as a result those fishing in these areas would enjoy an above average harvest.

A catch rate was computed for every data sheet submitted by the participants which was deemed relevant and useable. Although a total of 309 reports

4

COASTAL WINDS FOR OFFSHORE COHO ENVIRONMENTAL FORECAST

VALID 1500PDT THU - 1500PDT FRI, 9-10 AUGUST 73

DISCUSSION:
A WEAK UPPER LEVEL TROUGH IS PUSHING INLAND THROUGH OREGON TODAY
TRIGGERING WIDESPREAD SHOWERS ALONG THE COAST RANGE AND THUNDER-
STORMS THROUGH THE CASCADES. AS THE TROUGH MOVES FURTHER EAST
TONIGHT, A STRONG PUSH OF MARINE AIR WILL FILL THE VALLEY WITH
MARINE AIR. NORTHERLY WINDS WILL CONTINUE FRIDAY BUT THE ADDI-
TIONAL MOISTURE IN THE VALLEY WILL HOLD THERMAL GRADIENTS DOWN
SO NO STRONG COASTAL WINDS ARE EXPECTED THROUGH SATURDAY MORNING.

NEWPORT WINDS DURING THE PAST 24 HRS:
DATE TIME(PDT) DIRECTION SPEED(KTS)
 8   1600   NNW   12
        1800   NW-WNW   4
        2000   NNW   2
        2200   WNW-NW   3
 9   0000   NW   1
        0200   SW   3
        0400   SW   1
        0600   SW-W   3
        0800   WSW   3
        1000   SW-WNW   5
        1200   WNW   5
        1400   NW   6

FORECAST TONIGHT:
LIGHT VARIABLE WINDS MOSTLY WEST TO NORTHWEST.

FORECAST FRIDAY:
LIGHT WEST TO NORTHWEST WINDS IN THE MORNING BECOMING MOSTLY
NORTHWESTERLY 10-20 KTS IN THE AFTERNOON. MORNING LOW CLOUDS AND
FOG. MOSTLY SUNNY IN THE AFTERNOON EXCEPT FOR PERSISTENT FOG
OFFSHORE.

OUTLOOK SATURDAY:
MODERATE NORTH TO NORTHWEST WINDS....SUNNY IN THE AFTERNOON....
CHANCE OF PERSISTENT FOG OFFSHORE.

A. JOHNSON, JR.
CUEA STAFF METEOROLOGIST
9 AUGUST 1973

Figure 4.—Meteorological report used for coho forecast on 9 August.

Figure 5.—Coho forecast prepared on 9 August for 10 August fishing period.

Figure 6.—Coho forecast distribution system—summer 1973—Newport, Depoe Bay, and Pacific City, Oreg.

were submitted, only 150 were used in the analysis. The reduction is due to two factors: discarding the 15 to 30 June period in order to eliminate discrepancies caused by a lack of familiarity on the part of the participants with the data collection sheets; and discarding data sheets submitted by trip boat and charter boat operators as being irrelevant. Using these catch rates several frequency distributions were constructed, two of which will be discussed here. The first of these distributions is presented in Figure 8, showing the catch rates from 1 July to 16 August, which incorporates all of the data used in the analysis. As mentioned previously, the participants either used the forecast or did not, and in either case they were free to go to any area and fish.

The data in Figure 8 have been coded according to three categories. The first category contains catch rates for days when no forecast was issued or no track was shown on the data sheet. Given that a forecast was issued and a track shown, the second category contains catch rates for boats in the forecast area and the third contains catch rates for boats fishing elsewhere. The determination of whether a catch rate should go into category two or three was based on a 1-day lag of the data sheets from the forecast date. In other words, if a fore-

cast was issued on 7 July, tracks from data sheets of 8 July were used to place a boat. This procedure was followed to reflect the actual dissemination and utilization of the forecasts. A comparison was then made on the data in all three categories. The results are contained in Table 1. It can be seen that the forecast areas produced a somewhat higher catch rate. Considering the standard deviation, however, this cannot be considered statistically significant.

The second distribution of catch rates was developed by examining what is termed key forecast days. A "key day" is defined as one wherein a major change in oceanographic conditions is
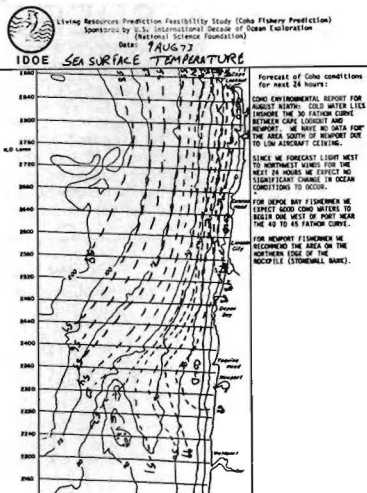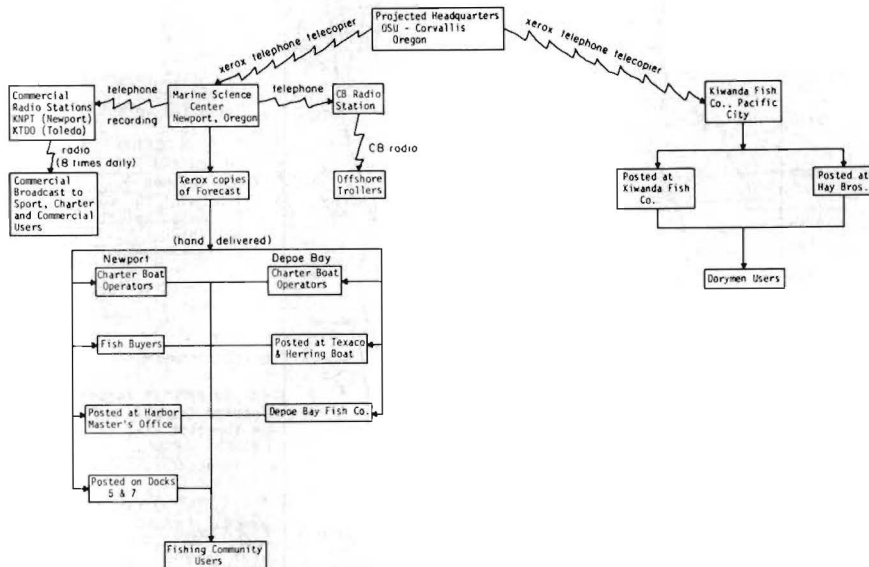
predicted to occur the following day. A major change, in turn, is defined as a significant movement (i.e., not anticipated) of those environmental conditions preferred by the coho salmon. The size of the forecast area, and therefore

Table 1.—Comparison of catch rates (lb/h) by users and non-users of the coho salmon forecast system.

	Overall	NF-NT[1]	Forecast area	Other areas
Mean	13.05	11.41	15.88	12.41
Median	10.0	9.0	10.0	9.0
Standard deviation	9.54	9.70	9.88	9.94
Number of reports	150	64	46	40

[1]NF = No forecast issued; NT = No track was shown on data sheet.

COHO DATA SHEET

LIVING RESOURCES PREDICTIONS FEASIBILITY STUDY
Sponsored by The Office of U. S. International Decade of Ocean Exploration

DATA REQUESTED: Please mark track and fishing positions on chart. Note any oceanographic observations made (for example: temperatures, fronts, slicks, color changes, birds, etc.). Try to pinpoint where fish were concentrated. Please log for each fishing period and fill out one sheet for each 24 hour day in which you fished. Use your own judgment on dividing up your fishing day into fish periods. They should be periods when you are catching fish. Time gaps will be assumed to be search periods.
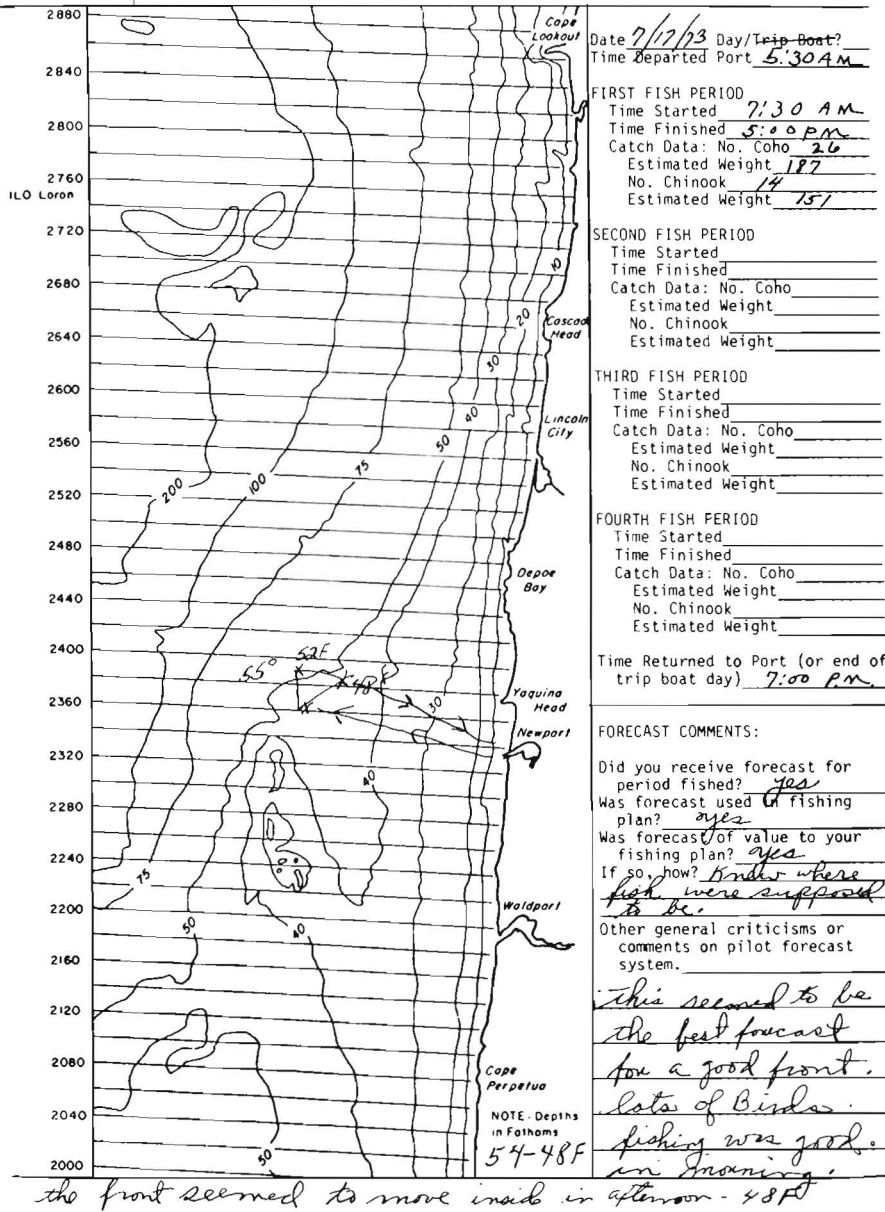
Date 7/17/73 Day/Trip Boat?
Time Departed Port 5:30 AM

FIRST FISH PERIOD
Time Started 7:30 AM
Time Finished 5:00 PM
Catch Data: No. Coho 26
Estimated Weight 187
No. Chinook 14
Estimated Weight 151

SECOND FISH PERIOD
Time Started ___
Time Finished ___
Catch Data: No. Coho ___
Estimated Weight ___
No. Chinook ___
Estimated Weight ___

THIRD FISH PERIOD
Time Started ___
Time Finished ___
Catch Data: No. Coho ___
Estimated Weight ___
No. Chinook ___
Estimated Weight ___

FOURTH FISH PERIOD
Time Started ___
Time Finished ___
Catch Data: No. Coho ___
Estimated Weight ___
No. Chinook ___
Estimated Weight ___

Time Returned to Port (or end of trip boat day) 7:00 P.M.

FORECAST COMMENTS:

Did you receive forecast for period fished? yes
Was forecast used in fishing plan? yes
Was forecast of value to your fishing plan? yes
If so, how? Know where fish were supposed to be.

Other general criticisms or comments on pilot forecast system.
This seemed to be the best forecast for a good front. Lots of Birds. Fishing was good in morning.

NOTE - Depths in Fathoms
54 - 48 F

the front seemed to move inside in afternoon - 48 F

Figure 7.—Typical coho data sheet.

---

statistically significant, a statistical test, Student's t-test, was applied to the data from Figure 9. The test is intended to show the likelihood that two samples were drawn from a common population. The null hypothesis for this test was H_0: Both samples were drawn from a common body of water. Using t-test computations, the conclusion is to reject the null hypothesis with more than a 98 percent degree of confidence that the hypothesis is in error. The interpretation of this test on our data is that it is very unlikely (less than a 2 percent probability) that the two samples came from a common population. In other words, the mean catch rate in the forecast areas on "key days" was significantly higher than the mean catch rate in non-forecast areas on those same days.

It should be noted at this point that there was considerable variability among the participants in the study in such things as the size of vessel and amount of equipment aboard, fishing gear, and, undoubtedly, in fishing skill. Any of these factors could affect the catch rates used in evaluating the forecast system. Unfortunately, it is not possible to determine the impact which they may have had due to the guarantee of anonymity promised the participants.
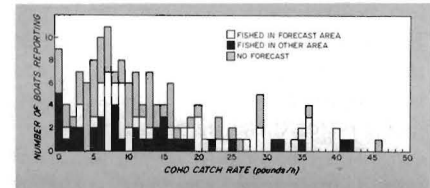
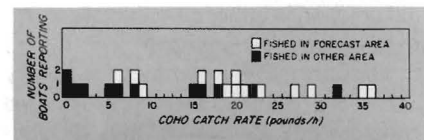**Figure 8.—Overall catch rates (lb/h) for period 1 July-15 August 1973.**

Figure 9.—Catch rates (lb/h) on "key days".

Table 2.—Comparison of catch rates (lb/h) on "key days" by users and non-users of coho salmon forecast system.

	Overall	Forecast area	Other areas
Mean	15.88	20.51	10.49
Median	16.0	20.0	6.0
Standard deviation	10.88	8.73	9.71
Number of reports	26	14	12

---

the concentration of fish, may or may not change. The justification for isolating on only a portion of the data lies in the standard procedures for evaluating forecasting systems. A system is judged as truly effective only if it can predict when changes will occur. For example, a weather forecaster gets no credit for forecasting that tomorrow will be the same as today. The data for the "key days" are shown in Figure 9 and the corresponding statistics are contained in Table 2.

In order to determine if the difference between mean catch rates in the forecast areas and the non-forecast area was

It is presumed, however, in light of the freedom to choose a fishing location, that the data represent a reasonably random sample, thus effectively neutralizing these factors.

RESULTS

The limiting factors, operationally, were the aircraft and weather. A small aircraft can effectively map an offshore area 60-80 miles long, out to 20 or so miles offshore, within its range of endurance. Within its range, the Cessna 182 Skylane proved to be an ideal economical aircraft for the system. During the 62-day life of the project no flights were missed due to aircraft, personnel, or equipment failure. The weather, however, was another matter.

In the Oregon area, where coastal upwelling is a major oceanographic phenomenon during the summer, the colder inshore waters, in contact with warmer moisture-laden marine air, induce a high incidence of low level fog. Except for an occasional summer storm, this fog was the primary reason for missed flights. During the test period, despite intensive effort, SST mapping flights were possible only 58.1 percent of the time. This fact leads to the conclusion that the aircraft should fly from a location as near as possible to the area to be mapped in order to take advantage of temporary periods of extended visibility.

The system was in operation for only one season; hence, it must be recognized as only one datum point in terms of long run potential. Nevertheless, within its own time frame, the system did prove to be operationally feasible. The pilot program was successful in locating 52°-56°F water 92.7 percent of the time. Statistical analysis of the catch rate data has shown the forecast system to be capable of locating harvestable stocks of coho salmon. In particular, on "key days," the catch rate in recommended areas was double that in other areas. For a more detailed statistical and economic evaluation see (O'Brien et al., 1974a, b, and c). Finally, this analysis lends credence to the hypothesis that coho salmon are a temperature dependent species. In view of these results, the system could provide a valuable input in the management of fisheries resources.

ACKNOWLEDGMENTS

LITERATURE CITED

Godfrey, H. 1965. Salmon of the North Pacific Ocean—Part IX. Coho, chinook and masu salmon in offshore waters. Int. North Pac. Fish. Comm., Bull. 16:1-39.

Hynd, J. S. 1968. How sea surface temperature maps aid tuna fishermen. Aust. Fish. Newsl. 27(5):23-29.

O'Brien, J. J., and K. J. Tamura (editors). 1972. CUE NOTES. A record of the Coastal Upwelling Experiment, CUE-1, off Oregon, summer 1972. Oregon State Univ., Corvallis.

O'Brien, J. J., B. M. Woodworth, and D. J. Wright. 1974a. The coho project. Vol. II. Environmental report. Florida State Univ., Tallahassee, and Oregon State Univ., Corvallis.

————. 1974b. The coho project. Vol. III. System evaluation report. Florida State Univ., Tallahassee, and Oregon State Univ., Corvallis.

————. 1974c. The coho project. Vol. I. Final report. Florida State Univ., Tallahassee, and Oregon State Univ., Corvallis.

Pearcy, W. G. 1971. Remote sensing and the pelagic fisheries environment off Oregon. In Proc. Symp. Remote Sensing Mar. Biol. Fish. Resour., p. 158-171. Tex. A&M Univ., College Station.

Pearcy, W. G., and J. L. Mueller. 1970. Upwelling, Columbia River plume and albacore tuna. Proc. 6th Int. Symp. Remote Sensing Environ., 1969. 2:1101-1113.