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APPLICATION OF REMOTE SENSING TECHNIQUES IN OCEANOGRAPHIC STUDIES OF THE BRITISH COLUMBIA SALMON FISHERY

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ABSTRACT

During the summer of 1981, an oceanographic study was conducted in conjunction with a major study of the British Columbia troll fishery for Coho, Pink and Chinook salmon. The study utilized aircraft and satellite remote sensing of water colour and temperature to define sea surface structure and expendable bathythermographs from Fisheries Patrol vessels to define subsurface features. A time lapse motion picture of the Coast Guard radar provided a continuous monitor of the fleet position and aggregation for comparison to in-water features. Fisheries observers and volunteer skippers collected sea surface temperature and chlorophyll samples and reported water colour along with data concerning the number, species and size of fish caught. Examples of the remote sensing data obtained are presented and discussed as they relate to other available oceanographic data. The problems and utility of the application of these techniques in fisheries research are also outlined.

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SYMPOSIUM ON REMOTE SENSING

INTRODUCTION

All fish have preferred environmental conditions under which they function best - conditions which keep them healthy, maximize their feeding success and allow them to successfully avoid predators. There is reason to believe that these preferences or requirements may at times exhibit themselves strongly enough to stop or alter fish movements in hetergeneous coastal conditions. Diversions or delays of migrating salmon can have important effects on their spawning success, and can cause severe problems for those managing the fishery. Whereas some types of physico-chemical boundaries or fronts can have adverse effect, some types of fronts lead to strong growth of phytoplankton and aggregation of zooplankton and small fish. In the ocean as in any environment aggregations of food organisms are important sources of food for foraging animals. It is recognized that salmon and other fish often gather along such boundaries to feed. Knowing where such aggregations are likely to occur will be important for fisheries managers.

The study described here was part of a pilot project to investigate the relationships between the ocean environment and the distribution of pink (Oncorhyncus gorbusha), coho (O. kitsutch)and chinook (O.tshawytscha) salmon in the coastal zone off southwestern Vancouver Island, British Columbia.

This work was part of a co-ordinated effort carried out by Seakem Oceanography Ltd., the Salmon Division of the Pacific Biological Station, Nanaimo and the Remote Sensing Division, Institute of Ocean Sciences, Sidney. Funding for the Seakem work was under the terms of a DSS contract let as a response to an unsolicited proposal. Our object was to describe the near surface oceanographic conditions as completely as possible, using several new techniques and avenues of obtaining data to reduce the expense involved. The work was still in progress at the time of writing.

COMPONENTS OF THE MONITORING PROGRAM

There were four principal components of the oceanographic study as summarized in table 1.

Satellite Imagery

Satellite imagery of the study area aquired by the American NOAA-6, NOAA-7 and NIMBUS-7 satellites was obtained for cloud-free days from the Scripps Institute of Oceanography Remote Sensing Facility, La Jolla, California. The data was geometrically corrected using a nearest neighbour interpolation and auto registered to a Mercator projection. The series of imagery thus obtained from the Advanced Very High Resolution (Infrared) Radiometer (AVHRR) on board the NOAA satellites provides a description of sea surface temperature accurate to $\pm.5^{o}C$ and at 1.1 km. resolution (example, figure 1). The Coastal Zone Colour Scanner (CZCS) on board NIMBUS-7 was designed to measure phytoplankton-chlorophyll concentrations using the upward flux of blue/green light from the sea, and is currently the subject of a great deal of work aimed at improving the calculations involved (Gower, 1980; Gordon et al, 1980). For our use here we have greatly simplified these operations by applying sensor gain corrections, a variable Rayleigh scattering function and an air-water transmission correction. As a result we can use the CZCS data in semi-qualitative fashion only, to map the most important water mass boundaries such as that separating the green coastal water from the relatively barren oceanic waters offshore (example, figure 2).

Airborne Surveys

For prolonged cloudy periods, when satellite imagery could not be acquired or for smaller scale surveys where visual observation was desired, low attitude airborne survey missions were mounted. The Institute of Ocean Sciences Colour Spectrometer (Walker et al, 1975) and a Barnes PRT-5 Radiation Thermometer were flown at 90m altitude in a twin engine Britain Norman Islander aircraft.

These non-imaging devices provided quantitative measures along the track of the aircraft. The IOS spectrometer uses an array of silicon diodes to measure water colour and in-vivo fluorescence by which the surface concentrations of the phytoplankton pigment chlorophyll can be quantified (Gower, 1980), while the PRT-5 uses infrared radiation emitted from the sea surface to measure water temperature. The data from these sensors, while having resolution on the order of 25 m depending upon integration time, viewing geometry and aircraft velocity, are usually averaged over large scales and presented as contour maps as in figure 3 (Borstad et al, 1980).

Sea Surface Data

Sea surface data for comparison with and calibration of remotely sensed data were obtained from several vessels operating within the study area. At approximately fortnightly intervals a Fisheries Patrol vessel made two 75km transects to the edge of the continental shelf. At twelve stations along these transects, surface temperature, salinity and chlorophyll concentration, water colour and secchi transparency were measured. Vertical temperature profiles were obtained using expendable bathythermographs (XBT).

As well as these repetitive observations made at the same stations other measurements of water temperature, colour, secchi transparency and chlorophyll concentration were made by 10 fisheries observers on board active troll boats. These observations were made in conjunction with extensive notes and measurements of the fish caught - species, size, age, stomach contents, etc. and will allow comparison of fisheries statistics such as catch per unit effort with oceanographic parameters.

Land Based Measurements

The distribution, number and movement of fishing vessels within the study area was recorded via a time lapse motion picture of a radar screen covering the southwest coast of Vancouver Island from the Coast Guard Vessel Traffic Management Installation at Ucluelet (see figure 4). Three or four consecutive images were projected onto map overlays and the positions of stationary or slow-moving, small vessels recorded. This allowed rejection of larger oceangoing ships and barge traffic and provided a continuous monitor of vessel numbers, distribution, and movements throughout the project. These data will be compared to available satellite, aircraft and ship data to test hypotheses linking fishing activity with frontal boundaries, water colour, temperature, bottom topography, etc. The data will also be used to describe the behaviour of the fishing fleet as it relates to weather, oceanographic conditions, fisheries openings and closings.

Most of the Canadian lighthouse keepers on the west coast keep daily records of sea surface temperature and salinity as well as of significant weather. As these data form part of very long time series (45 years at some locations) they can be used to compare present and past conditions, as well as to calibrate the satellite derived sea surface temperature data.

Other Data Sources

Supplementary data are also being obtained from several other groups working independently in the area. As indicated in Table 2, some of these data are in the form in interpreted analyses provided as a service (e.g. the Ocean Thermal Boundary Analysis). Other information will come available as scientists analyse and digest their own data.

DISCUSSION

One of the objects of this project was to investigate the extent to which remotely sensed data could be used to provide a continuous, coherent description of surface oceanographic conditions on large areas of the British Columbia continental shelf. We were also interested in comparing the distribution of fishing effort to oceanographic parameters such as water colour (as a measure of phytoplankton concentration), temperature and water mass boundaries or discontinuities. Because of the large areas and the very complicated distributions involved, spacecraft imagery was very valuable.

Satellite imagery has the advantage of providing instantaneous synoptic pictures of large areas not possible by any other practical means. For a seasonal or time series study however, the availability of good quality imagery can pose a problem, especially over cloudy areas such as the Canadian west coast.

For our study, the number of images obtained was a function of several factors. For NOAA-6 and 7, which both make two passes every day, the limiting factors were fog or cloud coverage, the hours of operation of the Scripps Remote Sensing Facility (data are not normally acquired on week-ends unless specifically requested); and the time required for us to search the Scripps facility data archive. This last problem will be alleviated later this year when the Scripps Facility completes a photographic quick-look archive. For the NIMBUS-7 CZCS data a fourth factor also operated to reduce the coverage available. The two hour/per day on-board power limitation on this satellite means that the CZCS sensor is turned off and on by NASA Goddard operators.

As an example of these limitations, for the 99 day period May to August 7, these were 70 NOAA-7 images, 20 NOAA-7 images and 38 CZCS images of our area in the Scripps archive. In 36 hrs operation on the Scripps Remote Sensing Facility computing system we were able to view 32 days data (45 images). Of these data we obtained 12 'good' NOAA images and 7 CZCS scenes (2 days in May, 2 days in June, 5 days in July and 3 days in the first week in August). This will be quite adequate to describe the evolution of at least the larger, longer lived features such as the large cold water plume extending offshore from the mouth of Juan de Fuca Strait between Vancouver Island and Washington State (figure 1). During the series of clear days in late July it will also be possible to examine the shorter duration; smaller scale changes.

Aircraft can also be used to survey coastal areas but the data obtained are rather different from photograph-like satellite products. The airborne sensors we operate are more suitable for smaller coastal areas. The aircraft surveys, while being non-imaging relatively expensive because of aircraft rental and the labour involved, and limited in area by the endurance of the aircraft and its occupants, do compare favourably with satellite imagery for several reasons. First, the airborne surveys can be conducted under overcast or cloudy conditions. On the Pacific Coast this is an important consideration. Second, the aircraft provides a platform from which visual observations may be made of other related parameters such as number type and activity of fishing vessels; lines of flotsam and jetsam such as may be concentrated along frontal boundaries; sea state including estimations of swell height and direction; and biological phenomena such as flocks of birds, sea mammals and swarms of large medusae. A third positive feature of the aircraft surveys is that they are more flexible - since they are under the control of the local project scientist, it is easier to obtain coincident comparative data from surface vessels.

In our operations, where several simplifications have been made, surface measurements are required at least a few locations within the area covered by the satellite or airborne sensors if the data are to be used in a quantitative sense. Both types of remote measurements suffer from atmospheric contamination of the signals. We have found that simple empirical corrections based on theory and sea surface measurements allow derivation of chlorophyll-like pigment concentrations from CZCS data. Good accuracy can be obtained in airborne measurements by flying at low altitudes to reduce the atmospheric effects.

In the airborne experiments (Gower, 1980; Borstad et al, 1980) we have found that under most conditions the water colour measurements relate closely to the chlorophyll concentration in a thin 1 to 2 m layer of water near the surface. For this reason our shipboard measurements for this project were reduced to surface samples and XBT (expendable bathythermographs) which could all be obtained from a moving vessel. Simplifying the shipboard data collection permitted use of unspecialized vessels such as the fisheries patrol vessels and increased the number of transects possible. Our time series, the likes of which has not often been possible before on the west coast because of the difficulty in obtaining ship time on research vessels, will allow us to describe the vertical structure of a coastal upwelling event which is visible in images in early July.

Our time-lapse camera was mounted on a small, seldom-used maintenance display screen so as not to disturb the normal operations of the Coast Guard Vessel Traffic Management staff. The microprocessor controller (designed by Dr. M. Press, Royal Roads Military College) and 16mm Bolex camera functioned very well and provided good quality images after the optimum exposure and aperture were chosen. We had no control over the operation of the radar itself however, and the difficulties encountered in this part of the study mostly relate to variability of the radar returns. These mostly result from alterations of the signal strength, repetition rate and pulse length by Coast Guard operators, but fluctuations of the power supply to the relatively recent installation have also been encountered. Our time-lapse camera on the maintenance display screen was unmanned and we therefore could not continuously readjust the screen fine tuning control. Under some combinations of operating and environmental conditions, rain and sea clutter were extensive. Because of the difficulties data were not always available for all parts of the study area and analysis at regular, short time intervals was not always possible. This problem was somewhat lessened by reference to the boat counts made by the military surveillance aircraft.

In spite of these problems the time-lapse radar movie dramatically emphasizes the large size and very dynamic nature of the fishing fleet. There are large fluctuations of both the amount and distribution of fishing effort within the study area during the summer, and these changes occur on time scales of days to months. Preliminary analysis indicates frequent concentration of vessels at particular locations apparently related to the bottom topography. As well as these 'favourite spots' there are often other congregations which may relate to colour or temperature boundaries. Airborne observations have confirmed that some fishing effort does occur near such discontinuities and efforts are now being made to see if this relationship can be also found over larger areas using satellite imagery and the radar-derived data.

All of our data has been or will be analysed days to months after collection. For research purposes this will suffice, but for in-season management real-time operations will be required. If useful relationships between remotely sensed data and fish abundance, behaviour or fishing activity can be established from the present work, this will be the next development in our activities.

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Table 1 Summary of Parameters Measured and Data Sources

Parameter	Platform	Sensor/ Measurements	Coverage	Spatial Resolution	Frequency
SATELLITE DERIVED:					
Water colour in 5 spectral bands. Chlorophyll content and turbidity inferred.	NIMBUS-7	Coastal Zone Colour Scanner (CZCS)	entire coastal zone from 955km altitude	0.8 km	~3 days of 5
Sea surface temperature	NOAA-6 NOAA-7	Advanced very high resolution Radiometer (AVHRR)	entire coastal zone from 820km altitude	1.1 km	4X/day
AIRCRAFT DERIVED:					
Water colour at 2 nm intervals between 400 and 1100 nm. Chlorophyll content and turbidity inferred	Britain Norman Islander	Inst. Ocean Sciences Colour Spectrometer	zigzag survey pattern ~50km from coast; 90 m altitude	100 m	2 or 3 times during project
Sea surface temperature		Barnes Precision Radiation thermometer (PRT-5)		200 m	
Frontal boundaries; position number and type of vessels;		visual observations			
SURFACE VESSELS:					
Surface temperature, salinity, chlorophyll concentration, (Secchi transparency and water colour), vertical temperature profiles	Canadian Fisheries Patrol Vessel	Sea surface samples expendable bathythermographs	2 lines of 6 stations to a pt 50 km offshore and back	stations ~10 km apart	every 2 weeks
Sea surface temperature, chlorophyll concentration, and water colour number, species and size of fish caught; various samples from fish for ageing, stock identification etc.	Troll Fishboats	Sea surface samples, fish catch log	everywhere along coast where fishing is taking place		3X/day
LAND BASED:					
Distribution, number and movement of vessels within study area (for comparison with oceanographic data)	Coast Guard Vessel Traffic Radar	Time lapse movie of S band Radar Screen	~100 km radius from radar installation on 700 m mountain near coast		picture every 5 min. May to Oct.
Sea temperature and salinity	Coastal Light Houses	Surface samples	6 light stations at 40-60 km intervals		1X/day
Sky condition, visibility, wind speed and direction, sea swell		Weather observations	along coast		

Table 2 Other Sources Providing Coincident Data

Parameter	Platform	Sensor/ Measurements	Coverage	Spatial Resolution	Frequency
SATELLITE DERIVED:					
Surface temperature charts (METOC analysis-DND Esquimalt, B.C.)	NOAA-6, NOAA-7 surface vessels	AVHRR, surface bucket thermometers	NE Pacific	-	2X/week
Ocean Thermal Boundary Analysis (NOAA-National Weather Service, Seattle)	NOAA-6, NOAA-7 surface vessels	AVHRR, surface bucket thermometers	NE Pacific & Coastal Zone	-	2X/week
AIRCRAFT DERIVED:					
Position, number and type of fishing vessels	Canadian Forces patrol Aircraft	visual observations	Canadian Coastal Zone	-	1-2X/week
SURFACE VESSELS:					
Surface temperature, Salinity Nutrient and Chlorophyll Concentration, Phytoplankton & Zooplankton Composition Vertical Temperature Profiles	Ships-of Opportunity (contracted by Dept. Fisheries & Oceans)	Continuous sensors discrete surface samples XBTs	Vancouver Island Western Coastal Zone	Continuous monitoring on single track along coast 10 km off	1X/6 weeks
Complete suite of biological oceanographic measurments describing SW Vancouver Island Continental Shelf planktonic conditions	Dept. Fisheries & Oceans Research Vessel (Ocean Ecology, Patricia Bay)	Continuous horizontal and vertical profilers	SW Vancouver Island Coastal Zone	Continuous sampling along grid perpendicular to coast	2-3X during summer
MOORED INSTRUMENTATION:					
Temperature, salinity current speed and direction; geostrophic currents; description of physical oceanography of SW Coastal Zone	moored current meters and hydrographic stations. Dept. Fisheries & Oceans (Coastal Zone, Patricia Bay)	moored current meters, CTD measurements	SW Vancouver Island Continental Shelf		Continuous

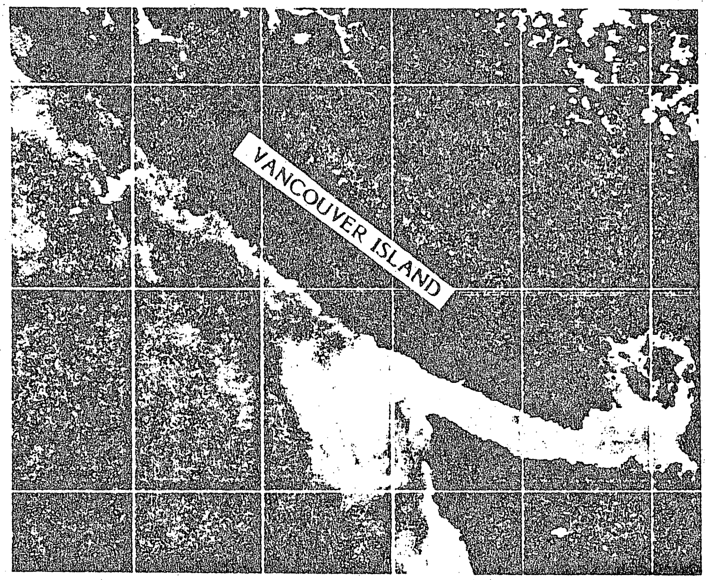

Figure 1. A NOAA-6 AVHRR infrared image acquired at 0920 hrs PDT August 6, 1981. Such imagery quantitatively represents sea surface temperatures to within $\pm 0.5^{\circ}C$

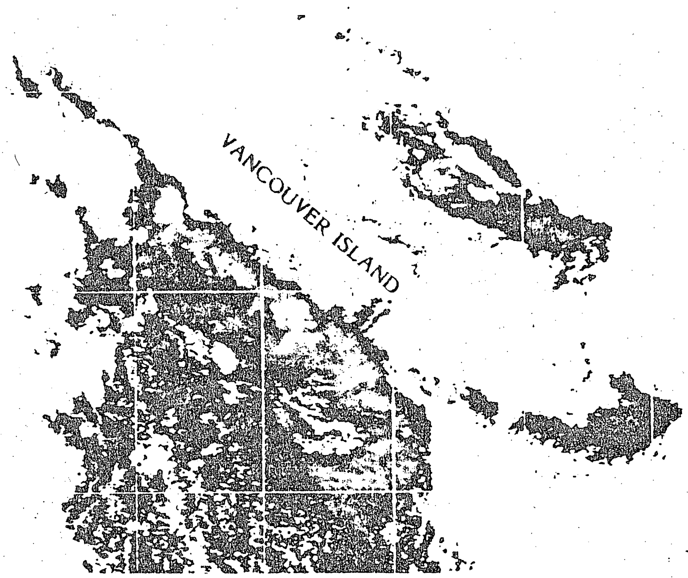

Figure 2. Distribution of the phytoplankton pigment chlorophyll a as calculated from data obtained near local noon July 7, 1981 by the Coastal Zone Colour Scanner (CZCS) on board NIMBUS-7. Dark areas to the left of cloud and land areas are a function of sensor problems.

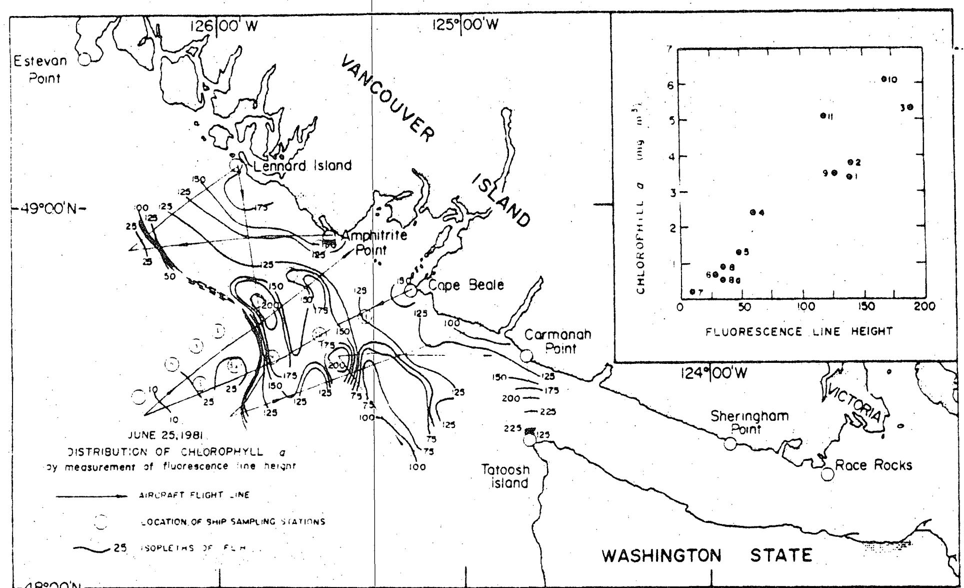

Figure 3. Distribution of the phytoplankton pigment chlorophyll a as determined from airborne measurements of *in vivo* fluorescence on June 25, 1981. Inset compares airborne measurements and surface samples taken the same day.

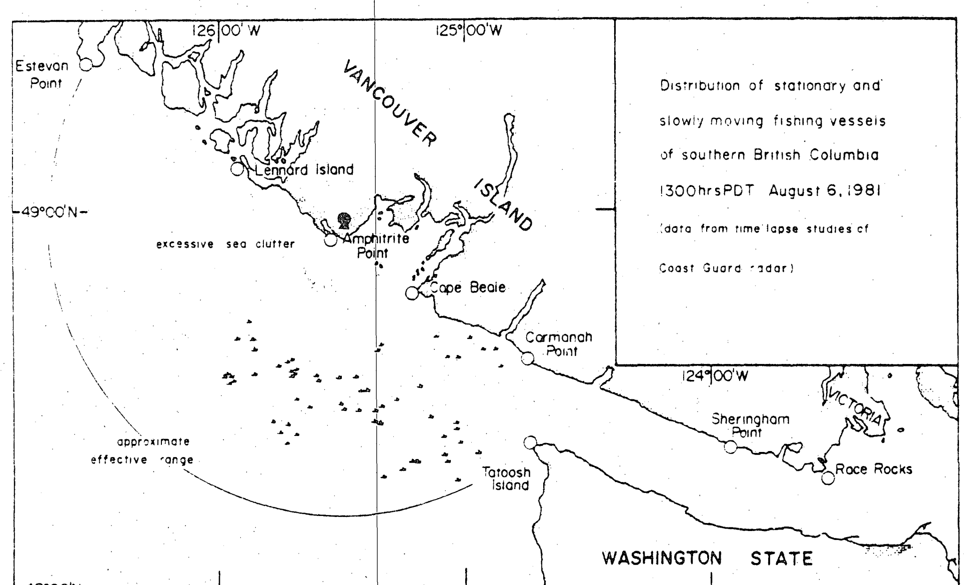

Figure 4. Distribution of fishing activity near 1300 PDT August 6, 1981 as calculated from time lapse studies of a radar screen at the Coast Guard Vessel Traffic Management facility near Amphitrite Point. This was the distribution of vessels at the time of the thermal infra-red image in figure 1.