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THE MARINE SURVIVAL OF SALMON PROGRAM

ANNUAL PROGRESS REPORT, 1990

The Biological Sciences Branch
Department of Fisheries and Oceans
Pacific Biological Station
Nanaimo, British Columbia
Canada V9R 5K6

T.D. Beacham (Program Coordinator)

Fisheries and Oceans
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Program Outline and Investigators Summaries for 1990/91

Produced by

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Part I - INTRODUCTION

by: Terry D. Beacham (Program Coordinator), Pacific Biological Station

Accurately forecasting the number of returning adults for specific stocks of Pacific salmon would be a significant aid in improved management of fisheries. An understanding of the mechanisms controlling survival and thus recruitment of Pacific salmon would allow forecasts of subsequent abundance to be more accurate than is currently the case and lead to improved management of the salmon resource. The Marine Survival of Salmon Program (MASS) began in the spring of 1987, concentrating research activities in Alberni Inlet, Barkley Sound, on banks off southwestern Vancouver Island, and along the west coast of Vancouver Island (Fig. 1), with the objective of understanding the mechanisms that determine variation in recruitment of Pacific salmon.

This fourth annual report of the MASS Program will present the investigators' summaries of the research projects for 1990. The summaries are grouped by the two main geographic areas of research: Barkley Sound, and the continental shelf.

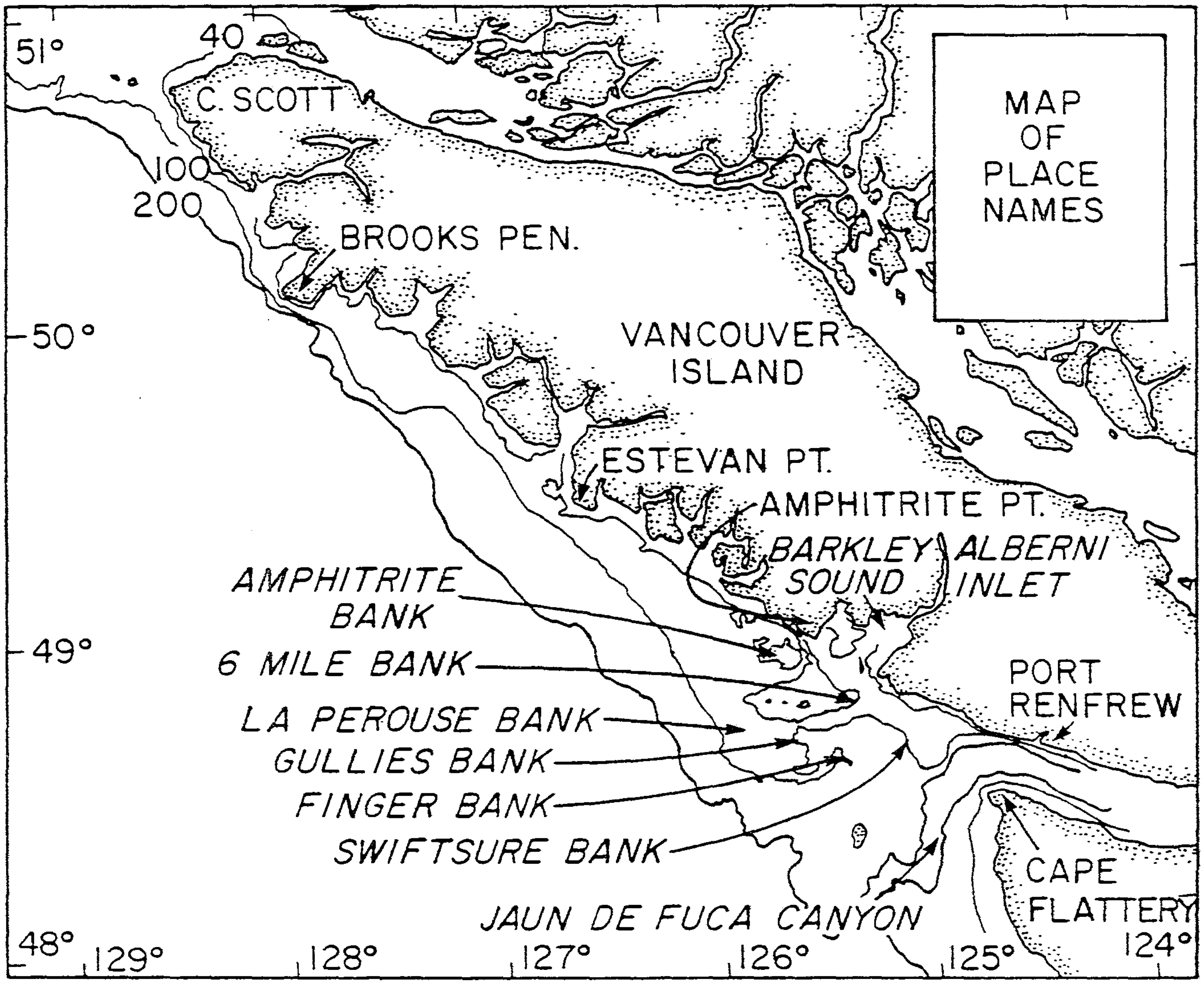


Figure 1. Map of the study area showing principal landmarks.

PART II - SUMMARY OF 1990/91 RESEARCH

BARKLEY SOUND STUDIES

Project: **ABUNDANCE, MIGRATIONS, AND PREDATION MORTALITY OF JUVENILE SALMON IN ALBERNI INLET AND BARKLEY SOUND, B.C. IN 1990.**

by: Brent Hargreaves, Bruce Patten, Bob Hungar, and Ted Carter. Biological Sciences Branch, Pacific Biological Station, Nanaimo, B.C.

INTRODUCTION

Our 1990 activities were similiar to previous years, with the main emphasis directed at determining the predation mortality of juvenile salmon during the early sea life period. The three major sub-projects in Alberni Inlet and Barkley Sound in 1990 included: 1) purse seining to determine the abundance, distribution, and migration timing of juvenile salmon, 2) gillnetting and balloon trawling to determine the abundance, distribution, and rates of predation of fishes feeding on juvenile salmon, and 3) experimental releases of tagged chinook salmon from Robertson Creek Hatchery, designed to test the hypothesis that predation during the early sea life period is a major source of mortality of juvenile salmon. The cooperative efforts and voluntary participation in these activities of many staff from the Salmonid Enhancement Program (S.E.P.) of the D.F.O. are greatly appreciated, and again were instrumental in the successful completion of this work in 1990.

ABUNDANCE AND MIGRATIONS OF JUVENILE SALMON

The purse seine sampling of juvenile salmon was conducted using the D.F.O. research vessel KETA on a bi-weekly schedule in 1990, commencing on 11 April and continuing until 12 July. Typically a complete series of 24 sets were completed every second week, at the same locations that have been used for the last three years (Fig. 2). All purse seine sampling was conducted during daylight. A total of 170 routine purse seine sets were completed in 1990, compared to 192 sets in 1989. This continued the trend from previous years of declining effort in purse seine sampling, as the emphasis has gradually shifted from sampling juvenile salmon to sampling predators (Fig. 3). In this report the purse seine data are presented as average catch-per-unit-effort (CPUE; catch-per-set) for all sets made in each two-week period. Vertical profiles of temperature and salinity versus depth were also obtained during each purse seine set in 1990.

The purse seine sampling indicated a return to more typical conditions for most species of juvenile salmon in Alberni Inlet and Barkley Sound in 1990. In general water temperatures at the sea surface tended to be in the same range as previous years throughout the study area during April - June, but substantially higher than previous years in late June and July. There were no major changes in the patterns of abundance or distribution of juvenile salmon in 1990. The relative timing of the migrations for each species was similiar to previous years, with sockeye showing the earliest peak in

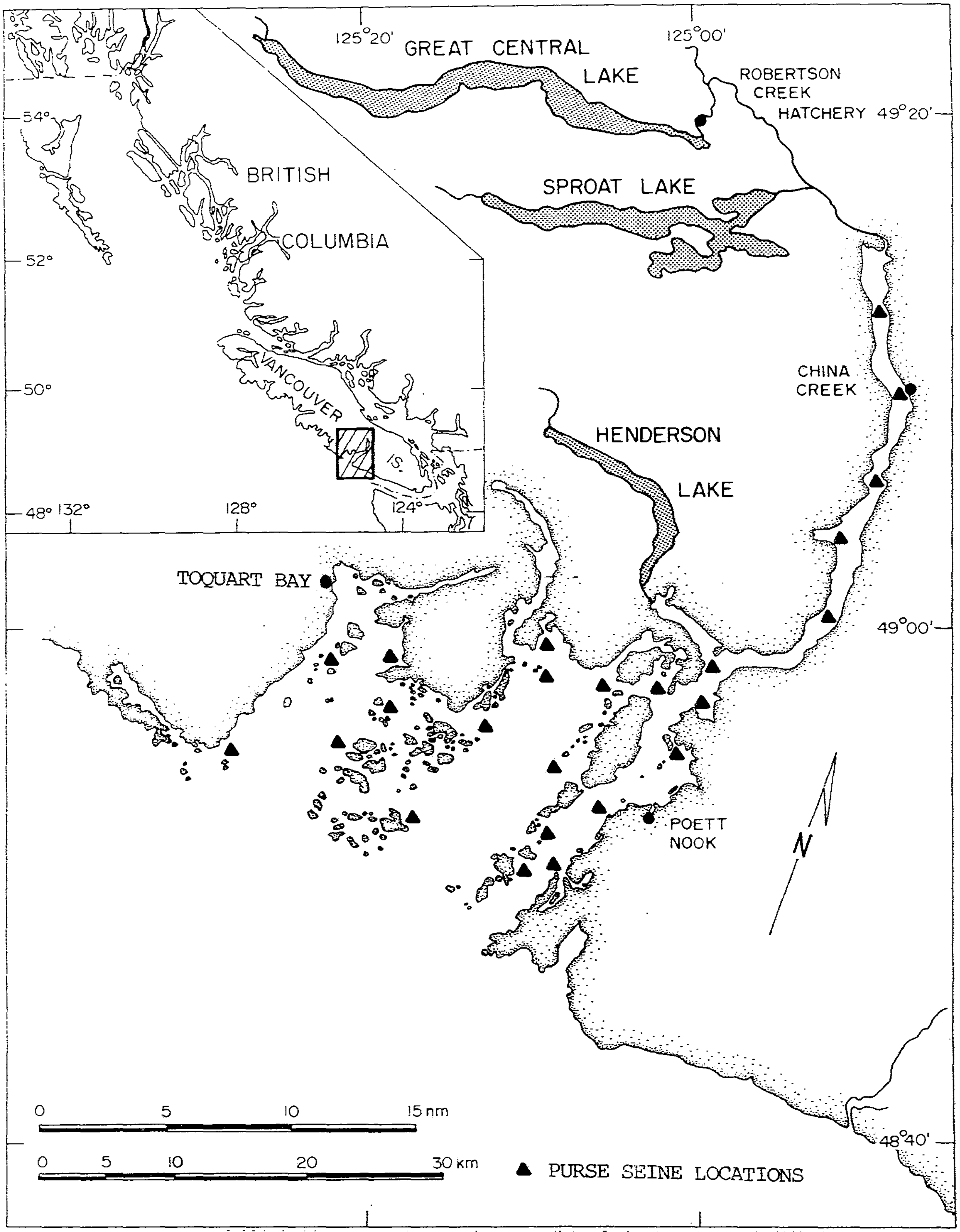


Figure 2. Study area for salmon predation mortality work in 1990, showing standard locations for purse seine sampling, and locations where tagged chinook were released in experiment.

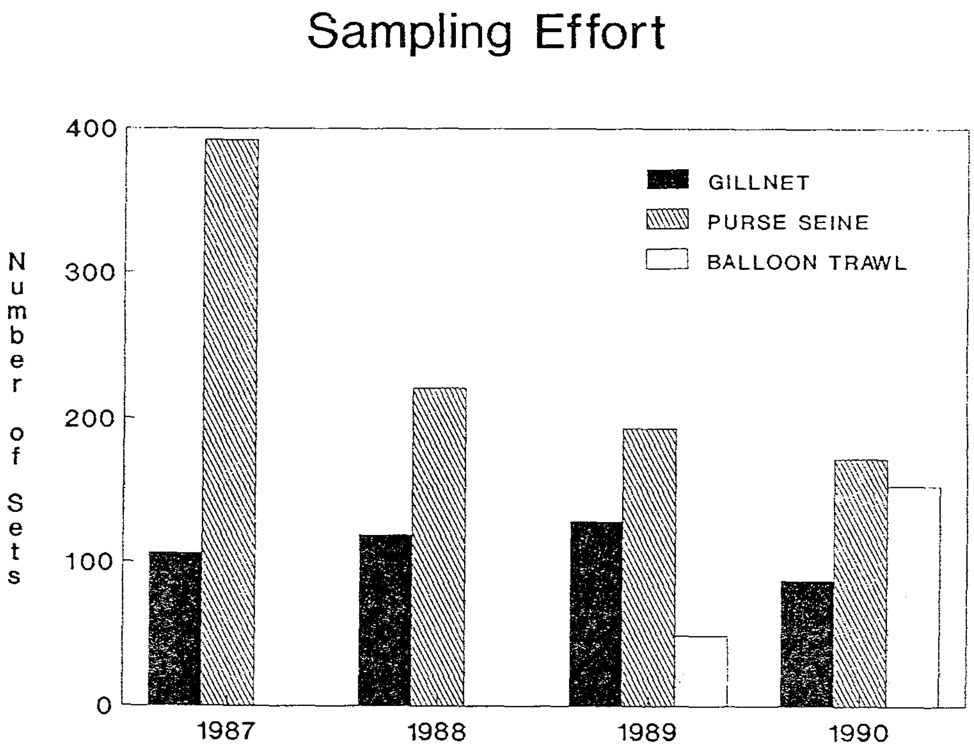


Figure 3. Summary of total sampling effort for each type of fishing gear, for each year of the study.

abundance (CPUE) in May, followed by coho and chum salmon in early June (Fig. 4a). As in previous years, the peak abundance of juvenile chinook salmon occurred later, in late June and early July.

The peak abundance of juvenile sockeye in Barkley Sound was roughly half, and occurred about two weeks earlier, than we observed in 1989 (Fig. 4b). However, the 1990 results were very similiar to those obtained in 1987 and 1988, and it appears that 1989 may have been unusual in terms of sockeye migration timing. All sockeye in the study area arise from natural production, with smolts entering the salt water from three major lakes which surround the study area (Sproat Lake, Great Central Lake, and Henderson Lake; Fig. 2). As in previous years, juvenile sockeye smolts moved rapidly through Alberni Inlet and Barkley Sound in 1990, and few were caught in the study area after the third week in June.

The peak abundance of juvenile coho salmon in Barkley Sound occurred in early June in 1990, the same period as in 1989 (Fig. 4c). The abundance of juvenile coho declined rapidly thereafter, indicating that coho migrated rapidly out through Alberni Inlet and Barkley Sound again in 1990. A total of 1,195,149 juvenile coho were released from Robertson Creek Hatchery in three releases between 15 April and 12 May 1991, at average sizes between 20 and 22

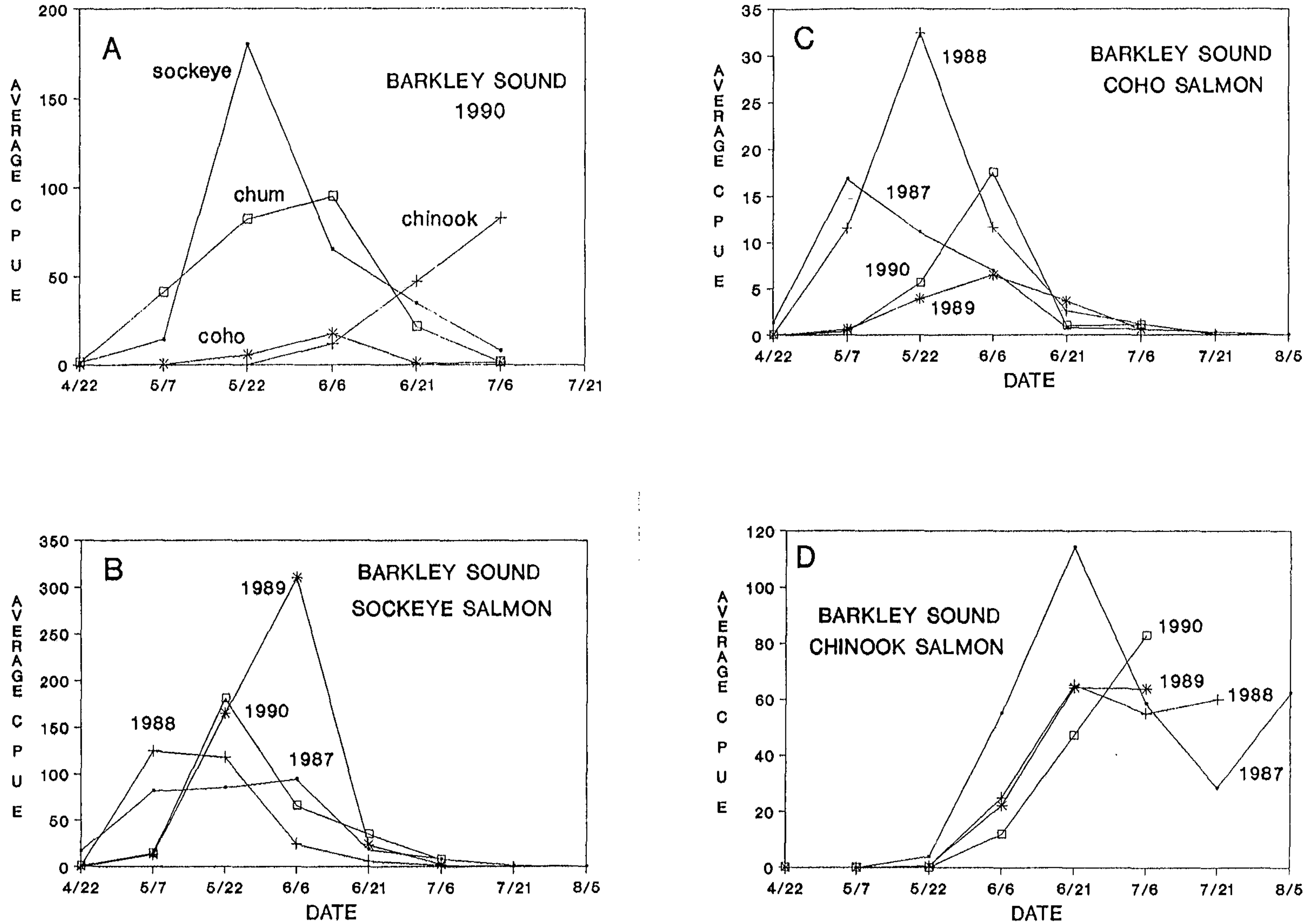


Figure 4. Relative abundance (catch-per-unit-effort) and migration timing of juvenile salmon in Barkley Sound in 1990 (A), and comparisons between years for juvenile sockeye (B), coho (C), and chinook salmon (D).

grams. Based on the size of coho we caught in the purse seine, and the proportion of tagged fish, many of the coho in Alberni Inlet and Barkley Sound originated from Robertson Creek Hatchery. Much of the interannual variation in timing of the peak abundance of coho we have observed also appears to result from variations in the timing of releases of coho from this hatchery.

In 1990 the abundance of juvenile chinook salmon was still increasing in Barkley Sound during early July, and may not have reached the maximum by the time our sampling ended on 12 July (Fig. 4d). Otherwise the pattern and timing of the chinook migration in 1990 was very similiar to that observed in both 1988 and 1989. Based on the results from previous years, chinook abundance in 1990 probably peaked and then leveled off during late July. As in previous years, the migration of juvenile chinook salmon out through Alberni Inlet and Barkley Sound was slower, and chinook resided and reared in Barkley Sound much longer, than all of the other species of juvenile salmonids. The interannual variations in chinook migration timing we have observed appear to result primarily from variations in the timing of releases from Robertson Creek Hatchery. Robertson Creek Hatchery released 9,359,548 juvenile chinook from the hatchery between 23 May and 5 June 1990. An additional 341,867 chinook from this hatchery were released directly into Alberni Inlet and Barkley Sound in experimental releases (see below). However, the level of production of additional "wild" chinook from the Somass River system is not currently known. Based on size distributions, and the ratios of tagged/untagged fish captured in the purse seine in Alberni Inlet, our data suggest that most of the chinook captured in Alberni Inlet and Barkley Sound originate from Robertson Creek Hatchery. However, there is some evidence from previous beach seine and trap sampling in the river that the behaviour of "wild" chinook (most probably from hatchery fish which spawn in the river) may be different from chinook released from the hatchery. If this is true, then the purse seine catch data possibly may not accurately reflect the additional contribution of "wild" chinook to total production. The relative importance of the "wild" chinook production in this system remains an important question, which could be resolved by using a mass-marking technique to mark all chinook released from Robertson Creek Hatchery in a particular year. Subsequent sampling of either the returning adults, or smolts during either the down-stream or early marine period, could be used to determine the ratio of hatchery versus "wild" production, and estimate wild production.

The abundances and migration timing of juvenile chum salmon in 1990 were similiar to previous years. The peak abundance of chum in Barkley Sound occurred during the first two weeks of June, the same period as in 1989 (Fig. 4a). In 1990 a total of 94,532 juvenile chum salmon from Nitinat Hatchery were released during 9-11 May in Cook Creek, which flows into Alberni Inlet. Virtually all (98.5%) of these chum were tagged with coded-wire tags and fin-clipped, and their large size (average 1.3 grams) compared to wild chum should have allowed us to easily distinguish the hatchery fish from the much smaller wild chum caught in the purse seine. However, only five fin-clipped chum were captured in the purse seine in 1990, indicating that most of the chum captured in both Alberni Inlet and Barkley Sound originated from wild production. Too few tagged chum were caught in 1990 to detect any behaviour differences between hatchery and wild chum.

PREDATION MORTALITY OF JUVENILE SALMON

In 1990 we used the D.F.O. vessel L. PACIFICA for field accomodation and two other vessels to sample potential fish predators of juvenile salmon. The D.F.O. vessel KETA sampled with a small balloon trawl, and the commercial fishing vessel RAVEN was chartered to conduct sampling with a multiple mesh-size gillnet. In both cases predator sampling was conducted from dusk to dawn, four nights per week, every second week. Each balloon trawl series consisted of 22 tows throughout the study area, with the first series beginning on 24 April and the last series ending on 19 July 1990. The gillnet sampling followed a similiar schedule, with one complete series of samples (20 sets) completed every two weeks. However, the gillnet sampling started on 2 May and terminated on 22 June 1990 when the contract for the charter vessel ended. A total of 153 balloon trawl sets and 87 gillnet sets were completed in 1990, compared to 49 and 126 sets respectively in 1989 (Fig. 3).

The results of the predator sampling indicate that the incidence of predation on juvenile salmon was higher in 1990. The stomach contents of 1355 potential predators were examined in 1990, compared to 5399 examined in 1989 (Table 1). In 1990 a total of 26 (9.6%) of the 272 fish caught in the gillnet, and 41 (3.8%) of the 1083 caught in the trawl had preyed upon juvenile salmon. Pacific hake were again the most important predators of all species of juvenile salmon in 1990, followed by walleye pollock. None of the spiny dogfish we captured in 1990 had preyed upon juvenile salmon.

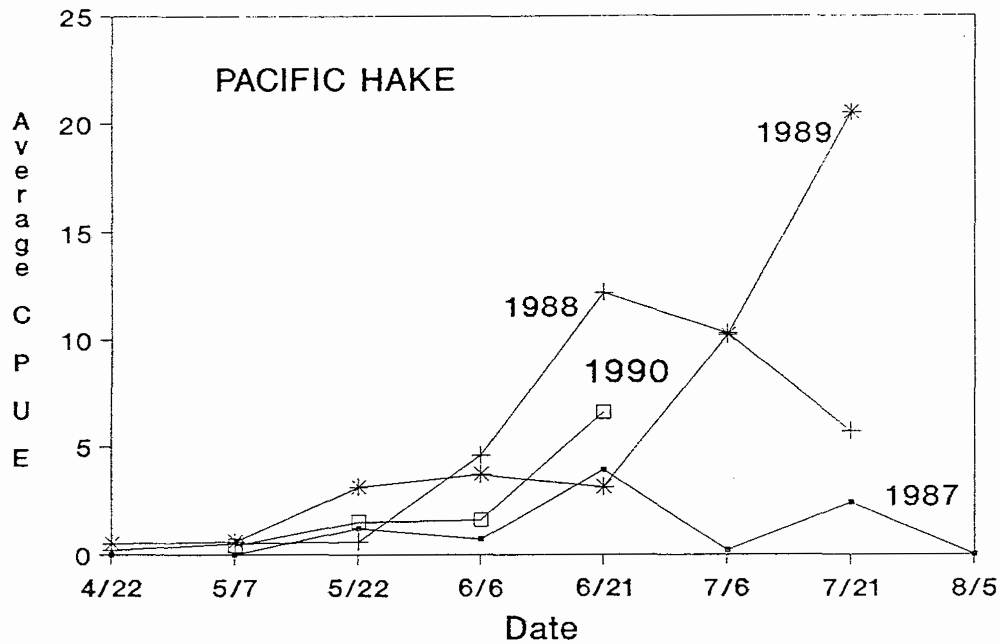
Although the sampling effort with trawl and gillnet in 1990 was comparable to 1989, both the total catches and catch-per-unit effort were much lower in 1990 for all predator species. The gillnet catches in 1990 indicate that the abundance of hake in Alberni Inlet and Barkley Sound was the lowest since 1987 (Fig. 5). The trawl catches confirm that the abundance of predators was much lower in 1990 throughout Alberni Inlet and Barkley Sound until at least the middle of July (Fig. 5).

Table 1. Summary of predator stomach contents data.

PREDATOR STOMACH CONTENTS

SPECIES	NUMBER EXAMINED / NUMBER EATING SALMON					
	1987	1988	1989		1990	
	Gillnet	Gillnet	Gillnet	Trawl	Gillnet	Trawl
HAKE	151/8	716/51	507/57	2784/59	189/21	798/41
POLLOCK	11/3	47/15	65/7	83/0	9/4	22/0
DOGFISH	168/6	262/0	1305/17	92/0	52/0	205/0
OTHER	594/0	570/0	459/18	104/0	22/1	58/0
Totals:	924/17	1595/66	2336/99	3063/59	272/26	1083/41
Percent:	1.9	4.1	4.2	1.9	9.6	3.8

GILLNET CPUE



BALLOON TRAWL CPUE

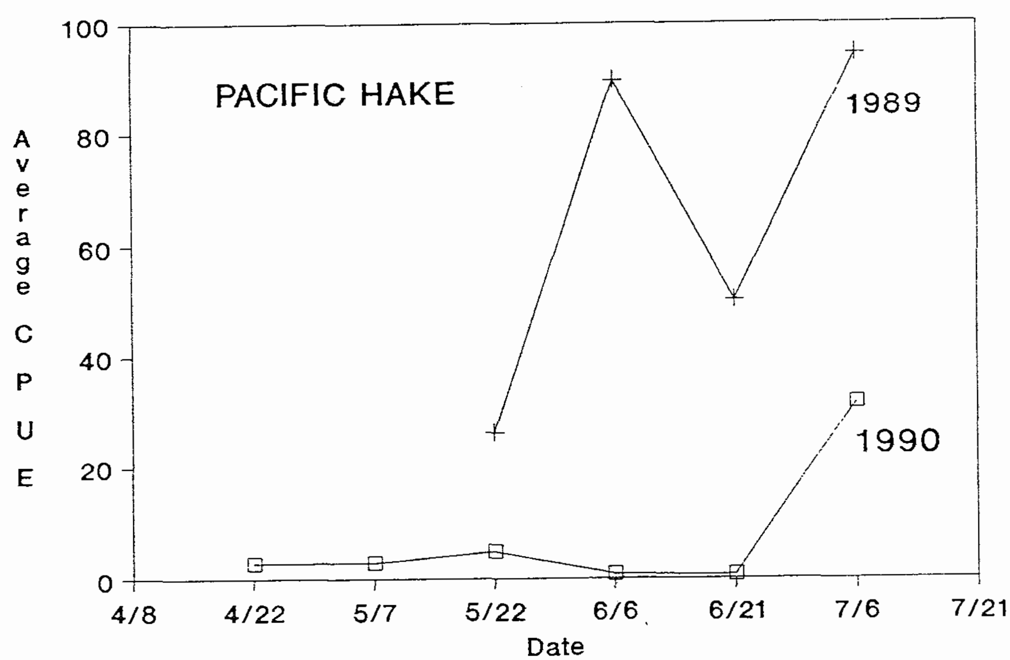


Figure 5. Relative abundance (catch-per-unit-effort) of Pacific hake caught by gillnet (upper panel) and balloon trawl (lower panel) each year.

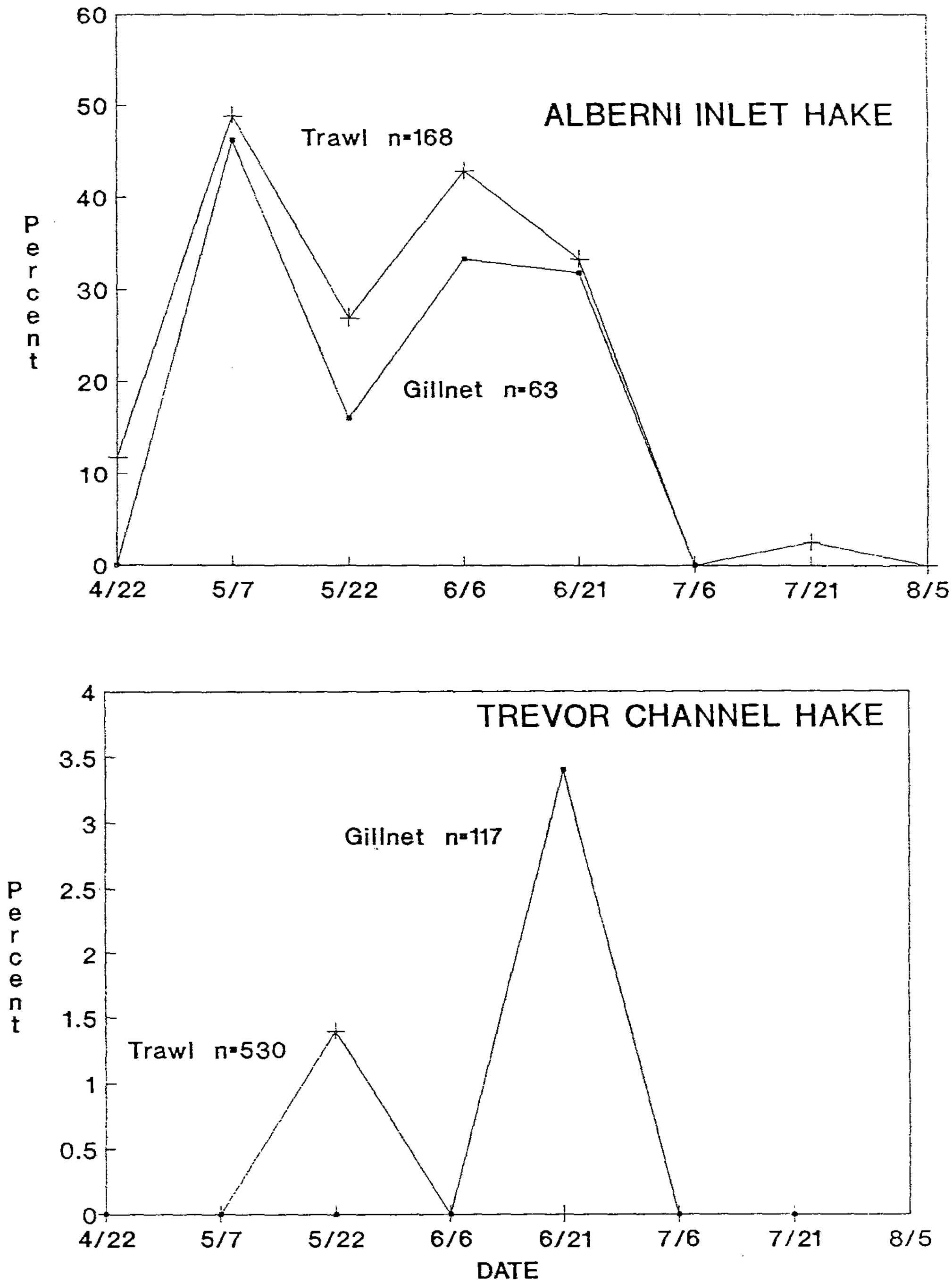


Figure 6. Percent of hake examined in 1990 in Alberni Inlet (upper panel) and Barkley Sound (lower panel) with juvenile salmon in their stomachs.

In 1990 the offshore migratory stock of hake did not arrive in Alberni Inlet and Barkley Sound until the middle of July. The gillnet CPUE data for 1990 indicate a low abundance of hake from April to mid-June, followed by an apparent increase in abundance near the end of June (Fig. 5). The validity of this increase is questionable, however, as it results from large catches in only two gillnet sets. Unfortunately the charter of the gillnet vessel ended in June in 1990, and we have no gillnet data in July to compare with the results from previous years. However, the data from the balloon trawl catches are more extensive and confirm the much lower abundance of hake and other predators in all time periods in 1990, compared to 1989 (Fig. 5). Although the average CPUE data from the trawl catches also suggest that the arrival of the main migratory stock of hake in Barkley Sound occurred during the first week of July, most of this increase actually occurred near the end of the second week in July. This is the latest arrival timing for migratory hake that we have observed in the four years of this study.

The spatial and temporal patterns of hake predation on juvenile salmon observed in 1990 were similiar to previous years. The highest incidence of hake predation on juvenile salmon occurred in Alberni Inlet during early May, when 49% of the hake examined had consumed one or more juvenile salmon (Fig. 6). The pattern of predation in Alberni Inlet was very similiar for hake caught in both the gillnet and balloon trawl. The predation rate was lower for hake caught in Trevor Channel, and once again no predation on juvenile salmon was observed by any species captured in either Imperial Eagle or Loudoun Channel in Barkley Sound. As in previous years, the proportion of hake preying on salmon gradually declined to zero percent by early July in all areas, as hake and other predators gradually switched to feeding on juvenile herring.

In general, our preliminary analyses of the 1990 data indicate that the predation mortality of juvenile salmon in Alberni Inlet and Barkley Sound was probably the lowest since 1987. Although the proportion of predators that preyed on juvenile salmon was highest in 1990, the total number of predators was much lower, which more than compensated for the higher incidence of predation. If the predation mortality hypothesis is correct, then the juvenile chinook and sockeye salmon that went to sea in the spring of 1990 should show the highest marine survival rate since 1987.

EXPERIMENTAL RELEASES OF HATCHERY CHINOOK

In 1990 we again conducted an experimental release of hatchery-reared chinook to: 1) determine the importance of release site on subsequent marine survival, and 2) test our hypotheses that predation by Pacific hake in Alberni Inlet and Trevor Channel is an important source of mortality for juvenile salmon. The experiment conducted in 1990 was again a cooperative effort, co-funded and involving many staff from both the Salmonid Enhancement Program and Biological Sciences Branch of the D.F.O. In 1990 a total of about 227,000 juvenile chinook were vaccinated against Vibrio anguillarum bacteria infection and coded-wire tagged at Robertson Creek Hatchery. Three tag groups totalling 63,325 chinook were released at China Creek Marina in Alberni Inlet on 17 May, three other tag groups (51,774 fish) were released on 19 May at Poett Nook in Trevor Channel, and three tag groups (47,769 fish) were released on 17 May at

Toquart Bay in Barkley Sound (Fig. 2). The chinook released at each of these locations were all transported the same distance by tanker truck from Robertson Creek Hatchery, transfered directly into two net pens in salt water, held for 24 hours, and then released. Three additional tag groups (62,320 fish) were also transported the same distance in the tanker truck, then returned to and released from the hatchery on 14 May. The tag groups released at the hatchery served as the experimental control. The first returns of tagged fish (2 year old jacks) from the 1990 experiment are expected in the fall of 1991, and final results will be available in 1994 when the last age group (five year old fish) have returned.

ACKNOWLEDGEMENTS

The 1990 MASS predation mortality project again demonstrated the effectiveness of cooperative work between various D.F.O. Branches. Drs. R.E. Thomson and M. Foreman (Institute of Ocean Sciences, Sydney) contributed much useful information concerning the physical oceanography of Barkley Sound and west coast of Vancouver Island. For the chinook offsite release experiment, E.A. (Ted) Perry (SEP, Vancouver) coordinated the funding, Don Lawseth (SEP, Robertson Creek Hatchery) managed the tagging and vaccination operations, Tom Forrest (SEP, Robertson Creek Hatchery) operated the tanker truck, and Biological Sciences Branch provided the vessels and net pens used to hold the chinook in salt water.

Many other people from the Salmonid Enhancement Program (SEP) again contributed substantially to the success of this project in 1990. Eighteen SEP staff each participated for either one or two weeks to crew the vessels for the fish sampling conducted in Alberni Inlet and Barkley Sound. Those involved this year included T. Forrest (Robertson Creek Hatchery), R. Argue (Prince George), J. Kambeitz, G. Taccogna, and S. Gidora (New West), K. Gooch and C. Sciankowy (Inch Creek Hatchery), A. Stobbart (Pitt River Hatchery), K. Lysack and D. Ewart (Quinsom Hatchery), S. Hollick-Kenyon and R. Godin (Capilano Hatchery), D. Johnson (Spius Hatchery), G. McBain (Sechelt), and W. Peterson, W. Krause, E. Woo, and G. Labinsky (Vancouver). We enjoyed and benefited greatly from working directly with all these people, and gratefully acknowledge their enthusiastic participation. We also appreciate the support provided by E.A. (Ted) Perry (SEP, Vancouver) who coordinated the SEP volunteer participation, and D. Griggs (Director, SEP) who provided partial funding for this project in 1990 and supported and encouraged the direct involvement of SEP staff in our field work. Our sincere thanks also goes to all the SEP hatchery and project managers, and other senior D.F.O. managers, who supported the involvement of SEP staff in this project in 1990 and previous years. This work could not have been accomplished without your continued support.

We also thank our two summer students Rob Dams and Ian Williams, who worked long hours in 1990 without complaint, for many months, often under conditions that were very challenging. Both provided competent assistance in all aspects of the 1990 field work.

Project: SOCKEYE SALMON RECRUITMENT VARIATIONS

by: K. D. Hyatt, M. Wright, P. Rankin, I. Miki and D. Kolody. Pacific Biological Station.

Several stocks of sockeye salmon (Oncorhynchus nerka) returning to locations in and around Barkley Sound on the West Coast of Vancouver Island (WCVI) have exhibited a pattern of declining returns in recent years. Returns of sockeye derived from the 1980 to 1986 brood years were low enough that commercial, sport and native fisheries were either eliminated or sharply curtailed during most return years between 1985 and 1990. Our studies are designed to: (1) generate data to test hypotheses about either the pattern or mechanisms associated with these declines and (2) to apply new information to improve both pre-season forecasting and in-season management of west coast sockeye fisheries.

Comparisons of freshwater and marine survival patterns for several sockeye stocks along the British Columbia coast over the past decade have permitted us to identify the spatial and temporal bounds within which mechanisms driving Barkley Sound sockeye recruitment declines probably operate (Hyatt et al. 1989). Findings to date indicate that:

(1) processes operating in the marine environment rather than in nursery lakes were primarily responsible for the recent declines in returns,

(2) declines between 1985 and 1990 were shared by sockeye stocks along the WCVI both inside and outside of Barkley Sound. However, low marine survival rates were not characteristic of sockeye stocks returning to most other areas of the coast,

(3) smolt-to-adult survivals of sockeye from WCVI appear to be responsive to changes in marine "climate" as indicated by a positive correlation (Ln survival = 0.929 salinity - 25.663; $r^2 = 0.66$, $p < .001$, $n = 23$) between survival and salinity variations (at Amphitrite Point) during the period of seaward migration by sockeye smolts (Hyatt et al. 1989).

The salinity survival relationship in combination with acoustic and trawl based estimates of presmolt abundance (Table 2) in nursery lakes has been used since 1987 as the basis for a new forecasting procedure (Hyatt and Steer, PSARC working paper 88-2) to estimate sockeye returns to Barkley Sound. Predicted returns over the past four years have been within 7 % of observed returns (Table 3) and these predictions have been of significant aid to fisheries personnel in management of the Area 23 sockeye stocks.

Table 2. Acoustic and trawl based estimates of sockeye smolt releases by stock and year.

	Smolt production (millions)			
Smolt Year	Henderson	Great Central	Sproat	Total for Barkley Sd.
1987	2.30	6.20	8.30	16.8
1988	.15	5.30	9.30	14.8
1989	.77	7.10	9.00	16.8
1990	4.88	9.09	10.55	24.5

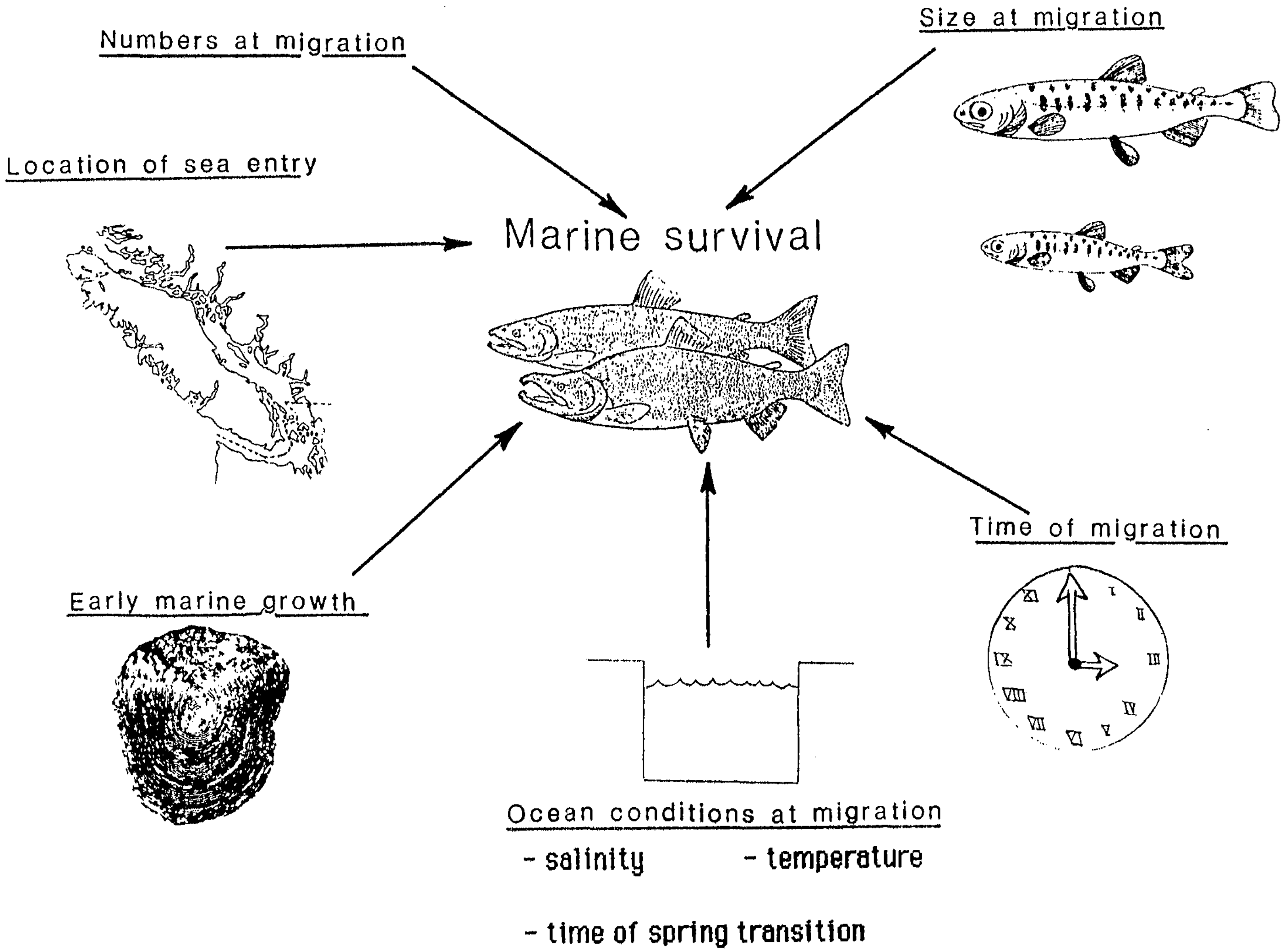
Table 3. Sockeye survival and adult return predictions based on measures of smolt abundance and the observed relation between mean salinity at Amphitrite Point and smolt-to-adult survival variations.

Smolt Year	% Survival Predicted	Return Year	Returns Predicted	Returns Observed	Deviations as % of Observed
1985	2.50	1987	650,000	635,665	2.0
1986	1.29	1988	795,475	850,000	6.4
1987	3.07	1989	428,042	443,031	3.4
1988	2.19	1990	443,400	425,000	4.3
1989	3.70	1991	667,742		
1990	7.55	1992			

SOCKEYE MARINE SURVIVAL AND IT'S COVARIATES

We have identified that sockeye marine survival variations are associated with ocean conditions as indexed by surface salinity within a restricted geographic region on the WCVI at the time that smolts migrate seaward. However, the significance of this association is not understood. The sea surface salinity (SSS) values are well within tolerable limits for young sockeye so a causal relationship between SSS and sockeye survival is unlikely. In conjunction with annual stock assessments we have expanded the range of variables under assessment (Fig. 7) to test for further associations between sockeye marine survival variations and factors which may be involved either directly or indirectly in determining marine survival. Identification of additional variables exhibiting a close asssociation with sockeye marine

Figure 7 Sockeye marine survival and potential covariates under study for Barkley Sound sockeye (Hyatt et. al. 1989).



survival may provide an important key to unlock the identity of the mechanisms actually controlling survival variations. Brief summaries of our progress in testing hypotheses about the nature of the mechanisms controlling marine survival variations follow.

LOCATION OF SEA ENTRY

Comparisons of marine survival patterns over time for sockeye stocks which enter the marine environment at different locations within Barkley Sound and along the B. C. coast provide a basis for testing hypotheses about the spatial organization of mechanisms determining marine survival. For example, between 1977 and 1980 marine survivals of sockeye originating from stocks along WCVI appeared to be quite variable suggesting that features unique to each stock, including location of origin, were important in determining survival success. However, sockeye smolts that migrated seaward between 1981 and 1984 from locations along the WCVI exhibited covarying patterns of declining marine survival (Hyatt et al. 1989) regardless of whether they initiated migrations from inside (Great Central, Sproat, Henderson stocks) or outside of Barkley Sound (Hobiton sockeye). This suggests that the mechanism(s) controlling sockeye marine survival during this interval did not operate strictly within Barkley Sound. By contrast, sockeye migrations involving points of sea entry within Georgia Strait (Chilko, Lake Washington stocks), on the Central Coast (Long Lake stock) or the North Coast (Babine stock) did not exhibit a similar pattern of decline. This suggests that the mechanism(s) determining marine survivals for the latter stocks differed significantly from those operating on sockeye salmon migrating along the west coast of Vancouver Island between 1981 and 1989.

SOCKEYE GROWTH RATES, PREY AVAILABILITY AND INTERACTIONS WITH PREDATORS

Over the past 10 years, the lowest (1 %) and highest (8 %) survival rates for sockeye originating from Barkley Sound were exhibited by juveniles migrating seaward during the springs of 1983 and 1978 respectively. Perhaps not coincidentally, juvenile sockeye that experienced the lowest survival rates migrated seaward during years (1983, 1984) when the coastal marine climate was clearly influenced by the strongest ENSO event of the last century (Thomson et al. 1984). Fulton and LeBrasseur (1985) presented evidence that prey availability for juvenile salmon might decline along the B. C. coast during ENSO years (years of high northward transport along the continental margin) by comparison with non-ENSO years. They speculated that changes to the prey base might retard marine growth rates of juvenile salmon and consequently reduce their survival rates through exposure to size biased predation for a longer than average interval. Our approach to testing this hypothesis has involved several steps including: (i) examination of the diets of juvenile sockeye salmon migrating through Barkley Sound to identify prey sizes and taxa of greatest importance for early marine growth, (ii) examination of prey abundance in Barkley Sound to characterize quantity of food available (Mackas and MacIsaac 1988, Forbes et al. 1990) relative to the "cropping potential" of juvenile salmon (Hyatt et. al., this study) and (iii) analysis of scale samples from adult sockeye to index early marine growth rates (first year) associated with sockeye year classes exhibiting high versus low marine survivals.

Analyses of diet and scale samples from two years have been completed to date and permit preliminary testing of the Fulton-LeBrasseur hypothesis for strong links between variations in food supplies, reduced early marine growth rates and low marine survivals. Results from diet analysis indicate some potential for interspecific competition for food supplies since various species of juvenile salmon (sockeye, chinook and chum) migrating through Barkley Sound rely on similar prey taxa (early stage euphasiids, medium sizes of copepods and brackish water cladocerans) during the spring and early summer period. However, scale analysis indicates that first year marine growth rates of juvenile sockeye that experienced the lowest survival rate (1983 smolt year) were not significantly lower than growth rates achieved by juvenile sockeye exhibiting one of the highest survival rates (1978 smolt year) of the past decade.

The above results are not supportive of the "Fulton-LeBrasseur hypothesis" that low marine survival rates for Barkley Sound sockeye are mediated by competition for limited forage, reduced marine growth rates and an increased period of vulnerability to predators during migration periods in years influenced by strong ENSO events. However, Holtby et. al. (1990) recently suggested that marine survival and early ocean growth of coho salmon were positively correlated with ocean conditions along WCVI. Differences between results of Holtby et. al. and the present study may be based on their examination of early marine growth of coho as indexed by the average distance over the first 5 ocean circuli (reflective of growth over an approximately 60 day period) rather than to the end of the first ocean year as measured by us for sockeye. Consequently we plan to extend our measurements of sockeye scales during 1991/92 to include a test for covariation in very early marine growth and marine survival by WCVI sockeye.

VARIATIONS IN SOCKEYE SIZE AT MIGRATION

Sockeye smolt size variations have been assessed annually for each of the three Barkley Sound stocks since 1981. Size differences were small during the early 1980's but have been large enough in recent years (Table 4) to potentially produce major differences in marine survival rates if size biased predation from piscivorous fish (e.g. hake) or birds (e.g. auklets) is very important to sockeye survival outcomes. For example Henderson smolts migrating seaward in 1986 at 1.51 grams may be expected to survive at a much lower rate than those initiating migration at 6.9 grams in 1988. Similarly large (6.80 gram) smolts originating from Great Central Lake (GCL) in 1988 may be expected to survive at a higher rate than their smaller 3.74 gram counterparts in 1987 (Table 4). Adult returns associated with large smolts from Great Central and Henderson lakes in 1988 will return to Barkley Sound at ages four and five in 1990 and 1991.

Table 4. Sockeye smolt size variations (weight in grams): 1986-1989.

Year	Henderson	Great Central	Sproat
1986	1.51	4.24	4.74
1987	5.90	3.74	4.26
1988	6.90	6.80	3.50
1989	4.00	4.34	4.63

In the 1989 MASS report we suggested that if smolt size variations were very important to survival outcomes, then positive deviations from the salinity based predictions of survival for GCL and Henderson stocks (i.e. 1990 returns derived primarily from very large smolts) should occur while little deviation would be observed for the Sproat (Sp.) stock during 1990 (i.e.1990 returns derived primarily from smolts of average size). Analysis of 1990 return observations suggests that these predictions were borne out since returns of Great Central and Henderson sockeye were approximately 67 % and 28 % higher than predicted while returns of Sproat sockeye were 24 % lower than expected. Consequently, further testing for a smolt size and marine survival effect appears warranted for Barkley Sound sockeye.

VARIATIONS IN TIME AT MIGRATION

Several independent studies involving timed releases of hatchery chinook and coho have demonstrated the importance of variations in time at release on marine survival rates of salmon. Although juvenile sockeye from natural populations do not have a controlled release date, there is considerable variability among stocks and years in the timing of their seaward migrations. We assessed the timing of sockeye smolt migrations from GCL and Sp. lakes between 1987 and 1990. Sproat smolts have migrated seaward one to three weeks earlier than GCL sockeye in 3 of 4 years of observations to date (Table 5).

Table 5. Date of 50 % migration of sockeye smolts from Sproat and Great Central lakes between 1987 and 1990.

Year	Sproat	Great Central	Difference
1987	May 01	May 08	1 week
1988	April 16	May 06	3 weeks
1989	April 30	May 01	1 day
1990	April 22	May 12	3 weeks

Timing differences detected to date are large enough to potentially contribute to differences in marine survival. These differences may be exploited to provide further definition of the characteristics of the mechanisms controlling annual marine survival variations. For example, circumstantial evidence accumulated in recent years by MASS and La Perouse Program studies suggests that pre-recruit survival of both herring and salmon along WCVI may be controlled largely by the amount of spatial and temporal overlap these species experience with northward migrating hake (see Hargreaves, this report; Ware and Tanasichuk, 1988). If hake predation is the major factor controlling smolt-to-adult survival variations of WCVI sockeye, then juvenile sockeye exhibiting greater spatial/temporal overlap with hake should on average exhibit lower survival rates than those experiencing less overlap. Thus, all other things being equal, sockeye migrating from GCL during 1988 should exhibit lower survival rates than those originating from Sp. since the latter population moved seaward earlier than GCL smolts which may have experienced as much as a 5 to 10 fold higher probability of encountering hake (Fig. 8a). By contrast, juvenile sockeye originating from both GCL and Sp. in 1989 should experience similar prospects for overlap with hake (Fig. 8b) and are expected to survive at similar rates if hake predation is the principle source of mortality.

Multiyear observations concerning juvenile sockeye and hake overlap in Barkley Sound and predicted differences in survival rates of the 1988-1990 smolt cohorts provide the most promising evidence yet for a critical role by hake in determining interrannual variations in sockeye marine survival i.e. predicted smolt-to-adult survivals have increased progressively from 2.2 to 3.7 to 7.6 % for the 1988-1990 smolt cohorts respectively (Table 3) as: (i) salinities have exhibited progressively higher values during the interval of sockeye smolt migration and (ii) migrant hake have arrived in Barkley Sd. progressively later in the spring/summer (Hargreaves, this report). Two aspects of these results are especially encouraging. First, we appear to be making progress in linking a physical variable (i.e. salinity), commonly observed to have value in predicting salmon survival, to a biological mechanism (i.e. hake predation) and second, predictions suggest higher marine survivals and increases in surplus sockeye for native, sport and commercial harvest in Barkley Sound during 1991 and 1992.

CREATION OF EXPERIMENTAL CONTROLS ON WILD STOCK OBSERVATIONS

Observations assembled above indicate that variations in smolt size, migratory timing and location of sea entry may all be involved in determining marine survival variations of sockeye originating from the WCVI. However, the interdependence of several of these variables in wild stocks of sockeye (e.g. smolt size, time at migration, total numbers migrating) is likely to weaken the use of uncontrolled observations as a basis for testing hypotheses about specific mechanisms as determinants of marine survival variations. For example, we predicted above that if hake predation in or around Barkley Sound is the principle mechanism controlling annual survival variations of sockeye, then, all other things being equal, smolts originating from GCL in 1988 should survive at a lower rate than those from Sp. since timing of hake and sockeye migrations to Barkley Sound favoured greater overlap of hake and GCL sockeye

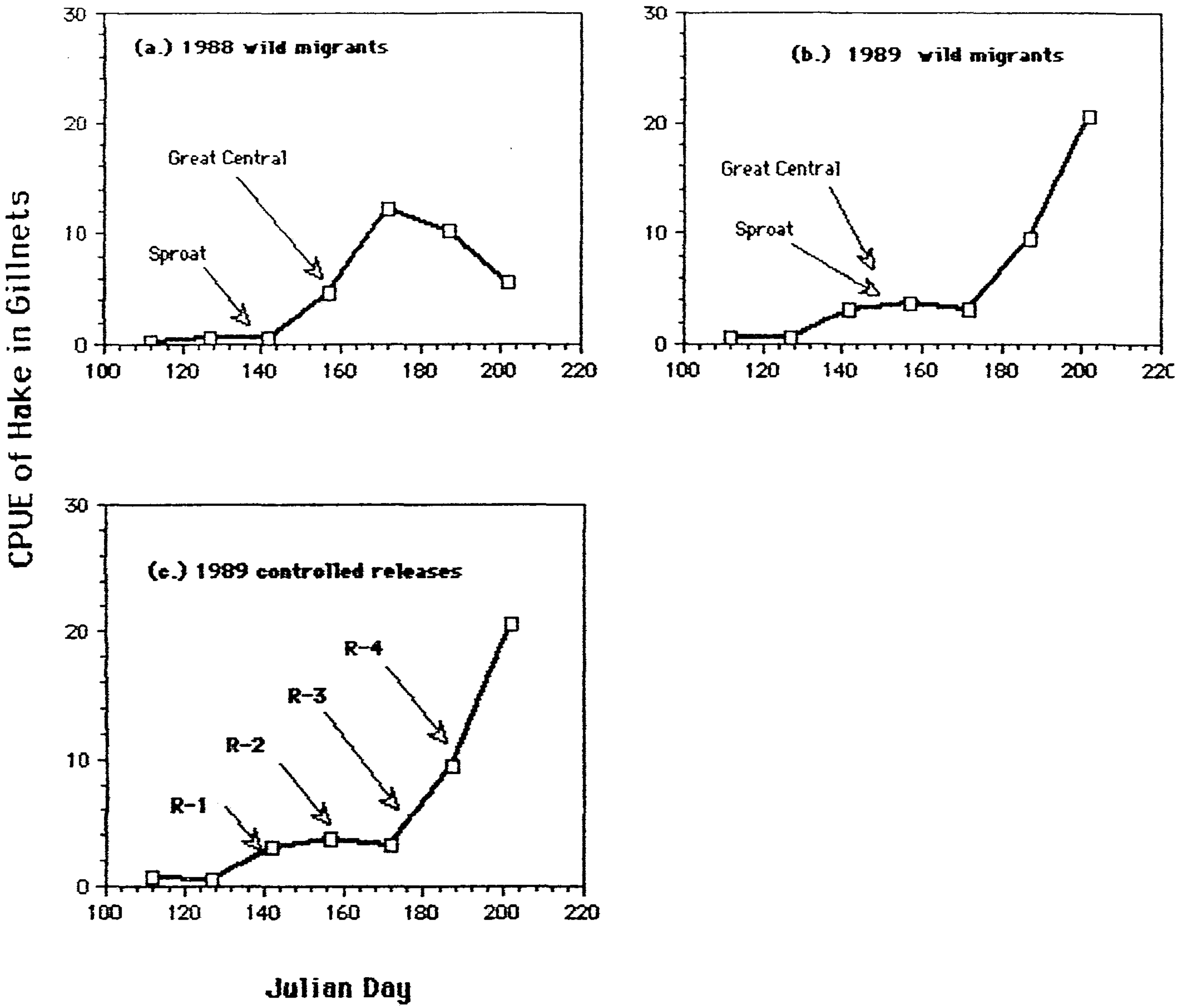


Figure 8 Timing of seaward migration by sockeye smolts (arrows) relative to hake abundance (curves) in Barkley Sound during (a) 1988 and (b., c.)1989. Hake catch per unit effort data are from Hargreaves et. al. (this report). Arrows in panels (a) and (b) indicate times by which approximately 50 % of juvenile sockeye from either Sproat or Great Central would reach the seaward margin of Barkley Sound. Arrows in panel (c) indicate the times at which separate coded wire tag groups of sockeye released from Hobiton and Cheewhat lakes would reach the northern margin of Barkley Sound.

than of hake and Sp. sockeye (Fig. 8a). Unfortunately smolts leaving GCL and Sp. during 1988 differed not only in migratory timing but also in average body size (i.e. GCL smolts were 94 % larger by weight than Sp. smolts) with the result that smolts originating from GCL in 1988 would be expected under a "size-and- survival hypothesis" to survive at a higher rate than those from Sp. Multivariate time series might eventually permit definition of the importance of interactions between factors such as time and size differences on wild stock survival rates. However, in the short run, controls for time or size effects on marine survival are required to interpret the applicability of wild stock survival observations to test the hypotheses outlined above.

Experimental releases of tagged groups of sockeye from small sockeye stocks located immediately south of Barkley Sound (Hobiton and Cheewhat lakes, Fig.9) were initiated in 1989 to provide control observations on within year effects of time and size differences on sockeye marine survival rates. Four groups (approximately 4,000 to 10,000 smolts per group) of small (2.8 g) and large (7.9 g) smolts were marked with coded wire tags and then released from Hobiton and Cheewhat lakes respectively during the springs of 1989 and 1990. Given average migration rates of about 3 km per day (Groot and Cook 1988), tagged groups of sockeye would arrive at the northern limit of Barkley Sound by dates spanning: (i) periods of peak abundance of smolts migrating from both Great Central and Sproat lakes (Fig. 8a-c) and (ii) periods of both low and high hake abundance (Fig. 8c). Given that coincident migration patterns and hake predation are key components of the mechanisms controlling marine survival variations by WCVI sockeye, we expect that early release groups (R-1 and R-2) will survive better than later ones (R-3 and R-4) in 1989 and that large Cheewhat smolts (7.9 g) will survive at higher rates than small (2.8 g) Hobiton smolts in 1989. By contrast, all 1990 release groups are expected to survive at higher rates than those released in 1988 and 1989 due to minimal overlap of all groups with late arriving hake in 1990. Survival patterns that conform or deviate from these expectations currently provide our best opportunity to critically test the consistency of predictions associated with the hake predation hypothesis.

MORTALITY EVENTS FOR ADULT SOCKEYE IN AREA 23 DURING 1990

Most research in the MASS Program has focused on investigations of mechanisms potentially influencing the survival of salmon during the early marine phase of their life history. However, during the summer and fall of 1990, adult sockeye returning to Barkley Sound and the Somass River experienced mortality events resulting from complex interactions among a variety of biological and physical events including: anomalously high summer temperatures of near coastal waters along WCVI, delayed migration of sockeye from Alberni Inlet through the lower Somass River, suboptimal dissolved oxygen conditions at the head of Alberni Inlet, high temperatures and low water flows in the Somass River, a proliferation of parasites and algal blooms in Alberni Inlet and Barkley Sound.

In response to requests from senior management within DFO, we completed supplementary stock assessments and undertook additional analysis to clarify the magnitude and causal factors for the 1990 losses of sockeye adults in terminal areas of Alberni Inlet and the lower Somass River. Although this work is only partially complete, some tentative conclusions follow. First, several lines of evidence support the view that roughly 100,0000 sockeye or 25 % of the total return to Area 23 perished during migration through Alberni Inlet and the Somass River i.e. losses of adult sockeye during 1990 were economically significant. Second, analysis for associations between physical variables (Alberni Inlet oxygen levels, riverine temperature and discharge) and migratory timing of sockeye in the Somass River supports the view that extreme migratory delays during 1990 were principally attributable to riverine conditions (high temperatures, low discharge). Exposure to low oxygen conditions and a rapidly increasing population of parasitic copepods in Alberni Inlet undoubtedly contributed to high mortalities of adult salmon migrating through terminal areas during late Aug. and early Sept. Spawning ground surveys indicate that adult sockeye that entered Great Central and especially Sproat Lake in late summer continued to experience above average pre-spawning mortalities such that final loss rates remain uncertain at this time. Independent estimates of the impact of 1990 events on brood year productivity by stock will be available given completion of juvenile production estimates from acoustic and trawl surveys to be completed by us in the various nursery lakes in 1991/92. However, it appears that in some years at least, low marine survival of sockeye may be controlled by conditions experienced during migrations by both juvenile and adult fish.

STUDIES PLANNED FOR 1991

During 1991 and beyond, we will continue our assessments of marine survival for several stocks of sockeye distributed along the B. C. coast. These data will eventually permit us to confirm or reject the hypothesis that sockeye survival patterns are uniqely associated with one geographic locale (e.g. Barkley Sound, WCVI) during specific study years of the MASS Program (note adults derived from juvenile sockeye migrating seaward in spring 1989 and 1990 will not complete returns until the fall/winter of 1994).

Observations assembled above indicate that variations in smolt size, migratory timing and location of sea entry may all be involved in determining marine survival variations. However, the interdependence of several of these variables in wild stocks of sockeye (e.g. smolt size, time at migration, total numbers migrating) is likely to confound future analyses of the nature of marine survival patterns. In addition, strictly descriptive studies of wild stocks generate only one marine survival observation a year from each sockeye population. Consequently, we will continue coded wire tag releases of sockeye from two to four stocks of WCVI sockeye over the next 2-3 years in order to: (1) establish experimental controls for the influence of variables such as time, size and location of migration on marine survival of wild sockeye and (2) to accelerate the rate of data retrieval on factors influencing marine survival variations.

Recovery of adult sockeye bearing coded wire tags began with recovery of approximately 8 tagged "jacks" at Cheewhat Lake in 1990. Adult recovery efforts will be intensified in 1991 and for several years thereafter as tag groups from multiple years of releases return to the Hobiton and Cheewhat

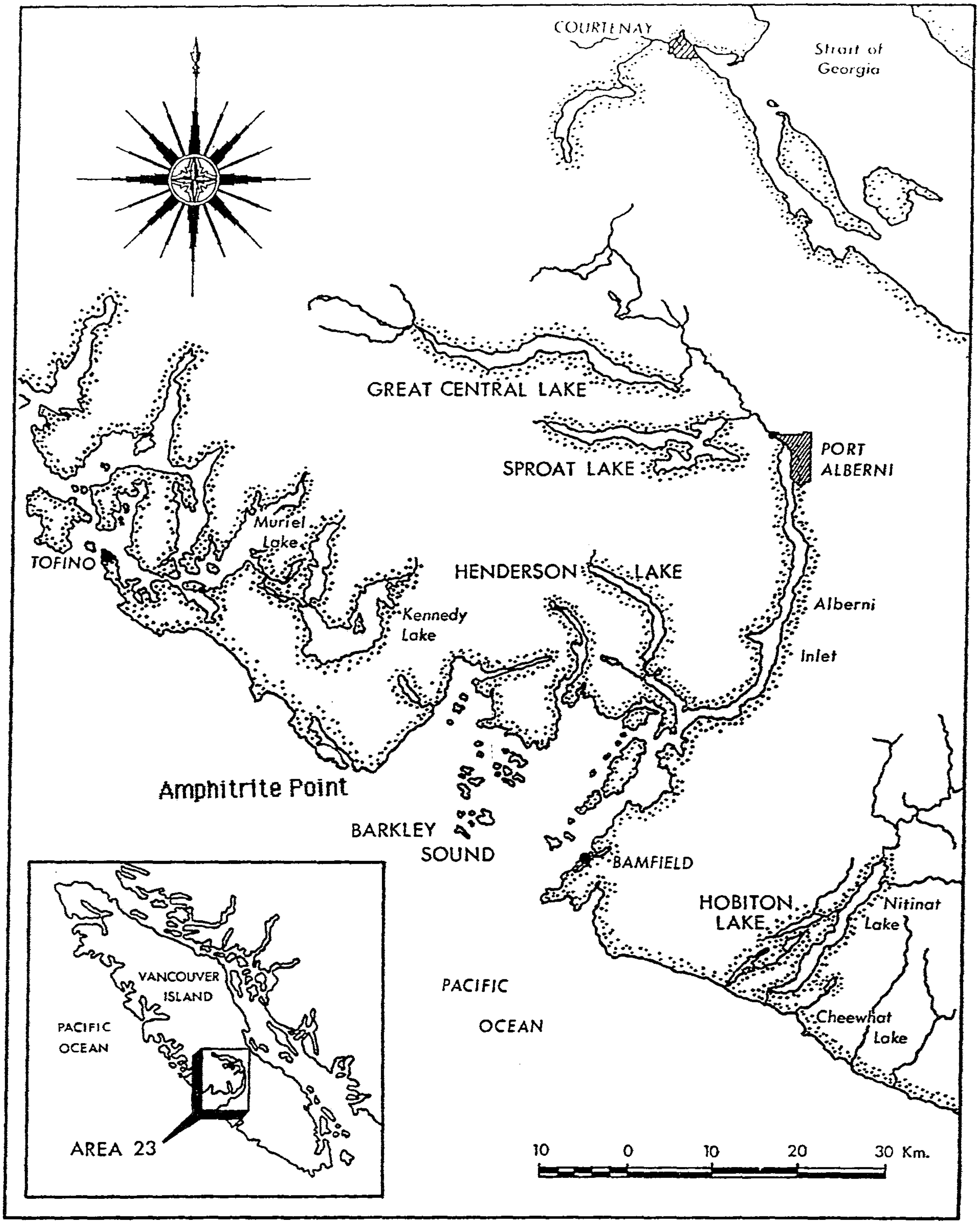


Figure 9 Lakes of origin for commercially important (Great Central, Sproat and Henderson) and experimental sockeye stocks (Hobiton, Cheewhat and Muriel) serving as the focus for WCVI marine survival variations studies. Coded wire tag release groups originating from Hobiton and Cheewhat lakes (south of Barkley Sound) must travel about the same distance to pass Amphitrite Point as smolts from the commercially important Great Central and Sproat stocks.

sites.

It is not known whether early marine growth patterns ofjuvenile sockeye fluctuate in association with their marine survival rates, size at migration, time at migration or location of sea entry. However, several hypotheses which stipulate that either predation or competition are important mechanisms determining marine survival require that this occurs. Quantitative estimates of growth of salmon during each year of marine residence can be obtained through analysis of scale samples obtained from returning adults. We are continuing to assemble a collection of scales from Barkley Sound adult sockeye sampled annually since 1970. Analysis of selected subsamples of these scales during 1989 provided a basis for tentative rejection of the "Fulton LeBrasseur hypothesis" linking marine survival extremes to the forage base and early marine growth patterns of salmon. However, given results of the study by Holtby et. al. cited above, additional scale analysis will be required to determine whether marine growth patterns or size and age at return are related in any logical fashion to the longer time series of measured marine survival variations for WCVI sockeye.

Events during the 1990 study year have revealed that declines in marine survival and overall productivity of salmon stocks on the WCVI may be mediated by mechanisms influencing not only juvenile but also adult stages of salmon life histories. In particular, it appears that climate mediated delays in migratory timing of adult salmon returns may reduce their productivity through both critical and chronic effects which are poorly understood. Consequently, additional effort will be invested during 1991 to investigate linkages among variations in climate variables, marine survival, return timing, and production trends for WCVI salmon stocks.

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Project: **NUMERICAL MODELLING STUDIES IN BARKLEY SOUND: STATUS IN MARCH** 1991

by: James Stronach, Seaconsult Marine Research Ltd. 820 - 1200 West 73rd Ave. Vancouver , B.C.

M.G. Foreman, T.C. Curran and T.S. Murty, Institute of Ocean Sciences, Sidney, B.C.

INTRODUCTION

In 1990 Seaconsult Marine Research Ltd. was contracted by the Department of Fisheries and Oceans to carry out numerical modelling studies of Barkley Sound. (Stronach and Ng, 1990). Two models were developed under this contract: a vertically integrated model of barotropic tides, and a baroclinic upper layer model. Boundary conditions for the tidal model were obtained from a finite element barotropic model of the shelf off Vancouver Island developed by Dr. M. Foreman (Foreman, 1990). The upper layer model was driven by tidal data from the barotropic Barkley Sound model, as well as by river and wind forcing based on historical data. Model results were compared with water level data and hydrographic data to give a preliminary assessment of performance. The status of these models in March 1991 is briefly described in this report.

BAROTROPIC TIDAL MODEL

The barotropic tidal model is an implementation of the GF8 baroclinic model of the Strait of Georgia, restricted to uniform density and a single layer. The model grid size is 400 m, providing good resolution of the complex geometry of Barkley Sound. Figure 10 shows the grid and the associated depth field. Elevation and velocity data along the open boundaries were obtained from an irregular grid finite element model of the west coast of Vancouver Island (Foreman, 1990). The resulting barotropic model was found to be stable, and produced tidal elevations in excellent agreement with observations. Harmonic constants for the modelled current were compared to harmonic constants from a current meter moored in Imperial Eagle Channel; good agreement was obtained for the vertically averaged part of the observed currents. The tidal data from a one month run were stored for later use by the upper layer model.

THE UPPER LAYER MODEL

The upper layer model used for Barkley Sound was an implementation of the GF4 model which was originally developed to simulate upper layer motion in the Strait of Georgia. The upper layer model is derived from the fully non-linear equations for two-layer flow, including the effects of mixing mass, salt and momentum across a permeable, moveable interface. The lower layer tidal solution is obtained from stored harmonic constants, allowing the upper layer model to be simplified to a set of equations for a single layer.

Tidal forcing was derived from the Barkley Sound barotropic model. Wind forcing was obtained from archived data at Cape Beale, Amphitrite Point, and Port Alberni. The Port Alberni data were copied to six additional artificial wind stations along Alberni Inlet, and modified in direction to accord with the local orientation of the inlet. This provides a more plausible wind field under the assumption that the Port Alberni anemometer data is typical of winds along the entire inlet. Fresh water enters Barkley Sound from 17 major and minor rivers, of which five are gauged. Drainage area calculations were used to obtain monthly mean values for the remaining 12 rivers. This distributed runoff results in a number of localized freshwater regions in Barkley Sound, in addition to Alberni Inlet. In particular, Pipestem Inlet and the region around its connection to Barkley Sound were noticeably fresher than water in neighboring regions of the Sound. The corresponding salinity distribution was found to be in close qualitative agreement with observations reported by Borstad et al. (1988).

Figures 10 to 14 show plots of salinity, layer thickness and velocity fields on an ebb tide produced by the Barkley Sound upper layer model. The upper layer is approximately 4 m thick in upper Barkley Sound, and increases in thickness in the seaward direction as the freshwater layer loses its identity in the open waters of the Pacific. As well, the preference for freshwater from Alberni Inlet to move down Imperial Eagle Channel is apparent, as is the freshening associated with Pipestem Inlet. The vector fields reveal relatively weak flows within Barkley Sound, in contrast to the stronger flows in the open Pacific. These vector plots represent only a single snapshot; a more representative picture of the surface circulation would be obtained by examining tidal and baroclinic

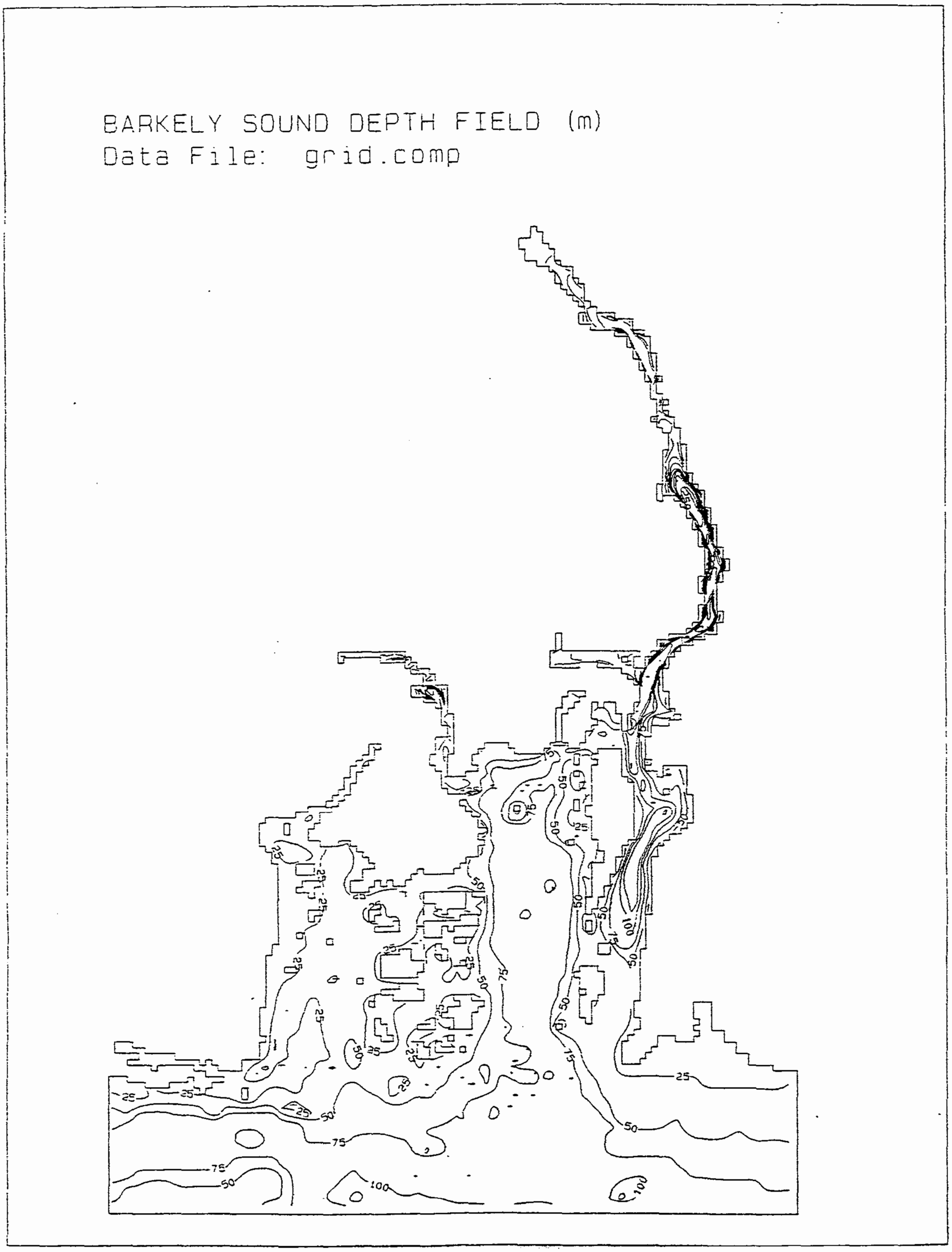

Figure 10. The Barkley Sound grid, drawn in model orientation, showing the depth field used in the barotropic and baroclinic models.

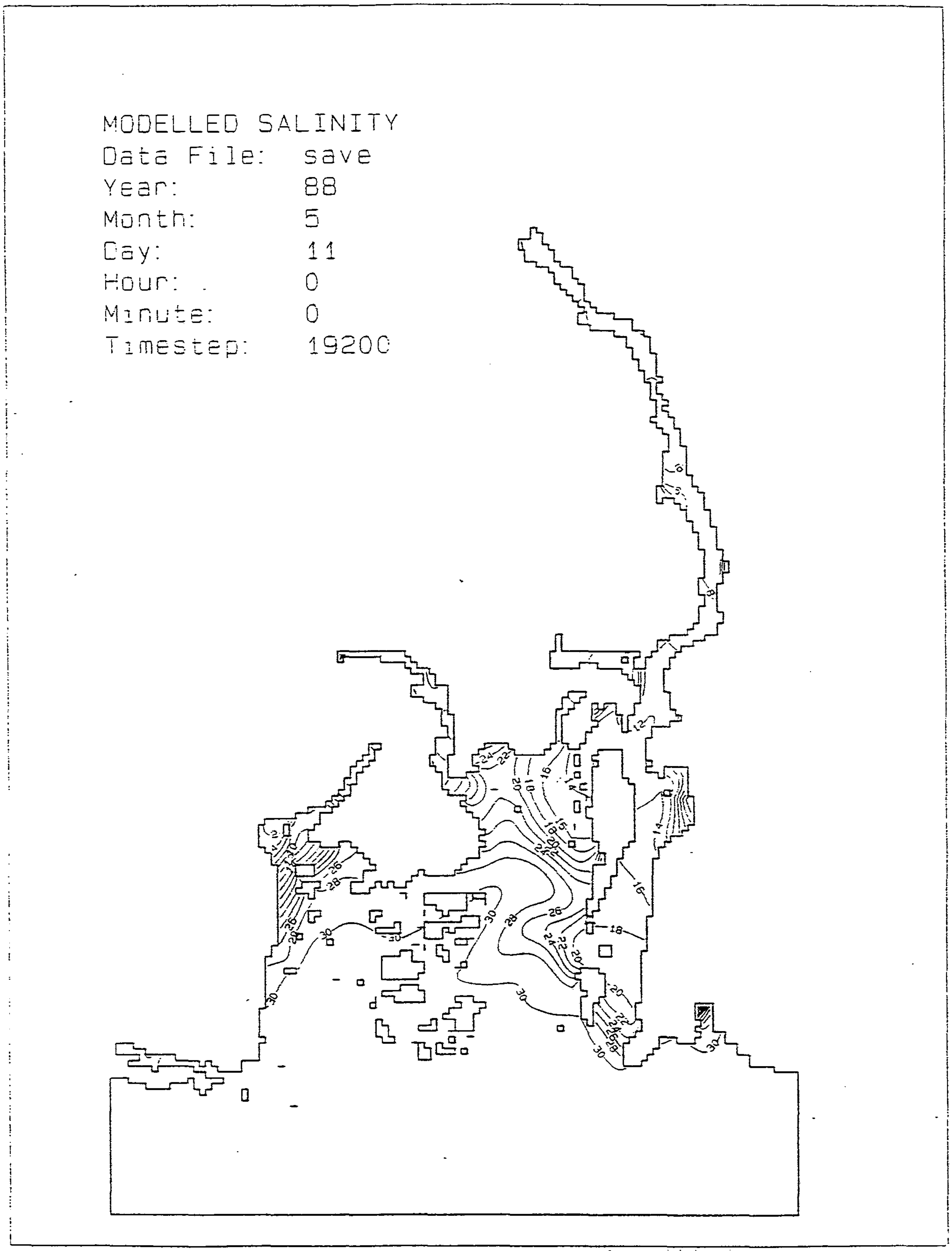

Figure 11. The salinity field produced by the upper layer model for hour 0, May 11, 1988.

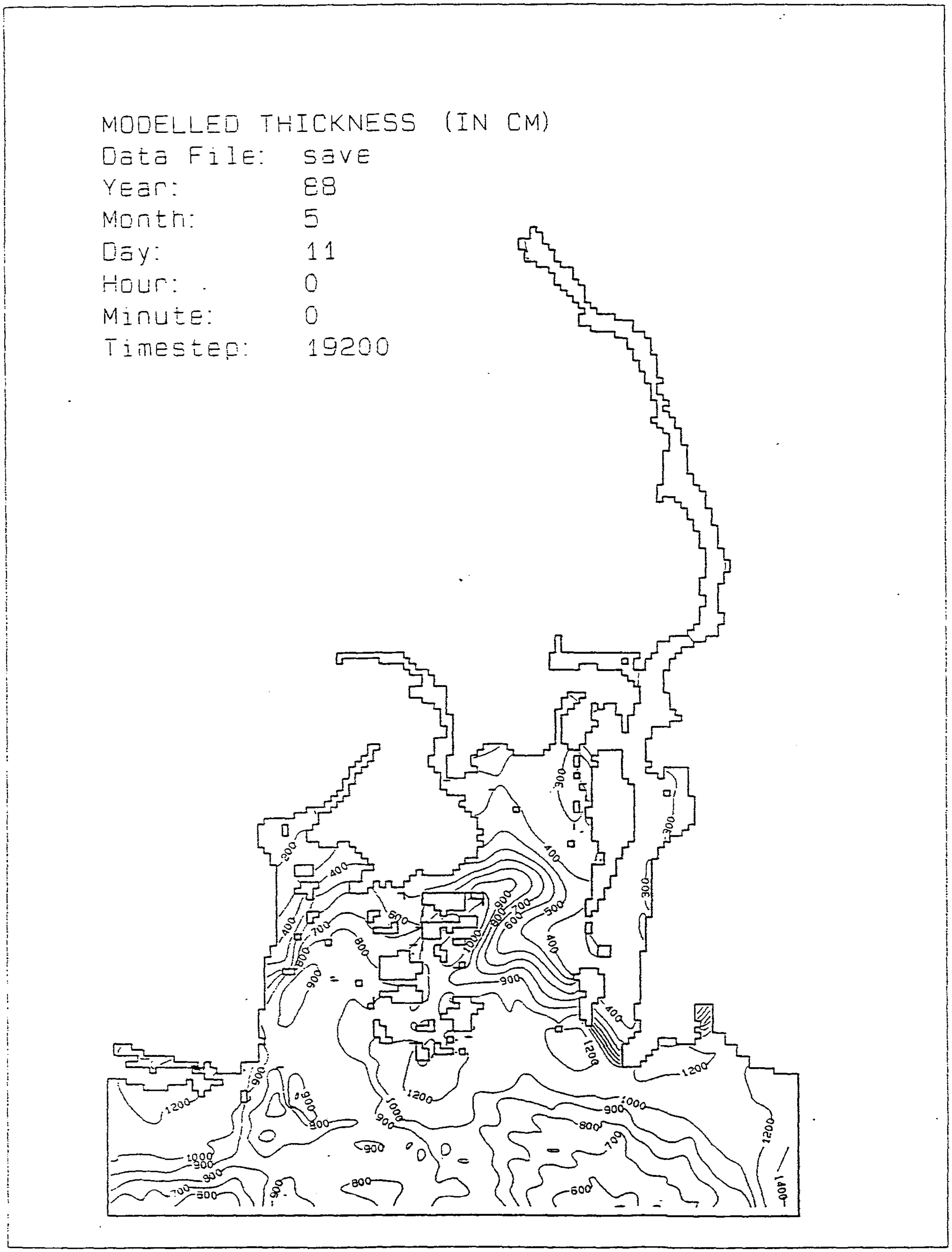

Figure 12. The upper layer thickness field produced by the upper layer model for hour 0, May 11, 1988.

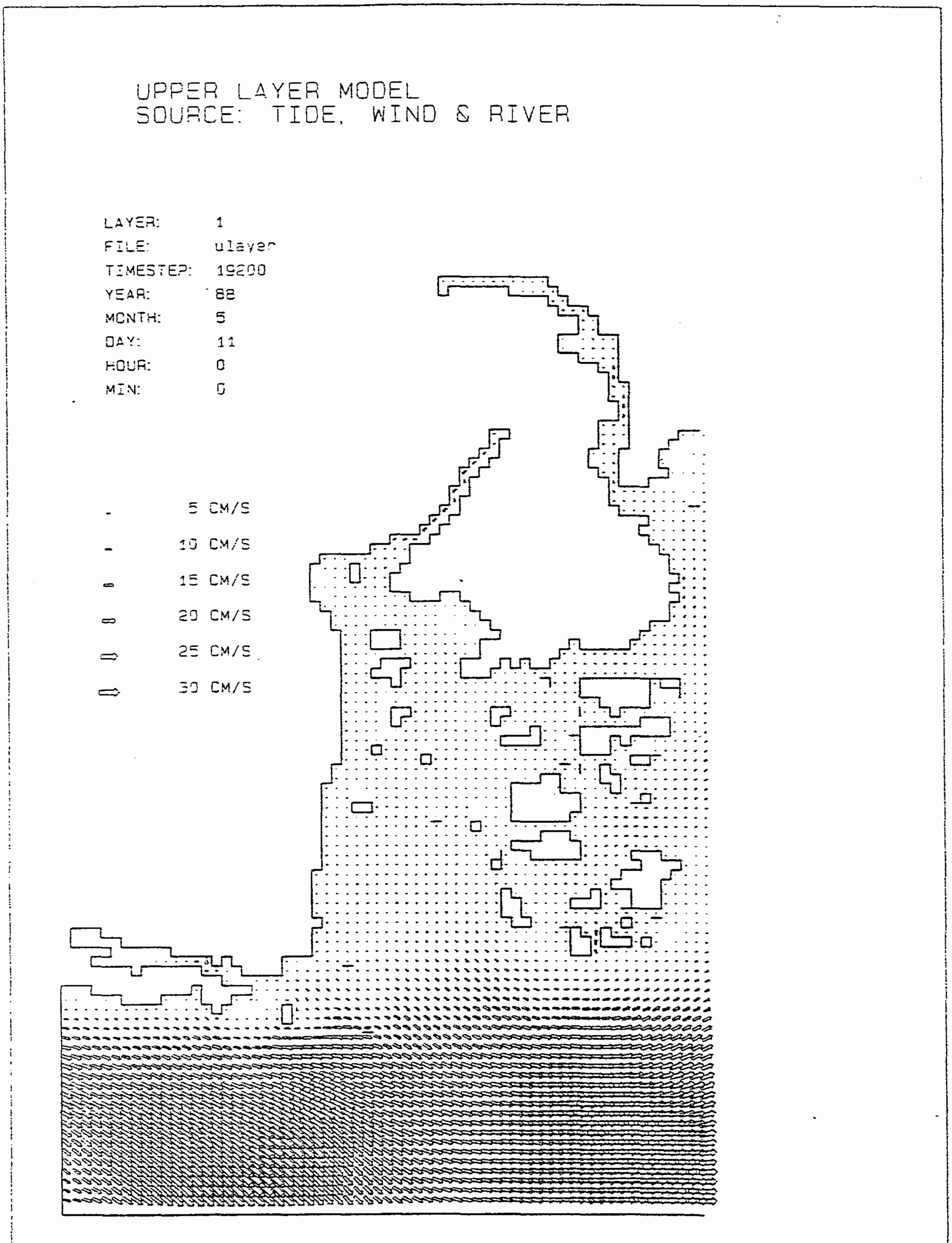

Figure 13. The velocity field produced by the upper layer model for hour 0, May 11, 1988. western half of the modelled region.

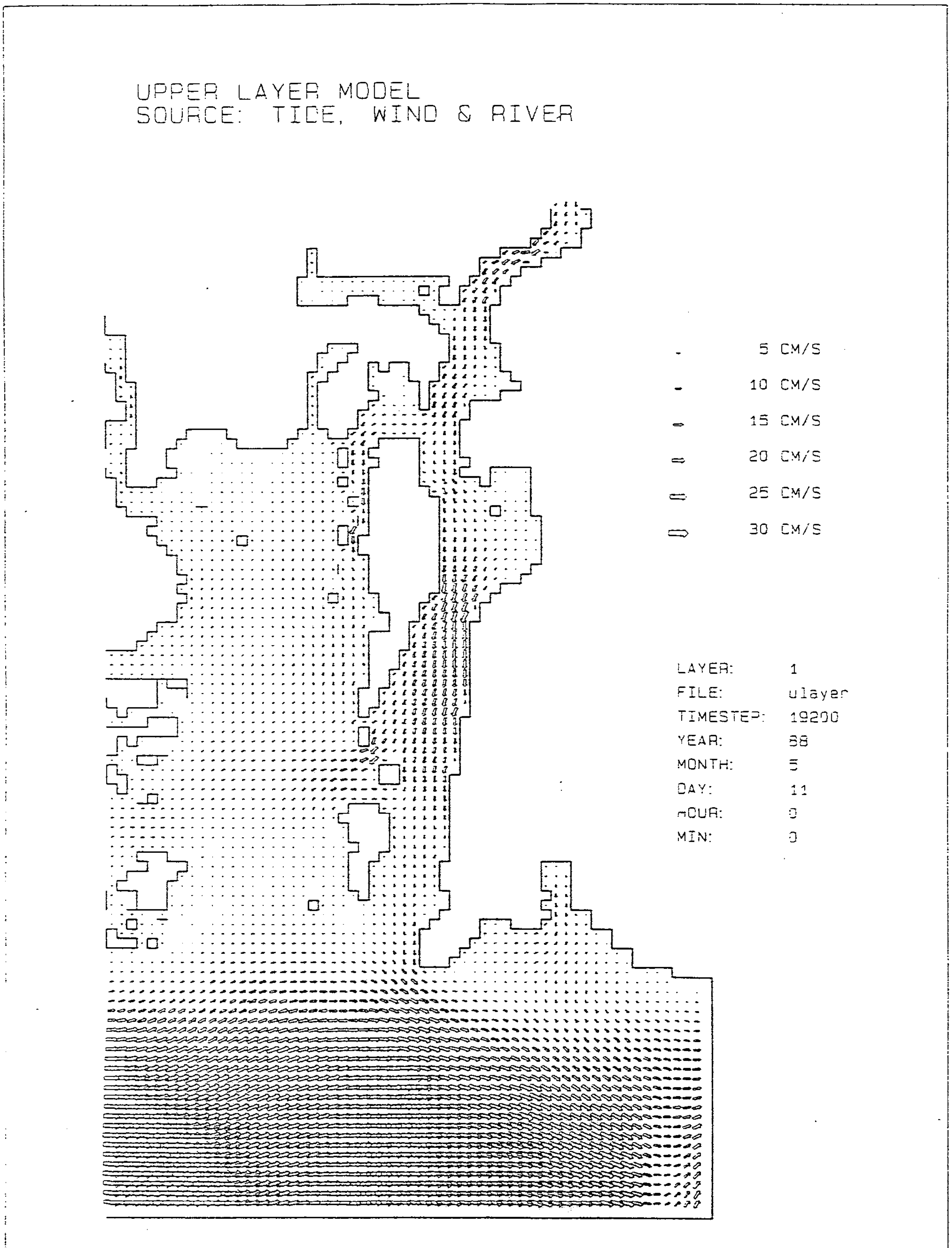

Figure 14. The velocity field produced by the upper layer model for hour 0, May 11, 1988, eastern half of the modelled region.

residual fields, as well as the response to typical wind events.

FUTURE PLANS

Given the success of the modelling to date, we propose this year to integrate its operation more closely with the study plans of fisheries biologists operating in the area. For instance, the model could be used to hindcast salinity distributions and velocities during juvenile salmon outmigration periods. As funds permit, model improvements in the following areas are planned:

- more realistic wind forcing by coupling to a mesoscale wind model(since the hydrodynamic model is limited more by a lack of physically correct wind forcing than by any other factor);
- development and testing of a full three-dimensional baroclinicmodel, as the motions throughout the water column affect biological processes in Barkley Sound;
- incorporation of an oxygen balance model for Alberni Inlet andstudies of bottom water replacement dynamics.
- development of ecosystem modelling, in conjunction with recent advances in remote sensing.

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CONTINENTAL SHELF STUDIES

Project: CHINOOK AND COHO ON THE OFFSHORE BANKS

by: J.F.T. Morris, M.C. Healey, B.J. Waddell

In 1990, we surveyed the chinook and coho populations on the offshore banks by troll vessel from April 23 - May 5 in conjunction with an IOS oceanographic cruise. This survey completed a four year sampling program that included fall surveys in 1987 and 1988 and two other spring surveys in 1988 and 1989. The objective of this joint fisheries and oceanographic program was to understand how oceanographic events determine the dispersion of salmon. We regard this as an important first step towards understanding the mechanisms that underlie published correlations between salmon survival and physical oceanographic factors.

All the surveys were similar in methods and approach in that we chartered commercial trollers to fish the offshore banks. However, the 1990 and 1989 spring surveys differed from the 1988 and 1987 surveys in that we chartered three trollers instead of one. Also, the 1990 spring survey differed from the one in 1989 in three ways: 1) it took place one month earlier; 2) the fishing effort was concentrated to the offshore banks south of Cape Beale to obtain more catch information in the region of the Tully eddy; and 3) the three vessels fished together on the same bank rather than independently in different parts of the survey area to determine whether coho and chinook abundances differ among sub-areas of the same bank on a daily basis.

This report summarizes the data collected on the 1990 spring survey on chinook and coho distributions, size composition, age composition, depth of capture, country of origin, diet, and feeding activity.

Figure 15 shows the fishing tracks made during the 1990 survey by the CFV Cowichan, Early Mist, and Dalmacian Star II.

Table 6 gives the geometric means and range of chinook and coho catch rates for the sub-divisions of the offshore region defined by the La Perouse program (Fig. 16). Overall chinook catch rates declined each year from a geometric mean of 10.4/h in 1988 to 5.3/h in 1990. In 1990, chinook catch rates were highest on Finger Bank and 7&12 Mile Bank at 17.88/h and 9.75/h, and lowest on Swiftsure Bank at 1.08/h. Catch rates of the two largest chinook size classes, legal-size chinook that are equal to and greater than 67 cm in fork length and 61-66 cm chinook, were highest within the Finger Bank - 7&12 Mile Bank - Gullies region. Catch rates of the 31-40, 41-50, and 51-60 cm chinook were highest within the Finger Bank - 7&12 Mile Bank - Eddy region. Only the legal-size and 61-66 cm chinook were abundant on the Gullies. Coho catch rates increased each year from a geometric mean of 1.5/h in 1988 to 5.0/h in 1990. In 1990, coho catch rates were extremely high on Pachena and the Eddy at 15.76/h and 13.86/h.

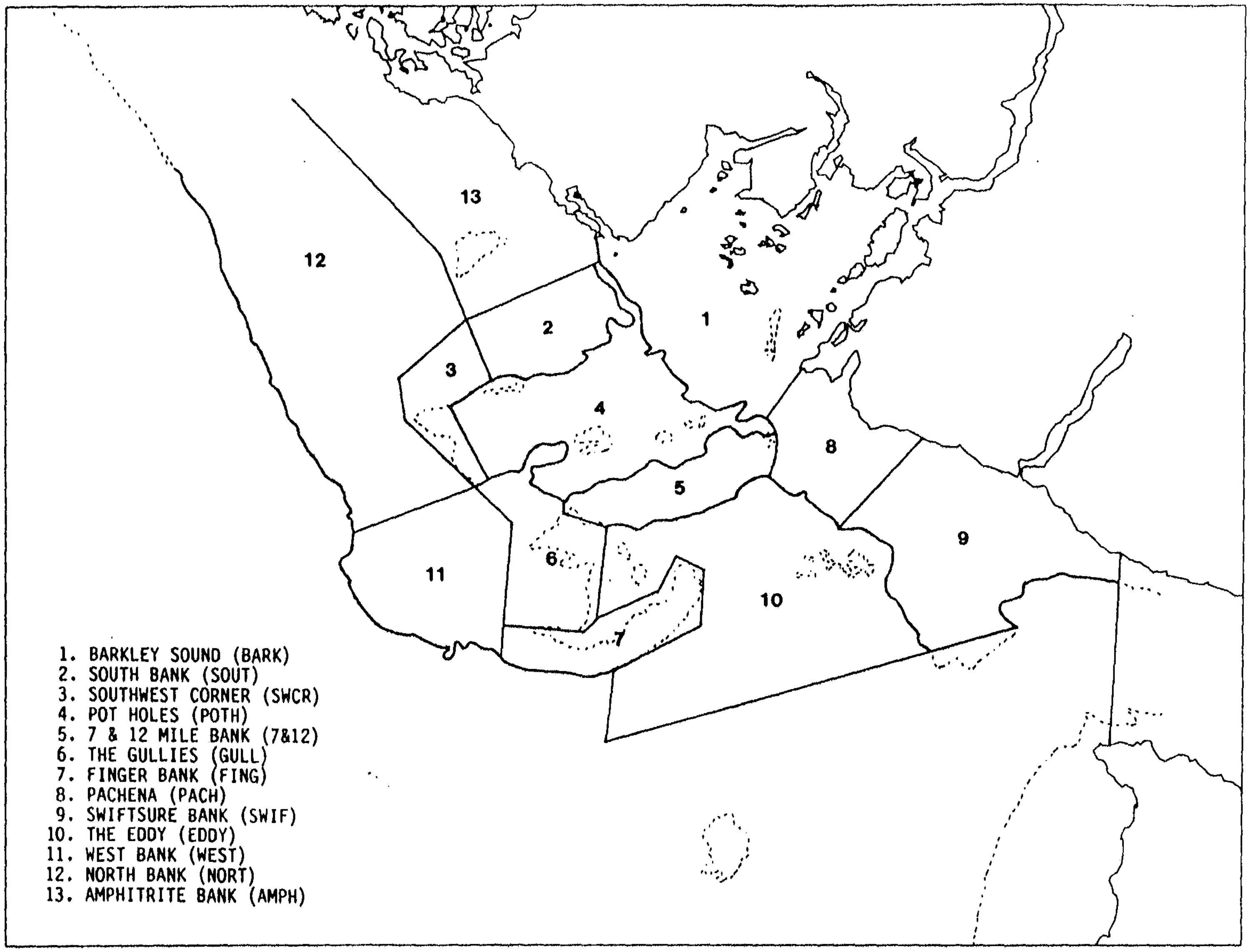

Figure 15. Offshore areas defined by the La Perouse program.

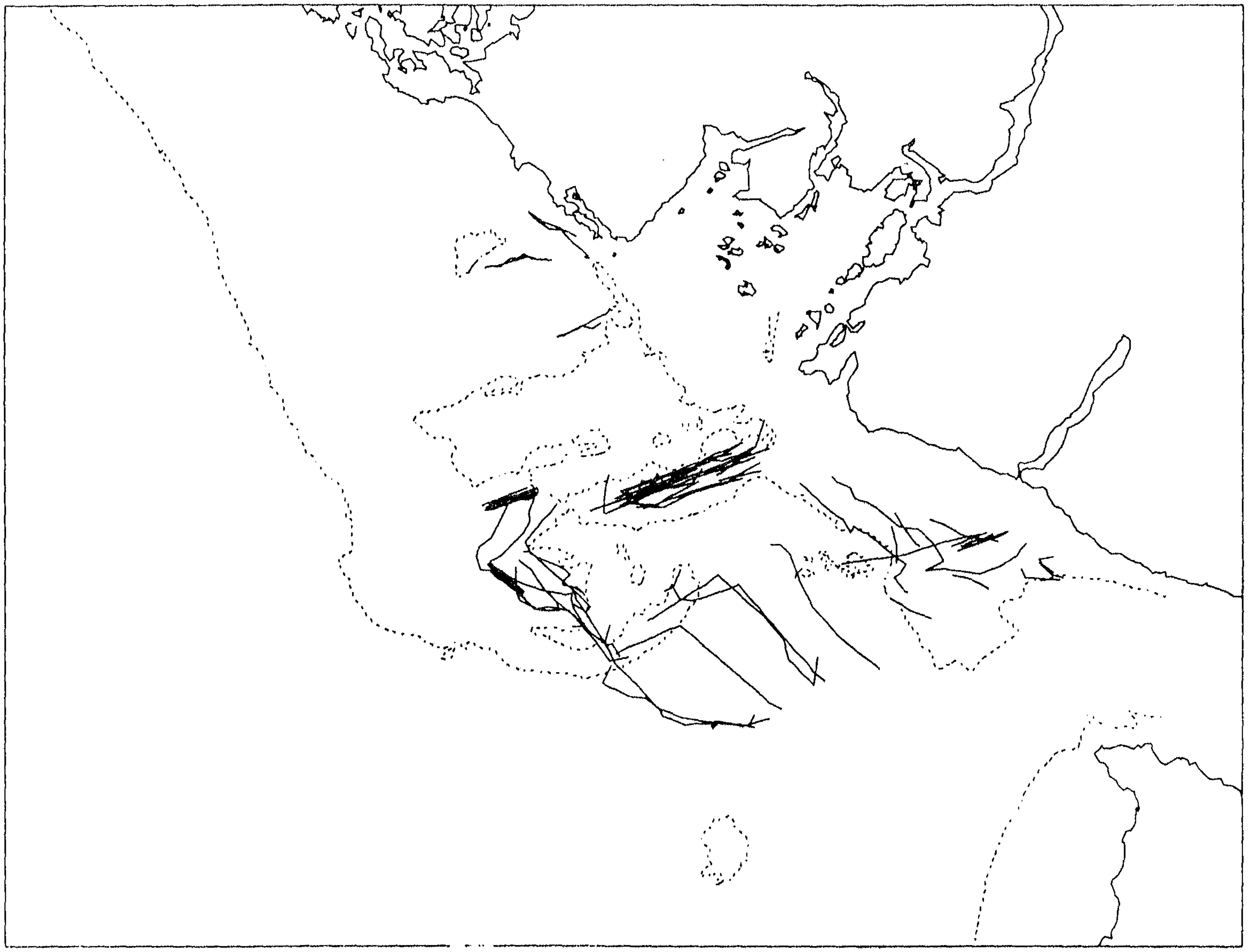

Figure 16. Fishing tracks made by the CFV COWICHAN, EARLY MIST, and DALMACIAN STAR II on the 1990 survey.

Table 6. 1990 chinook and coho geometric mean CPUE (number caught per hour) for each area by fish size interval (N = # of time intervals; GMEAN = geometric mean).

	AREA	N	GMEAN CPUE	MIN CPUE	MAX CPUE
ALL CHINOOK	FINGER BANK	7	17.88	7.6	30.3
	7 & 12 MILE BANK	28	9.75	1.8	28.6
	THE EDDY	11	6.08	2.7	12.5
	THE GULLIES	29	5.79	0.0	19.8
	PACHENA	2	2.49	1.4	4.1
	SOUTH BANK	3	1.30	1.1	1.6
	SWIFTSURE BANK	20	1.08	0.0	3.8
	ALL AREAS	100	5.28	0.0	30.3
		(F = 24.71, df = 6/99, P>F = 0.0001)			
LEGAL SIZE CHINOOK	FINGER BANK	7	2.91	0.0	8.3
	THE GULLIES	29	2.29	0.0	6.9
	7 & 12 MILE BANK	28	2.18	0.0	7.2
	THE EDDY	11	0.58	0.0	3.1
	SOUTH BANK	3	0.42	0.3	0.8
	SWIFTSURE BANK	20	0.30	0.0	1.5
	PACHENA	2	0.21	0.0	0.5
	ALL AREAS	100	1.41	0.0	8.3
		(F = 9.82, df = 6/99, P>F = 0.0001)			
ALL UNDERSIZED CHINOOK	FINGER BANK	7	13.26	6.2	30.3
	7 & 12 MILE BANK	28	7.20	1.7	21.4
	THE EDDY	11	5.30	2.7	8.4
	THE GULLIES	29	3.06	0.0	13.7
	PACHENA	2	2.33	1.4	3.6
	SOUTH BANK	3	0.87	0.8	1.0
	SWIFTSURE BANK	20	0.79	0.0	2.8
	ALL AREAS	100	3.68	0.0	30.3
		(F = 21.59, df = 6/99, P>F = 0.0001)			
CHINOOK 61 - 66 cm	FINGER BANK	7	3.28	0.9	7.7
	7 & 12 MILE BANK	28	1.57	0.0	5.9
	THE GULLIES	29	0.91	0.0	3.9
	THE EDDY	11	0.40	0.0	1.5
	PACHENA	2	0.21	0.0	0.5
	SWIFTSURE BANK	20	0.08	0.0	0.8
	SOUTH BANK	3	0.00	0.0	0.0
	ALL AREAS	100	0.84	0.0	7.7
		(F = 12.57, df = 6/99, P>F = 0.0001)			

Table 6 (cont'd)

	AREA	N	GMEAN CPUE	MIN CPUE	MAX CPUE
CHINOOK 51 - 60 cm	FINGER BANK	7	3.56	1.4	18.2
	7 & 12 MILE BANK	28	2.36	0.0	7.2
	THE EDDY	11	1.52	0.3	2.9
	PACHENA	2	1.03	0.5	1.8
	THE GULLIES	29	0.97	0.0	6.8
	SOUTH BANK	3	0.51	0.3	0.8
	SWIFTSURE BANK	20	0.23	0.0	2.3
	ALL AREAS	100	1.25	0.0	18.2
		(F = 9.51, df = 6/99, P>F = 0.0001)			
CHINOOK 41 - 50 cm	FINGER BANK	7	1.98	0.9	3.6
	7 & 12 MILE BANK	28	1.30	0.0	5.6
	THE EDDY	11	1.21	0.4	2.4
	THE GULLIES	29	0.47	0.0	1.7
	SOUTH BANK	3	0.24	0.0	0.5
	PACHENA	2	0.21	0.0	0.5
	SWIFTSURE BANK	20	0.13	0.0	0.9
	ALL AREAS	100	0.72	0.0	5.6
		(F = 9.60, df = 6/99, P>F = 0.0001)			
CHINOOK 31 - 40 cm	FINGER BANK	7	2.78	0.5	6.5
	THE EDDY	11	1.81	0.7	3.3
	7 & 12 MILE BANK	28	1.23	0.0	4.5
	PACHENA	2	0.67	0.5	0.9
	THE GULLIES	29	0.65	0.0	3.2
	SWIFTSURE BANK	20	0.13	0.0	1.7
	SOUTH BANK	3	0.08	0.0	0.3
	ALL AREAS	100	0.85	0.0	6.5
		(F = 10.05, df = 6/99, P>F = 0.0001)			
CHINOOK 21 - 30 cm	FINGER BANK	7	0.28	0.0	1.9
	PACHENA	2	0.21	0.0	0.5
	7 & 12 MILE BANK	28	0.17	0.0	1.7
	SWIFTSURE BANK	20	0.14	0.0	0.9
	THE EDDY	11	0.13	0.0	0.4
	THE GULLIES	29	0.10	0.0	0.8
	SOUTH BANK	3	0.00	0.0	0.0
	ALL AREAS	100	0.14	0.0	1.9
		(F = 0.54, df = 6/99, P>F = 0.7760)			
COHO	PACHENA	2	15.76	7.4	32.3
	THE EDDY	11	13.86	2.4	42.3
	7 & 12 MILE BANK	28	6.16	1.6	19.0
	THE GULLIES	29	4.23	0.7	16.0
	FINGER BANK	7	3.48	0.0	27.8
	SWIFTSURE BANK	20	3.17	0.0	36.0
	SOUTH BANK	3	0.89	0.3	1.4
	ALL AREAS	100	5.01	0.0	42.3
		(F = 5.35, df = 6/99, P>F = 0.0001)			

The age classes 0.1+, 0.2+, 0.3+ made up 19.7%, 31.3%, and 40.9% of the chinook population on the offshore banks. The age class 1.1+ made up 90.1% of the coho. These age 1.1+ coho averaged 42.6 cm and ranged from 35 to 54 cm in fork length.

Chinook were caught at an average depth of 36.7 m, but 21-30 cm chinook were caught at an average depth of 28.4 m. Coho were caught much shallower than any size class of chinook, at an average depth of 13.4 m.

United States stocks make up most of the chinook and coho population on the offshore banks as determined by coded-wire tag recoveries. Of the 127 CWT chinook recovered from our surveys from 1987 to 1990, 56.7% originated from the Columbia River system, 20.5% from the Georgia Strait - Puget Sound - Hood Canal production areas in Washington State, 3.9% from coastal rivers in Washington State, 5.5% from coastal rivers in Oregon, 1.6% from the Sacramento River system in California, 10.2% from the Fraser River system, and 1.6% from the east coast of southern Vancouver Island. Of the 75 CWT coho, 63.7% originated from Georgia Strait - Puget Sound - Hood Canal production areas in Washington State, 13.3% from the Columbia River system, 10.7% from the lower Fraser River system, and 9.3% from rivers on the east coast of southern Vancouver Island.

Chinook fed principally on fish and euphausiids as determined by percent frequencies of occurrence in stomachs. However, the occurrance of fish increased and euphausiids decreased with increasing chinook size. Fish and euphausiids occurred in 33.3% and 100% of the 21-30 cm chinook stomachs; whereas fish and euphausiids occurred in 79.7% and 31.9% of the legal-size chinook stomachs. Herring were positively identified in 29.2% of the legal-size chinook stomachs, but their actual occurrance was probably much higher than this. Chinook did not feed heavily on pteropods. Coho fed principally on euphausiids, fish, and pteropods. These food items occurred in 51.0%, 43.9%, and 49.7% of coho stomachs. Coho preferred sandlance over herring; sandlance and herring were positively identified in 29.7% and 6.5% of the stomach samples, respectively.

Table 7 gives the medians and ranges of dry stomach content weights to wet fish weight (SW/FW) ratios of sampled chinook and coho among the offshore banks. SW/FW ratios are a measure of feeding success. Chinook SW/FW ratios were relatively high on the Gullies and 7 & 12 Mile Bank, intermediate on Swiftsure Bank, and low on Finger Bank and the Eddy. Coho SW/FW ratios were relatively high on the Gullies and 7 & 12 Mile Bank and low in the Eddy and Swiftsure Bank. High SW/FW ratios were not associated with chinook and coho abundances.

In general, large chinook were abundant within the relatively small Finger Bank - 7 & 12 Mile Bank - Gullies region where they fed principally on herring. The abundance of large chinook here may be related to bottom topography. Smaller chinook and coho were more dispersed over the study area and, unlike large chinook, they were abundant in the Eddy region. Here, the smaller chinook fed principally on euphausiids and the coho fed on euphausiids, pteropods, and sandlance. Neither chinook of any size class nor coho were abundant on Swiftsure Bank.

Table 7. Summary statistics of the dry stomach content weight (g)/ estimated fish weight (kg) ratio (SW/FW ratio) by area.

	AREA	N	MEDIAN	MIN	MAX
1990 CHINOOK	WEST BANK	1	0.297	0.297	0.297
	THE GULLIES	**101**	**0.275**	**0.000**	**16.367**
	7 & 12 MILE BANK	**128**	**0.260**	**0.000**	**11.308**
	SWIFTSURE BANK	**36**	**0.173**	**0.000**	**5.099**
	SOUTH BANK	8	0.089	0.000	1.843
	FINGER BANK	**29**	**0.065**	**0.000**	**8.662**
	THE EDDY	**58**	**0.041**	**0.000**	**6.159**
	PACHENA	4	0.000	0.000	0.960
	(Kruskal-Wallis Test: $X^2 = 17.21$, df = 7, $P>X^2 = 0.0161$)				
1990 COHO	SOUTH BANK	6	0.232	0.000	6.221
	THE GULLIES	**58**	**0.184**	**0.000**	**9.695**
	7 & 12 MILE BANK	**62**	**0.129**	**0.000**	**5.627**
	FINGER BANK	8	0.065	0.000	3.048
	THE EDDY	**58**	**0.027**	**0.000**	**5.607**
	SWIFTSURE	**54**	**0.021**	**0.000**	**13.562**
	PACHENA	9	0.000	0.000	0.354
	(Kruskal-Wallis Test: $X^2 = 19.31$, df = 6, $P>X^2 = 0.0037$)				

In addition to the survey, we repeated experiments that were started in 1989 to test the effects of vessel density on catch rates of commercial trollers and to provide replicate measures of catch rate in the same area over short time periods. The results of these experiments provided a firmer statistical basis for comparing survey catch rates among locations and for comparing survey catch rates with catch rates in the commercial fleet.

SUMMARY OF THE CHINOOK AND COHO ON THE OFFSHORE BANKS PROJECT

1990 was the last year for which surveys of coho and chinook on the offshore banks were planned. It is appropriate, therefore, that we summarize what we found about the distribution of these species over the four years of the project (1987-1990).

Coho in their first ocean year did not appear on the fishing banks until September or October, and chinook not until October or November. Chinook may, in fact, not move onto the banks in abundance until after the fall transition in oceanographic conditions. Older chinook were present on the banks during all seasons.

Virtually all the tagged coho and chinook captured on the banks were of U.S. origin. Although the fishing banks, and perhaps the Eddy are important nursery grounds for chinook and coho, they are not the nursery grounds for Canadian stocks from nearby river systems (e.g. no tags from Nitinat and Robertson Creek hatcheries were recovered).

Chinook, in particular, tended to aggregate on 7 & 12 Mile Bank, Finger Bank, the Gullies, and Swiftsure Bank but aggregations were not consistently found at any location from season to season and from year to year. Aggregations of small and large chinook did not necessarily coincide. Coho also aggregated, but their aggregations were less predictable than those of chinook. Coho and small chinook were more dispersed than large chinook. Coho and small chinook also tended to occupy the Eddy whereas large chinook did not.

Large chinook were distributed near the bottom and their aggregations could be related to bottom topography. Small chinook and coho were distributed near the surface. Their aggregations were not easily related to bathymetry and may have been associated with local features of ocean circulation.

For neither chinook nor coho was there any association between feeding success and aggregation behaviour. Although aggregations may have been related to food distribution, members of an aggregation did not appear to gain any benefits in terms of increased feeding rate.

In general, we were unable to confirm our original hypothesis, that aggregations of salmon would be associated with local eddy circulation. In some instances high catches were within eddy-like features, but in others they were at the margins of eddies where directional flow was strongest. In particular, the attractiveness to fish of certain locations, such as Swiftsure Bank, 7 and 12 Mile Bank, and the Gullies, remains unresolved.

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Project: LOSSES OF CONTINENTAL SHELF PRODUCTION TO THE DEEP OCEAN OFF BROOKS PENINSULA

by: Rod Forbes and Ken Denman, Institute of Ocean Sciences

participants: Rod Forbes, Ken Denman, Robin Brown, Dave Mackas and Rick Thomson, IOS; Steve Calvert and Maureen Soon, UBC

From 1986 to date we have studied the trajectories and the development of plankton populations in cold water filaments that form recurrently off Brooks Peninsula. These filaments move a substantial proportion of nutrient input and production occurring on the shelf to the deep ocean. We have been able to document the offshore fluxes of nutrients, phytoplankton and zooplankton carried by these upwelling filaments. Our objective in 1990 was to measure the vertical particulate loss rates at the shelf edge that are attributable to these filaments.

Two moorings with sequential sediment traps were deployed along the shelf break, one in a path frequently traversed by filaments (JET) and one to the north (NOJET) (Fig. 17). Each mooring had a current meter and beam transmissometer at 35m, a 12-cup sequential sediment trap at 200m, and a current meter 6.5m below the trap. The moorings were deployed in late April, serviced on 18 July, and recovered in early October. This enabled us to obtain a continuous record of particulate losses from the photic zone from 26 April to 30 September, with each sample representing the flux during one week. Satellite imagery and current measurements will enable us to establish how changes in the surface mixed layer are reflected in material collected by the traps.

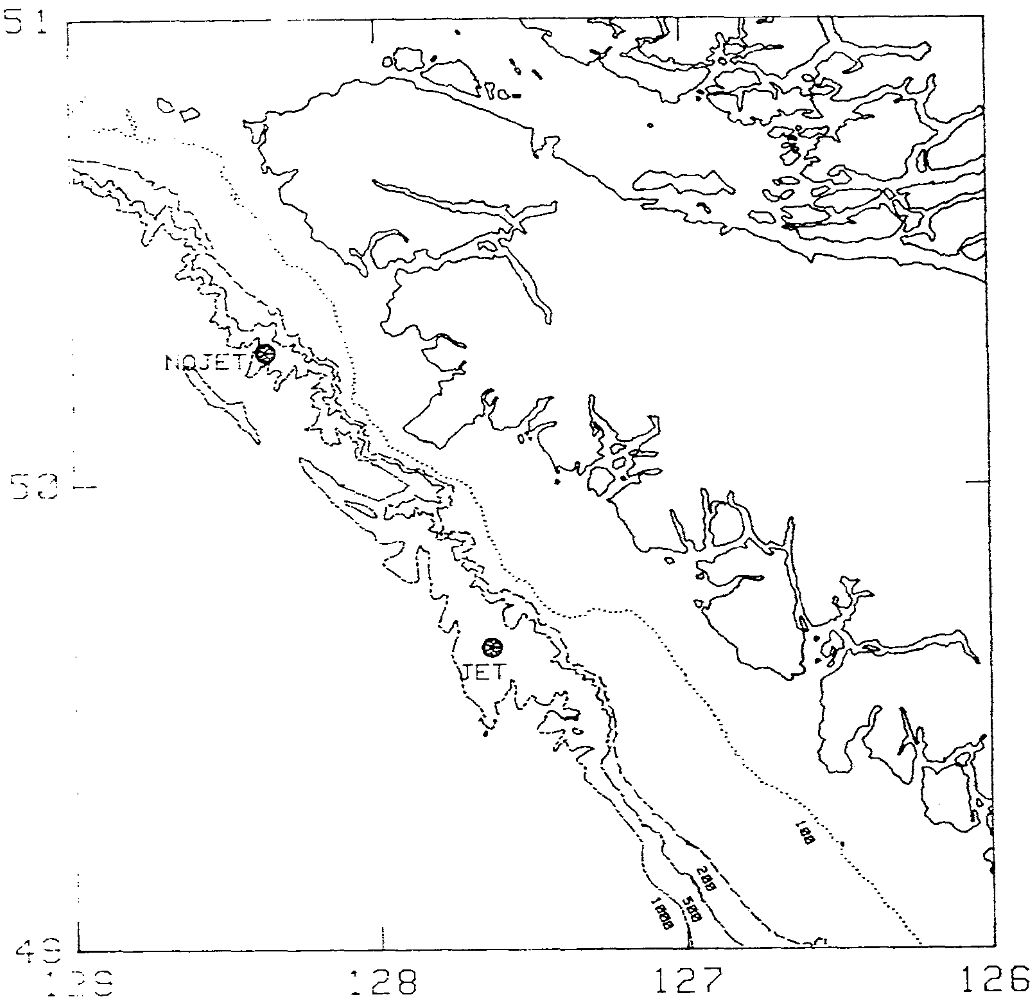

Figure 17. Location of sequential sediment traps along the shelf break.

Acoustic doppler current profiler (ADCP) measurements in April indicated that surface currents along the west coast of Vancouver Island were generally weak and variable. Drifters deployed in the vicinity of the trap sites during July showed a well-developed filament over the site of the JET trap. They also indicated that the summer Shelf Break Current, heading southeast, was relatively strong and located further offshore than is typical, with the NOJET site well within its trajectory. ADCP measurements in October indicated that the fall transition had already occurred. Surface currents in most areas along the west coast were 10 - $25 cm.s^{-1}$ to the northwest, although in some locations along the shelf break there was movement toward the southeast. Unusually high chlorophyll concentrations were encountered in the study area during July, with approximately 175 $mg.m^{-2}$ at the JET site and $250mg.m^{-2}$ at NOJET. In addition, an extreme red tide occurred off a substantial portion of the west coast of Vancouver Island during late August and early September. Although it was centred off the southwest coast, samples indicated that it reached at least as far north as Brooks Peninsula and possibly further north. Exceptional surface temperatures may have contributed to these conditions. The surface temperature anomaly at Amphitrite point was generally +1 to +2°C from January to the end of September (pers. com. Howard Freeland, IOS).

Dry weight mass flux to both sediment traps was substantial and highly variable (Fig. 18), ranging from 18 to $2104mg.m^{-2}.day^{-1}$ at JET and from 35 to $785mg.m^{-2}.day^{-1}$ at NOJET in the <1000μm size fraction. Contrary to expectations, the flux at NOJET exceeded JET, with a total of $43.3g.m^{-2}$ dry weight at NOJET compared with $39.9g.m^{-2}$ at JET over the period that the traps were deployed. However the total *a* pigment (chlorophyll plus phaeopigments) flux was slightly less at NOJET ($172mg.m^{-2}$ compared to $177mg.m^{-2}$), as was the biogenic silicate flux ($16.2g.m^{-2}$ and $17.3g.m^{-2}$). Biogenic silicate not only comprised a high proportion of the total mass flux, but the two were highly correlated (Fig. 19), indicating that diatom remains, probably largely packaged in fecal pellets, comprised the bulk of material entering the traps throughout the study period. Particulate carbon and nitrogen analyses are not yet complete, but carbon can be expected to form 10 to 15% of the mass dry weight.

Other analyses in progress or remaining to be done include calcium, carbonate carbon, $0^{13}C$ and $0^{15}N$, phytoplankton identity and abundance, total pigment profile by HPLC, fecal pellet abundance and sources, and scanning electron microscopy of representative material from the samples. Substantial effort is being put into establishing the relationship between the types and abundance of actively swimming zooplankton retained in the traps and the zooplankton community composition of the surrounding water. Detailed sampling to determine the depth distribution, identity and abundance of animals at the trap sites was conducted in April, July and October, using the BIONESS multiple net sampling system. This was supplemented by vertical net hauls at those times and in June. The results will be compared with zooplankton remains in the trap samples.

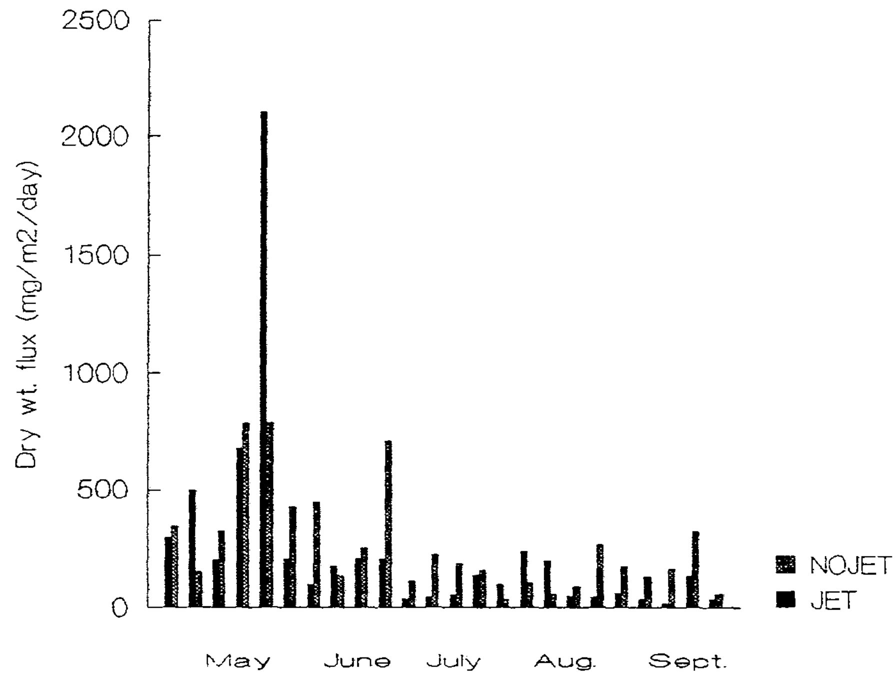

Figure 18. Dry weight flux to sediment traps along the shelf break.

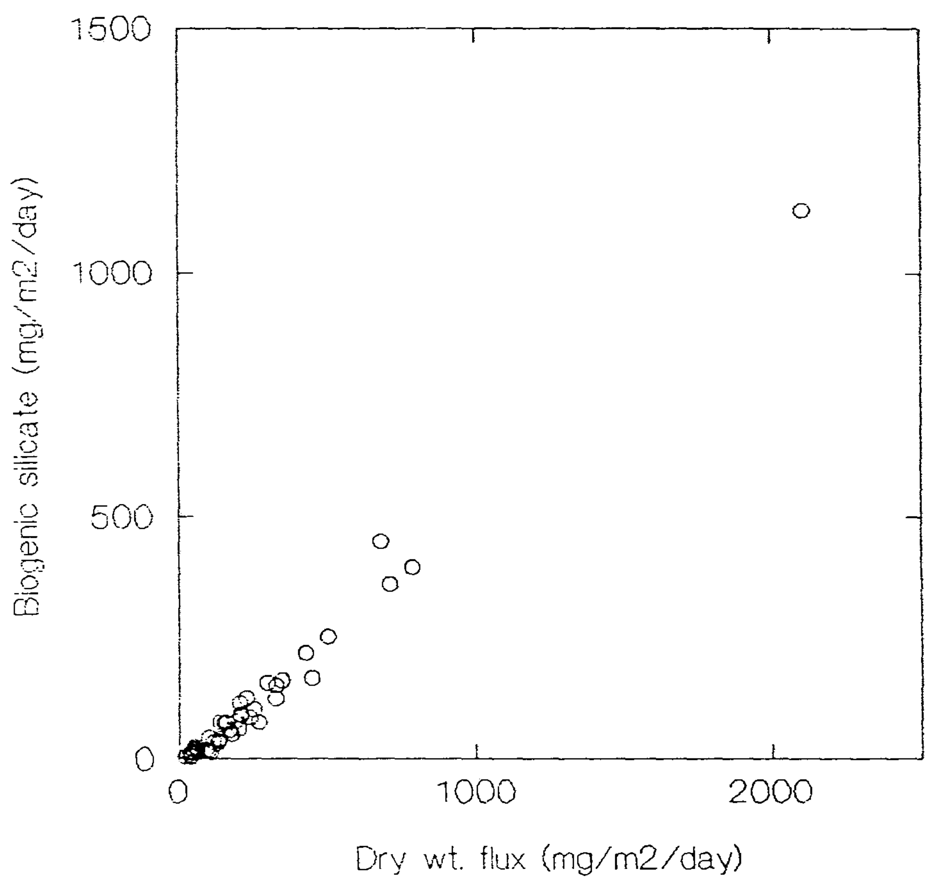

Figure 19. Biogenic silicate versus dry weight flux for material entering the sediment traps in study period.

Project: **NUMERICAL MODEL RESULTS FOR THE SOUTHWEST COAST OF VANCOUVER ISLAND**

by: M. Foreman, Institute of Ocean Sciences

The two-dimensional, finite element, tidal model that has been described in previous years has now been extensively validated (Foreman and Walters, 1990) and attention has turned to applications and the extension to three dimensions. Deficiencies in the accuracy of the 2D model currents are almost completely due to the exclusion of density variations and vertically-varying mean currents such as the Vancouver Island Coastal Current. It is hoped that these deficiencies will be rectified with the three dimensional model.

In collaboration with Howard Freeland, work continued this past year on developing and comparing two methods for removing tides from ship-mounted acoustic Doppler current profiler (ADCP) measurements (Foreman and Freeland, 1991). The first technique predicted tidal currents using model results corrected by historical observations. These values were then subtracted from the ADCP observations and the residual currents were then examined for evidence of mean flow patterns. Using three days of data collected in October 1988, this approach produced residual currents that corresponded well with geopotential surfaces calculated from simultaneous salinity and temperature measurements. These currents also showed clear evidence of the Juan de Fuca Eddy (Freeland and Denman, 1984). The second tide-removal technique was the direct harmonic analysis of ADCP measurements using polynomials to approximate the spatial variability of the tidal parameters. Although this approach has been successful in regions where the M2 constituent is dominant (Candela et al., 1990), we found the removal process to be very sensitive numerically and unable to remove the tides for our 3-day data set.

A second application for the 2D tidal model was the determination of particle retention around Swiftsure Bank. This work was done in collaboration with Antonio Baptista and Roy Walters (Foreman et al., 1991). Retention charactersitics of the bank, in the absence of wind-driven and buoyancy-driven currents, were estimated by using Lagrangian particle tracking techniques to calculate average Stokes and Lagrangian residual velocities. (See Figure 20) In particular, a first order estimate of the average Stokes velocity due to spatial variations in the amplitudes and phases of eight tidal constituent velocities suggested cancellation of the Eulerian residual eddy due to tidal rectification, and no particle retention. These estimates were confirmed with a series of 29-day drifter experiments using the 2D tidal model. Using an extension of these same experiments, it was also demonstrated that the Eulerian eddy around Swiftsure Bank did not confer any energy advantage to fish (with a simple swimming strategy) who wish to remain around the bank.

Using corrected model currents, a calculation was also performed to determine whether or not tidally mixed fronts might be important off the southwest coast of Vancouver Island. Such fronts are the surface signature of transition zones between stratified waters and tidally well-mixed waters, and are traditionally regions of plentiful nutrients. Figure 21 shows contours of the tidal mixing parameter $Tm=\log10(h/Dt)$; where h= depth, and the tidal dissipation, Dt, is proportional to the root mean square spring tidal velocity.

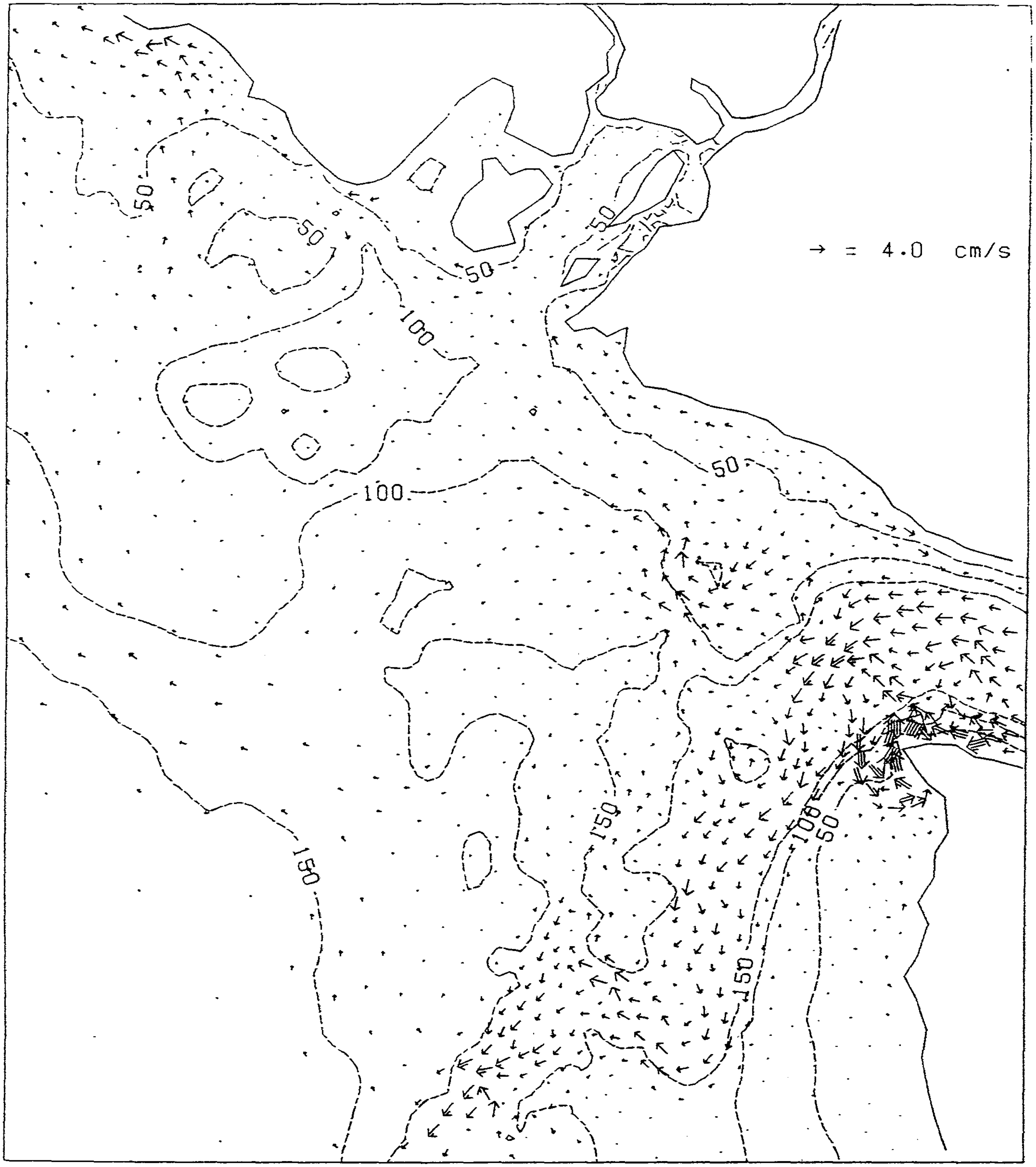

Figure 20. Estimated average Lagrangian velocities calculated from eight tidal constituents and the tidally rectified currents. Each full shaft in multi-shafted vectors represents 4 cm/s. Depth contours are in metres.

Around Georges Bank and in the North Sea, fronts lie (approximately) along the Tm=1.9 contour (Loder and Greenberg, 1986). As seen in Figure 21, only along the shore northwest of Cape Flattery does Tm attain values this low. Satellite observations show patterns that may be fronts in this region, as well as in Juan de Fuca Strait, and off Cape Beale. Notice that the model also predicts relatively low Tm values in these two regions. However it is important to point out that the tidal currents are too small to permit the formation of fronts around the offshore fishing banks.

The 3 dimensional model is presently under development in collaboration with with Dan Lynch and Roy Walters. Using temperature and salinity observations from Rick Thomson's extensive La Perouse data set, a typical winter density field has been calculated. This field will be combined with appropriate inflows westard from Juan de Fuca Strait and northward along the Washington coast to calculate a typical (non-tidal) winter 3D flow field. Work in the coming year will concentrate on further development of the numerical techniques and the computation of flow fields at times of the year when there is observational data for validation.

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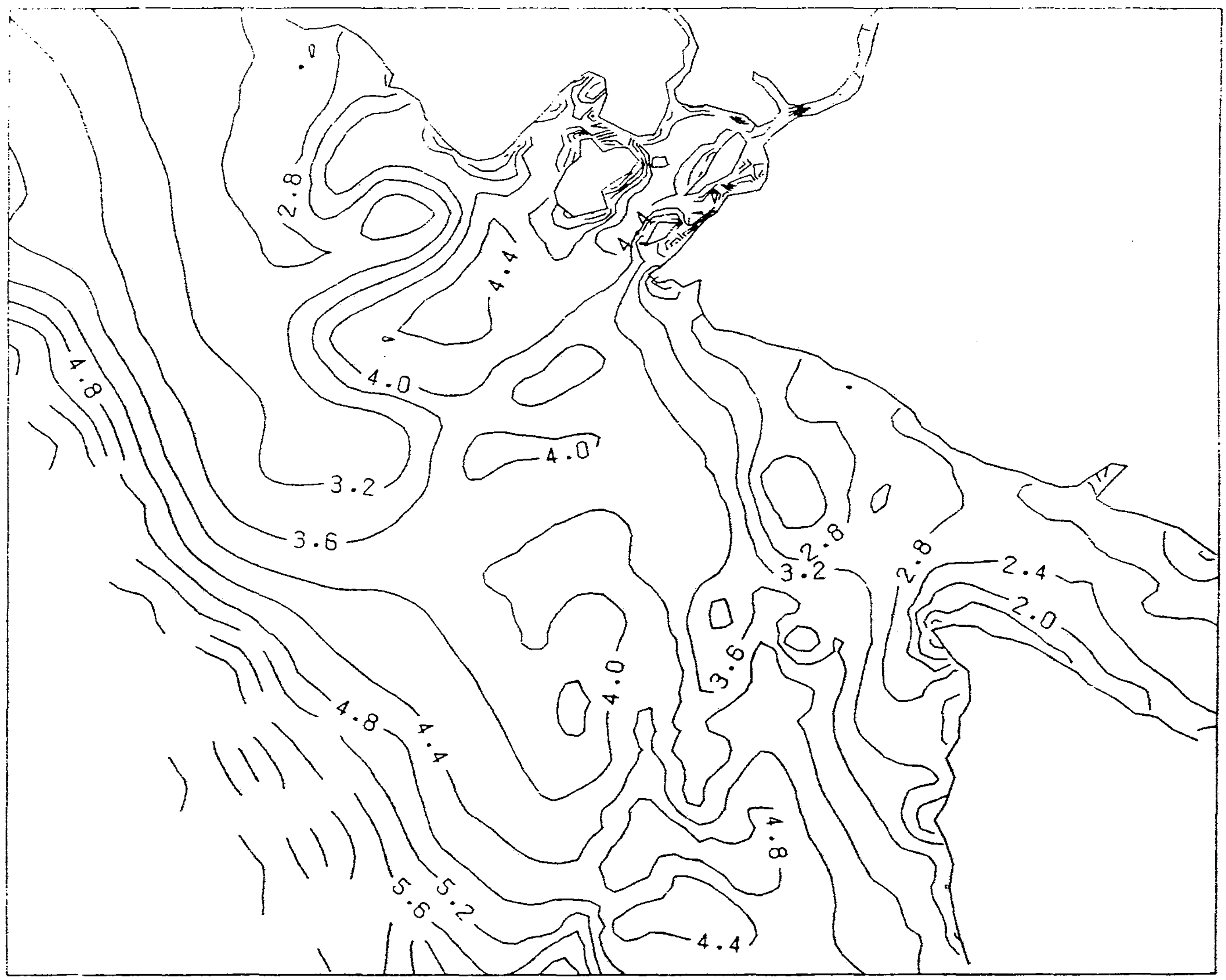

Figure 21. Tidal mixing parameter Tm (W/m*m) calculated using model spring tides corrected in accordance with historical observations.

Project: DISTRIBUTION AND MIGRATION OF JUVENILE PACIFIC SALMON IN COASTAL WATERS OF BRITISH COLUMBIA

by: C. Groot, K. Cooke, J. Morris, B. Waddell, and B. Thomson, Pacific Biological Station, and M. Healey, Westwater Research Centre, University of British Columbia.

INTRODUCTION

The objective of this project was to examine the distribution, migratory routes, run timing, speed, and direction of movement of juvenile Pacific salmon (Genus Oncorhynchus) along the west coast of Vancouver Island and Queen Charlotte Islands, and in Queen Charlotte Sound and Hecate Strait. This information will form the basis for assessing the influence of oceanographic conditions on the migratory movements of juvenile Pacific salmon along the west coast of British Columbia, as part of the Marine Survival of Salmon (MASS) program.

TEST FISHING METHODS

Fishing operations were carried out between September 7-19, 1990, with the W.E. RICKER using twin Bernard-Sigmund beam trawls (Hargreaves and Hungar 1991). The nets were attached to 10.3 m long beams, top and bottom, and rigged for towing aft and abeam of the vessel from 10.5 m outriggers located port and starboard midships. The nets had a 9.1 m wide and 12.2 m deep opening and were about 85 m in length. Mesh sizes of the trawl body ranged from 4.05 cm to 0.38 cm. The codends were equipped with a 1.9 cm mesh liner, 5 m in length, for retention of juvenile fishes. The bottom beam of each net had deflectors to pull the beam downward when towed, to force the net open.

The effective fishing depth was dependent upon warp length, vessel speed, and sea conditions. The warp lengths were set so that in relatively calm seas and at optimum towing speed the top beam of each trawl was towed at the surface. Optimum towing speed was estimated at 7.2 km/h (4 kn) based on vessel horsepower, propeller pitch, manoeuvrability of the vessel while towing, and catchability of juvenile salmonids (Hargreaves and Hungar 1991). Towing speeds during this survey ranged from 5.0 km/h (2.8 kn) to 7.6 km/h (4.2 kn) and vessel speed over the ground varied from 2.9 km/h (1.6 kn) to 8.5 km/h (4.7 kn), depending upon wind, sea, and tidal conditions. Swell heights of 1.5-2 m caused the top beam of the nets to periodically break the surface, momentarily decreasing the effective fishing depth. During towing the vertical opening of each net was assumed to only fish to a depth of about 5 to 6 m (Hargreaves and Hungar 1991).

Once deployed, the nets remained in the water for the duration of a transect. The codends of each net were hauled alternately after 1 h of fishing time. Occasionally, only one net was fished when catch rates were very high. When the codend was hauled in, the tow beams of the net being sampled tended to scissor inboard, thus constricting the net opening vertically. The net continued to fish but at a reduced rate. Performance of the paired net was not affected during retrieval.

The vessel was maintained on a relatively constant course and speed for each transect and sampling of the surface waters continued during day and night. We fished parallel transects, separated by 40 km (21.6 nm), from Cape Caution to Aristazabal Island in Queen Charlotte Sound, and from Cape St. James to Tasu Sound along the west coast of the Queen Charlotte Islands, and from Triangle Island to Brooks Peninsula along the west coast of Vancouver Island. Figure 22 shows the survey area and Figure 23 indicates the transect lines. We assumed that parallel transects from the 100 m depth contour nearshore to about 30 km offshore to about the 1800 m (1000 fm) shelf break, would provide the necessary data to establish the extent of offshore migration exhibited by juvenile salmon. We were specifically interested in determining the distribution of the Barkley Sound juvenile sockeye, to assess their coastal migratory patterns.

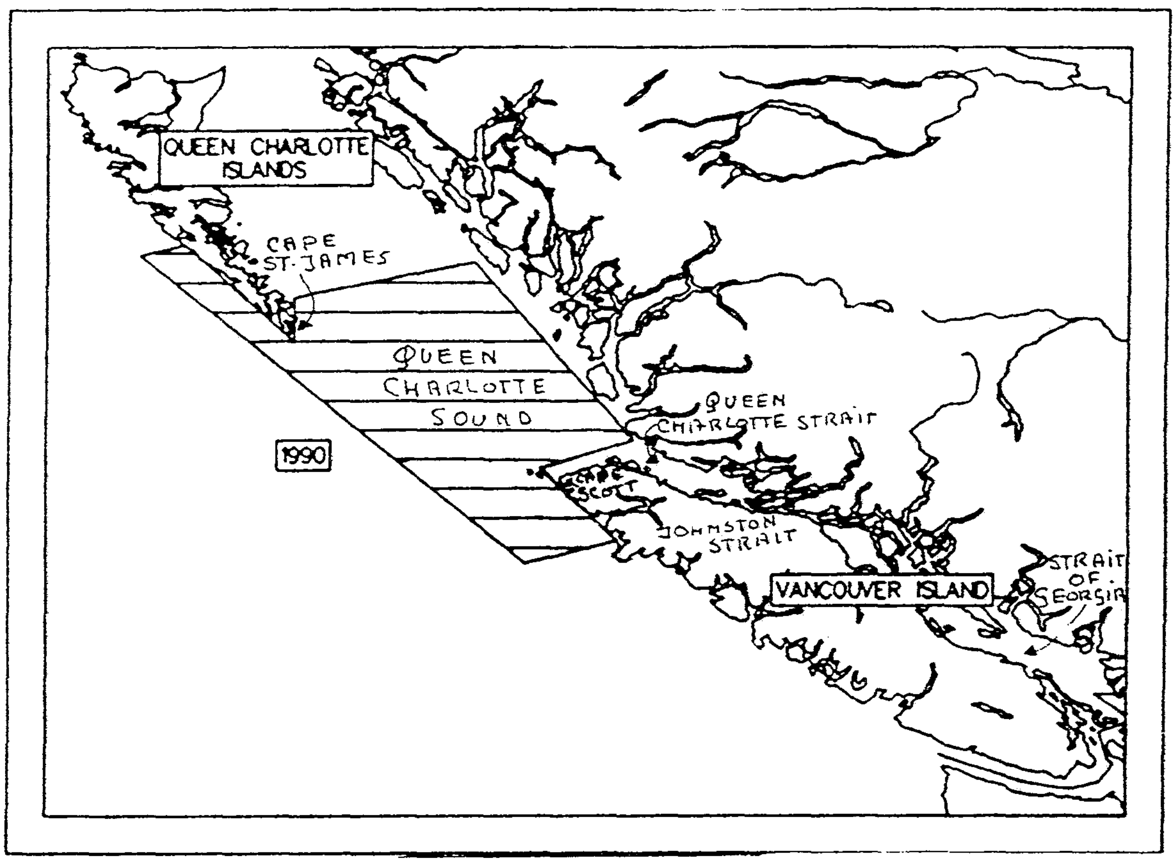

Figure 22. Survey area: September 7 - 19, 1990.

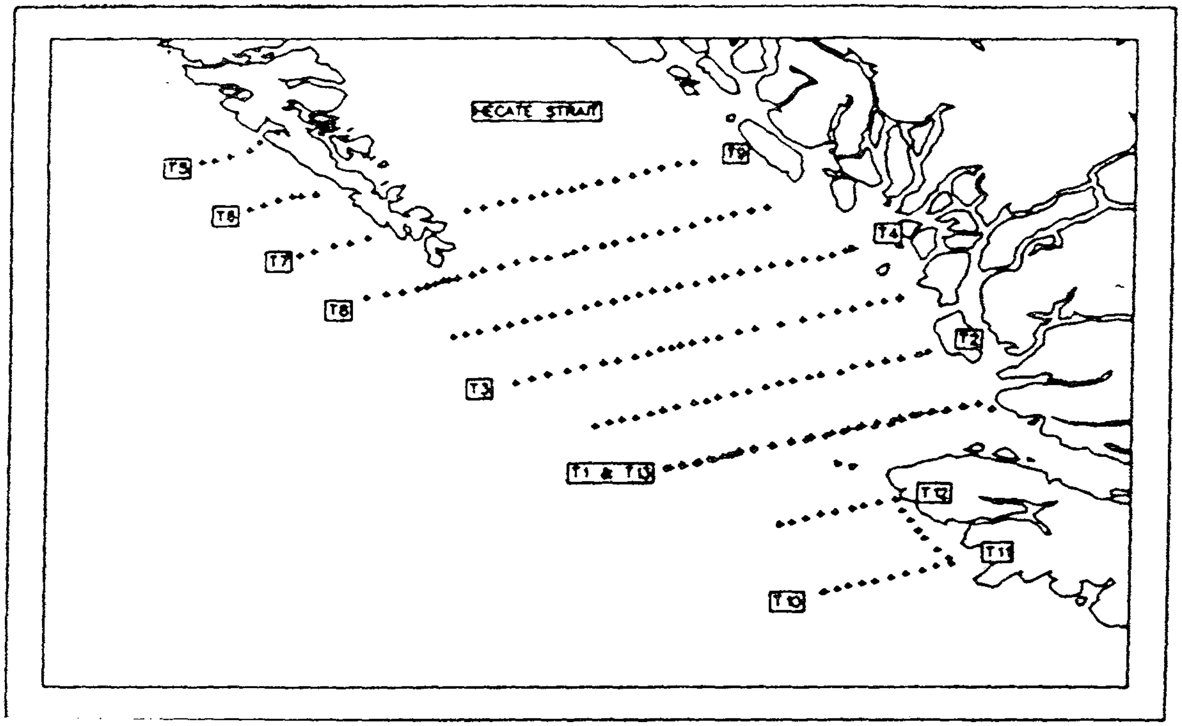

Figure 23. Survey area: symbols along transect lines represent codend haul locations.

In addition to catches of juvenile Pacific salmon, juvenile sablefish (Anoploloma fimbria), Pacific herring (Clupea harengus pallasii), Pacific saury (Cololabis saira), and a number of other marine fishes were also captured (Cooke et al. 1991). Total numbers of each species from each set were recorded or, when abundant, estimated by number or weight. Fork lengths were recorded for all salmon and sablefish, and for a maximum of 100 (when available) of other species captured. Mean length and total catch were estimated from sub-samples of large catches of Pacific herring, Pacific saury, and lanternfishes (Myctophidae species). Jellyfish catches were noted when quantities were significant. All juvenile salmon and juvenile sablefish were examined for external wounds and preserved for laboratory examination.

CTD casts were made at the beginning and end of all but two transects, to maximum depths of 100 m, to determine temperature and salinity of the water column. XBT casts, for additional temperature profiling, were employed at intervals of 20 km along the transects and on two occasions where CTD casts were not feasible. We also monitored sea-surface temperature from a hull-mounted intake module. The temperature and salinity data will be analyzed in conjunction with data from subsurface current moorings deployed in Queen Charlotte Sound and Hecate Strait and from drogue tracking experiments in this area by B. Crawford (Institute of Ocean Sciences, Sydney, B.C.) from August to

September, 1990, to determine to what extent current dynamics and water-flow patterns affect juvenile salmon migration.

Water temperatures were anomalously warm throughout the survey area, ranging from 16°C at the surface to 10-14°C at 10 m depth. Warm waters apparently extended a considerable distance offshore because the commercial tuna fleet was fishing about 50 km seaward of our sampling sites along the west coast of the Queen Charlotte Islands. The warm water intrusion might explain the capture of the two Opahs (Lampris regius), a species more commonly found in tropical oceans. Regions of cooler water existed in the Cape St. James area of the Queen Charlotte Islands and near the entrance to Queen Charlotte Strait.

The nets occasionally differed in their respective catch rates. It appeared that the direction of the wash caused by the rotation of the ship's propeller, weather conditions (eg. amount of ship's shadow present under sunny skies), and local currents contributed to variable catch rates. Further study into the selectivity and catch rates of the nets is required.

RESULTS

The fishing operations from September 7-19, 1990, covered about 390 hours and included 376 sets over 13 transects. In total, 106 juvenile sockeye (O. nerka), 2576 pink (O. gorbuscha), 1256 chum (O. keta), 74 coho (O. kisutch), and 2 chinook (O. tshawytscha) were captured. The distribution and the relative abundance of these 5 species of young Pacific salmon are illustrated in Figures 24-28.

Pink and chum salmon juveniles were most abundant along the northwest coast of Vancouver Island, in the centre of Queen Charlotte Sound, and around Cape St. James (Figs. 25 and 26). Very few (only 7 pinks) were captured along the west coast of the southern Queen Charlotte Islands. Sockeye and coho juveniles occurred in much lower numbers than pink and chum, and they were distributed more in the southeastern part of Queen Charlotte Sound with some along the northwestern coast of Vancouver Island (Figs. 24 and 27). Only two chinook juveniles were collected in the 376 sets (Fig. 28).

In addition to juvenile Pacific salmon, 3711 sablefish, 4564 Pacific herring, and 15994 Pacific saury were captured. Juvenile sablefish (Fig. 29) and Pacific herring (Fig. 30) were widely distributed in Queen Charlotte Strait and were less abundant along the northwestern coast of Vancouver Island and almost absent along the westcoast of the southern Queen Charlotte Islands. Pacific saury (Fig. 31) were the most abundant species captured and were most prevalent on the ocean side of the sampling area and along the northwest coast of Vancouver Island and the west coast of the southern Queen Charlotte Islands. They were not present in the eastern part of Queen Charlotte Sound.

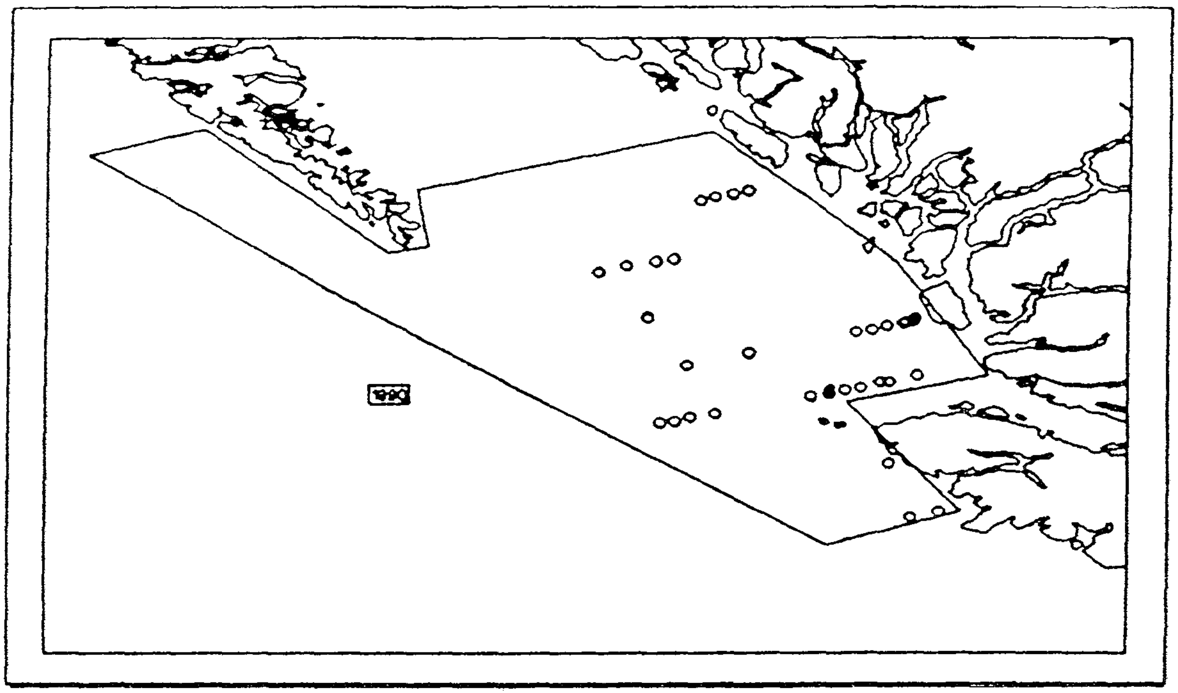

Figure 24. Sockeye catch by haul for 1990. Survey area outlined in solid line. circles represent catch: **OPEN** = 1-10; **CLOSED** = 11-100.

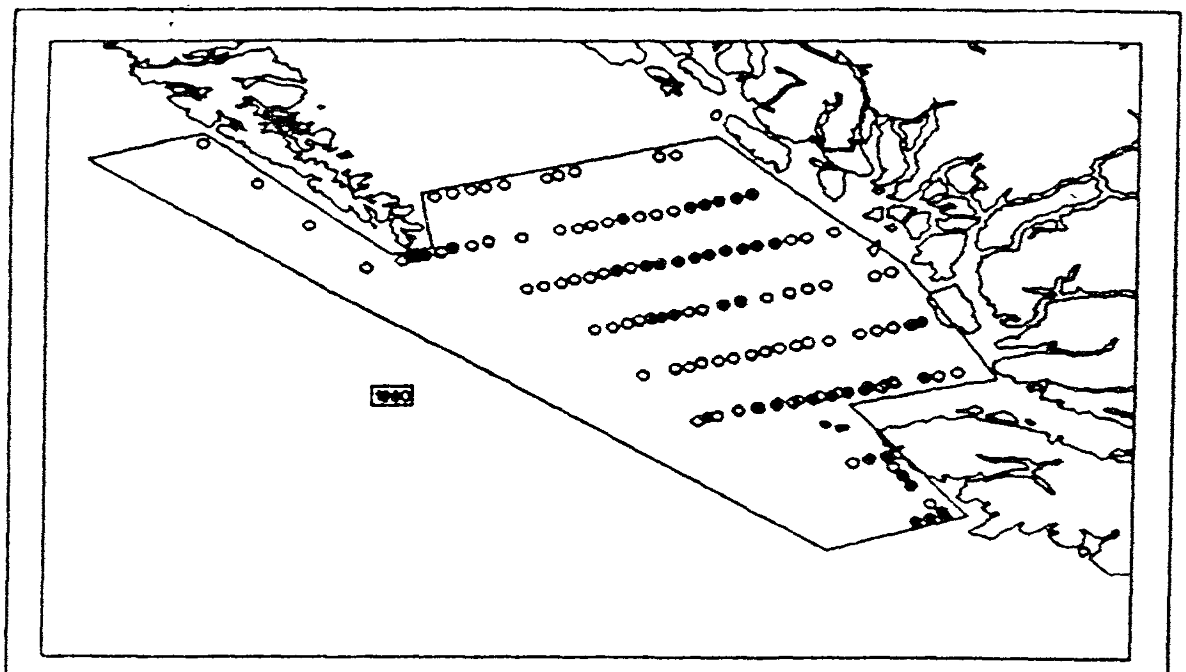

Figure 25. Pink catch by haul for 1990. Survey outlined in solid line. Circles represent catch: **OPEN** = 1-10; **CLOSED** = 11->100.

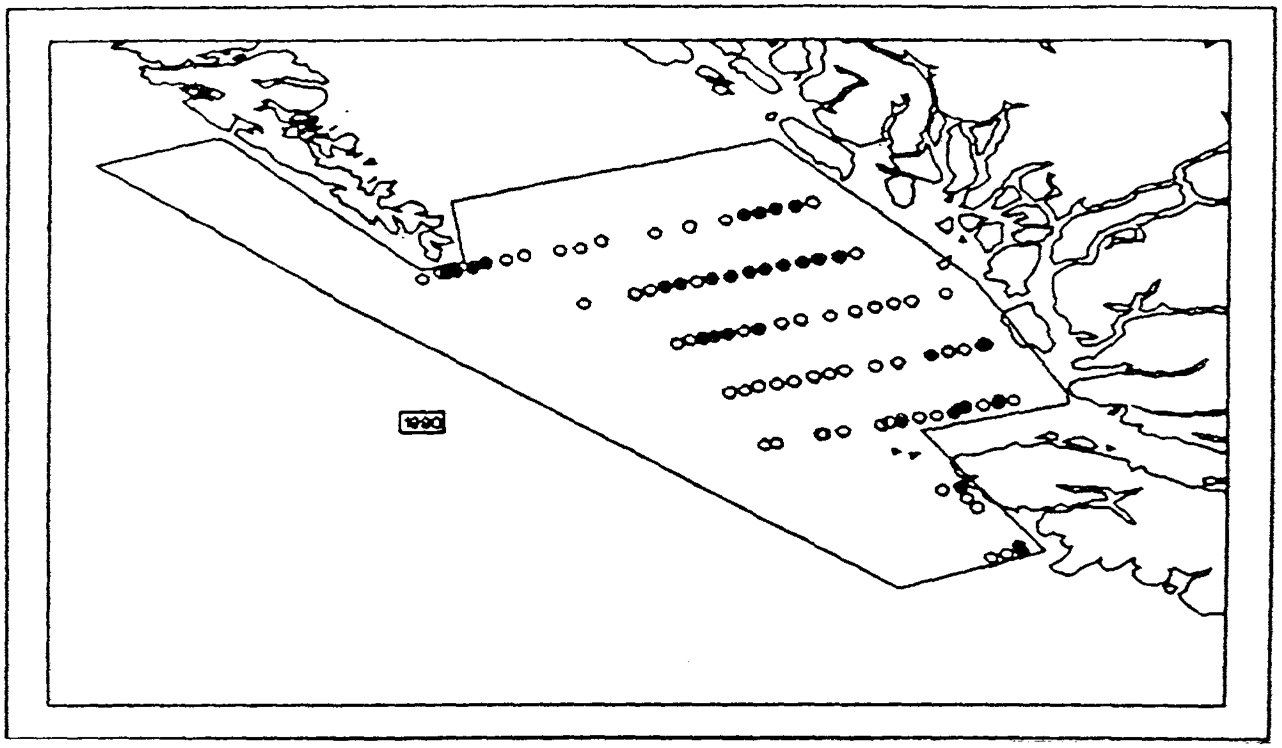

Figure 26. Chum catch by haul for 1990. Survey outlined in solid line. Circles represent catch: **OPEN** = 1-10; **CLOSED** = 11->100.

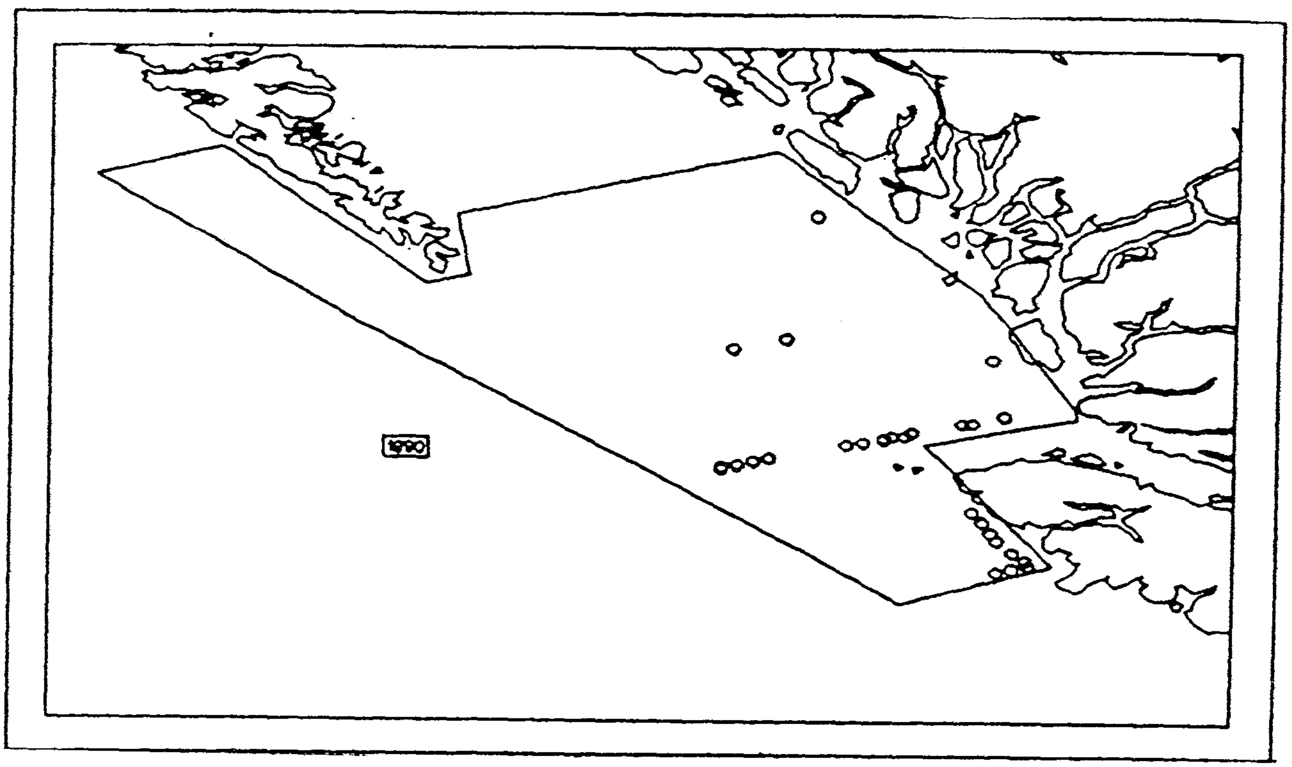

Figure 27. Coho catch by haul for 1990. Survey outlined in solid line. Circles represent catch: **OPEN** = 1-10; **CLOSED** = 11-100.

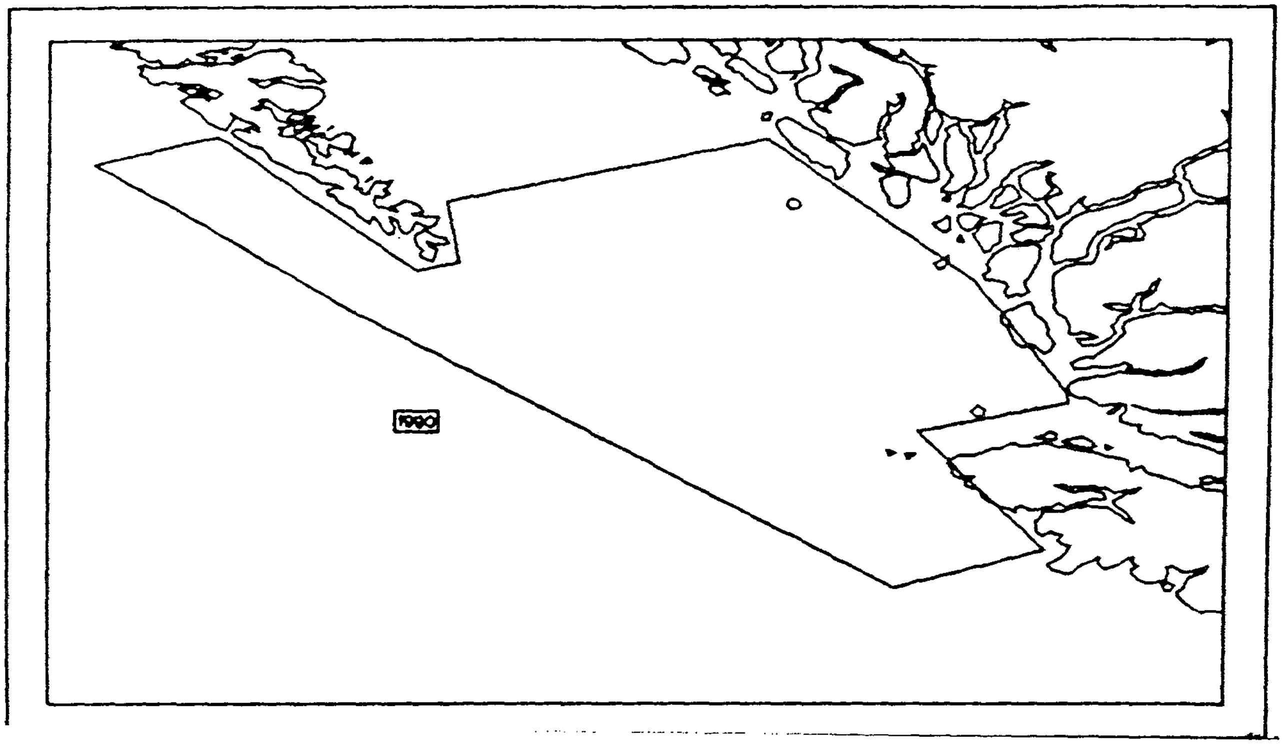

Figure 28. Chinook catch by haul for 1990. Survey outlined in solid line. Circles represent catch: **OPEN** = 1-10; **CLOSED** = 11-100.

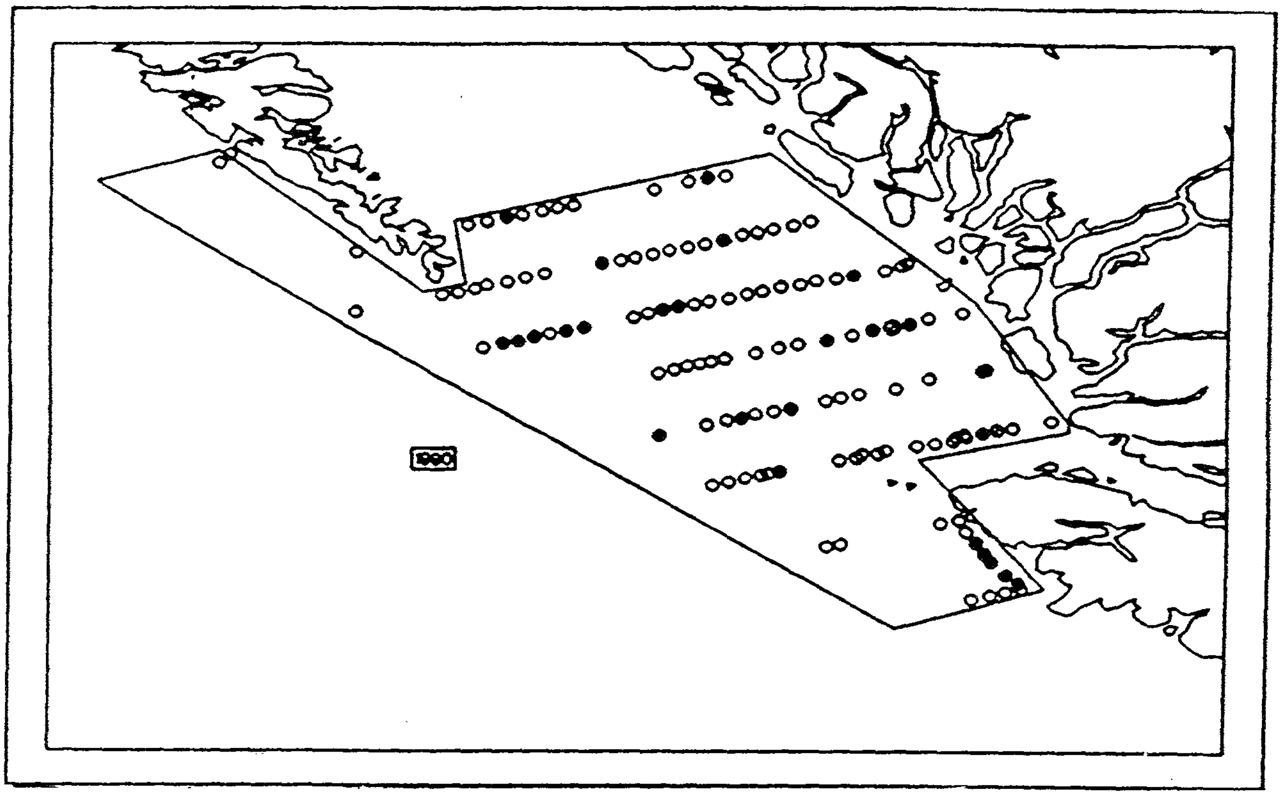

Figure 29. Sablefish catch for 1990. Survey outlined in solid line. Circles represent catch: **OPEN** = 1-10; **CLOSED** = 11->100.

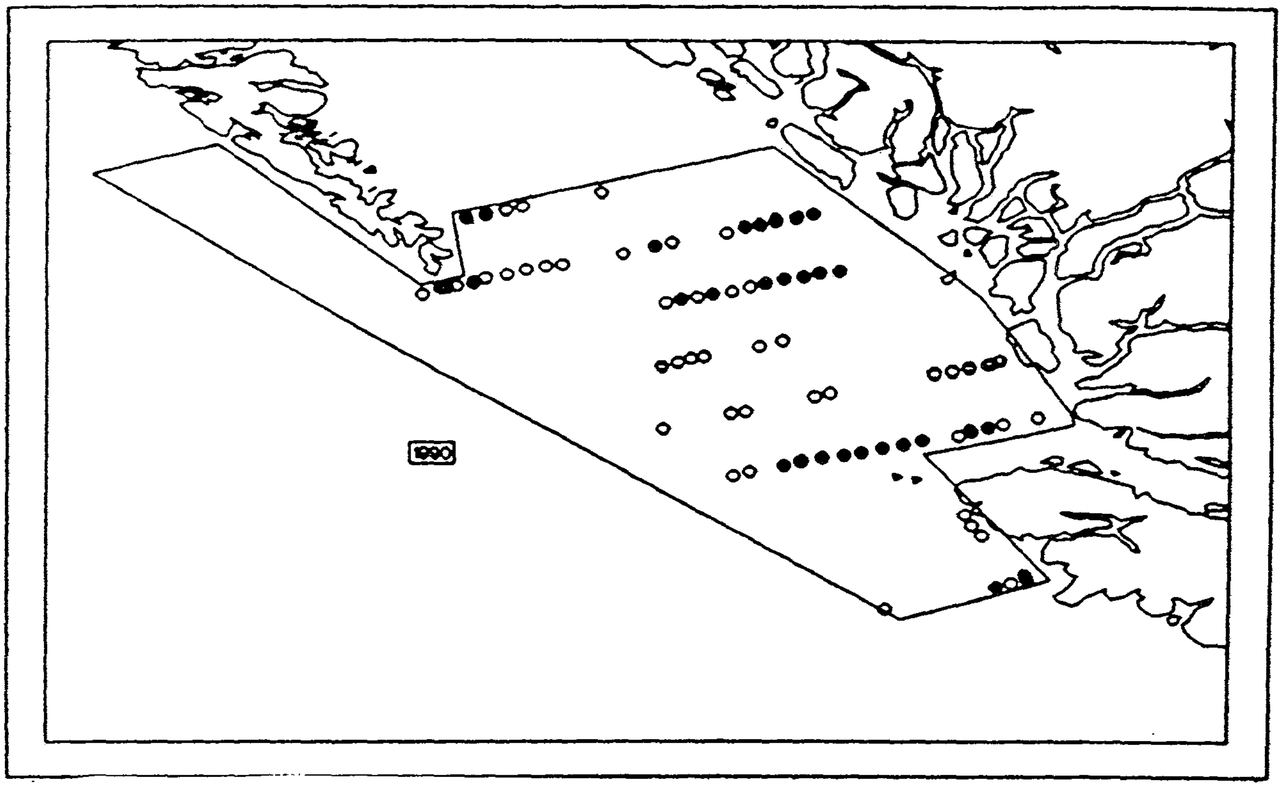

Figure 30. Herring catch for 1990. Survey outlined in solid line. Circles represent catch: **OPEN** = 1-10; **CLOSED** = 11->100.

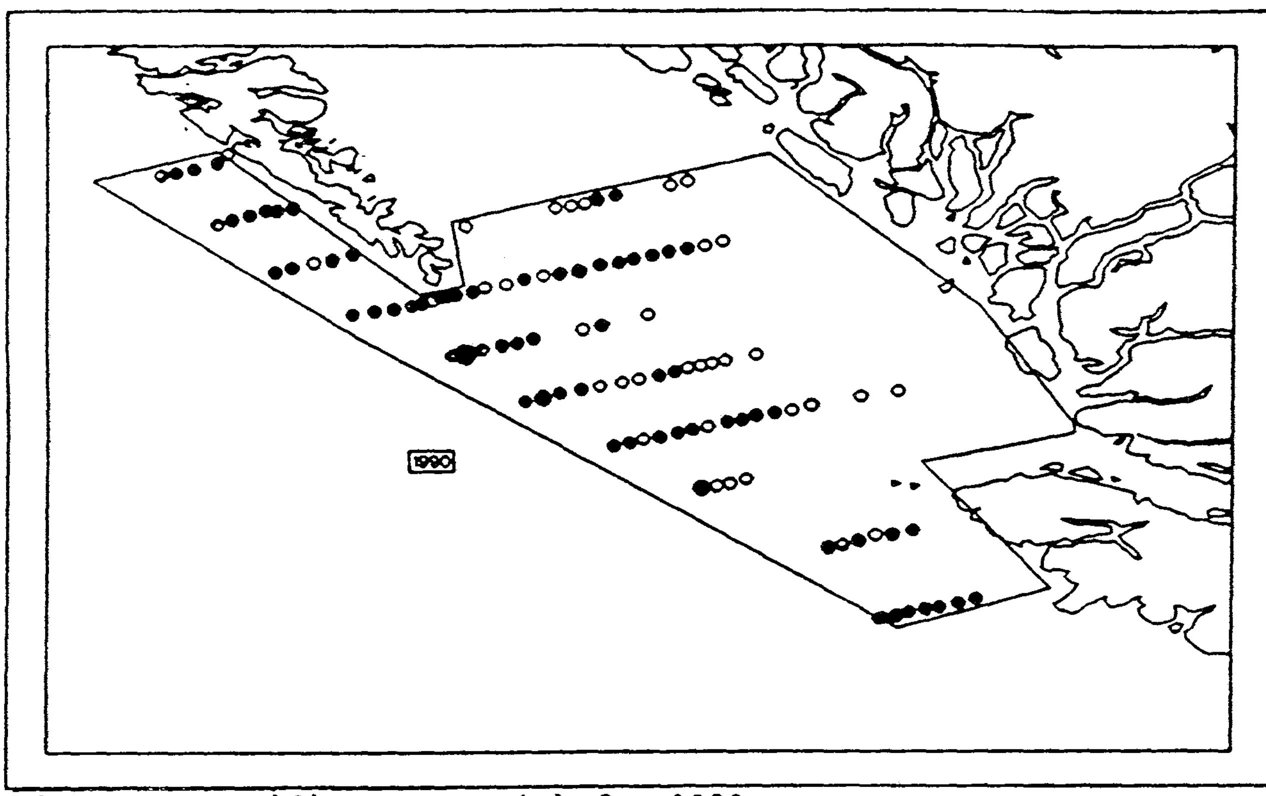

Figure 31. Pacific saury catch for 1990. Survey outlined in solid line. Circles represent catch: **OPEN** = 1-10; **CLOSED** = 11->100.

CONCLUDING REMARKS

The concentration of sockeye, pink, chum, and coho catches along the northwestern coastline of Vancouver Island, within 10 to 20 km of shore, seems to support Hartt and Dell's (1986) hypothesis that juvenile Pacific salmon migrate northward in a band within 30 km of shore along the westcoast of North America. The young salmon may disperse over a greater area as they enter Queen Charlotte Sound but a general northward progression in migration is still evident and the lack of young salmon along the seaward boundary of the study area further supports this hypothesis (Figs. 24-27).

The distribution of juvenile sockeye, pink, and chum in Queen Charlotte Sound may suggest another scenario. It is possible that the movement of juvenile salmon westward into Queen Charlotte Sound reflects a west and northwest progression of south coast mainland stocks entering the sound from Johnstone and Queen Charlotte straits. This could explain the solitary concentration of juveniles found at the southern tip of the Queen Charlotte Islands in the Cape St. James area (Fig 25 and 26).This hypothesis suggests that west-coast Vancouver Island stocks move offshore early on in their migration and do not traverse Queen Charlotte Sound. The lack of young salmon along the ocean side of the sampling area between Cape Scott and Cape St. James could mean that the fish had not progressed that far yet. It will be necessary to develop stock identification methods for pink, chum, and sockeye juveniles originating in southern British Columbia and northern Washington waters, to resolve which hypothesis best explains the migratory behaviour of these juvenile salmonids.

In general, more juvenile salmon were captured at night than during the day, suggesting that either they swim deeper or are better able to avoid capture during the day.

It is not clear why sockeye juveniles occurred in such low numbers (106) west of Vancouver Island and in Queen Charlotte Sound as compared with pink (2576) and chum (1256). We used a migration rate of 3-5 km/day for juvenile sockeye based on observations in Babine Lake (Johnson and Groot 1963), Barkley Sound (Cooke and Groot 1990), and the Strait of Georgia (Groot and Cooke 1988) to calculate the seasonal migratory progression of these fish. At this rate of travel and a northward directed migration, Barkley Sound sockeye would have been located north of Cape Scott by early September. Their relative absence in this area could indicate that they (1) generally migrated deeper than the net was fishing (below 6 m); (2) were better able to avoid the net than pink and chum; (3) migrated closer to shore and out of reach of our gear; or (4) had already moved out of the sampling area, either north- or westward.

We discount suggestion (1) as unlikely because we caught ample numbers of pink and chum in the surface layer and previous studies have shown that young sockeye primarily occupy the upper 5 m of the water column, along with pink and chum (Groot and Cooke 1987; Cooke et al. 1990). Suggestion (2) also seems unlikely because the young sockeye captured were equal or smaller in size than the pink and chum (13.5 cm mean body length compared with 13.8 cm and 16.0 cm, respectively). Migration very close to shore, suggestion (3), has been observed for Fraser River junvenile sockeye during migration out of the Strait of Georgia (Groot and Cooke 1987). This possibility needs to be further investigated by seining close to shore concurrently with beam trawling. Movement westward out of the survey area, suggestion (4), is themost plausible explanation for the generally low catch rates of juvenile sockeye salmon. It is unlikely that the smolts could have travelled northward out of our survey area before the end of September at a migration rate of 3-5 km/d. However, a westward movement is contrary to Hartt and Dell's (1986) hypothesis and is different from the migratory behaviour of Fraser River juvenile sockeye observed in the Strait of Georgia by Groot and Cooke (1987). Further offshore sampling is required to resolve this problem (see Hargreaves and Hungar in this report).

Juvenile coho smolts were primarily captured in near shore areas along the westcoast of Vancouver Island and just north of the tip of Vancouver Island (Fig. 27). Very few occurred in Queen Charlotte Sound and none were found west of the southern Queen Charlotte Islands. Only two juvenile chinook salmon were captured during the 12 day survey in Queen Charlotte Sound and west Vancouver Island waters (Fig. 28). It is possible that these two species, (1) were not present in the survey area, (2) occupied deeper layers of the water column, or (3) were able to avoid the net. It is known that chinook generally swim deeper than the other Pacific salmon species, which most commonly occur in the upper 10 meters of the water column. Further sampling surveys will be necessary to indentify the factors governing coho and chinook distribution along the west coast of Vancouver Island and in Queen Charlotte Sound.

ACKNOWLEDGEMENTS

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Project: **JUVENILE SALMON ABUNDANCE AND DISTRIBUTION ALONG THE WEST COAST OF VANCOUVER ISLAND IN SUMMER, 1990.**

by: Brent Hargreaves and Bob Hungar. Biological Sciences Branch, Pacific Biological Station, Nanaimo, B.C.

INTRODUCTION

Existing data indicate that the mortality of salmon in the ocean is highest when salmon are young, and declines rapidly as they grow older (e.g. Ricker 1976). The recruitment of all species of salmon also appears to be determined early, possibly during the first summer and fall after the young salmon enter the ocean (e.g. Parker 1968; Mathews and Buckley, 1976). The importance of the early sea-life period is widely recognized, and many studies have been conducted in near-shore areas during the spring and early summer. There is also an extensive literature concerning maturing and adult salmon on the high seas (e.g. French et. al. 1976). However, remarkably little is known about the abundance, distribution, and mortality of salmon during the late summer and fall of their first year in the ocean, immediately after the juveniles leave near-shore coastal areas.

Historically the most comprehensive data set available for this period is from 3073 sets which were made with fine-mesh purse seines between April and October from 1956 to 1970 (Hartt and Dell 1986). This sampling effort was distributed along the northeast Pacific coast from Cape Flattery, Washington to Yakutat, Alaska, and in the northern Gulf of Alaska and eastern Bering Sea. Based on these data, Hartt and Dell 1986 concluded that "juvenile sockeye, chum, and pink salmon upon entering the ocean, apparently did not scatter randomly, but followed a definite migratory route. Those entering the ocean from Washington State, British Columbia, and southeastern Alaska migrated northward relatively near the shore. The great majority remained within a coastal belt less than 20 miles wide".

In the summer of 1990 we used the newly developed Bernard Sigmund Beam Trawls to begin to test this hypothesis. We developed this unique new fishing gear during the past four years for sampling juvenile salmon and other important commercial fish species in the surface waters of the continental shelf and open waters of the North Pacific Ocean. On the 1990 cruise fishing was conducted from the W.E. RICKER each day during 25 July to 10 August, to determine the abundance and distribution of juvenile salmon along the west coast of Vancouver Island, British Columbia. This survey followed a rectangular grid pattern which started south of Barkley Sound and ended off Cape Scott (Fig. 32). The near-shore transects were typically kept within 0.2 nautical miles of shore. The transects perpendicular to the coast all extended offshore at least 30 nautical miles, and beyond the edge of the continental shelf. The gradual broadening of the continental shelf from north to south resulted in a maximum offshore distance of 42 miles for transect B. All fish samples were collected with the top beam of the trawls at the sea surface, at tow speeds of 2.5 to 4.0 knots, mainly during daylight hours.

During the sixteen day survey 329 trawl sets were successfully completed, yielding a total of more than 6000 juvenile salmon. In general the abundance of juvenile pink, chum, and sockeye salmon tended to be fairly even from near shore out across the continental shelf (Fig. 33). There were two areas where we found high concentrations of juvenile salmon, one far offshore near Barkley Sound, and another close to shore, just south of Brooks Peninsula. In general the results from this cruise do not support the hypothesis of Hartt and Dell (1986) that the great majority of juvenile salmon remain within a narrow coastal belt less than 20 miles wide as they migrate north. In 1990 we found some of the largest concentrations of juvenile salmon occurred far offshore, well beyond a distance of 20 nm. Some of the largest catches also occurred near the outer ends of the offshore transects, 30 - 40 nm offshore, suggesting that our sampling probably did not extend far enough offshore to define the full offshore extent of the distribution of juvenile salmon. The main concentrations of juvenile salmon actually occurred along the outer edge of the continental shelf.

Large numbers of juvenile fish of several other important species were also captured, including more than 1100 sablefish, 61,000 herring, and 800 rockfish. The new data on juvenile sablefish is particularly exciting, as there is virtually no previous information on the abundance and distribution of this development stage of this important commercial species. A variety of potential predators of juvenile salmon and other commercial species in coastal waters were also captured on our 1990 cruise, including various rockfish, Pacific hake, spiny dogfish, blue sharks, and chub mackerel. Of these, several specimens of black rockfish (Sebastes melanops) had juvenile salmon in their stomachs in both fresh condition and an advanced state of digestion. This species may prove to be an important, but previously unrecognized, source of mortality for juvenile salmon on the continental shelf.

The successful survey cruise in July 1990 marks the completion of the development of the BERNARD-SIGMUND trawls. This gear represents a major advance in the tools available for sampling juvenile salmon and many other many important pelagic fish species. It significantly extends our capacity to conduct multi-species, ecosystem level, fisheries investigations in coastal and offshore waters, work which could not previously be undertaken due to the severe limitations of both commercial and conventional research fishing gear.

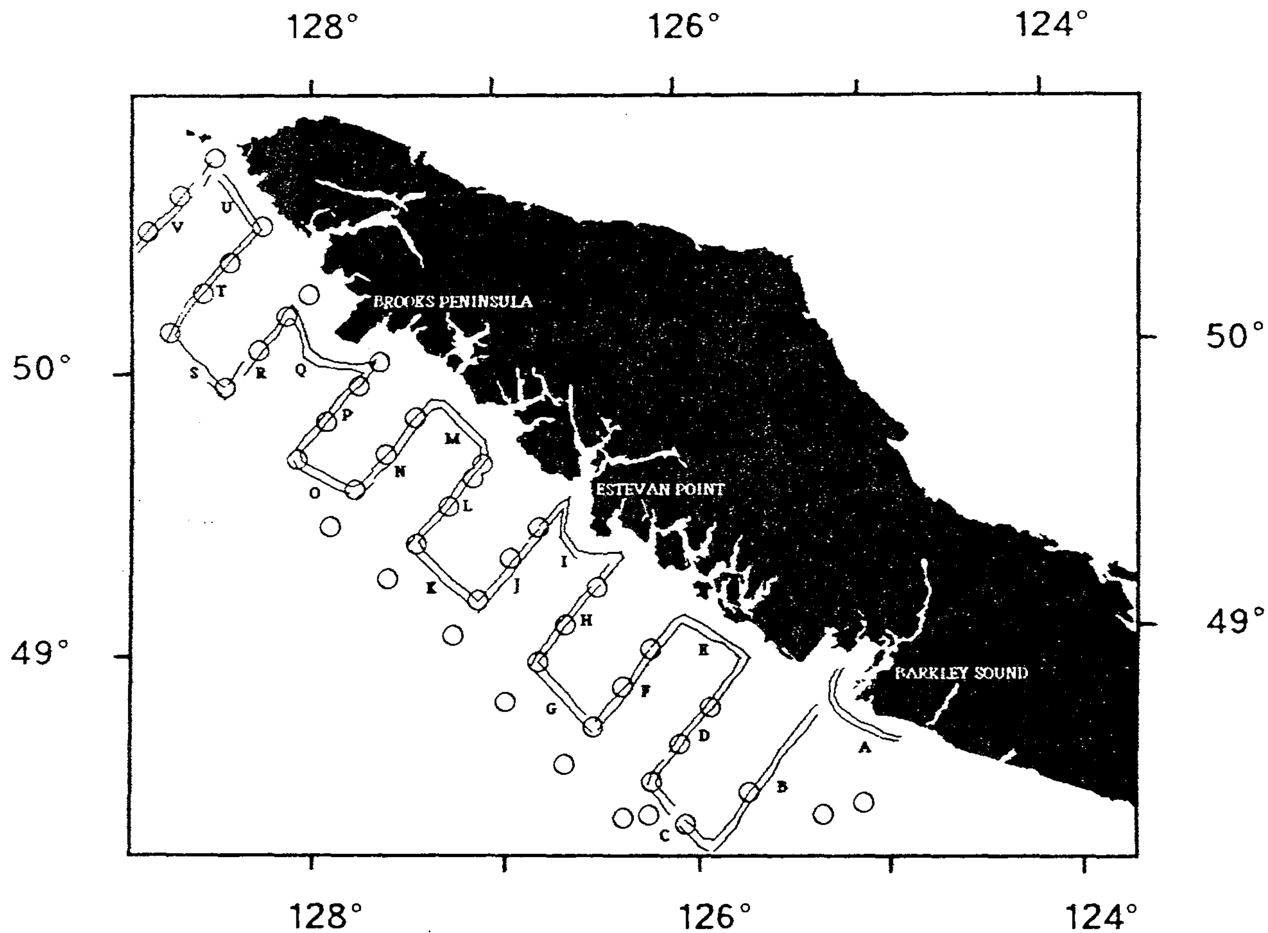

Figure 32. Parallel lines indicate cruise trace for fish sampling with Bernard-Sigmund trawls. Open circles indicate locations of CTD vertical profiles.

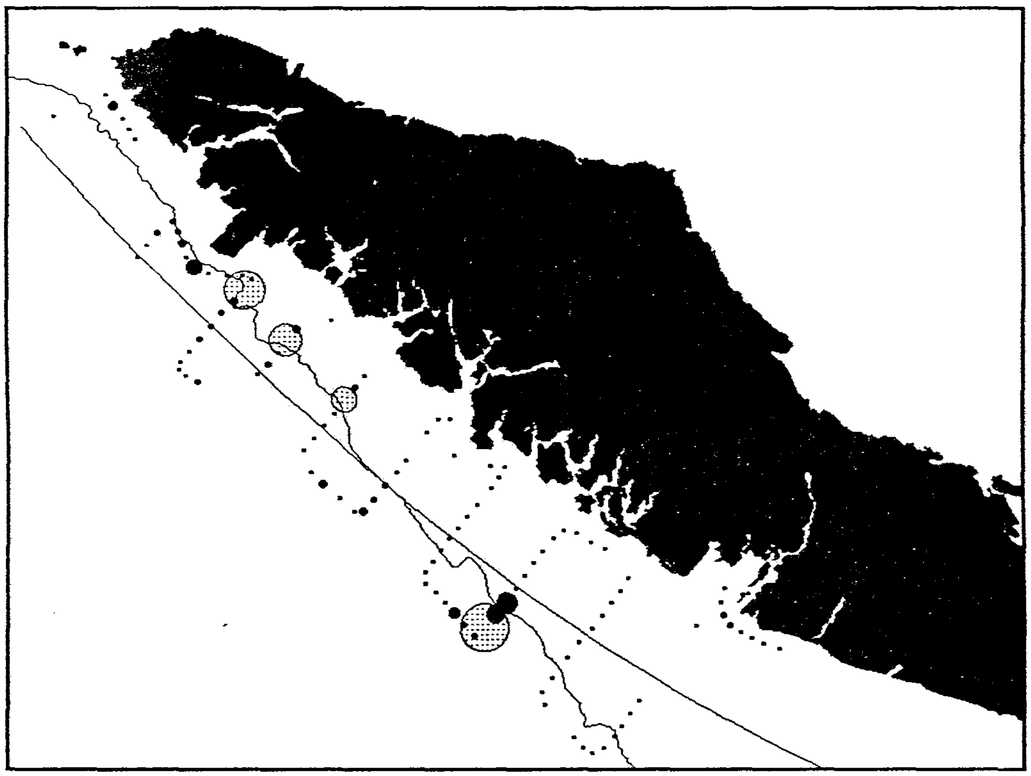

Figure 33. Catches of juvenile salmon for all species combined (size of dots is proportional to catch). Curved line indicates distance of 20 n miles offshore, irregular line shows position of shelf break (200 f depth contour).

ACKNOWLEDGEMENTS

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