Outer Continental Shelf Environmental Assessment Program

Final Reports of Principal Investigators

Volume 66 February 1990

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service
Office of Oceanography and Marine Assessment
Ocean Assessments Division
Alaska Office

U.S. DEPARTMENT OF THE INTERIOR
Minerals Management Service
Alaska OCS Region
OCS Study, MMS 90-0007

"Outer Continental Shelf Environmental Assessment Program Final Reports of Principal Investigators" ("OCSEAP Final Reports") continues the series entitled "Environmental Assessment of the Alaskan Continental Shelf Final Reports of Principal Investigators."

OCSEAP Final Reports are published by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Ocean Assessments Division, Alaska Office, Anchorage, and primarily funded by the Minerals Management Service, U.S. Department of the Interior, through interagency agreement.

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The facts, conclusions, and issues appearing in these reports are based on research results of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), which is managed by the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and funded (wholly or in part) by the Minerals Management Service, U.S. Department of the Interior, through an Interagency Agreement.

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EARLY LIFE HISTORY OF PACIFIC HERRING: RELATIONSHIPS OF LARVAL DISPERSAL AND MORTALITY TO ENVIRONMENTAL CONDITIONS

FINAL REPORT OF PORT MOLLER PLANNING STUDY

by

Michael McGurk
Triton Environmental Consultants Ltd.
205–2250 Boundary Road
Burnaby, B.C., Canada V5M 3Z3

John E. Edinger and Edward M. Buchak
J. E. Edinger Associates, Inc.
37 West Avenue
Wayne, Pennsylvania 19087-3226

Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 711

October 1989

Acknowledgments

This study was wholly funded by the Minerals Management Service of the Department of the Interior, through an interagency agreement with the National Oceanic and Atmospheric Administration, Department of Commerce, as part of the Alaska Outer Continental Shelf Environmental Assessment Program (OCSEAP).

I thank the Contracting Officer's Technical Representative, L. Jarvela (NOAA, National Ocean Service, Anchorage, Alaska) for his assistance in locating sources of information. The figures in Chapter 2 were prepared by J. E. Edinger Associates, Inc. and redrafted by D. Warburton (Triton). The manuscript was printed by G. Ricard.

Abstract

A review of the scientific literature on the transport of pelagic fish eggs and larvae by oceanic and estuarine transport systems shows that a strong link is believed to exist between transport and survival of young fish, particularly for Pacific herring, Clupea harengus pallasi, larvae. Until recently, most studies of this subject were semi-quantitative and so could not be used to reject hypotheses that explain apparent coupling between oceanographic phenomena, survival of fish eggs and larvae, and subsequent recruitment in fish populations. However, recent advances in hydrodynamic modelling and in computational hardware have made feasible the direct integration of three dimensional, time-varying hydrodynamic computations over the appropriate time and space scales. It is no longer necessary to resort to semi-quantitative methods.

This report recommends that the Generalized Longitudinal, Lateral and Vertical Hydrodynamic and Transport (GLLVHT) model (Edinger and Buchak 1985) be used for studies on the population dynamics of herring larvae in Port Moller, Alaska. The structure of the model is briefly summarized. A computational grid with 250 to 327 cells and a cell area of 3.06 km^2 is established for the Port Moller area. The oceanographic and meteorological data required to initialize, validate and verify the model is summarized.

A preliminary sampling plan is prepared for Port Moller based on the data requirements of the GLLVHT model. Mobilization must begin by mid-April and the field program should run to the end of July. Oceanographic conditions are expected to be transient during the sampling period, so Port Moller should be instrumented during the study. Water pressure sensors should be placed at the western entrance to Port Moller and near Bear River. A current meter may be required near Frank's Lagoon. Temperature and salinity should be measured along the boundaries of the system as well as at each plankton station. A meteorological station should be established near the entrance to Port Moller, and flow rates of at least two of the major tributaries draining into Port Moller should be measured.

At least 26 plankton stations must be sampled once every 2 to 4 d. Three stations must be established along the boundary of the system, and the remainder should be placed on longitudinal and lateral transects within Moller and Herendeen Bays. Series of horizontal tows at different depths should be taken at some of the deeper stations, whenever it is logistically possible.

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1. Introduction

1.1 Objectives of the study

Triton Environmental Consultants Ltd. (formerly Envirocon Pacific Ltd.) was contracted by the Ocean Assessments Division of NOAA in June, 1989, to conduct a reconnaissance and planning survey of Pacific herring, Clupea harengus pallasi, larvae of Port Moller, Alaska. This contract had two phases. The first phase was to measure the densities of larvae. McGurk (1989c) reported that there was a major spawning of herring larvae in Port Moller on May 29, 1989, and recommended proceeding to the second phase.

Phase II consists of a review of the state of the art in computer modelling of the transport and population dynamics of pelagic fish eggs and larvae, recommendations on the most appropriate modelling technique, and a preliminary plan for sampling herring eggs and larvae in Port Moller and for collecting environmental data that would satisfy the data requirements of the models. This document is the final report of the second phase of the Port Moller reconnaissance and planning project. It consists of a report on hydrodynamical modelling that was prepared by J. E. Edinger Associates, Inc. for Triton Environmental Consultants Ltd. (section 2), and a preliminary sampling plan for Port Moller based on the recommendations of their report (section 3).

1.2 Background

The need for computer modelling of the population dynamics of Pacific herring larvae in Alaska was first identified by McGurk (1989b) in his report on the early life history of herring larvae in Auke Bay, Alaska. This recommendation was based on the finding that the growth and condition of herring larvae in Auke Bay were only weakly limited by food because food density was relatively high throughout the study period. Thus, non-trophic factors such as offshore dispersal and predation may have been as important to the survival of the fish as food densities. This finding was consistent with research that has indicated that the mortality of eggs and larvae of some species of fish is a multifactor process involving dispersal and predation, and that it was not solely determined by the density of food in the first-feeding stage as Hjort (1914) proposed (Stevenson 1962, Frank and Leggett 1982, Moller 1984, Iles and Sinclair 1982, Taggart and Leggett 1987, McGurk 1989a).

Even in species in which food density is a critical factor in the survival of larvae, as it is for northern anchovy, Engraulis mordax, in southern California (Lasker 1975, Peterman and Bradford 1987), the interaction between the fish and patches of their food of the critical density for successful feeding and growth is mediated by oceanographic and

meteorological processes, which may best be synthesized and studied using hydrodynamic modelling.

The role of dispersal has particular importance in the study of the population dynamics of Pacific herring larvae because several authors have proposed that it is the critical factor that determines survival of the larvae. Stevenson (1962) proposed that the success of a year class of Pacific herring from Barkley Sound, British Columbia, was determined by how many larvae avoided being swept offshore to unfavorable habitat. Two decades later Iles and Sinclair (1982) proposed a physical mechanism that may underly Stevenson's (1962) "transport" hypothesis. They suggested that Atlantic herring, Clupea harengus pallasi, only spawn in "retention zones", which are defined as relatively shallow regions of coastal water that are well mixed by tide-driven turbulence and which are surrounded by deeper stratified water. It is not clear from their work whether larvae are expected to be actively or passively retained in a zone, but the probability of survival of the larvae is supposed to be directly related to their probability of remaining within the zone.

A second reason for examining the dispersal of Pacific herring larvae is related to the underlying purpose of these researches: to assess the potential impact of oil and gas development on Alaska's continental shelf on herring resources. It is important to know where the herring larvae go once they hatch in order to guage the probable impact of an oil spill in coastal waters. Do larvae stay in coastal embayments throughout the larval and juvenile stages? or is a significant proportion of the population transported offshore or along shore?

A third reason for studying dispersal is that it is necessary in order to obtain accurate estimates of mortality rates of larvae. This topic is examined in detail in section 2.0.

In summary, any study of the early life history of Pacific herring in Alaska should include measurements of their growth, mortality and dispersal, and it should also include measurements of the interactions of the larvae and their biological and physical environments. Hydrodynamic modelling is an essential component of both activities.

Modelling of dispersal of fish eggs and larvae cannot be done without close cooperation between biologists and physical oceanographers. Therefore, Triton Environmental Consultants Ltd. decided to obtain expert advice from J. E. Edinger Associates, Inc. in order to plan a sampling regime for Port Moller herring larvae that would be compatible with hydrodynamic modelling.

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2.
Numerical Hydrodynamics, Transport and Fate of Fish Larvae: A Review of the Subject and a Plan for Modeling the Transport and Population Dynamics of Pacific Herring Larvae of Port Moller, Alaska

Prepared for:

Triton Environmental Consultants Ltd.
205-2250 Boundary Road
Burnaby, B.C., Canada V5M 3Z3

Prepared by:

John Eric Edinger
Edward M. Buchak
J. E. Edinger Associates, Inc.
37 West Avenue
Wayne, Pennsylvania 19087-3226

September 1989

JEEAI Document No. 89-96-R

2.1 Introduction

Norcross and Shaw (1984) recently reviewed the biological literature on the oceanic and estuarine transport of planktonic fish eggs and larvae and concluded that, in general, the production of fish eggs and larvae appears to be coupled with natural oceanographic transport systems such as gyres, coastal currents and other directional current systems. Under "normal" conditions eggs and larvae that are released into such systems are transported towards sources of food and away from predators, but under unusual conditions eggs and larvae may be transported to areas of low food production or high predator density, or not transported at all, and so the young fish may suffer catastrophic mortality. In this way oceanographic transport is believed to play an important role in determining the success or failure of year classes.

There are exceptions to this generalization, as Marliave (1986) has shown for the larvae of rocky intertidal fish. Dispersal in these species is quite limited and is determined by oceanographic features on the scale of meters rather than kilometers. There are also a variety of specialized hypotheses on the coupling of oceanographic features and egg and larval survival that have been developed from research on unique features of the early life histories of single species of fish. Some of the most well-known of these hypotheses are Stevenson's (1962) "transport" hypothesis for Pacific herring, Clupea harengus pallasi, larvae, Lasker's (1975) "stability" hypothesis for northern anchovy, Engraulis mordax, larvae (see also Peterman and Bradford 1987), Iles and Sinclair's (1982) "retention zone" hypothesis for Atlantic herring, Clupea harengus harengus, larvae, and Frank and Leggett's (1982) "safe-site" hypothesis for capelin, Mallotus villosus, larvae.

In most of the studies reviewed by Norcross and Shaw (1984), the coupling of the fate of fish eggs and larvae with their transport by advective and dispersive processes was done in a semi-quantitative manner. Water circulation patterns were identified from limited models or field measurements and egg and larval distributions were measured from plankton tows, and then the two sets of observations were linked by speculative hypotheses. An exception to this generalization is Talbot's (1977) study of the dispersal of plaice, Pleuronectes platessa, eggs and larvae in the Southern Bight of the North Sea.

In the past decade it has become clear that further progress in the field of fisheries oceanography requires, among other things, much more accurate information on the population dynamics of fish eggs and larvae and on the dynamics of their prey and predators than has so far been gathered because without accurate estimates of mortality and dispersal the hypotheses listed above cannot be tested and rejected. The problem is a technical one of reducing the error around the estimates of mortality and dispersal so that temporal and spatial variation in mortality and population density can be compared to temporal and spatial variation in the density of prey and predators. The solution to the problem is to measure all losses of eggs and larvae from the sampling

area that are due to advection and dispersion. Natural mortality is the loss rate remaining after these rates have been subtracted from the total loss rate. This kind of analysis is not possible with semi-quantitative methods.

Several recent papers have addressed this problem by developing simple mathematical models of losses due to advection and dispersal. Munk et al. (1986), Heath and MacLachlan (1987) and McGurk (1989b) used models of the dispersion of patches of herring larvae. Although the models were derived from equation (1) below, their use was restricted by several gross assumptions:

(1) only the distribution of larvae was modelled, there was no link between the physical and biological environments;

(2) larvae were assumed to exist as patches residing in an environment with no boundaries;

(3) the shape of the patches of larvae was assumed to be symmetrical, either a perfect circle or an ovoid;

(4) the vertical axis was ignored by depth-averaging the densities of herring larvae;

(5) rates of diffusion and advection along the two horizontal axes were assumed to be constant with time and distance from the origin; and

(6) mortality rates were assumed to be constant with time.

Taggart and Leggett (1987a, 1987b) used time-series models, regression models, and simple simulation models to calculate the movement of capelin larvae.

In this report, we intend to show that recent advances in time-varying hydrodynamic and transport modeling as well as advances in computer hardware have made feasible the direct integration of three dimensional, time-varying hydrodynamic and transport computations without resorting to the use of simpler semi-quantitative descriptions (Edinger and Buchak 1980, 1985). These computations produce input-output mass transport coefficients which can used by biologists to calculate time-varying coefficients of mortality and dispersal of fish larvae at any place or time that the biologists decide is important.

Spawning of Pacific herring takes place along sheltered coasts in semi-enclosed embayments. Numerous field studies reviewed by McGurk (1989a,b) (see also recent papers on Atlantic herring larvae by Townsend et al. 1986, Henderson 1987, Heath et al. 1988, Heath and Rankine 1987, Stephenson and Power 1988, and Chenoweth et al.

Dx, Dy, Dz = dispersion coefficients in each of the coordinate directions; and
Z = mortality rate.

The term on the left-hand side is the local change in storage per unit volume over time. The first three terms on the right-hand size represent the change in advection with currents in each of the coordinate directions. The second three terms represent the change in dispersion with mixing in each of the three coordinate directions. The last term is linear mortality over a time increment or a function of age-class.

Conceptually, the egg and larval transport problem is an initial value problem. Given the initial spatial distribution of the eggs or young larvae, the spatial distribution over time can be determined by currents, dispersion and mortality, subject to the boundary conditions of no transport through physical or shoreline boundaries and exchange at open boundaries.

Practically, as indicated by McGurk (1989b), the problem is to determine the instantaneous mortality, Z, as a function of age given the spatial distributions of the eggs and larvae at different ages and at different times. In many cases Z has been calculated by assuming that the egg and larval patches are observed over a very large volume with very low densities at their boundaries, e.g. Hewitt et al. (1985). Therefore, the advective and dispersive exchanges at the boundaries can be neglected and mortality can be evaluated by equating change in storage with mortality, i.e $\partial N/\partial t = -ZN$, and fitting some type of relationship to the balance. In other cases where boundaries could not be located because the sampling area was too small to overlap the margins of the patch of larvae, e.g. McGurk (1989b), advection and diffusion were assumed to be constant with space and time and each term in equation (1), including mortality, was evaluated with non-linear regression techniques.

Both the conceptual and practical problems involve knowing the velocity components U, V, W and the dispersion coefficients Dx, Dy, Dz as functions of space and time. These can be determined from the time-varying three dimensional hydrodynamic relationships. In these evaluations, the velocity components are known to the spatial detail of the waterbody computational grid and the temporal detail of the boundary data. Also, the more spatial and temporal detail with which the velocity components are known, the less important become the dispersion processes.

It should also be noted that the mortality function may be more complex than simple linear decay for some fish eggs and larvae. Hewitt et al. (1985) reported that jack mackerel, Trachurus symmetricus, larvae of the California Bight exhibit a mortality rate that declines exponentially with age, i.e $Z = t^{-b}$. This is known as Pareto-type mortality. Other mortality functions are possible. For example, mortality may be related to the carrying capacity of the environment by the Lotka-Volterra predator-prey relationship

1989), show that the spatial scales of herring larval distributions are of the order of 2 to 20 km horizontally and 10 to 60 m vertically with temporal scales of 10 to 40 d. For semi-enclosed waterbodies and coastal waters of this spatial scale, the computational aspects of determining currents and dispersion is essentially a boundary data problem. This means that computations depend on specifying the open boundary water surface elevations due to tides and winds, the open boundary temperature and salinity structure which determines density driven baroclinic circulation, the water surface meteorological conditions for wind shear, windwave radiation stresses and heat exchange, and freshwater inflows along with the waterbody hydrography. The three dimensional hydrodynamic and transport relationships then generate the circulation and transport to the detail with which the boundary data is specified.

Formulating transport as a boundary data problem also has some prognostic features including determining the changes in abundance of larvae with age that might take place due to different wind, tide, density forcing of circulation, and dispersion at waterbody boundaries.

Establishing the hydrodynamics and transport of fish eggs and larvae as a boundary value problem does not require much more hydrographic and meteorological data than has been used in empirical studies of the interaction of larval abundance and hydrodynamics, e.g. Taggart and Leggett (1987a). Also, the amount of computational effort is not much more extensive than the time-series analyses undertaken in the same study.

2.2 Egg and Larval Transport

As indicated by McGurk (1989b) a starting place for formulating the fish egg and larval transport problem is the basic time-varying three dimensional advective-dispersive conservation relationship with mortality. This can be written in three rectangular coordinate spatial dimensions and time as

$$\partial N/\partial t = -\partial UN/\partial x - \partial VN/\partial y - \partial WN/\partial z + \partial(Dx\partial N/\partial x)/\partial x$$

$$+\partial(Dy\partial N/\partial y)/\partial y + \partial(Dz\partial N/\partial z)/\partial z - ZN \qquad (1)$$

where

N = densities;
U = x-direction horizontal velocity component;
V = y-direction horizontal velocity component;
W = z-direction vertical velocity component;

Z = a(N-K)/K, where a is a constant and K is the carrying capacity of the environment. K may be defined by food density, temperature, salinity, and the spatial distribution of tidal and wind energy dissipation throughout the waterbody, which can be evaluated from the results of the hydrodynamic computations (Garrett et. al. 1978).

A real problem in evaluating the mass balance [equation (1)] is that fish larval sampling takes place over relatively large volumes, and is separated by relatively long time intervals compared to the spatial and temporal detail with which the hydrodynamics can be evaluated. Hence the mass transport due to the detailed currents must be integrated over time and space to coincide with the larval sampling. As shown in section 2.4 below, this problem can be solved efficiently by evaluating transfer coefficients for mass between the larger sampling volumes integrated over the sampling intervals (Edinger and Buchak 1988a, 1988b).

2.3 Hydrodynamics and transport

The hydrodynamic and transport relationships in three dimensions and time are well known from basic physical oceanography, e.g. Pond and Pickard (1978). Fairly recent is their formulation to practical numerical computations that can be efficiently applied over the time and space scales of the larval transport problem, e.g. Edinger and Buchak (1980, 1985), Edinger et al. (1989), Buchak and Edinger (1989a). For purposes of discussion and illustration of the processes included in their evaluation, they are examined below in the form in which they are integrated in the semi-implicit (over time) finite difference form of the GLLVHT (Generalized Longitudinal, Lateral and Vertical Hydrodynamic and Transport) model of Edinger and Buchak (1985).

The hydrodynamic and transport relationships used in GLLVHT are: the horizontal momentum balances for the horizontal velocity components, U and V in the x- and y-coordinate horizontal directions, with z taken positive downward

$$\partial U/\partial t = g\partial z'/\partial x - g/\rho \int_{z'}^{z} (\partial \rho/\partial x)\partial z + fV - \partial UU/\partial x - \partial VU/\partial y - \partial WU/\partial z$$

$$+ \partial Ax(\partial U/\partial x)/\partial x + \partial Ay(\partial U/\partial y)/\partial u + \partial Az(\partial U/\partial z)/\partial z + SMx \qquad (2)$$

$$\partial V/\partial t = g\partial z'/\partial y - g/\rho \int_{z'}^{z} (\partial \rho/\partial y)\partial z - fU - \partial UV/\partial x - \partial VV/\partial y - \partial WV/\partial z$$

$$+ \partial Ax(\partial V/\partial x)/\partial x + \partial Ay(\partial V/\partial y)/\partial y + \partial Az(\partial W/\partial z)/\partial z + SMy \qquad (3)$$

Local continuity for the vertical velocity component W of

$$\partial W/\partial z=-\partial U/\partial x-\partial V/\partial y \tag{4}$$

Vertically integrated continuity for the surface elevation, z', of

$$\partial z'/\partial t=-\int_z^h \partial U/\partial x-\int_z^h \partial V/\partial y \tag{5}$$

the constituent transport relationships for n number of constituents, e.g. salinity and heat, of

$$\partial Cn/\partial t=-\partial UCn/\partial x-\partial VCn/\partial y-\partial WCn/\partial z+\partial(Dx\partial Cn/\partial x)/\partial x$$

$$+\partial(Dy\partial Cn/\partial y)/\partial y+\partial(Dz\partial Cn/\partial z)/\partial z+Hn \tag{6}$$

and an equation of state relating density, ρ , to constituents as

$$\rho=g(C1,C2,...,Cn) \tag{7}$$

These relationships have six unknowns: U, V, W, z', ρ, and Cn, in six equations, assuming that the momentum and constituent dispersion coefficients: Ax, Ay, Az, Dx, Dy, and Dz, can be evaluated from velocities and the density structure.

In the x and y momentum balances, the right-hand terms are successively the baroclinic or water surface slope, the barotropic or density gravity slope, the Coriolis acceleration, the advection of momentum in each of the three coordinate directions, and the dispersion of momentum in each of the coordinate directions. The baroclinic and barotropic slopes are arrived at from the hydrostatic approximation to vertical momentum, and horizontal differentiation of the density-pressure integral by Leibnitz' rule. The baroclinic slope is the vertical integral of the horizontal density gradient and becomes the major driving force for density induced flows that vary with depth. Even a vertically mixed waterbody, as indicated by salinity and temperature, that has horizontal density gradients can have significant density induced flows.

The hydrodynamic relationships are integrated numerically, implicitly forward in time, by evaluating the horizontal momentum balances as:

$$\partial U/\partial t = g\partial z'/\partial x + Fx \tag{8}$$

$$\partial V/\partial t = g\partial z'/\partial y + Fy \tag{9}$$

where U, V and z' are taken simultaneously forward in time and all the other terms are incorporated in Fx and Fy are lagged in time. Equations (8) and (9) are substituted either by cross-differentiation or algebraically from the finite difference forms into vertically integrated continuity to give the surface wave equation of:

$$\partial^2 z'/\partial t^2 + g\partial\left(\int_{z'}^{h}(\partial z'/\partial x)\partial z\right)/\partial x + g\partial\left(\int_{z'}^{h}(\partial z'/\partial y)\partial z\right)/\partial y = \int_{z'}^{h} Fx\,\partial z + \int_{z'}^{h} Fy\,\partial z \tag{10}$$

The computational steps in GLLVHT on each time step of integration are;

(a) to evaluate Fx and Fy from U, V, W, ρ known from the previous time step;

(b) to solve the surface wave equation for new z' for the spatial grid using a modified form of Gaussian elimination by back substitution;

(c) to solve for new U and V using equations (8) and (9);

(d) to solve for W using equation (4);

(e) to re-evaluate z' from equation (5) for precision; and

(f) to solve the constituent relationships, equation (6).

The semi-implicit integration procedure has the advantage that computational stability is not limited by the Courant condition that $\partial x/\partial t$, $\partial y/\partial t < (ghm)^{1/2}$ where g is the gravitational constant and hm is the maximum water depth that can lead to inefficiently small time steps of integration. Since the solutions are semi-implicit, e.g. explicit in the constituent transport and the time lagged momentum terms, the stability is controlled by the Torrence condition $U\partial t/\partial x$, $V\partial t/\partial y < 1$. Hence, the integration time step can be chosen to realistically represent the details of the boundary data which is about 15 min for tides and up to 1 h for meteorological data.

There are a number of auxiliary relationships which enter the computations and bring the boundary data to bear on the evaluation. First, the vertical momentum dispersion coefficient and vertical shear is presently evaluated from (but not limited to) a Von Karman relationship modified by the local Richardson number, Ri, as

$$Az=kL^2/2[(\partial U/\partial z)^2+(\partial V/\partial z)^2]^{1/2}F(Ri) \tag{11}$$

where Ri is the ratio of vertical buoyant acceleration to vertical momentum transfer, k is the Von Karman constant, L is a mixing length that can be a function of depth and time, and F(Ri) is the Richardson number function.

Wind surface stress enters the relationships for each of the coordinate directions as

$$Az\partial U/\partial z|_{z'}=W(Wx) \tag{12}$$

and

$$Az\partial V/\partial z|_{z'}=W(Wy) \tag{13}$$

where W(Wx) and W(Wy) are surface shear functions of wind speed.

In addition to surface windshear, there are two further windwave effects that enter the momentum relationships through the specific momentum terms, SMx and SMy, due to the spatial change in windwave height (H) and period (T) as $g\partial(H^2/T)/\partial x$ and $g\partial(H^2/T)/\partial y$. These are the windwave gradients. One is for windwaves that propagate into the waterbody region from offshore and are not found in the z' boundary elevation record, and for which the spatial distribution of H and T can be found from a wave refraction computation for the waterbody region geometry, e.g. Koutitas (1988). The second is due to the change of H and T along the wind fetch and is a function of fetch length and duration of given windspeeds. These are known as Darbyshire-Draper relationships. The windwave gradients also decay with depth from known windwave properties, but fundamentally they augment the longwave barotropic slope by the difference in average wave heights along the coordinate direction and enter directly into the momentum balance.

Bottom friction enters the computations through a Chezy friction relationship as

$$Az\partial U/\partial z|_h=(g/Ch^2)U^2 \tag{14}$$

$$Az\partial V/\partial z|_h=(g/Ch^2)V^2 \tag{15}$$

where Ch is the local Chezy friction coefficient and h is the bottom elevation at which bottom friction is evaluated.

The horizontal momentum and constituent dispersion coefficients: Ax, Ay, Dx, and Dy, have not been adequately evaluated within three dimensional numerical models but are thought to be primarily a function of the scale of the computational grid. In GLLVHT they are presently evaluated from grid size using an Okubo (1971) length scaling. Experience has shown that the velocity computations, and hence advection and dispersion in the constituent relations, become less sensitive to the horizontal momentum and constituent dispersion coefficients the more detailed the integration time step and spatial detail.

The source and sink terms, Hn, in the constituent balances, equations (6), depend on the constituent being examined. For heat, the source and sink terms are mainly for surface heat exchange, radiation attenuation through the water column and advective sources such as river inflows. Surface heat exchange includes incoming shortwave solar radiation and longwave atmospheric radiation, their reflective loss components, and the water surface temperature dependent processes of back radiation, evaporation and conduction. These terms are evaluated to different degrees of detail ranging from the heuristic equilibrium temperature relationships of Edinger et al. (1974) to the complete term by term heat budget methods of Jirka et al. (1978) in subroutines to the hydrodynamic and transport models depending on the detail with which meteorological data is available.

For egg and larval transport, as expressed in equation (1) which is identical to equations (6), the major source and sink term is egg and larval mortality that can be expressed and evaluated in many different ways. In principle, the egg and larval transport problem could be evaluated directly from equations (6).

2.4 Mass transport relationships

Compared to the temporal and spatial detail with which the numerical hydrodynamics and transport can be resolved, egg and larval sampling takes place over finite volumes at finite times. For example, Fig. 2.1 shows the volumes used by McGurk (1989c) for reconnaissance surveys of Port Moller. Sampling of each of these volumes took at least 2 d because of the distances that the research vessel had to travel. For comparison, Fig. 2.4 shows the 1750 m x 1750 m grid being examined for hydrodynamic and transport computations in three dimensions at about 15 min intervals. This grid will be described in greater detail in section 2.6. It is expected that the egg and larval sampling volumes will be refined with more horizontal and vertical detail in later sampling, but that they will still be of relatively large size compared to the size of the grid shown in Fig. 2.4 due to net tow distances and spatial coverage. It is expected that future egg and larval sampling will be at time intervals of days with the added logistical complication that not every sampling volume will be sampled on each day.

The problem is to integrate the hydrodynamic and transport results over time and space from the detailed grid shown in Fig. 2.4 to the regional volumes and sampling intervals of the larval sampling typified by Fig. 2.1. One method described by Lawler et al. (1988) is to compute from the detailed model the horizontal and vertical fluxes over the interfaces of the larger scale regional volumes used for larval transport and then integrate these fluxes through time. This is the same as constructing a circulation box model for the larval regions. This method has the complication that integrating the detailed velocities over space and time introduces additional dispersive and transport terms, as shown by Hamrick (1987). These terms must be accounted for in the larger scale mass transport model. Also, when integrating over many tidal cycles there is the problem of accounting for Stokes transport due to surface layer variations.

A method that overcomes the above difficulties is to use the detailed hydrodynamic and transport model to compute mass transfers between the larger grid regions over the time period of integration in order to obtain time and space averaged mass transport coefficients for independent computations of transport for the larger regions at the larger time steps (Edinger and Buchak 1988a, 1988b). For these computations, the larger regional grid is superimposed on the detailed grid in any desired manner.

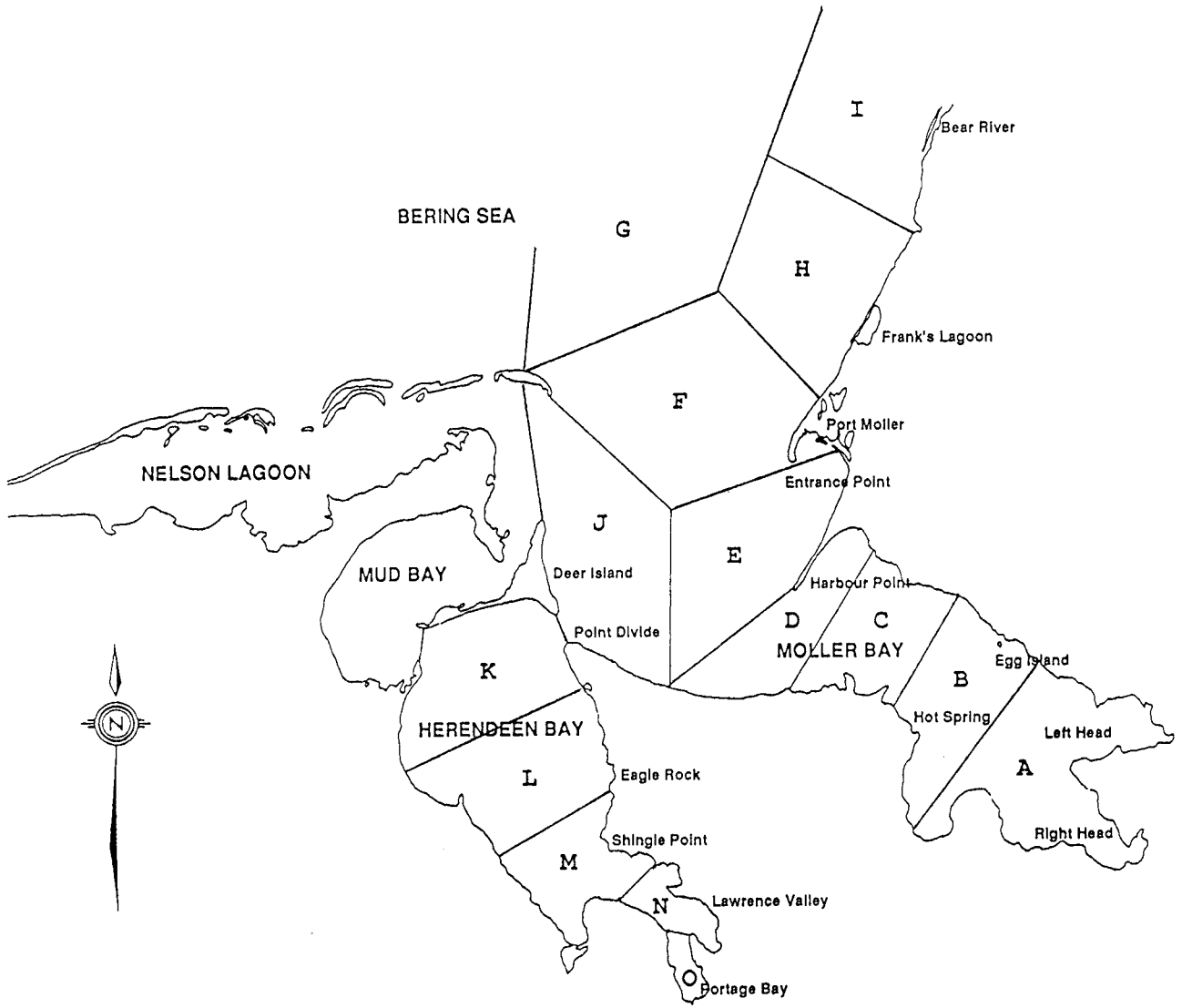


Fig. 2.1. Map of Port Moller.

The transport coefficients between the regional grid volumes, V_k, where k is the index of the regional grid volume, over the period of integration between sampling periods are determined by initializing the detailed grid cells within a region at a constant constituent concentration, CI. Each of the coarse regions is initialized with a different numbered constituent that can be transported throughout the detailed grid by equations (6) and located in any other coarser region at the end of the period of integration. The transport coefficient is determined from the initial mass MI_j in region j and the mass at the end of the period of integration $M_{i,j}$ in region i that originated in region j, or

$$A_{i,j}=M_{i,j}/MI_j \tag{16}$$

where $A_{i,j}$ is the mass transport coefficient from region j to region i and is the fraction of mass transported over the period of integration. For the waterbody, there is a matrix of mass transfer coefficients representing the transport between each pair of coarser regions.

Mass must be conserved over the whole waterbody, and this is maintained by balancing the internal mass transfers against exchange at the open boundaries by evaluating the boundary sinks and sources. At the boundary sink, the transfer from region j out at the boundary, $M_{b,j}$, is determined as

$$M_{b,j}= MI_j- \sum_{i=1}^{kt} M_{i,j} \tag{17}$$

where kt is the total number of coarser regions. The total mass lost at the boundary from all regions becomes

$$MB= \sum_{i=1}^{kt} M_{b,j} \tag{18}$$

and the transport coefficients from region j to the boundary sink become

$$A_{b,j}= M_{b,j}/MI_j \tag{19}$$

and the boundary "volume" of exchange becomes MB/CI.

At the boundary, the source mass into each region is

$$M_{i,b} = MI_i - \sum_{i=1}^{kt} M_{i,j} \tag{20}$$

for which the mass at the boundary is also

$$MB = \sum_{i=1}^{kt} M_{i,b} \tag{21}$$

which assures continuity of the system and can be determined as a check on the computations. The transport coefficients from the boundary to region i are thus

$$A_{i,b} = M_{i,b}/MB \tag{22}$$

and the mass transport relationship for the mass MS_k in each coarse region k then becomes

$$\partial MS_k/\partial t = \sum_{j=1}^{kt} A_{k,j}\, MS_j - \sum_{i=1}^{kt} A_{i,k}\, MS_k + BI_k - BO_k + SS_k \tag{23}$$

where the first term on the right hand side is the mass into region k from all other regions. The second term is the mass out of region k to all other regions. $BI_k = A_{k,b}$ VB CB is the mass in from the boundary where CB is the time varying boundary concentration or density, $BO_k = A_{b,k}\, MS_k$ is the mass out of the region to the boundary, and SS_k are the source and sink rate processes in each region for the particular constituent being examined. Essentially, equation (23) is a time and space integrated form of equation (1), where the transport terms have been replaced by transport coefficients.

The time varying egg and larval mortality rates are incorporated in the source and sink or SS_k term. This term can be evaluated over regions and times from the egg and larval data using equation (23) with the added complication that not all regions are sampled at all times. Different inverse and statistical fitting techniques for performing this evaluation are presently being examined.

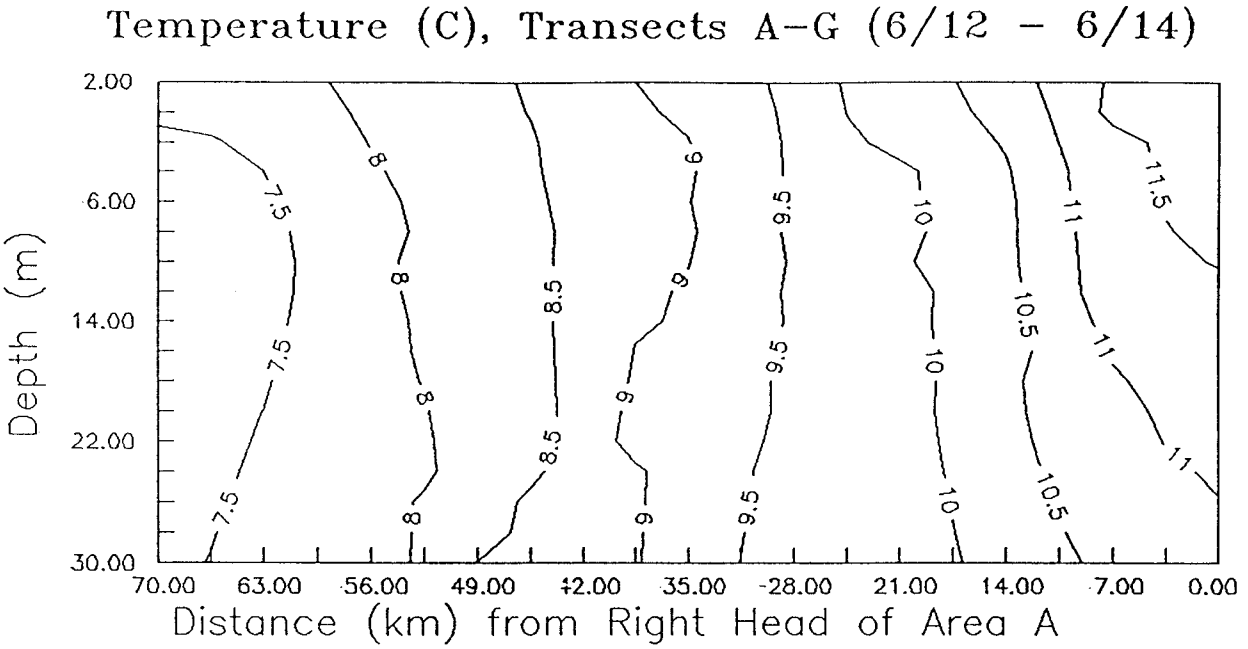
The procedure is thus to evaluate the $A_{i,j}$ between sampling times from a "long" run of the hydrodynamic and transport equations, and then use these transport coefficients as input to a simpler program or model to evaluate equation (23). Typically, the hydrodynamic and transport run is a matter of hours on a mini-computer or advanced PC and the separate mass transport equation evaluation from the generated transport coefficients is a matter of minutes. Thus, a mortality function such as the Pareto function could be evaluated from the data by using successive simulation techniques. Also, the simpler mass transport program or model is readily transportable to others for further evaluation.

2.5 Port Moller hydrography

This section reviews the existing hydrographic and oceanographic information from McGurk (1989c) and from the "Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska -- Volume II Bering Sea". The information is reviewed to determine the general hydrographic characteristics of Herendeen-Moller Bay from bathymetry and from a limited set of reconnaissance survey temperature and salinity stations, and the general hydrodynamic and meteorological boundary conditions to which these bays are responding. One purpose of this review is to determine the required characteristics of the model configuration.

If Port Moller is defined by a boundary extending across from Point Edward on the west to Entrance Point on the east, then it has a surface area of 5.93×10^8 m^2, a volume of 4.57×10^9 m^3, and a mean depth of 7.7 m (Fig. 2.1). About 27% of the surface area of the bays is intertidal and both Moller and Herendeen Bays are incised by channels of 20 to 30 m deep with depths up to 86 m in Portage Bay of Herendeen Bay. The distance across the boundary between Point Edward and Entrance Point is about 10.1 nm or 18.7 km. Herendeen Bay and Moller Bay are each about 58 km long.

Salinity and temperature profiles are given in McGurk (1989c) for the center of the reconnaissance survey volumes for the period of June 12 to June 14, 1989 (Fig. 2.1). These profiles are shown as composite longitudinal vertical plots through Moller Bay in Fig. 2.2 (transects A-G) and through Herendeen Bay in Fig. 2.3 (transects O-G). It should be noted that the salinity in the head of both bays dropped substantially between June 12 and June 14 due to freshwater inflow.



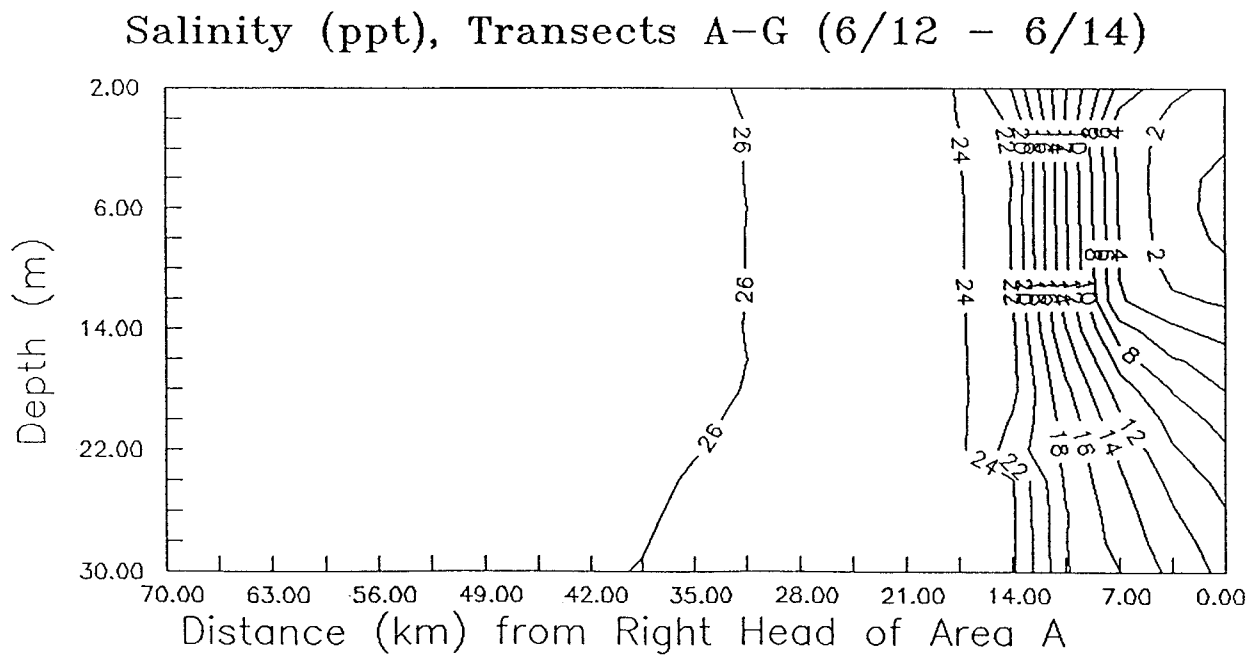
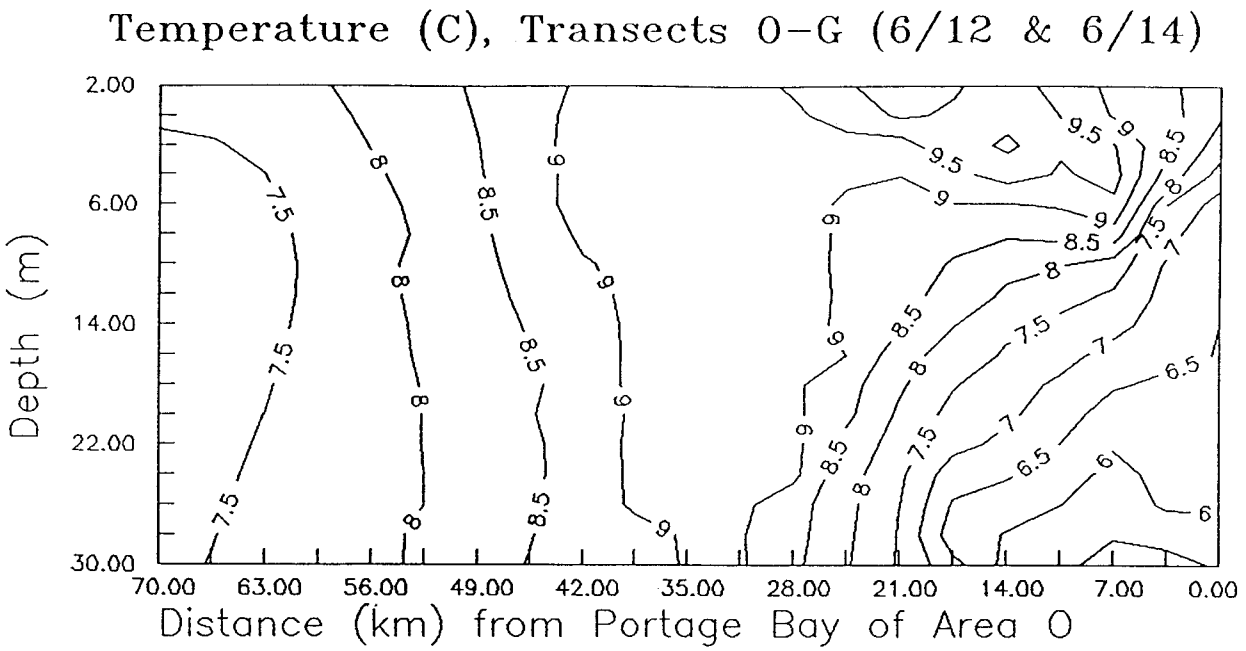


Fig. 2.2. Temperature and salinity isopleths of Moller Bay.



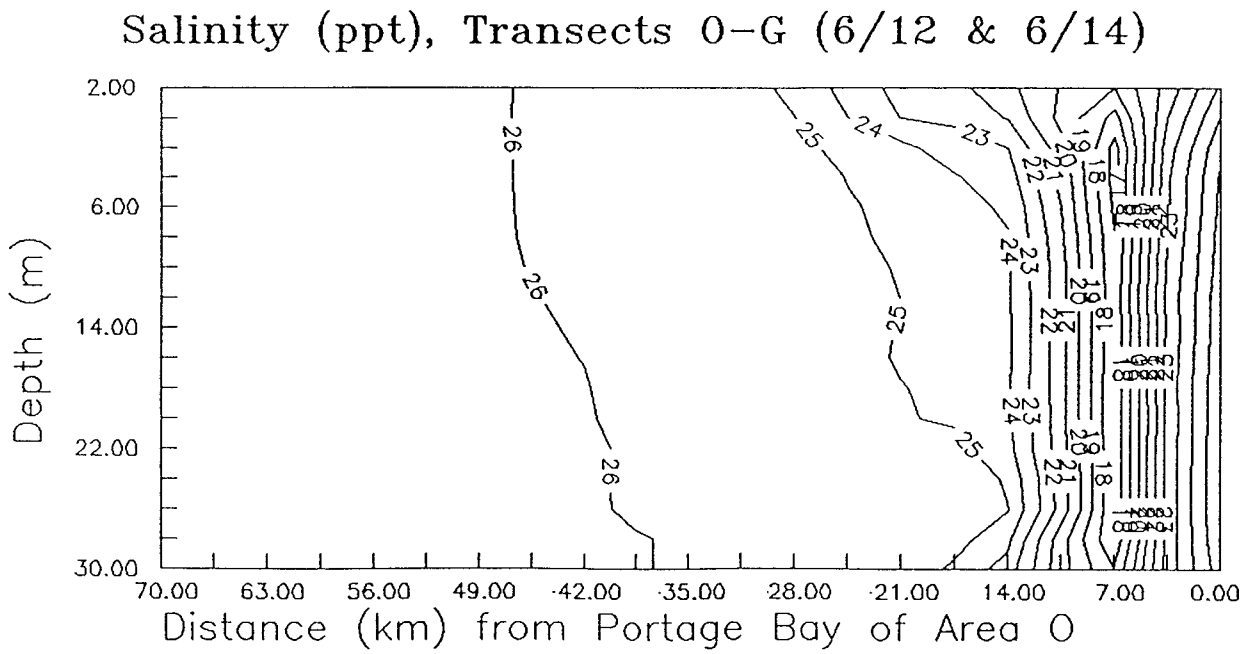


Fig. 2.3. Temperature and salinity isopleths of Herendeen Bay.

Salinities in both bays increase from the headwaters out to the boundary with a sharp transient longitudinal gradient in the headwaters. The baroclinic gradients are such that this lighter water would rise to the surface layer and spread toward the boundary of the system over the next few weeks. It would create more stratified conditions further down the bays, which would, in turn, create lower layer baroclinic inflows. These inferences on the longitudinal and vertical baroclinic circulation illustrate the short term transient flows and transport that can exist during larval transport periods.

The temperatures in Moller Bay over the reconnaissance surveys decrease longitudinally from about 11.5^{o}C in the headwaters to 7.5^{o}C out near the boundary while the temperatures in Herendeen Bay increase longitudinally from about 7^{o}C in the headwaters to a maximum of 9^{o}C near Mud Bay and then decrease to 7.5^{o}C near the boundary. The lower Herendeen Bay headwater temperatures may be due to a combination of freshwater inflows and the deeper water in Portage Bay. The higher temperatures at the head of Moller Bay and near Mud Bay may be due to circulation and mixing of heat off the surrounding flats.

There is no information on freshwater inflow rates during the reconnaissance surveys. The Atlas indicates a mean annual precipitation for the Port Moller region of 115 cm and, assuming a drainage area of 1 x 10^{9} m^{2} and a runoff coefficient of 0.5 to account for evapotranspiration, the mean annual runoff is estimated to be about 18 m^{3} s^{-1}. It is expected that most of the runoff occurrs during snowpack melt and would be at a substantially higher rate than the mean rate calculated above.

The Atlas provides some information on tidal and coastal current conditions along the open boundary. It shows tidal ranges increasing northeastward along the coast from 2.4 m near Cold Bay to 4.5 m near Port Heiden. The tides are mixed semi-diurnal and diurnal in period and progressive from west to east. This indicates that there would be a dynamically significant increase in amplitude in tide across the 10.1 nm boundary from Point Edward to Entrance Point. No co-tidal lines are given, but based on the tide being a progressive wave, it is estimated that there is about an 0.8 h phase shift between the two Points.

A mean slope across the boundary could be significant. The Atlas indicates a coastal drift of 1 to 5 cm s^{-1} from west to east parallel to the boundary for which a friction slope could be estimated. The report of Cline et. al (1982) indicates that the coastal drift region extends out from the shoreline to about the 50 m contour. The Atlas indicates that maximum tidal currents along the coast increase from about 30 to 40 cm s^{-1} near Cold Bay and reach a maximum as high as 100 cm s^{-1} near Port Moller.

There is little seasonal salinity and temperature data available off the mouth of Moller Bay. However, Cline et. al (1982) indicates that salinity and temperature are fairly well mixed in the offshore coastal region and influenced by freshwater runoff.

There is sufficient information available above, and from other reports, to construct "typical" tidal, salinity and temperature boundary conditions and to construct mean monthly meteorological conditions to compute "stationary state" circulations within Moller Bay and Herendeen Bay for further description of its circulation. However, as indicated above, conditions during actual sampling periods are likely to be quite transient and should be instrumented for direct measurements during these periods.

2.6 Model configuration

The reconnaissance sampling regions examined by McGurk (1989c) and shown in Fig. 2.1 are essentially laterally averaged segments. Thus, if this were the scale to be examined, then modelling could be performed using the laterally averaged, longitudinal and vertical model presented in Buchak and Edinger (1984). However, it is expected that the egg and larval sampling regions will be refined to incorporate lateral as well as vertical and longitudinal detail, particularly to include the shoreline spawning regions shown in McGurk (1989c). Also, the scales of the initial spawning patches are such that lateral as well as longitudinal and vertical transport are important in describing them.

As indicated previously in section 2.1, the time and space scales of the herring egg and larval distributions are such that the time varying three dimensional GLLVHT hydrodynamic and transport model can be efficiently utilized.

The first step in its setup is to determine an appropriate size of the computational grid. The grid should be sufficiently detailed to incorporate the major features of the shoreline configuration and the bathymetry. It should also allow for computational efficiency, here determined for use on a mini-computer or advanced PC. However, larger computers could be utilized.

Efficient computations can be achieved for configurations with 200 to 300 cells. For a surface area of 5.93×10^8 m^2, this gives a surface area per cell of 2.9×10^6 m^2. From the map there appears to be no gain in taking advantage of the model capability to have different ∂x and ∂y. Thus, a square cell configuration of 1750 m appears reasonable for computational efficiency.

Fig. 2.4 shows the Moller Bay-Herendeen Bay map scaled to a 1750 m grid. It shows that the major shoreline configuration is preserved and that the major bathymetric features can be accommodated. For vertical resolution, the GLLVHT model has the capability of layer thicknesses varying with depth so that thinner layers can be used between below the surface and the shallower topography and thicker layers used for the deeper channel regions. This grid can be modified as more information becomes available.

2.7 Boundary data requirements

The boundary condition data required by the GLLVHT model are:

(1) water surface elevations at the open boundary;

(2) salinity and temperature profiles at the open boundary;

(3) windspeed and direction for wind surface shear and windwave setup;

(4) for surface heat exchange, shortwave solar radiation or an appropriate surrogate such as cloud cover or percent clear sky, air temperature, dewpoint temperature or relative humidity, and windspeed; and

(5) freshwater inflow rates and temperatures.

Practically, these data are available at different levels of sophistication ranging from:

(1) direct observations of all of the input variables preceding and during the study period of interest; to

(2) reconstructing some of the variables missing from a complete set by various techniques; to

(3) using general information available from the Atlas to construct analytic boundary conditions.

The level of boundary data available in turn dictates the kinds of simulations that can be made ranging from "realtime" data based simulations with a complete set of observed data to "stationary-state" types of solutions for constructed analytic boundary conditions.

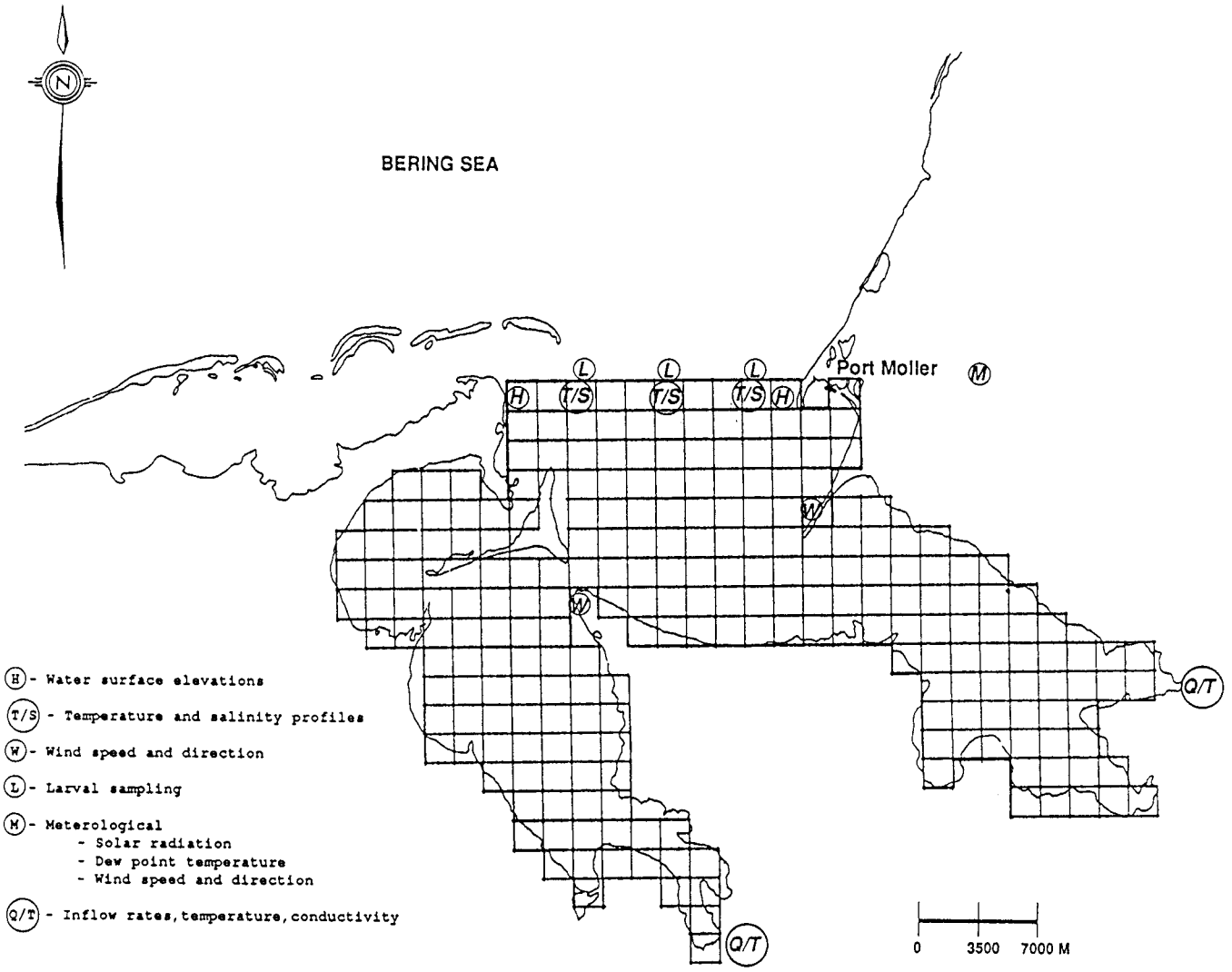


Fig. 2.4. Grid for hydrodynamic model of Port Moller.

Except for a period from May to September 1989, spanning the McGurk (1989c) larval reconnaissance surveys, during which wind speed and direction, and air temperature stations were established at Point Divide and Harbor Point, there does not appear to be extensive realtime data available (Jarvela 1989). Apparently there was no water surface elevation or pressure measurements taken during this period, particularly near the Point Edward to Point Entrance boundary. During this period, extensive current meter data were collected that would serve the purposes of model verification to be discussed later.

The choice of the level of time series boundary data is partially dependent on its availability. Hence, the levels desired are outlined here for each category of data from the most desirable (level 1) to the least available from the literature (the lowest level in each category). They are as follows:

2.7.1 Water surface elevations

Water surface elevations are required at the open boundary to the model, which for this discussion only is assumed to extend from Entrance Point to Point Edward. The following are the choices for water surface elevation data:

(1) either water surface elevation or pressure recorders. One near each point. Hourly data acceptable, as is 15 min data, if available; or

(2) one surface elevation or pressure recorder only at Entrance Point. Hourly or more frequent record; or

(3) water surface elevation record from somewhere along the coast within 10 to 20 mi that may already be available; or

(4) calculated amplitudes and phases of tidal constituents: K1, O1, S1, etc. available for this region from analytic description of tides. The ones given in the NOAA atlas for Bristol Bay are a little too gross, but usable.

2.7.2 Temperature and salinity

The instruments must be placed across the boundary (Entrance Point to Point Edward). The heirarchy of preference is:

(1) three moored T/S chains reading out hourly at 2 to 5 m depth intervals; or

(2) three T/S stations occupied daily from synoptic boat surveys; or

(3) reconstructed boundary T/S for period of interest from historical Bristol Bay data.

2.7.3 Meteorological data

Meteorological data are required for calculations of windshear, windwave radiation stress, and surface heat exchange. There are two meteorological stations: one at Point Divide and the other at Harbour Point. For windshear and windwave calculations only windspeed and directions are required hourly, but for surface heat exchange the required variables are:

(1) short wave solar radiation. Direct measurements or either cloud cover or percent possible sunshine;

(2) air temperature;

(3) dew point or relative humidity; and

(4) windspeed.

The hierarchy is:

(1) direct measurements at the two meteorological stations already in place;

(2) measurements at a nearby weather station or airport within 20 to 30 mi; or

(3) smoothed heating and cooling curves from geographical data. For example, extrapolate compiled coefficients of surface heat exchange and equilibrium temperature curves to the region using historical climatic data for Bristol Bay.

2.7.4 Freshwater inflows and temperatures

The hierarchy of preference is:

(1) direct daily measurements for one or two of the major tributary drainage areas into Moller Bay and Herendeen Bay; or

(2) daily measurements at a coastal river somewhere along the coast that can be extrapolated to the tributaries of either Bay on the basis of drainage areas; or

(3) calculations on a weekly scale from precipitation and snow pack computations. In this case, precipitation data and air temperature data are also required; or

(4) estimates based on mean runoff for the region from geographical data.

2.8 Initialization data

The model needs to initialized to temperature and salinity distributions throughout the Bays about a week before the egg and larval studies begin. Thus, the collection of the boundary data must begin at least one week before egg and larval sampling begins.

The model is initialized and started from rest. The semi-implicit solution of the hydrodynamics and transport is such that the tidal velocities develop within a few tidal cycles, the wind responses develop over the next few days and the slower baroclinic circulation develops over about 1 wk.

The temperature and salinity data for the starting period should be collected to as much horizontal and vertical spatial detail as possible, and in as short a time as possible, within the logistical limits of synoptic surveys. The vertical measurements can usually be collected to the detail of the vertical resolution of the model. Logistically, it may be possible only to occupy centerline temperature and salinity stations to about the detail given in Figs. 2.3 and 2.4, then interpolate to the rest of grid. In that case, it will take the model the equivalent of 1 wk or more to develop the shoreline and shallow area salinity and temperature details in response to freshwater runoff and surface heat exchange.

2.9 Verification data

Validation and verification are two distinct processes in modeling. Validation includes all of the procedures for checking the arithmetic logic of the computations, including the steps leading from the differential forms of the model given in equations (2) through (7), the setups and conversions necessary for entering the time varying boundary data as performed in the TVDS (time varying data selector) routine, and the mass balance inventories required for equations (16) through (23). The GLLVHT model has been validated on numerous occasions and validation is an ongoing process from case study to case study. This process is often called re-validation.

Verification is the step of comparing the model results to some kind of standard. There are different types of verification procedures, but the one of interest for Port Moller is a comparison to observed field data. The degree of verification that can be achieved depends on the amount and kind of field data that can be made available during the period of analysis. However, verification is limited by the level of boundary data available as outlined above and it would not be expected that a model run for constructed "stationary-state" boundary conditions would verify well against data

collected for a specific short term study period although the main features might be reproduced.

For salinity and temperature verification, it is expected that T/S profiles will be taken with each egg and larval tow and these are usually adequate data for verification purposes particularly if there are large salinity and temperature gradients and changes over time between egg and larval sampling. Also, time series records of temperature and salinity at specific points provide additional and detailed verification. Temperature and salinity (conductivity) sensors are often attached to current meters as discussed below. The degree of verification that can be expected with the above types of T/S data has been summarized by Edinger and Buchak (1987).

For the purpose of verification, it would be useful to have water surface elevation recorders in the bays independent of the boundary data elevation recorders. These should be deployed as far from the boundary as possible, preferably one in Portage Bay of Herendeen Bay and another in the Right Head of Moller Bay.

Another level of verification uses continuously recording current meters, as shown for a number of cases in Buchak and Edinger (1989b). As discussed above, the use of this level of verification depends on logistics and economics to determine the number of current meters to deploy. However, the deployments given in the attachments to Jarvela (1989) used in the May to September 1989 studies appear to be adequate.

The ultimate verification of the model would be against observed larval distributions initialized from spawning distributions and fecundity. However, since a major purpose of the study is to evaluate mortality rates from the mass balance relationships given in equation (23), the egg and larval distributions will not provide independent data for verification.

2.10 Open coastal boundaries

In this report we have examined the feasibility of combined hydrodynamic, transport and fate modeling for Moller and Herendeen Bays using the well-defined open boundary extending from Point Edward to Entrance Point. However, McGurk (1989c) reports that herring spawning may extend along the coast from Port Moller to Bear River. Also, one of the primary objectives of this research is to assess the direction and magnitude of offshore transport of herring larvae (section 1.0). Neither of these objectives is well served by a model that stops at the entrance to Port Moller. However, to model the open coastal region northeast of the entrance requires a separate analysis.

Fig. 2.5 shows the hydrodynamic and transport modeling with an open coastal boundary and boundary data requirements. The southwest terminus of the boundary is presently established at Point Edward but can be extended to include Nelson Lagoon.

In order to extend to an open boundary, additional time series boundary data is required. This includes water surface elevation or pressure recorders near Bear River and a current meter recorder near Frank's Lagoon.

A current meter record for the open coastal boundary is crucial for model calibration because it is used to determine mean slopes and open boundary tidal conditions near the southwest edge of the grid. This is necessary to allow for the passage of the net northerly drift current that was identified in the hydrography section, and to determine the proper intertidal transport. Calibration of the open boundary tidal conditions from the current meter record will need to be performed by successive simulations.

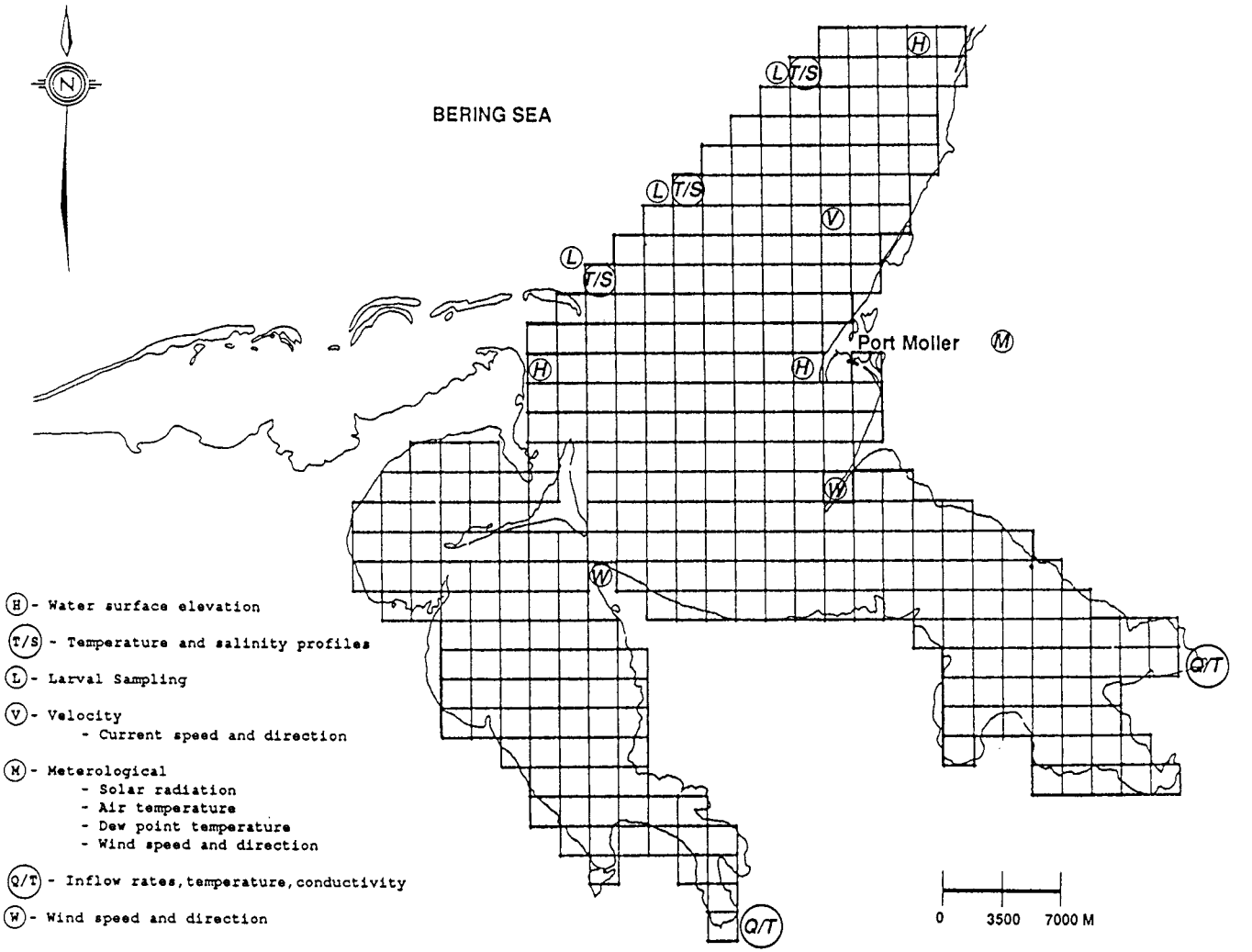


Fig. 2.5. Grid for hydrodynamic model with an open coastal boundary.

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3. Preliminary Sampling Plan

3.1 Schedule

The field program is expected to last at least 3.5 mo based on an expected mobilization date of April 15 to 17 and an expected end date of July 31.

The earliest date of field activities is determined by the requirements of the hydrodynamic model. As discussed in section 2.8 of this report, the collection of all oceanographic and meteorological data must begin at least 1 wk before the earliest date of sampling of herring eggs and larvae. This is necessary because starting at rest the hydrodynamic model requires a week's worth of data to simulate the complete baroclinic circulation of Port Moller. Thus, in order to have a functioning hydrodynamic model for the earliest dates of egg and larval sampling requires at least 1 wk of previous data collection.

The survey of herring larvae in Port Moller in June 1989 showed that the earliest herring spawning in the Moller Bay had occurred on or about May 15, 1989 (McGurk 1989b). The date of earliest spawn is expected to vary between years, so a conservative estimate of the date on which the search for herring eggs and larvae should begin is May 1. Therefore, oceanographic and meteorological data collection should begin on April 21. This means that the field party should plan to arrive in Port Moller on at least April 17 in order to put the boat into the water, fix any mechanical problems with the engines or the scientific equipment, and position the recording instruments in Port Moller. Problems with malfunctioning equipment are guaranteed to happen, as the 1989 reconnaissance survey showed, and the field schedule should be extended backwards in time in order to account for these difficulties.

The field program should continue until the larvae of the last cohort to hatch into Port Moller has reached an age at which they can no longer be captured with plankton nets. A third cohort probably spawned in Port Moller in mid-June of 1989 (McGurk 1989b), which means that larvae entered the water column by June 30. If larvae can be tracked for 30 d after hatch, as were the larvae of Auke Bay, Alaska (McGurk 1989a), then field activities should continue to at least the end of July. Demobilization is not expected to take more than several days.

3.2 Tasks

3.2.1 Mobilization and instrumentation

The first task after arriving in Port Moller is to launch the research vessel and test its engines. Once the boat is functioning properly, the next task is to instrument Port

Moller. As stated in section 2.5 of this report, the oceanographic conditions during the actual sampling period are expected to be quite transient, so data on temperature, salinity, water elevations, freshwater flow rates, and meteorological events must be collected by instruments operating before and during the sampling period.

The number of instruments to be placed in and near Port Moller, and their locations, depends on the objectives of the study and on the resources available to NOAA. One of the objectives of the study is to determine what proportion of the larvae are transported out of or into the Port Moller estuarine complex and what proportion is retained in the complex. This requires using an open coastal boundary (Fig. 2.5) rather than establishing a boundary at the entrance to Port Moller (Fig. 2.4). This is particularly important if spawning happens to occur along the coast between Entrance Point and Bear River as has happened in previous years (McGurk 1989b). However, such a decision would also require placing a current meter near Frank's Lagoon in order to establish tidal conditions at the open boundary. The experience of the 1989 field season in Port Moller suggests that this may be an expensive and time-consuming operation (personal communication, L. Jarvela, NOAA, Ocean Assessments Division, Anchorage, Alaska). In the following discussion, I assume that the open coastal boundary will be monitored.

At least one and preferably two water surface elevation or water pressure recorders must be placed at the ends of the boundary stretching from Point Edward to Bear River. A current meter must be placed near Frank's Lagoon. Three temperature/salinity chains must be moored on the open coastal boundary between Point Edward and Bear River. In the absence of T/S chains, the field crew must begin a program of taking T/S profiles at three stations on the boundary at least once a day for the remainder of the field season. At least one meteorological station must be placed near the Port Moller boundary. Finally, a program of monitoring the flow rates of at least two major tributaries that drain into Port Moller, one in Moller Bay and one in Herendeen Bay, must be started and maintained for the remainder of the field season.

3.2.2 Egg stage

The only interaction between research on the egg stage and hydrodynamic modeling concerns the need to obtain daily temperatures and salinities on the spawning beds in order to calculate hatching dates.

3.2.3 Larval sampling

Locations

As discussed in section 2.0, hydrodynamic modelling imposes two limitations on the locations of plankton sampling stations: at least three stations must be placed on the boundary to the system, and samples must be taken along lateral transects as well as longitudinal transects within Moller and Herendeen Bays. Apart from these requirements, the location of other stations should be based on biological and/or logistical criteria.

Fig. 3.1 shows the proposed locations of the plankton stations. Three stations are placed along the open coastal boundary and 3 stations are placed along a transect running between Entrance Point and Point Edward. Inside these two transects is one station at Bear River and a second just off Frank's Lagoon. Inside the Port Moller complex are: four stations along a transect running from Entrance Point to the northwestern end of Herendeen Bay; seven other stations in southern Herendeen Bay; and seven other stations in Moller Bay, for a total of 26 stations. This is not a large number; 15 stations were occupied during the 1989 reconnaissance survey (McGurk 1989b).

Wherever possible stations within Moller or Herendeen Bays have been placed on lateral as well as longitudinal transects. However, this means that some of the stations close to the shores will only be accessible during high tides and great care will have to be taken to avoid snagging the gear on the bottom.

Schedule

The hydrodynamic model does not place any restrictions on the intervals of time between visits to each sampling station. Instead, this will depend on such factors as the state of the weather, the number of available personnel, the schedule of visits to the T/S stations and the flow monitoring stations at the head of Port Moller, and other tasks, e.g. surveys of spawn location and intensity, as well as the requirement to obtain samples of larvae at different ages and stages of development for each cohort.

The Port Moller complex is too large to sample each station every day, but the entire set of stations should be visited at least once every 7 d. Therefore, the expected time interval between samples at each station is about 2 to 4 d.

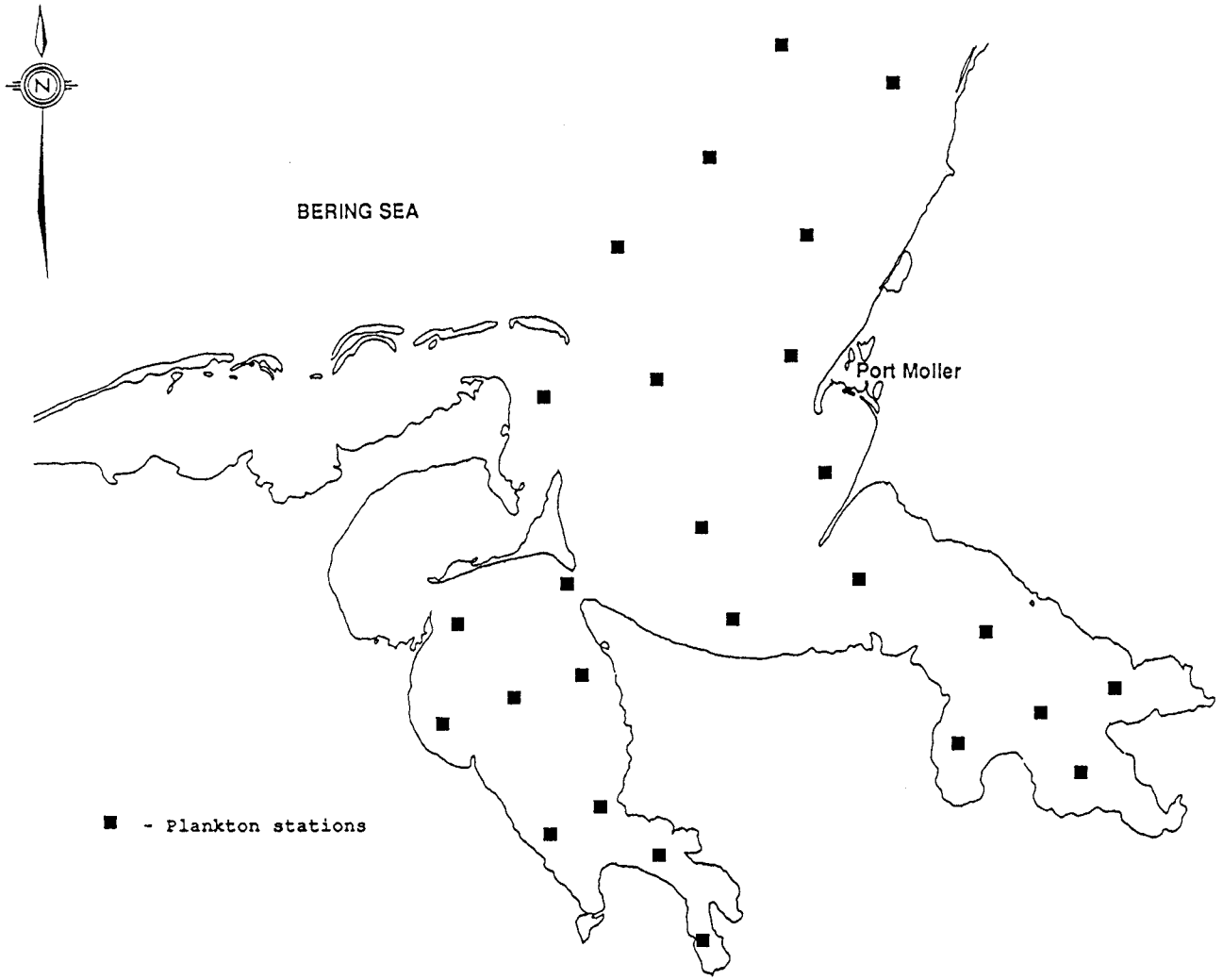

Fig. 3.1. Map of proposed plankton stations.

Depth

Most plankton stations in Moller Bay are too shallow for anything other than oblique tows through the entire water column, but stacks of horizontal plankton tows at two or three different depths may be possible at deeper stations in the Bering Sea and in southern Herendeen Bay. It would be preferable to conduct some series of stacked tows in order to take advantage of the hydrodynamic model's ability to predict transport at depth, and also to investigate the possibility that herring larvae may use vertical movements between counter-flowing currents to retain themselves in coastal embayments (Stephenson and Power 1988). Stacked tows cannot be performed at every station that is sufficiently deep because they are time-consuming.

3.3 References

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EARLY LIFE HISTORY OF PACIFIC HERRING: RELATIONSHIPS OF LARVAL DISPERSAL AND MORTALITY TO ENVIRONMENTAL CONDITIONS

FINAL REPORT OF 1989 PORT MOLLER RECONNAISSANCE SURVEY

by

Michael McGurk
Triton Environmental Consultants Ltd.
205–2250 Boundary Road
Burnaby, B.C., Canada V5M 3Z3

Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 711

October 1989

Acknowledgments

This study was wholly funded by the Minerals Management Service of the Department of the Interior, through an interagency agreement with the National Oceanic and Atmospheric Administration, Department of Commerce, as part of the Alaska Outer Continental Shelf Environmental Assessment Program (OCSEAP).

I thank the Contracting Officer's Technical Representative, Laurie Jarvela (NOAA, National Ocean Service, Anchorage, Alaska) for his advice and support. John Dermody (Raven, Inc.) and Rae Baxter provided essential boat-handling skills and biological experience. Most of the samples were sorted and enumerated by David Warburton and Violet Komori. Len Schwarz of the Kodiak office of the Alaska Department of Fish and Game (ADFG) provided data on the 1989 herring fishery in Port Moller and reviewed a draft of this report. Kathy Rowell of the ADFG Division of Commercial Fisheries (Anchorage, Alaska) provided unpublished data on fecundity of herring from the Togiak district of the eastern Bering Sea. Figures were produced by David Warburton, Ken Stubbs, and John Edinger; the manuscript was printed by Gail Ricard.

Abstract

A reconnaissance of the plankton community of Port Moller, Alaska, in June, 1989, found that it contained enough Pacific herring, Clupea harengus pallasi, larvae to justify a large-scale study of their population dynamics.

At least 3 cohorts of herring larvae hatched into Port Moller between May 1 and June 30, 1989. Cohort 1 hatched on May 29, 1989, from eggs spawned on May 15 and cohort 2 hatched on June 10-11 from eggs spawned on May 27-29. A third cohort was expected to hatch into the water column in late June because a third group of adult herring was the target of a mid-June commercial sac-roe fishery in Port Moller.

Cohort 2 was composed of 2 groups of larvae separated by about 0.8 mm in average length. The group of larger fish was most abundant and it was concentrated at the head of Moller Bay. The group of smaller fish was less abundant and it was concentrated at the head of Herendeen Bay. The difference in size and age between the 2 groups may have been caused by lower water temperatures in Herendeen Bay than in Moller Bay. Growth of larvae was significantly higher in Moller Bay, 0.25 mm d^{-1}, than in Herendeen Bay, 0.12 mm d^{-1}.

Cohort 1 consisted of 3.1143×10^8 larvae with a mean age of 14 d, and cohort 2 consisted of 7.0641×10^9 larvae with a mean age of 5 d. The biomass of the spawners that produced cohort 2 was estimated by back-calculation from the number of 5 d old larvae to have been 1,788 to 2,241 MT. This was 1 to 27% higher than the spawning biomass estimated from aerial surveys, 1,764 MT.

The mean density of herring larvae in Port Moller was 15 times greater than the mean density of herring larvae measured in Auke Bay, Alaska, in 1988. The biomass of spawners that produced cohort 2 was at least 130 times larger than the largest spawning biomass estimated for Auke Bay in 1988. These numbers show that the abundance of herring in Port Moller is at least one order of magnitude greater than that measured in Auke Bay. Therefore, phase II of this contract, development of a quantitative model of herring transport, is recommended to proceed.

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1. Introduction

This is the final report of the 1989 reconnaissance survey of Port Moller, Alaska. The objectives of the survey were to measure the densities of Pacific herring, Clupea harengus pallasi, larvae and map herring spawning habitat in order to determine whether Port Moller would support a large-scale study of the population dynamics of herring larvae. This survey reports that sufficiently high concentrations of herring larvae were found to justify such a study.

McGurk (1989b) recommended that studies of herring larvae in the Bering Sea be based in an area that has consistently received large amounts of spawn, arbitrarily defined as greater than 2.5 linear km of spawn. However, it is difficult to measure the magnitude of herring spawn in the Port Moller estuarine complex because of the poor 'seeing' conditions. In the 8 yr that the Alaska Department of Fish and Game (ADFG) has been conducting aerial surveys in Port Moller only the surveys flown in 1989 are thought to have provided accurate assessments of spawning biomass (personal communication, L. Schwarz, ADFG, Division of Commercial Fisheries, 211 Mission Road, Kodiak, Alaska 99615). This is because frequent rain, fog and high winds often prevents aerial surveys. Even in good flying conditions schools of adult herring and clouds of milt are difficult to see because strong tidal currents in the shallow water create a coffee-colored mixture of water and silt that obscures vision. The presence of flocks of shore birds is not a good indicator of the presence of herring spawn in Port Moller because, unlike southeast or southcentral Alaska, the spawn in Port Moller is laid on sub-tidal vegetation because winter ice scours intertidal vegetation.

This situation is encountered in other fisheries in which eggs are inaccessible because they are either deposited on the seafloor at depths of 10 m and greater or because the adults retain the eggs until they hatch. In these cases stock size may be estimated by back-calculation from the densities of newly-hatched larvae. Stock size of Atlantic herring, Clupea harengus pallasi, in the North Sea has been calculated from the number of larvae (estimated from plankton surveys) using a linear regression of stock size [estimated from virtual population analysis (VPA)] on larval abundance (Postuma and Zijlstra 1974, Saville 1981, Burd 1985), but this method can only be applied to those stocks for which sufficient information is available on commercial catches and age structure to perform a VPA, and for which at least 3 yr of plankton surveys are available. Neither of these requirements are met for the Port Moller stock of Pacific herring.

A second method of estimating stock size is to back-calculate it from larval abundance using a model of the population dynamics of the egg and larval stages. This method only requires a single survey of larval abundance, but the survey must cover the entire area

occupied by the larvae. The method also requires accurate estimates of mortality during the egg and larval stages. The difficulties involved in ensuring complete spatial coverage of the larvae, and of measuring the mortality rates of the eggs and larvae has restricted the utility of this method. Sinclair et al. (1979; cited in Auger and Powles 1980) first attempted to use it to estimate the size of the Atlantic herring stock of the Bay of Fundy, and Auger and Powles (1980) used it to estimate the size of the stock of Atlantic herring near Isle Verte in the St. Lawrence estuary. Both attempts were inconclusive because of uncertainty about the egg and larval mortality rates.

However, recently Nichols et al. (1987) was successful in using this method to estimate the stock size of Norway lobster, Nephrops norvegicus, in the western Irish Sea. A key factor in their success was the accurate measurement of larval mortality rate. In the last decade much information has become available on the probable ranges of mortality rates of eggs and larvae of Pacific and Atlantic herring. In this report, I use this method in order to estimate spawning stock size of Pacific herring in Port Moller.

This report includes a brief review of the available biological information on the herring of Port Moller. This was done in order to estimate the number of spawning runs and their approximate dates, to derive estimates of parameters used in the population model, and to define the limits of scientific knowledge about this stock.

2. Study Site

The Port Moller estuarine complex is the largest embayment on the northern shore of the Alaska Peninsula (Fig. 1). It has a total surface area of 876 km^2 enclosed in 4 shallow bays: Moller Bay, Mud Bay, Herendeen Bay, and Nelson Lagoon. Mean depth at lower low tide ranges from 4 to 17 m, except at the head of Herendeen Bay, where mean depths of 35 to 45 m are encountered.

Extensive mud flats occur in Nelson Lagoon, Mud Bay and along the southern shores of Moller and Herendeen Bays. At low tides the former bays are impassable and the rest of Port Moller can only be navigated through narrow channels. The mud flats are strewn with boulders, and, near the shore, with large eelgrass beds.

Sears and Zimmerman (1977) report that the intertidal zones of Nelson Lagoon and Mud Bay consist primarily of mud, and those of Herendeen and Moller Bays consist primarily of gravel with some mud and bedrock. The shore northwest of the entrance to Port Moller up to the mouth of Bear River is a long sandy beach.

The tidal range within the Port Moller compex is estimated to be 3 m, and tidal currents are relatively strong, reaching maximum ebb and flood velocities of approximately 150 cm s^{-1} (U.S. Department of Commerce).

The area surrounding Port Moller is remote and sparsely inhabitated. The native community of Nelson Lagoon (population: 500) is established on the barrier islands of Nelson Lagoon. The Peter Pan Seafoods fish processing plant (staff: 200) operates at Entrance Point from May to September of every year.

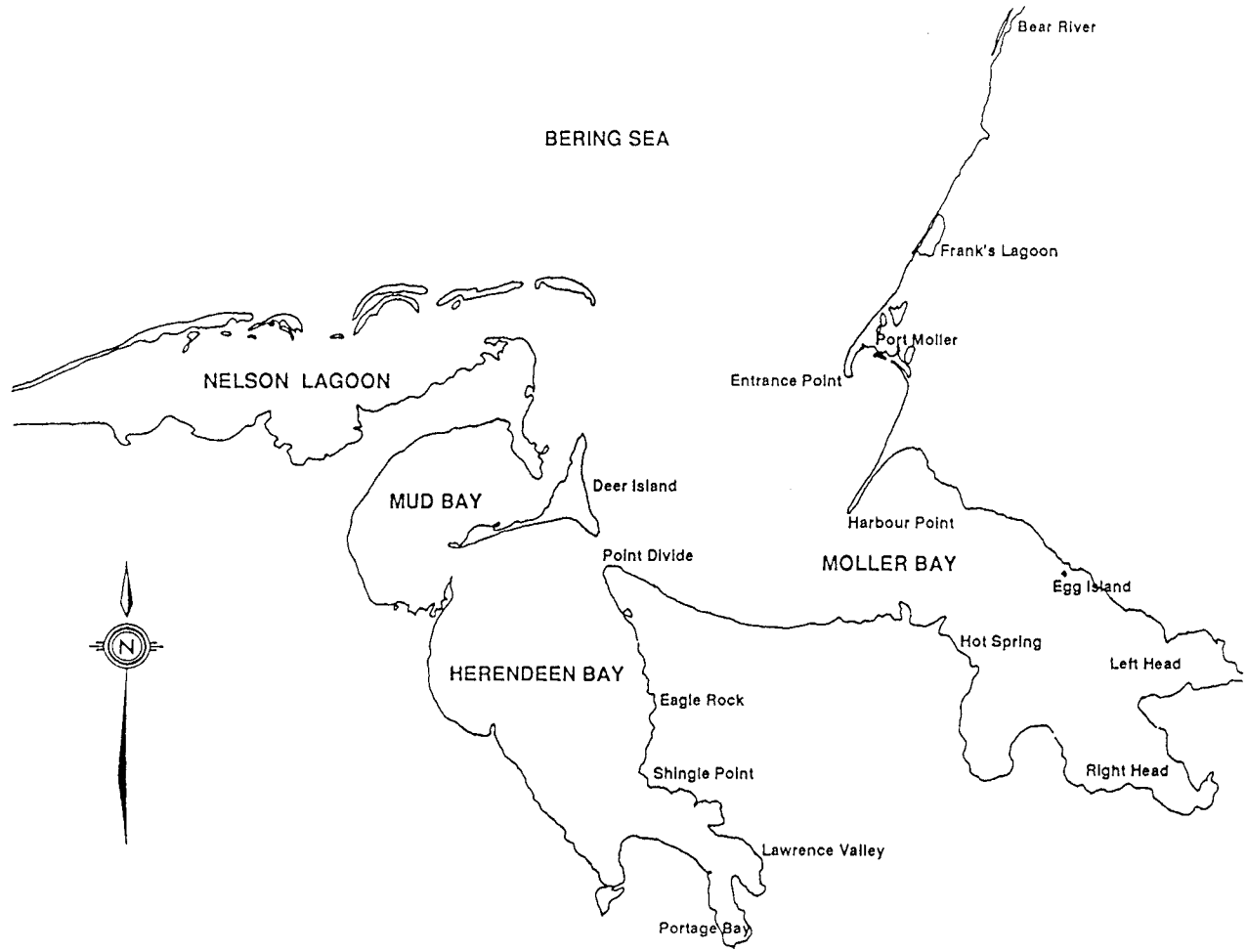


Fig. 1. Map of Port Moller.

3. Materials and Methods

3.1 Review of Port Moller herring biology

Information on the herring of Port Moller was obtained from two sources: Annual Reports of the Alaska Peninsula - Aleutian Islands management area written by biologists of the Division of Commercial Fisheries of the Kodiak office of ADFG; and by a search of the scientific literature on fish and fisheries of the Bering Sea.

3.2 Aerial surveys of spawning biomass

ADFG estimates spawning biomass in the Port Moller area with aerial surveys. The methodology of these surveys is described by Anonymous (1986). Observers fly at an altitude of about 450 m and count the number of schools of herring and measure the length and width of each school. The surface area of each school is the product of the length of the school and its width. Each school is classified into one of three size classes based on its surface area: small schools with an area $\leq$ 50 m^2; medium-sized schools with a surface area > 50 m^2 and $\leq$ 450 m^2; and large schools with a surface area >450 m^2. The number of schools in each size-class is converted to Relative Abundance Indices (RAI) by assuming that 1 small school = 1 RAI, 1 medium-sized school = 5 RAI, and 1 large school = surface area/50 m^2. Aerial observers also classify the 'seeing' conditions on each date with a 5-point rating system: 1 = excellent, 2 = good, 3 = fair, 4 = poor, 5 = unsatisfactory.

Biomass of herring measured in one survey is calculated as

$$(1) \quad B_Y = \sum^{i} \sum^{j} RAI_{Yij}\, b_j$$

where B_Y = spawning biomass (MT) observed on Julian date Y, RAI_{Yij} = the number of relative abundance units observed in the jth depth class of the ith area of Port Moller on date Y, and b_j = a conversion factor having values of 1.38 MT RAI^{-1} for schools in water 5 m deep or less, and 2.34 MT RAI^{-1} for schools in depths greater than 5 m. Conversion factors were calculated from surveys of schools of known biomass and surface area in known water depths that were conducted with chartered commercial fishing vessels in Bristol Bay in 1983. If more than one survey of Port Moller was conducted in a single day, then the largest number of RAIs recorded in each of the ith areas was chosen as the most accurate index of biomass, rather than the mean number of RAIs, because the observers were more likely to underestimate the number of schools than they were to overestimate the number.

3.3 Plankton sampling

Fifteen plankton stations in Port Moller were sampled at least once during the reconnaissance survey. Fig. 2 shows the locations of the stations and Table 1 lists their code letters, geographic locations, and positions along the major axes of the Bays.

The first step in defining the axes was to divide the Port Moller complex into 2 parts: Moller Bay and the Bering Sea; and Herendeen Bay. This was necessary because the length frequency distributions of the herring larvae, the spatial distribution of the percent yolk sacs, the growth rates, and the densities of the larvae showed that the population dynamics of the larvae in Herendeen Bay were different from the dynamics of the larvae in the rest of the Port Moller complex.

The second step was to define an x-coordinate for each sampling station within a part. This was done by, first, defining the geographic center of each section and connecting the centers of adjacent sections with straight lines. The origin of the x-axis in Moller Bay was the midpoint of a line drawn across the base of the peninsula separating the Left and Right Heads of Moller Bay. The origin of the x-axis in Herendeen Bay was the head of Portage Bay. The distance between a station and its origin was measured by dropping a perpendicular line from the station to the nearest connecting axis, and then following the shortest distance to the origin along the connecting axis.

Table 1 also lists the total area of the section surrounding each station, the portion of this area that is below lower low tide, and the portion that is intertidal. It also lists the mean ($\pm$ 1SD) depths of the subtidal portion of each section. The boundaries of the sections were created by drawing lines at an equal distance between adjacent stations. In most cases, the lines were oriented perpendicular to the major axis of each bay. Areas were measured by planimetry from hydrographic map number 16363 produced by the U.S. National Ocean Survey (NOAA). The mean depth of the subtidal portion of each section was calculated from soundings taken at mean lower low tide that are shown on the hydrographic map. The depth of each section at the time its central station was occupied was calculated by adding the average depth shown in Table 1 to the water depth above lower low tide due to the average stage of the tide at the time that each plankton sample was taken (Table 8). Therefore, the volume of water present in each section at the time it was sampled was

$$(2) \quad V_{ti} = A_{Si} (H_{Si} + H_{ti}) + A_{Ii} H_{ti}$$

where V_{ti} = total volume (m^3) of water in section i at time t, A_{Si} = area (m^2) of subtidal portion of section i, A_{Ii} = area (m^2) of intertidal portion of section i, H_{Si} = mean depth

Fig. 2. Map of plankton stations

Table 1. Plankton stations in Port Moller.

Site code	Site description	Latitude	Longitude	Section area (m^2) sub-tidal	inter-tidal	total	Section depth (m) mean	SD	n	range	x-coordinate (m) Moller	Herendeen
Upper Moller Bay												
A	off entrance to Left Head	55 50'15"	160 19'10"	28917525	48498450	77415975	4.4	5.2	94	15.2	7980	
B	off Egg Island	55 52'45"	160 24'15"	21526050	34234200	55760250	6.0	5.1	65	19.8	14763	
C	off Hot Spring	55 53'28"	160 29'15"	28074637	10438838	38513475	5.6	6.1	97	25.6	19870	
D	inside Harbor Point	55 54'20"	160 34'20"	24184387	19256725	43441125	6.4	11.7	70	67.7	25935	
Lower Moller Bay												
E	between Harbor and Entrance Points	55 56'58"	160 35'20"	49017150	9077250	58094400	6.1	6.3	225	47.5	30962	
J	between Deer Island and Harbor Point	55 56'03"	160 42'05"	68727750	56473462	125201212	5.6	6.1	293	42.1	36149	
Bering Sea												
F	1 km off Entrance Point	55 59'22"	160 37'08"	95246287	972563	96218850	8.2	5.2	280	23.8	36069	
G	10 km off Entrance Point	55 05'25"	160 42'34"	216946275	0	216946275	17.2	5.3	205	29.3	48358	
H	off center of Frank's Lagoon	56 03'46"	160 31'49"	75730200	0	75730200	8.0	4.0	133	17.4	45805	
I	off mouth of Bear River	56 09'45"	160 27'00"	35660625	0	35660625	9.6	6.5	73	20.1	57935	
Herendeen Bay												
K	inside Point Divide	55 52'47"	160 50'18"	58548262	69440962	127989225	6.0	10.3	175	95.1		24100
L	off Eagle Rock	55 49'45"	160 46'52"	26907562	34623225	61530787	3.8	5.1	148	29.3		18035
M	off Shingle Point	55 46'42"	160 46'13"	37929937	4733137	42663075	16.4	14.6	119	60.4		11252
N	off Lawrence Valley	55 44'28"	160 40'36"	8234362	778050	9012412	45.4	28.6	36	104.2		4389
O	center of Portage Bay	55 43'00"	160 41'08"	6548587	324187	6872775	33.9	25.1	20	69.5		1676
			Total	782199596	288851049	1071050661						
Mud Bay				0	55500900	55500900						
Nelson Lagoon				0	174801900	174801900						
			Total	782199596	519153849	1301353461						

(m) of subtidal portion, H_{ti} = depth (m) above mean lower low tide at time t due to the daily tidal cycle.

Plankton samples were taken with 3 m long bongo nets each having a mouth diameter of 0.6 m, a mesh width of 333 μm and a hard plastic codend. The nets were towed at approximately 1 to 2 m sec^{-1} in a double oblique pattern from the surface to 30 m, or to the midpoint of the water column if the water was less than 30 m deep, and then back to the surface. A General Oceanics mechanical flowmeter was placed off center in one of the two nets in order to measure the volume of water filtered in a tow. The contents of the codends were preserved immediately in 5% formaldehyde and seawater. All of the plankton samples were collected between 0800 and 1900 h.

Temperature and salinity profiles were measured with a conductivity-temperature meter at each station immediately after each tow.

All fish larvae were sorted from the preserved plankton under a dissecting microscope. Herring larvae were counted and abundance was expressed as number per m^3 filtered by the nets. The densities of newly-hatched herring larvae are expected to be reliable measures of their true density, but the true density of mid- and large-size fish larvae is known to be underestimated by plankton nets catches because these fish are large enough to detect and evade the net. The measured densities of herring larvae were corrected for evasion of the plankton net using McGurk's (1989a) equation

(3) $N_{ti} = n_{ti}0.1355\exp(0.270L_{ti})$

where N_{ti} = density (m^{-3}) at time t and site i corrected for net evasion, n_{ti} = measured density (m^{-3}) at time t and site i, and L_{ti} = length (mm) of larvae at time t and site i. This equation was derived from the ratios of night to day catches of Pacific herring larvae captured in Bamfield Inlet, British Columbia. The rationale for the use of this equation is described in Appendix F of this report.

Standard lengths of 100 randomly-chosen herring larvae from each sample were measured with an ocular micrometer. Length was corrected for shrinkage caused by capture in a towed net using a Gompertz model calibrated for Pacific herring larvae by McGurk (1985).

Larvae were assigned to cohorts based on their body length. The number of cohorts and the average lengths of the fish in each cohort at each sampling date were identified by examination of length frequency plots. It was assumed that the number of fish was normally distributed with length.

The average age of larvae in a sample that contained at least one yolk sac larva was calculated from the fraction of the sample that retained a yolk sac. The procedure was based on the fact that the number of days from hatching to exhaustion of the yolk sac of Pacific herring larvae decreases exponentially with temperature. Alderdice and Velsen (1971: Table 4) reported times from hatching to yolk exhaustion for 12 combinations of salinity and temperature. Response surface analysis showed that the times were not significantly related to salinity, and that the best relationship with temperature was

(4) $Y = 40.9T^{-0.84}$
$r^2 = 0.67, n = 12, P=0.001, SE_b = 0.19$

where Y = time from hatching to yolk exhaustion (d) and T = temperature (°C) (Fig. 3). Therefore, the age of a sample containing any yolk sac larvae was

(5) $t_i = 40.9T_i(1 - f)$

where t_i = age (d) of a sample taken at site i, T_i = mean temperature (°C) of the upper 30 m of the water column at site i, and f = the fraction of sample consisting of yolk sac larvae. Mean temperature was assigned on the basis of where the larvae were captured. Age of larvae captured in Upper Moller Bay and Herendeen Bay was calculated from the respective mean temperatures of those Bays, but the age of larvae captured in Lower Moller Bay was calculated from the mean temperature of both Upper and Lower Moller Bays, and the age of larvae from the Bering Sea was calculated from the mean temperature of the Bering Sea and the entire Port Moller complex.

The mean age of a sample that did not contain any yolk sac larvae was calculated from the mean length of the larvae in the sample using the the growth equation for the area, Moller Bay/Bering Sea or Herendeen Bay, in which the sample was taken.

Growth rate of herring larvae was assumed to be constant

(6) $L_t = L_0 + Gt$

where L_t = length (mm) at age t (d), L_0 = length (mm) at hatch (t=0), and G = growth rate (mm d^{-1}).

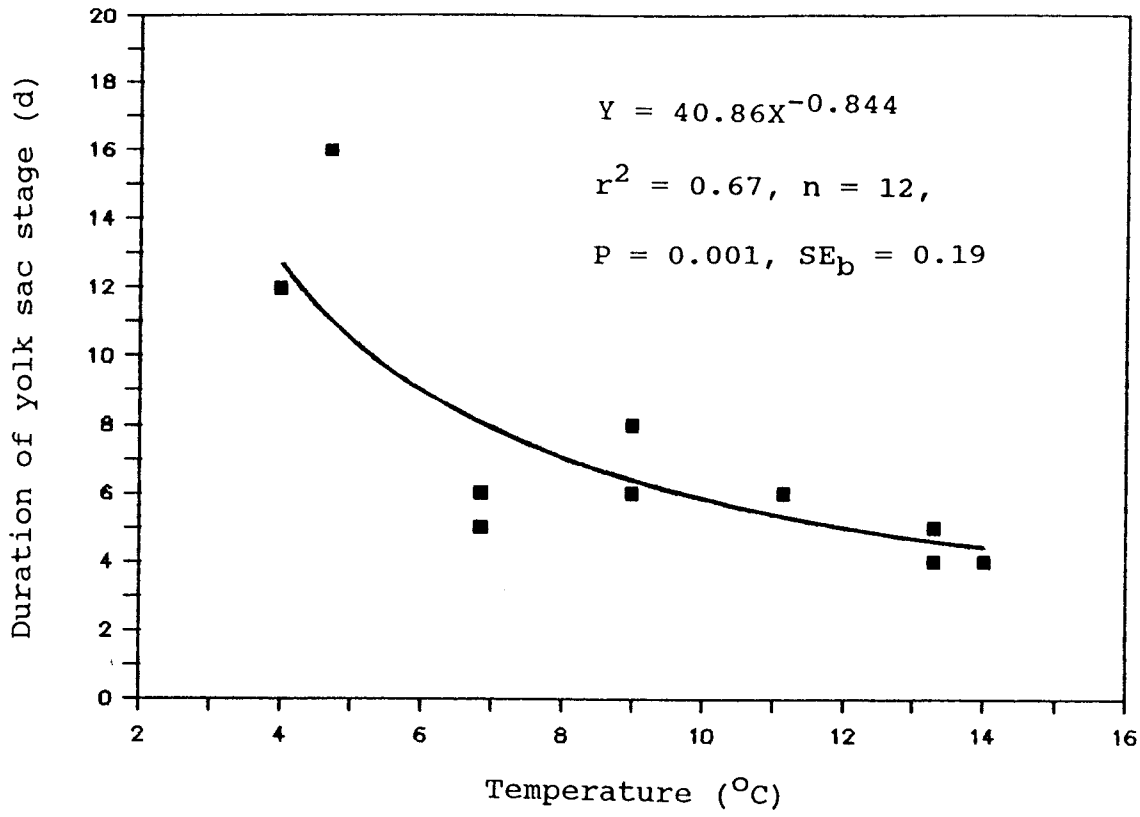


Fig. 3. Temperature-dependence of duration of yolk sac stage [data from Alderdice and Velsen (1971)].

Hatching dates of cohorts of herring larvae were back-calculated from the midpoint of the sample collection dates as

$$(7) \qquad Y_H = Y_L - \frac{(L - L_0)}{G}$$

where Y_H = Julian date at hatch, and Y_L = Julian date corresponding to the mean length L (mm) of the samples.

Spawning dates were back-calculated from the hatching dates as

$$(8) \qquad Y_S = Y_H - \frac{100}{D(T)}$$

where Y_S = Julian date of spawning and D(T) = the daily percent development of the eggs at a mean surface water temperature of T (°C). D(T) was calculated using Alderdice and Velsen's (1971) equation

(9) $D(T) = 0.7448 + 0.4375T + 0.0235T^2$

3.4 Population model

Biomass of adults was back-calculated from the number of eggs as:

(10) $$B = \frac{2 N_e}{10^6 F_r}$$

where B = biomass (MT), N_e = total number of newly-spawned eggs, F_r = relative fecundity (number of eggs/g total body weight). The right-hand side of equation (10) is doubled because a sex ratio of 1:1 is assumed. This is a standard assumption for estimating the stock biomass of Pacific herring from spawn survey data, e.g. Schweigert and Stocker (1988).

N_e was back-calculated from the number of newly-hatched larvae as:

(11) $$N_e = \frac{N_0}{s_1 s_2 s_3}$$

where N_0 = total number of newly-hatched larvae, s_1 = fraction of eggs that survive predation during incubation, s_2 = fraction of surviving eggs that hatch larvae, and s_3 = fraction of newly-hatched larvae that are viable. Hatching mortality is assumed to occur only during hatching, so there is no interaction between the three survival rates. s_1 was estimated as

(12) $s_1 = \exp(-Z_e t_e)$

where Z_e = instantaneous daily egg mortality (d^{-1}) due to predation and t_e = duration of egg incubations (d), i.e. 100/D(T). Z_e was estimated after a review of measurements of egg mortality in Pacific and Atlantic herring egg beds reported in the scientific literature (section 4.4.1). s_2 and s_3 were also estimated from a review of the scientific literature (section 4.4.1).

N_0 was back-calculated from the number of larvae at age t using two assumptions about mortality rate: that it was constant with age over the early larval period, i.e.

(13a) $N_t = N_0 \exp(-Zt)$

where N_t = number of larvae at age t (d) and Z = a coefficient of instantaneous daily mortality (d^{-1}); and that it decayed as a power function of age (Hewitt et al. 1985), i.e.

(13b) $N_t = N_0 t^{-\beta}$

where β = coefficient of instantaneous daily mortality.
Thus, N_0 is calculated as either

(14a) $N_0 = N_t \exp(Zt)$

or

(14b) $N_0 = N_t t^{\beta}$

The total number of herring larvae at age t in Port Moller was the sum of the numbers of larvae in each section of the area

$$(15) \qquad N_t = \sum^{i} N_{ti} V_i$$

where N_{ti} = density (number m^{-3}) of larvae of age t at station i of Port Moller.

N_{ti} was not measured at every station at each date, and in some stations at which it was measured, it was too small to be detected. Therefore, it was necessary to estimate N_{ti} at those stations using a simple application of turbulent diffusion theory (Okubo 1980). Depending on which mortality function is used, the distribution of larvae in each of the two parts of the Port Moller complex should follow the function

$$(16a) \qquad N_{ti} = \frac{C}{4\pi HKt} \exp\left(\frac{-x^2}{4Kt} - Zt\right)$$

or

$$(16b) \qquad N_{ti} = \frac{Ct^{-(\beta+1)}}{4\pi HK} \exp\left(\frac{-x^2}{4Kt}\right)$$

where C = the number of larvae hatched per unit volume, H = the mean depth (m), K = the coefficient of radial diffusion ($m^2\ d^{-1}$), and x = the distance (m) of a station from the origin of its x-coordinate system.

Equations (16a) and (16b) were fit to the density data by non-linear multiple regression after transformation with natural logarithms. Zero counts were excluded because they could not be assigned an age, and because they do not represent true zero counts but only indicate that that the density of larvae at a station was lower than the limit of detection of the sampling gear. The entire equation was fit to the data, and then if β, Z or K were not significant ($P>0.05$), the terms that contained these coefficients were removed in a backwards stepwise fashion until a version was derived in which all parameters were significant.

3.5 Location of spawning habitat

Three methods were used in order to locate herring spawning habitat: dredges of subtidal habitat, surveys of beaches at low tide by foot and by all-terrain vehicles, and an aerial survey. A summary of the dredges made in the Port Moller complex, and of the beaches surveyed by foot and motorcycle, was included in the Field Report of the 1989 Port Moller Reconnaissance Survey (Envirocon Pacific Ltd. 1989) and will not be discussed further in this report. One aerial survey of the entire Port Moller complex was conducted at low tide on the afternoon of June 16. This survey was far more effective in revealing the distribution of intertidal vegetation in Port Moller than either of the 2 other methods.

Information on the location of traditional herring spawning beaches, and on the relative frequency of spawning at a site, was obtained from an interview with Warren Johnson of Kenai Float Planes (Nelson Lagoon, Alaska), who has 10 yr of experience flying surveys for herring fishermen in Togiak and Port Moller, and from correspondance with Len Schwarz, assistant ADFG Management Biologist for the Port Moller fishing district.

4. Results

4.1 Review of Port Moller herring biology

4.1.1 Commercial catches

Native subsistence fisheries for herring and herring food and bait fisheries undoubtedly occurred in the Port Moller area in pre- and post-Contact eras, but they were never adequately documented. Herring are known to have been harvested for food by people living in coastal villages on the northeastern shore of the Bering Sea since at least 500 B.C. (Hemming et al. 1978, cited by Fried and Wespestad 1985). An extensive midden at Hot Spring in Moller Bay indicates that Aleuts and/or Eskimos lived at this site for centuries. Presumably, they also harvested herring for food. Notched stones commonly used as weights on gillnets were found at this site (personal communication, Rae Baxter, NOAA, National Ocean Service, 222 W. 8th Ave., #56, Anchorage, Alaska 99513-7543). Ruins of two fish canneries are visible on the shores at the head of Herendeen Bay. Although their primary focus was canning salmon, they may also have harvested herring for food and bait. The fish processing plant at Entrance Point has operated continuously since the first decade of this century. It freezes some of the herring caught in Port Moller and then ships it to Japan for processing.

Investigation of herring stocks in the Bering Sea only began in 1975 under the Outer Continental Shelf Environmental Assessment Program (OCSEAP). The principal investigator was ADFG. Aerial surveys of the Port Moller area by ADFG personnel in 1976 reported numerous schools of herring in Herendeen Bay (Warner and Shafford 1979). However, aerial surveys conducted from Port Moller to Bering Strait between April 30 and June 28, 1979, did not find any spawning schools along the entire northern shore of the Alaska Peninsula (Barton and Steinhoff 1980). This demonstrates the poor 'seeing' conditions which are often encountered on this coast. Since 1984 ADFG field crews have been placed in the Port Moller area where they have caught herring in test nets.

Commercial landings of herring from the Port Moller area were first reported in 1982. Since then an average of 508 (SD = 166, n = 8) MT have been harvested each year in a sac roe fishery (Table 2). More than 70% of the catch was taken from Herendeen and Moller Bays, and the remainder of the catch was taken off the Bering Sea coast between Entrance Point and the mouth of Bear River.

Table 2. Annual harvest (MT) of Port Moller Pacific herring.

Location	1982	1983	1984	1985	1986	1987	1988	1989	TOTAL	Percent
Deer Island	0	0	0	66	38	0	0	0	104	2.56
Herendeen Bay	254	464	164	91	102	146	7	61	1289	31.73
Moller Bay	164	33	227	233	238	313	259	389	1856	45.68
Bear River/E. Bering Sea coast	42	74	0	261	430	7	0	0	814	20.03
Total	460	571	391	651	808	466	266	450	4063	100.00

4.1.2 Spawning dates

Commercial catches of herring from Port Moller from 1983 to 1988 were landed from May 9 to June 23 (Fig. 4 and Appendix A). With two exceptions, most catches were taken during a time period of 20 d or less. A bimodal distribution of catches with date in 1987 and 1989 indicates that more than one spawning group was harvested in those years: one in mid- to late-May and a second in early- to mid-June. Percent roe yield of the 1987 catches exhibited a similar bimodal pattern (Appendix A), as did the biomass of pre-spawning herring estimated by ADFG's aerial surveys (Appendix B).

Table 3 summarizes the mean dates of earliest possible spawning. These dates were calculated by weighting calendar dates by the amount of commercial landings, or by the percent roe yield, or by the biomass of spawners estimated from ADFG's aerial surveys. Spawning presumably occurs at those mean dates or several days later. Table 3 shows that there are at least two spawning groups that use Port Moller: a group that appears between May 11 and May 29, and a second group that appears between June 2 and June 23. Table 3 also shows that the first group spawns every year in Port Moller, but that the second group apparently only spawns every second year in Port Moller.

These results must be interpreted with caution because they are based on data from the commercial fishery. One of the problems with such data is that no further information is collected once the catch quota has been met and the fishery is closed. Since the quota is usually met within 2 to 3 wk of opening the fishery on the May spawning run, any information on succeeding runs is not collected. Thus, the frequency of occurrence of second or even third spawning runs is most likely underestimated by this data.

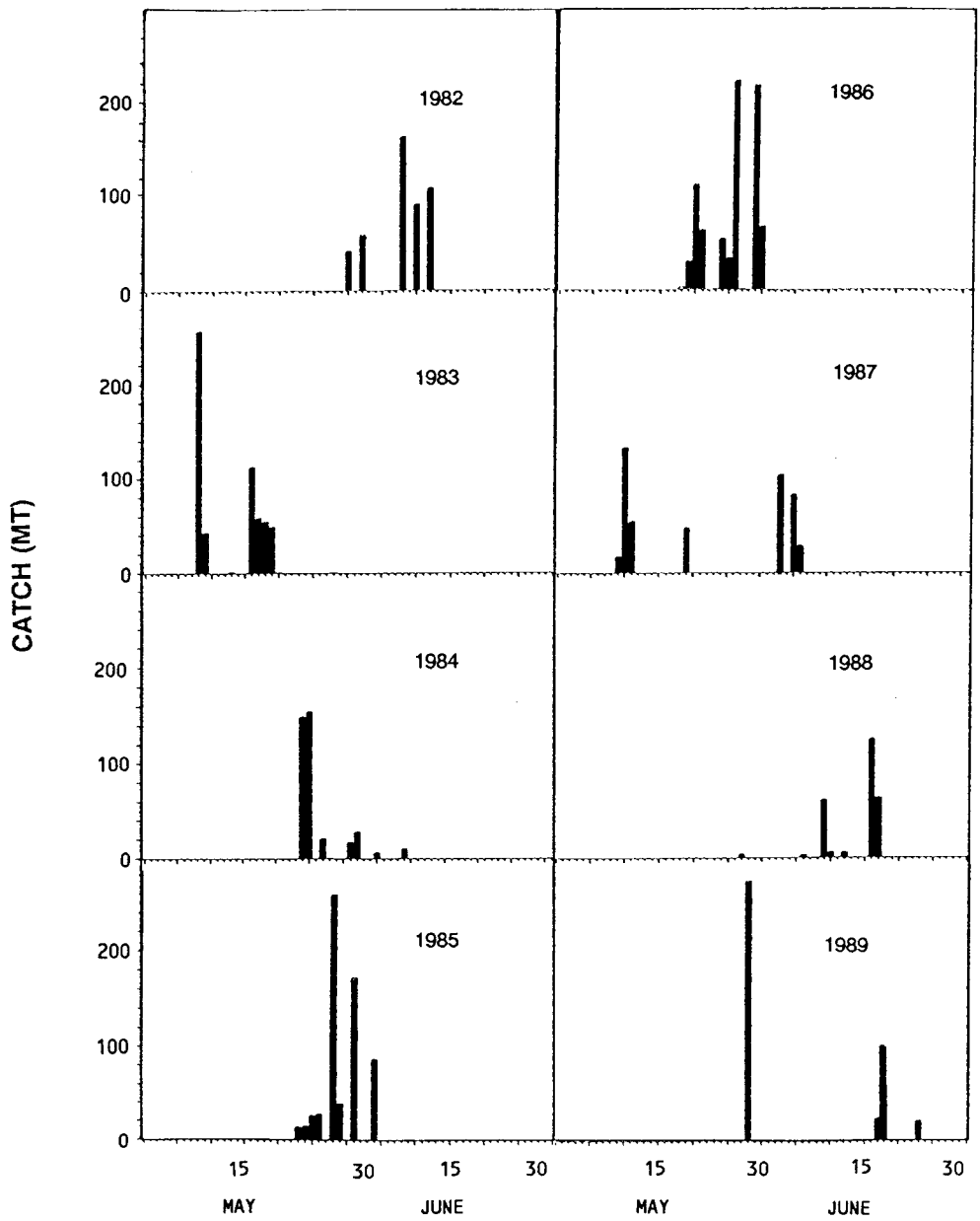


Fig. 4. Dates of herring harvest in Port Moller.

Table 3. Earliest dates of herring spawning in Port Moller based on commercial landings, percent roe yield of the catches, and estimated biomass of spawners from ADF&G's aerial surveys.

		Mean date of spawning		
Year	Spawning run	Commercial landings	Percent roe yield	Aerial surveys
1982	early	-	-	-
	late	June 7	-	-
1983	early	May 13	-	-
	late	-	-	-
1984	early	May 26	-	May 25
	late	-	-	June 4
1985	early	May 30	-	-
	late	-	-	-
1986	early	May 25	-	-
	late	-	-	-
1987	early	May 11	May 11	May 15
	late	June 3	June 4	June 2
1988	early	May 28	May 28	May 25
	late	June 14	June 17	June 4
1989	early	May 29	May 29	May 29
	late	June 18	June 19	June 14

Notes:
1. Dashes indicate that data is not available.

4.1.3 Spawning biomass

Appendix B lists the biomass of herring observed by ADFG's aerial surveys in 1984, 1987, 1988 and 1989. There are no estimates of spawning biomass for 1983 and 1986 because bad weather and muddy water prevented the observers from counting any herring schools. The numbers for all years except 1989 are considered minimum estimates because of the poor 'seeing' conditions that are often encountered in Port Moller; 1989 was an excellent year for aerial observation. It was the first year in which aerial observers were able to see schools of adult herring actually rolling into shallow water to spawn.

On May 28, 1989, a substantial biomass of herring was spotted by industry aerial observers travelling southwest along the coast of the Alaska Peninsula between Port Heiden and Port Moller. This area was outside the Moller fishery district and so it was open to fishing; a harvest of 225 MT was taken. On May 29, 1989, approximately 1,182

MT of herring was observed by ADFG pilots near Bear River northeast of Port Moller. A 6 h opening of the fishery was declared and 284 MT were taken in upper Moller Bay. On May 30, peak biomasses of 1,016 and 748 MT were observed in Herendeen and Moller Bays, respectively, for a total spawning escapement of 1,764 MT. These fish must have spawned quickly and then left because only 7 MT were observed on May 31 and June 1. The sac-roe fishery remained closed until more herring moved into the area.

A spawning escapement of 1,764 MT is equivalent to 1.764×10^{11} newly-laid eggs, assuming a sex ratio of 1:1 and a relative fecundity of 200 eggs g^{-1} of female body weight.

Two weeks later another group of spawners began to enter the estuary. From June 9 through 12 industry pilots reported small groups (180 to 270 MT) of herring entering Moller and Herendeen Bays. ADFG pilots observed 343, 154 and 332 MT of herring in Moller Bay on June 13, 15 and 16, respectively. The Port Moller district was opened to the fleet on June 16 and 167 MT were taken between June 16 and June 23. The fishery was closed for the year on July 15.

4.1.4 Age structure

The age distribution of Port Moller herring is characterized by strong year classes (Fig. 5). The fish that hatched in 1977 dominated the spawning population from 1981 to at least 1983. In 1981, as 4 yr olds, they comprised over 70% of the entire spawning population, and their presence was still marked by greater than usual percentages of 9 and 10 yr old fish in May 1986 and May-June 1987, respectively. Another strong year-class hatched in 1981 and entered the spawning population as 3 yr olds in 1984. It dominated the population from 1985 to 1987.

A second important feature of the age structure is that the modal age of fish that spawn in June is 1 to 2 yr lower than that of fish that spawned in May. This is most obvious in the age structure of the 1987 spawners. Apart from this difference, the May and June age distributions are similar, especially in the relative frequencies of the 8, 9 and 10 yr old age classes.

4.1.5 Size and growth

The only published data on the size and average growth rates of herring from Port Moller is the 1982 annual management report of ADFG's Kodiak office. This document shows that Port Moller herring range in length from 212 mm at age 3 yr to 301 mm at age 9+ yr:

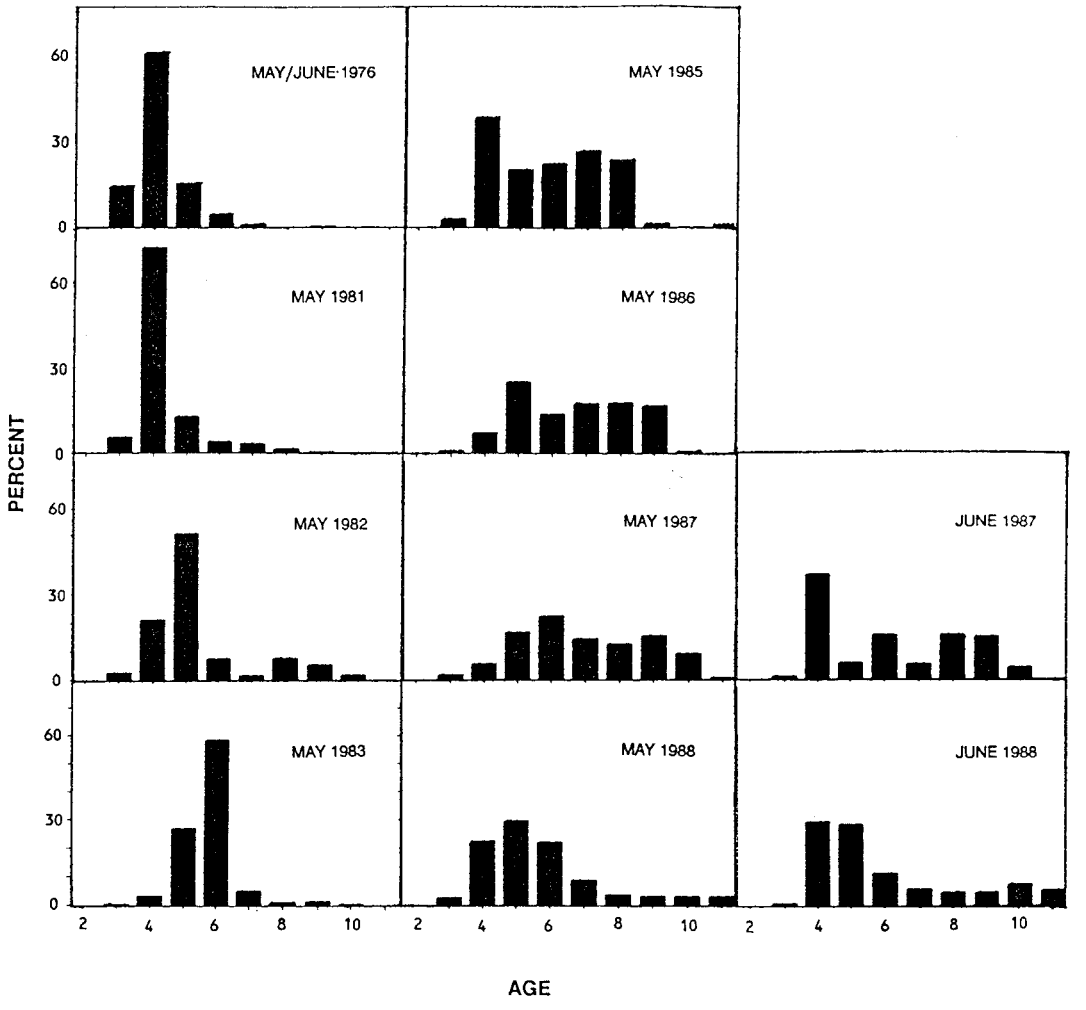


Fig. 5. Age structure of Port Moller herring.

Age (yr)	3	4	5	6	7	8	9+
Mean length (mm)	212	242	260	266	275	292	301

A von Bertalanffy growth model (Ricker 1975) best described this data,

(17) $L_t = 328.36\{1 - \exp[-0.22(t + 1.85)]\}$

where L_t = mean length (mm) at age t (yr). These parameters are similar to those reported by Fried and Wespestad (1985) for herring from Togiak and Norton Sound.

There is no published weight-length data for Port Moller herring. Fried and Wespestad (1985) report that no geographic differences were found in the weight-length regressions between Togiak and Norton Sound herring, and so they used a single relationship,

(18) $W = 1.0 \times 10^{-6} L^{3.479}$

where W = total body weight (g) and L = length (mm).

4.1.6 Fecundity

There is no published information on the fecundity of herring from Port Moller, but there are two sets of fecundity measurements available for herring from the Bering Sea. Warner and Stafford (1979) reported 86 measurements of fecundity and length for herring collected from the Togiak district of the eastern Bering Sea in 1977; and in 1985 the Alaska Department of Fish and Game collected more Togiak herring for fecundity analysis (personal communication, K. Rowell, ADFG, Division of Commercial Fisheries, 333 Raspberry Road, Anchorage, Alaska 99518). This second set of data has yet to be analysed, but fecundities of 19 of the 1985 fish were sent to me for my examination.

Covariance analysis showed that the slope of the regression of ln(egg number) on ln(length) of the Togiak herring was significantly ($P<0.001$) lower for the fish collected in 1977 than for the fish collected in 1985, which means that the two data sets cannot be combined. Length-specific fecundity of Pacific herring is reported to decrease with increasing latitude (Nagasaki 1958, Paulson and Smith 1977, Hay 1985), and between-year differences in the fecundity-size relationship have been reported to be relatively minor in comparison, at least in herring from British Columbia (Hourston et al. 1981). Thus, the difference between the 1977 and 1985 data is most likely due to the use of different techniques of counting egg numbers. Fecundity of both sets of fish was

measured with the gravimetric method, but Warner and Stafford (1979) dried the ovaries before weighing sub-samples of eggs whereas in 1985 ADFG personnel used the wet weights of the ovaries.

The relative fecundity (F_r) of the Togiak herring was calculated in order to determine which of the two sets of data was most reliable. The weight of the fish caught in 1977 was estimated from their length using the weight-length regression for Togiak herring reported by Fried and Wespestad (1985) [equation (18)]

		Relative fecundity (g^{-1})		
Year	Area	mean	SD	n
1977	Togiak, Alaska	147.9	36.9	86
1985	Togiak, Alaska	205.0	30.5	19

F_r of the 1977 fish was highly significantly (t-test: $P<0.001$) lower than that of the 1985 fish, and also highly significantly (t-test: $P<0.001$) lower than F_r for herring from both British Columbia and California (Hay 1985)

		Relative fecundity (g^{-1})		
Year	Area	mean	SD	n
1974	North coast, B.C.	204.0	40.4	1715
1974	West coast, B.C.	217.1	34.2	855
1974	St of Georgia, B.C.	224.5	16.9	723
1980	North coast, B.C.	186.8	33.3	921
1980	West coast, B.C.	197.2	31.5	290
1980	St of Georgia, B.C.	205.2	53.5	431
1975	California	216.2	20.7	37

F_r of the 1985 Togiak herring was not significantly different from that of the B.C. or California herring (t-test: $P>0.05$). Therefore, I conclude that the 1985 Togiak data is the only accurate fecundity data for herring of the eastern Bering Sea, and that Warner and Stafford (1979) underestimated the fecundity of the herring collected in 1977. Following Hay (1985), I assume that F_r of all Pacific herring, including the Port Moller fish, is approximately 200 g^{-1}.

4.2 Temperature and salinity

The temperature and salinity profiles of each plankton station are shown in Appendix D. Figs. 6 and 7 show the isopleths of temperature and salinity for Moller and Herendeen Bays, respectively. These plots were taken from a report prepared for Triton Environmental Consultants Ltd. by J. E. Edinger Associates, Ltd. (Edinger and Buchak 1989). These data indicate that most of the Port Moller complex except for Herendeen Bay follows the pattern seen in a typical estuary. The highest temperatures and lowest salinities are found at the head of Moller Bay where the water is shallow and diluted by freshwater inflow, and the lowest temperatures and highest salinities are found in the Bering Sea off Bear River. Between these areas (stations A to G) is a gradient of decreasing temperatures and increasing salinities.

Both temperature and salinity at the head of Moller Bay were highly variable. At station A salinity decreased from a mean of 23.22 ppt on June 13 to a mean of 4.28 ppt on June 14. This variability was due to changes in freshwater inflow, as is shown by the fact that variability decreased with increasing distance from the head of the Bay.

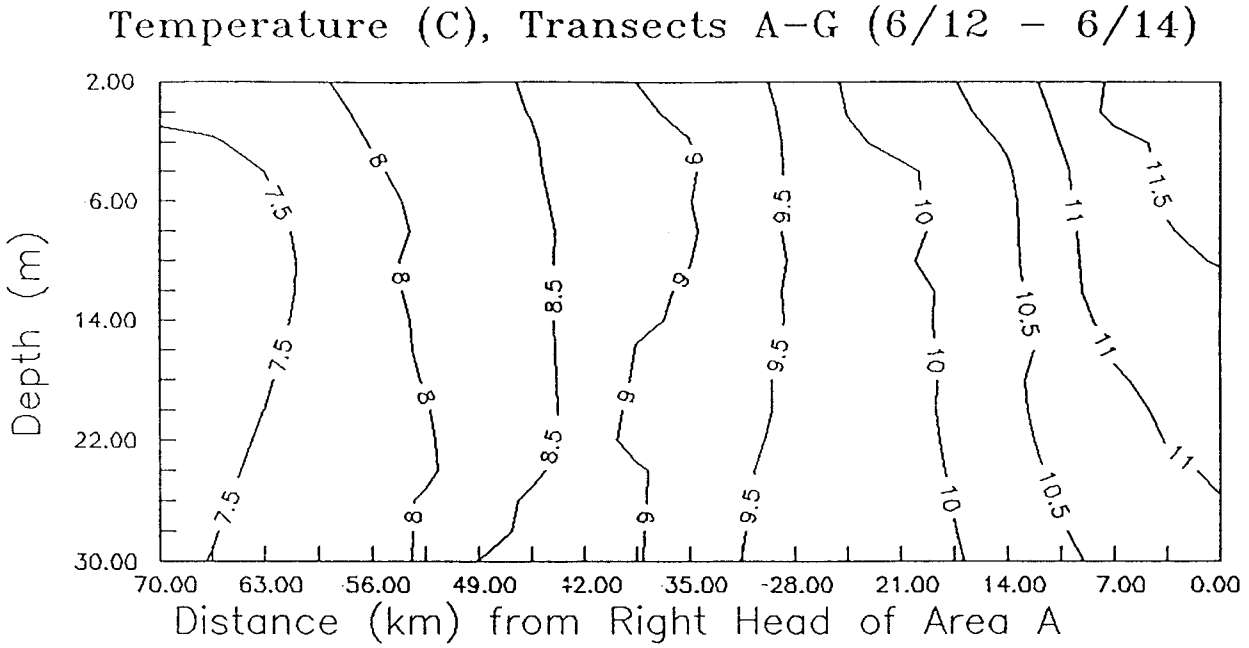
A lower gradient of temperature and salinity is shown by the stations in Herendeen Bay (O, N, M, L, K). Although temperatures were higher than those measured in the Bering Sea, they were generally lower than those measured in upper Moller Bay. This was due to the deep water at the head of Herendeen Bay.

4.3 Population dynamics of herring larvae

A total of 25 plankton samples were taken between June 11 and June 14, 1989, of which 22 contained at least 1 herring larva. A total of 11,314 herring larvae were sorted from these 22 samples, of which 1,594 had their lengths measured and the presence or absence of a yolk sac recorded.

4.3.1 Number of cohorts

The lengths of all herring larvae measured in this study are listed in Appendix E, and plotted in Fig. 8. The length frequency plots for the combined catches of June 11, 12 and 14 are not normally distributed, which indicates a mixture of cohorts. At least 2 cohorts of herring larvae were present: cohort 1 had lengths greater than about 11.0 mm, and cohort 2 had lengths ranging from 7.5 to 11.0 mm. Cohort 2 larvae were found in all of the 22 samples that contained herring larvae, but cohort 1 larvae were found in only 10 of the 22 samples.



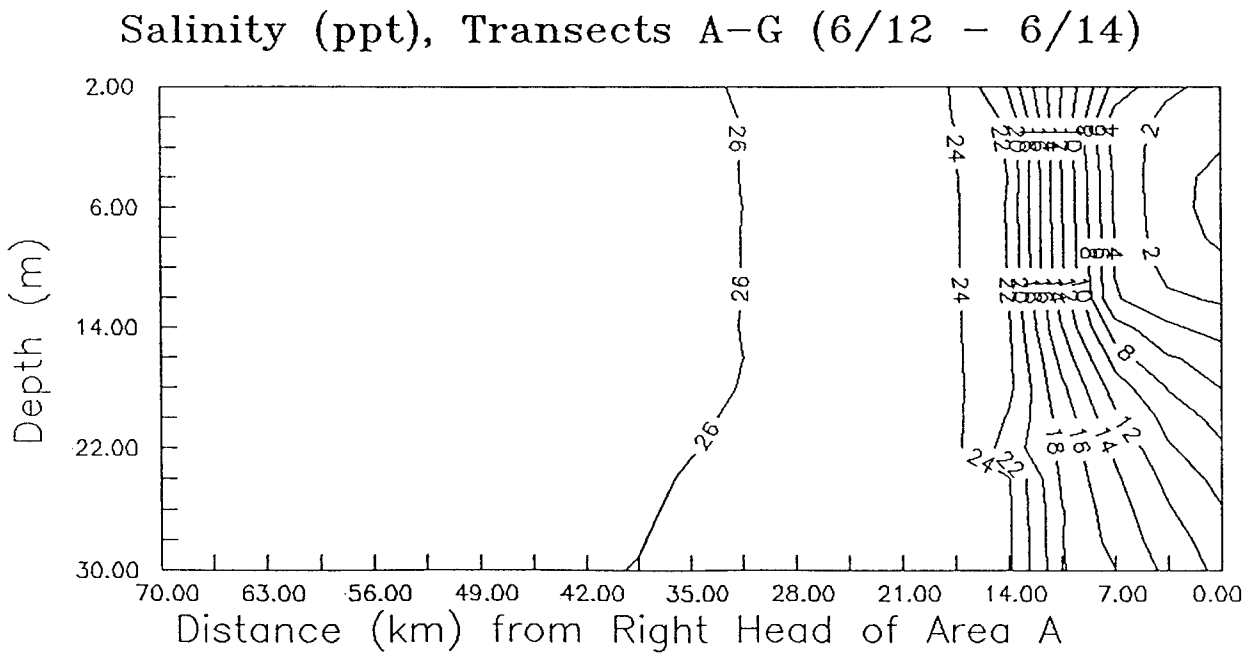
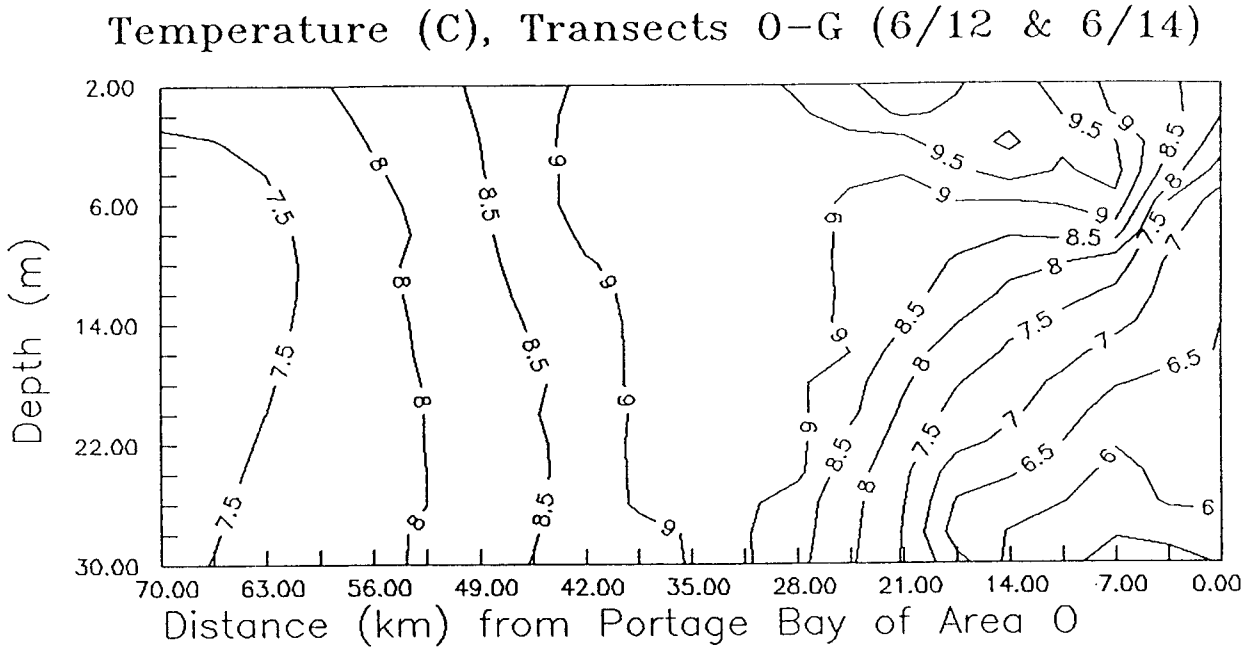


Fig. 6. Temperature and salinity isopleths of Moller Bay.



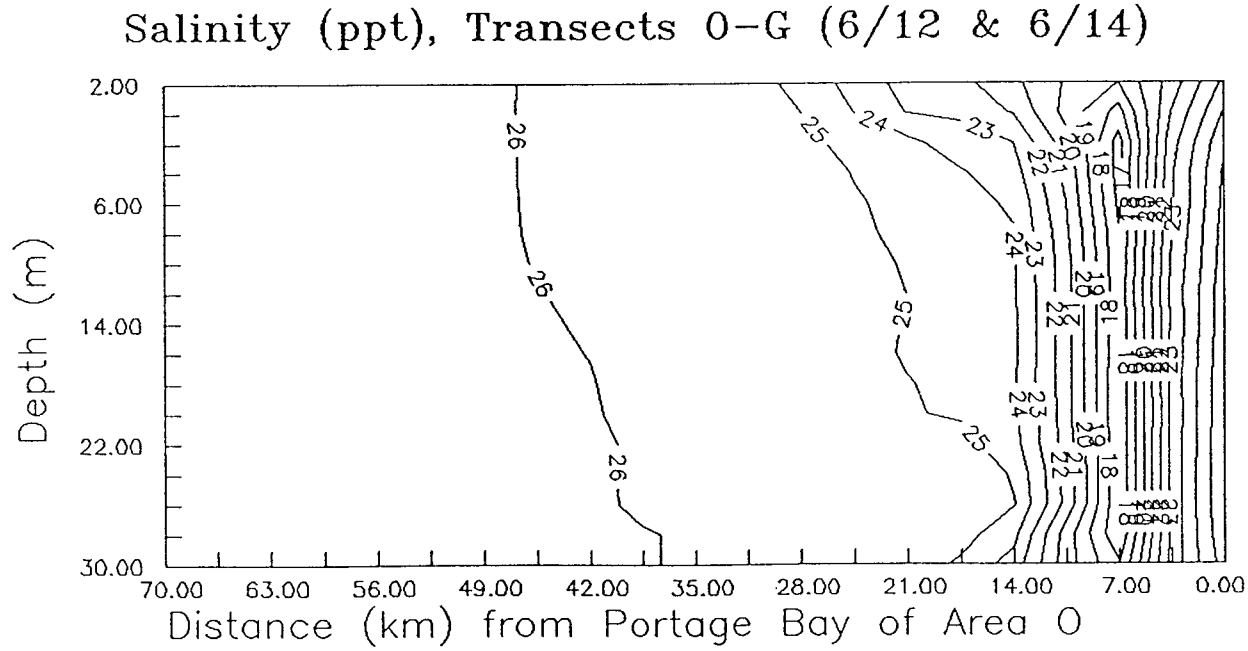


Fig. 7. Temperature and salinity isopleths of Herendeen Bay.

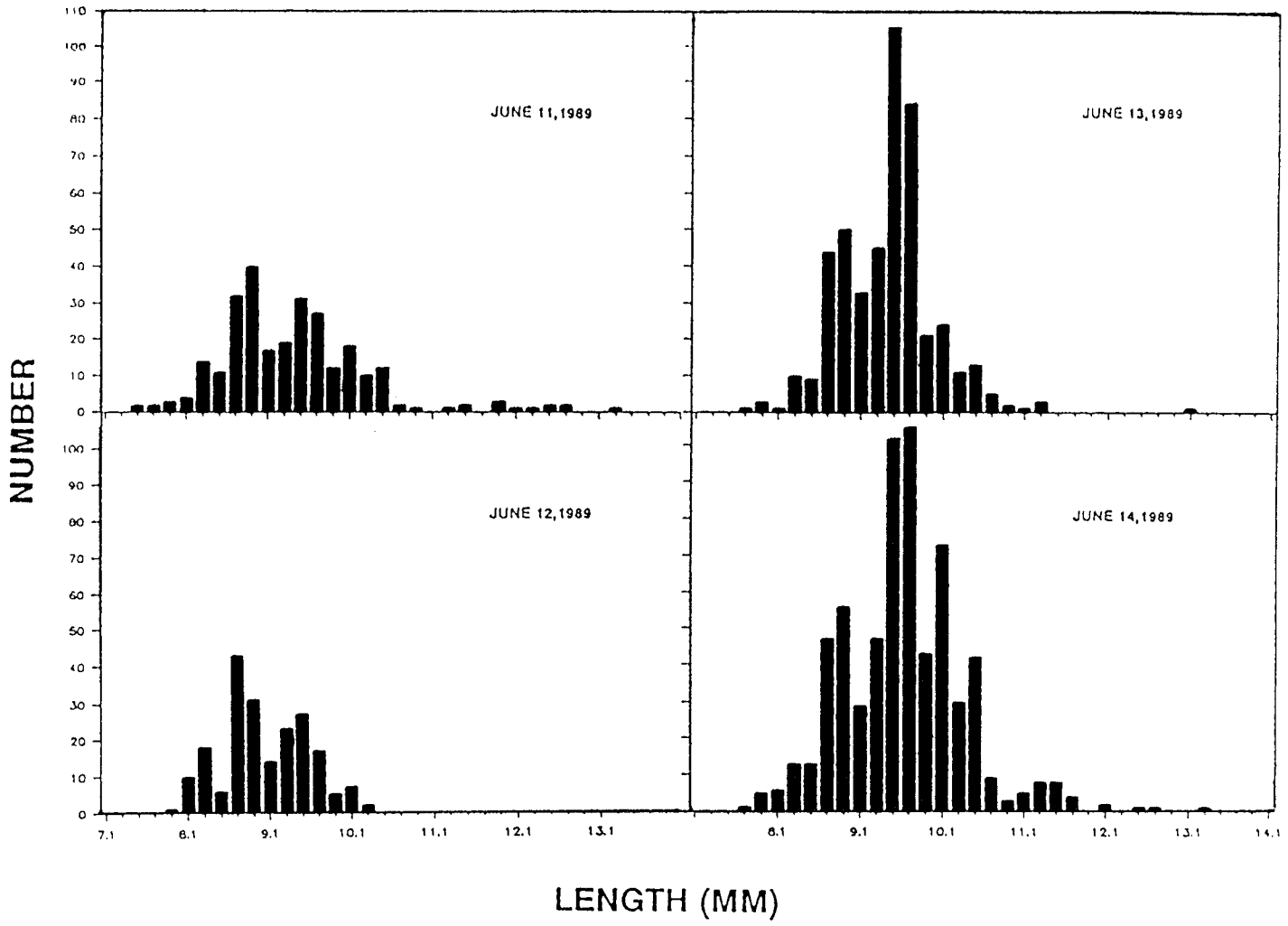


Fig. 8. Length frequencies of herring larvae.

The length frequency plots also show that cohort 2 appears to have 2 modes separated by about 0.8 mm: one at 8.7-8.9 mm, and a second at 9.5-9.7 mm. This observation suggests that cohort 2 may have been composed of 2 groups of larvae. Either one group hatched before the first, or the 2 groups hatched on the same date, but the larvae of the first mode grew at a slower rate than the larvae of the second mode.

This observation is supported by percent yolk sac data (Table 4), which shows that there were 2 centers of high percent yolk sac: one at station A in upper Moller Bay on June 11, and a second at stations K and M in upper Herendeen Bay on June 12. It is not likely that the centroid of cohort 2 was advected from one bay to the other in 1 d. Instead, this data suggests that there were 2 groups within cohort 2: one which hatched into upper Moller Bay, and a second which hatched into upper Herendeen Bay.

4.3.2 Age and growth

It was not possible to calculate initial ages of cohort 1 larvae using equation (5) because they had all exhausted their yolk, but ageing was possible for 19 of the 22 samples containing cohort 2 larvae because they contained at least 1 yolk sac larva. Table 4

Table 4. Mean lengths, percent yolk sacs, and age of herring larvae of cohort 2.

	Mean length (mm)				Percent yolk sacs				Age (d)			
Site	June 11	June 12	June 13	June 14	June 11	June 12	June 13	June 14	June 11	June 12	June 13	June 14
Upper Moller Bay												
A	8.8		9.6	9.8	40		5	16	3.7		5.8	5.1
B				9.5				29				4.3
C			9.3	9.5			25	13			4.6	5.3
D	9.3		9.1	9.4	28		49	10	4.4		3.1	5.5
Lower Moller Bay												
E			9.3				13				5.3	
J				9.4				0				-
Bering Sea												
F	9.8				12				5.6			
G												
H		10.2				0				-		
I												
Herendeen Bay												
K		8.8		9.1		67		4		2.3		6.8
L				9.4				0				-
M		8.7		9.3		66		13		2.4		6.2
N				9.5				3				6.9
O		9.1				10				6.4		

Note:
1. Age = 40.86*T^-0.8437*(1-f), where f = fraction of yolk-sac larvae.
2. Dashes indicate age was not calculated because f = 0.

shows that the percent yolk sacs for cohort 2 larvae ranged from 3 to 67%, and the ages ranged from 2.3 to 6.9 d.

Covariance analysis showed that the intercept of the regression of length on age was not significantly ($P>0.05$) different between larvae from Moller and Herendeen Bays, but that the growth rate, G, of Moller Bay fish was significantly ($P = 0.0013$) higher than that of Herendeen Bay fish. Therefore, separate regressions were calculated for each group (Fig. 9).

Moller Bay and Bering Sea:

(19a) $L = 8.20 + 0.25t$
$r^2 = 0.53$, $n = 11$, $SE_b = 0.08$, $0.01<P<0.05$

Herendeen Bay:

(19b) $L = 8.47 + 0.12t$
$r^2 = 0.76$, $n = 6$, $SE_b = 0.03$, $0.01<P<0.05$

These growth equations were used to estimate the age of samples with no yolk sac larvae from their mean length.

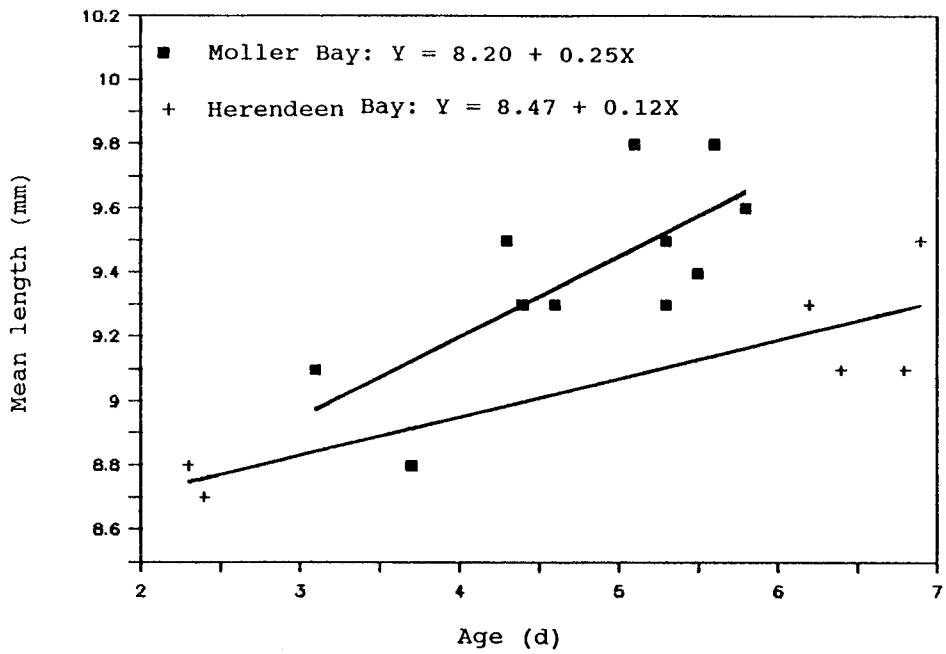


Fig. 9. Growth of herring larvae.

The growth of herring larvae in Port Moller are within the range reported for other populations of Pacific and Atlantic herring larvae (McGurk 1984, 1989b). The difference in growth rate between fish in Moller Bay and fish in Herendeen Bay is most likely a response to higher water temperatures in Moller Bay than Herendeen Bay.

4.3.3 Timing of cohorts

The hatching dates of cohorts 1 and 2 were back-calculated from their mean lengths on June 12 to have been May 29 and June 10, respectively (Table 5). The hatching date of cohort 2 was also estimated to be June 11 by forward-calculation from the approximate date of spawning on May 29 as derived from aerial surveys and the records of landings from the commercial fishery. Therefore, the interval between the hatching dates was approximately 11-12 d.

The spawning dates of cohorts 1 and 2 were further back-calculated from the hatching dates to be May 15 and May 27, respectively. Combined with a range of spawning dates for cohort 3 of June 14 to 18, based on commercial catches and aerial survey data, this gives an estimate of the duration of the interval between spawning dates that range from 12 to 21 d.

4.3.4 Dispersal and mortality

The greatest densities of herring larvae in both cohorts 1 and 2 were measured at station A at the head of Moller Bay (Table 6). Density decreased with increasing distance from this site, declining to a non-detectable level at stations G and I in the Bering Sea. The exceptions to this rule were the densities of cohort 1 and 2 larvae in Herendeen Bay; a consistent increase in density was measured at stations M and O near the head of the Bay.

This pattern of distribution supports the conclusions concerning the double origin of cohort 2 that were suggested by the bimodal length frequencies, by the two centers of high percent yolk sacs, and by the lower growth rates of larvae in Herendeen Bay.

The densities of cohort 1 herring larvae in Moller Bay and the Bering Sea were best fit by a diffusion model with no mortality term. The parameter values of this model are shown in Table 7. The densities of cohort 1 herring larvae in Herendeen Bay could not be fit by any version of equation (16) because there were only 2 non-zero counts. Therefore, in calculations of spawning stock biomass, cohort 1 larvae were assumed to be distributed at a geometric mean density of 0.063 m^{-3} at all stations in Herendeen Bay. The densities of cohort 2 herring larvae in Moller Bay and the Bering Sea were best fit with equation (16b), but the densities of cohort 2 larvae in Herendeen Bay were

Table 5. Dates of spawning and hatching for herring of Port Moller.

	Date of spawning			Date of hatching		
Cohort	catches plus aerial surveys	back-calculation from hatch date	duration of interval between cohorts (d)	forward-calculation from spawning date	back-calculation from length-at-date	duration of interval between cohorts (d)
1	-	May 15		-	May 29	
2	May 29	May 27	12-14	June 11	June 10	11-12
3	June 14-18	-	15-21	-	-	-

Notes:

1. Dashes indicate no data available.
2. Dates of spawning for cohorts 1 and 2 were back-calculated from the hatch dates using equation (8) and assuming a mean surface temperature of 9.5 degC. See Note 4 for explanation of calculation of hatching dates.
3. Date of hatching of cohort 2 was forward-calculated from the spawning date estimated from aerial surveys and fishery catches by using equation (9) and assuming an average surface water temperature of 9.64 degC for Moller and Herendeen Bays.
4. Dates of hatching of cohorts 1 and 2 were back-calculated from mean lengths of 12.0 and 9.2 mm, respectively, on June 12 by using equation (7) and assuming a growth rate of 0.25 mm d^-1 and a mean length at hatch of 8.4 mm.

Table 6. Number and density of herring larvae in Port Moller, 1989.

Date	Site code	Time	Sample number	Volume filtered by net (m^3)	Cohort 1 number	Cohort 1 measured density (m^-3)	Cohort 1 corrected density (m^-3)	Cohort 2 number	Cohort 2 measured density (m^-3)	Cohort 2 corrected density (m^-3)	Total number	Total measured density (m^-3)
Upper Moller Bay												
11-Jun-89	A	1200	3	133.181	81	0.608	2.162	813	6.104	8.902	894	6.713
11-Jun-89	D	0915	1	88.610	4	0.045	0.156	59	0.666	1.142	63	0.711
11-Jun-89	D	0945	2	212.309	1	0.005	0.012	132	0.622	1.038	133	0.626
13-Jun-89	A	1515	13	208.965	32	0.153	0.694	3133	14.993	27.134	3165	15.146
13-Jun-89	C	1425	12	249.464	0	0.000	0.000	1640	6.574	10.972	1640	6.574
13-Jun-89	C	1625	14	187.584	0	0.000	0.000	875	4.665	7.578	875	4.665
13-Jun-89	D	0850	11	217.141	0	0.000	0.000	491	2.261	3.576	491	2.261
14-Jun-89	A	1630	22	113.319	0	0.000	0.000	1652	14.578	27.848	1652	14.578
14-Jun-89	B	1705	23	162.419	10	0.062	0.213	1042	6.416	11.301	1052	6.477
14-Jun-89	C	1745	24	190.745	1	0.005	0.018	97	0.509	0.896	98	0.514
14-Jun-89	D	1825	25	177.934	2	0.011	0.045	244	1.371	2.351	246	1.383
Lower Moller Bay												
13-Jun-89	E	1710	17	200.881	0	0.000	0.000	68	0.339	0.565	68	0.339
14-Jun-89	J	1350	16	117.924	1	0.008	0.027	14	0.119	0.204	15	0.127
Bering Sea												
11-Jun-89	F	1543	4	124.853	0	0.000	0.000	8	0.064	0.122	8	0.064
12-Jun-89	G	1110	7	259.873	0	0.000	0.000	0	0.000	0.000	0	0.000
12-Jun-89	H	0915	5	151.599	0	0.000	0.000	1	0.007	0.014	1	0.007
12-Jun-89	I	0955	6	229.480	0	0.000	0.000	0	0.000	0.000	0	0.000
14-Jun-89	F	0800	15	191.611	0	0.000	0.000	0	0.000	0.000	0	0.000
Herendeen Bay												
12-Jun-89	K	1255	8	153.803	0	0.000	0.000	3	0.020	0.028	3	0.020
12-Jun-89	M	1600	10	197.766	0	0.000	0.000	225	1.138	1.615	225	1.138
12-Jun-89	O	1440	9	220.743	0	0.000	0.000	200	0.906	1.433	200	0.906
14-Jun-89	K	1300	21	260.937	2	0.008	0.030	25	0.096	0.151	27	0.103
14-Jun-89	L	1140	20	166.415	0	0.000	0.000	21	0.126	0.216	21	0.126
14-Jun-89	M	1035	19	209.269	8	0.038	0.132	274	1.309	2.185	282	1.348
14-Jun-89	N	0915	18	261.454	0	0.000	0.000	155	0.593	1.044	155	0.593
		TOTAL			142			11172			11314	
		MEAN		187.531	6	0.038	0.140	447	2.539	4.413	453	2.577
		SD		48.363	17	0.123	0.445	744	4.243	7.752	751	4.284
		N		25	25	25	25	25	25	25	25	25

Notes:

1. Corrected density = measured density*0.1355*exp(0.270*L), where L=mean length.

Table 7. Parameter values (+ 1SE) of diffusion-mortality models.

		Cohort 1		Cohort 2		
				Moller		
Parameter	Units	Moller	Herendeen	constant mortality	Pareto mortality	Herendeen
$\ln(C/4\pi HK)$	d	2.1126	-	7.1880	8.7716	2.1534
		(0.7947)		(1.0259)	(1.6766)	(0.2795)
K	m^2 d^-1	5.3796x10^6	-	1.3608x10^7	1.3265x10^7	1.2504x10^7
		(1.9965x10^6)		(0.1908x10^7)	(0.1806x10^7)	(0.1677x10^7)
Z	d^-1	-		0.5279	-	-
				(0.2085)		
β		-	-	-	2.6218	-
					(0.7757)	
n		8	2	15	15	7
r^2		0.55	-	0.86	0.87	0.92
radj^2		0.47		0.83	0.84	0.92
P		0.036	-	<0.0001	<0.0001	0.0007

Notes:

1. SE = standard error; n = sample size;
   radj^2 = 1 - (n/n - i)(1 - r^2), where i = number of parameters;
   P = statistical probability of the fit of the model.
2. Dashes indicate the parameter or model was not significant (P>0.05).

best fit with a model with no mortality term. A model with a constant rate of mortality [equation (16a)] explained 1% less of the variance in the densities of cohort 2 larvae of Moller Bay than equation (16b). The residuals of these models were not correlated with t, lnt, x, lnx, Julian date, or time of day at which the tow was taken.

The coefficients of diffusion of cohort 2 larvae were not significantly different (t-test: $P > 0.05$) between those captured in Moller Bay and those captured in Herendeen Bay, but they were 2.3 to 2.5 times higher than the K of the cohort 1 larvae, a difference that is very significant (t-test: $0.001 < P < 0.01$). The lower K for cohort 1 larvae may have been due to the fact that these fish were 9 d older than the cohort 2 fish. Herring larvae cease dispersal as they age and begin to school.

Only one estimate of mortality was obtained, from cohort 2 larvae in Moller Bay; β was significantly higher than 1.0 (t-test: $P < 0.01$) and Z was significantly higher than 0.0 (t-test:$0.02 < P < 0.05$).

In order to determine if the unexplained variance in larval density was caused by violations of the two major assumptions of the models: constant or Pareto-type mortality and Fickian diffusion, the diffusion term and the mortality term on the right-hand side of equation (16b) were moved to the left-hand side to produce diffusion-corrected and mortality-corrected densities. These corrected densities were then plotted against t and $x^2\ t^{-1}$, respectively, and examined for any residual pattern that would indicate a choice of an inappropriate model. Figs. 10 and 11 show no evidence of residual pattern, indicating that that the assumptions of Pareto-type mortality and Fickian diffusion are correct.

However, the plot of diffusion-corrected densities against age for cohort 2 larvae of Moller Bay shows that a constant mortality rate could be substituted for a Pareto-type mortality rate with little decrease in predictive ability of the model. Although this observation has little consequence for the choice of the best predictive model of densities of cohort 2 larvae in Moller Bay, it has important consequences for the back-calculation of the density of newly-hatched larvae because the Pareto-type model predicts much higher densities at $t = 0$ for cohort 2 than the constant-mortality model. This topic is examined in greater detail in section 4.4.1.

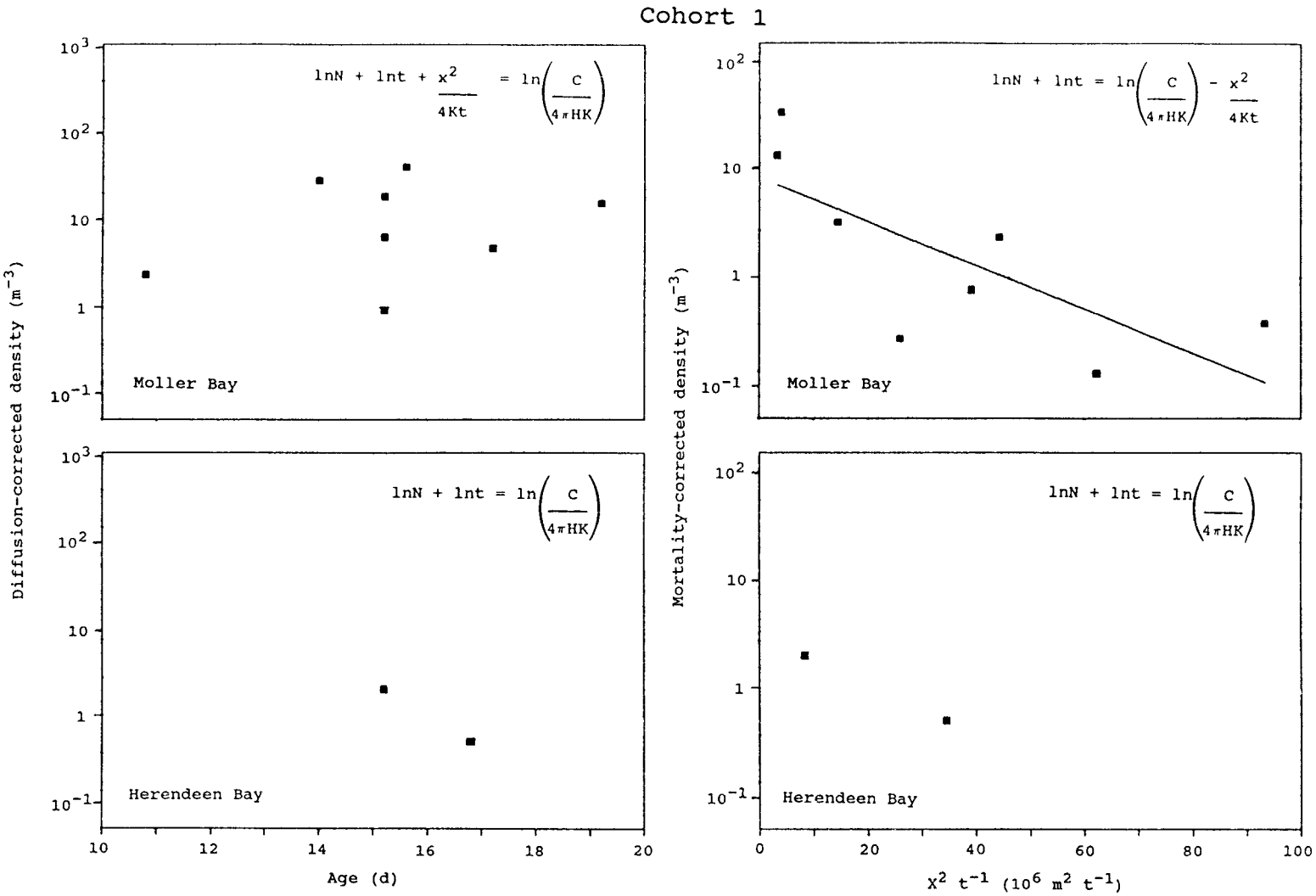


Fig. 10. Diffusion- and mortality-corrected densities of cohort 1 larvae.

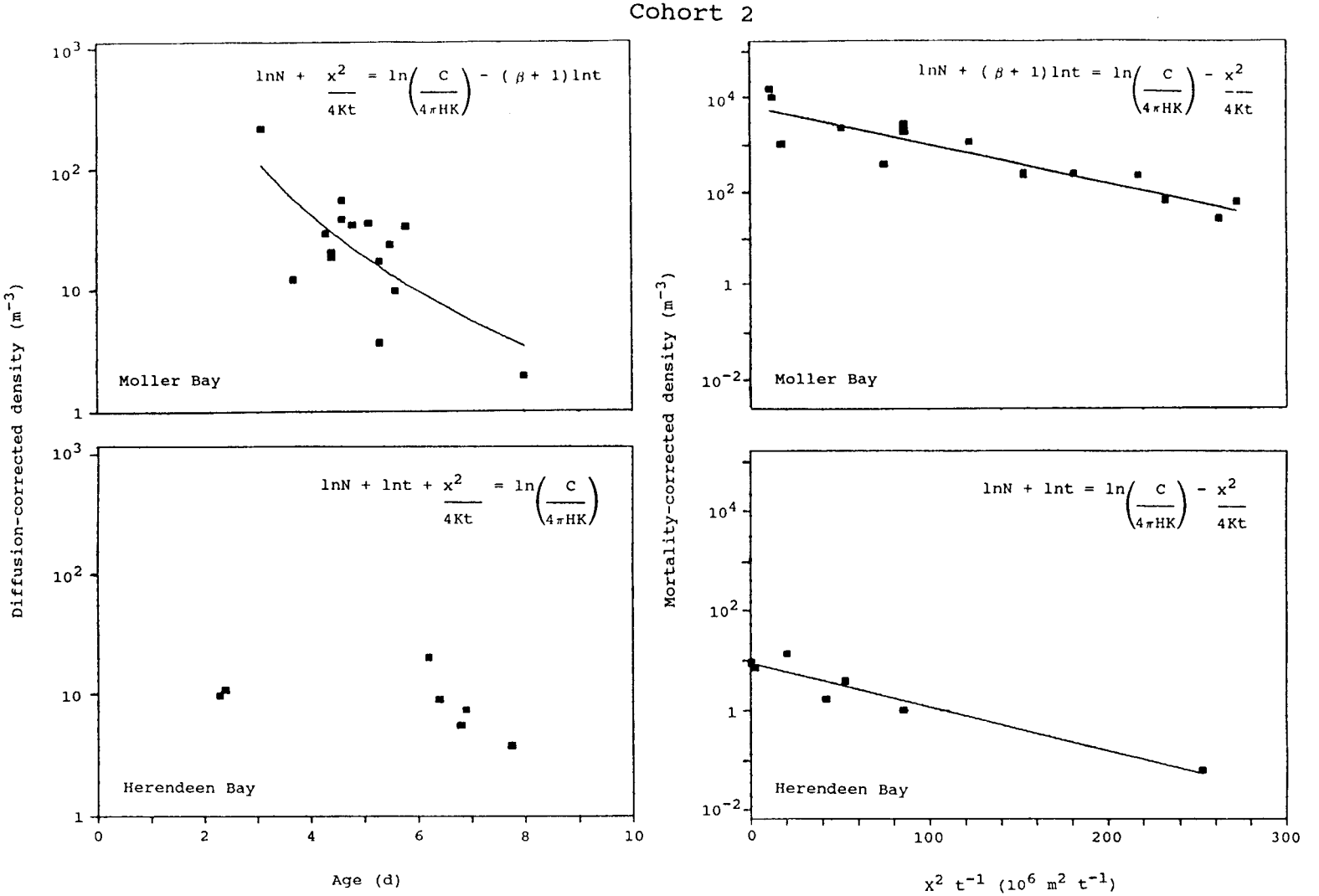


Fig. 11. Diffusion- and mortality-corrected densities of cohort 2 larvae.

4.4 Spawning biomass

4.4.1 Parameter estimates

Survival during the egg stage (s_1)

In the absence of any information on s_1 for the herring eggs of Port Moller, we must choose a range of values from those reported in the scientific literature. There is little consensus on the magnitude of losses of herring eggs due to exposure and predation. Early research in British Columbia on the effects of bird predation (Outram 1958), wave action (Taylor 1964), and exposure and water depth (Taylor 1971, Jones 1972) on the survival of naturally-spawned Pacific herring eggs produced loss rates ranging from 25% to 55%. These are equivalent to Z_e = 0.017 to 0.047 d^{-1}, assuming an average egg incubation time of 17 d at an average water temperature of 8°C (Alderdice and Velsen 1971). However, Haegele et al. (1981) argued that the total loss from exposure and bird predation is closer to 10% or less (or Z_e = 0.006 d^{-1} or less) in southern British Columbia (B.C.) because most of the eggs in that region are laid in subtidal habitat and so only a small fraction of the total number of eggs is exposed to dessication, wave action or predatory birds during each tidal cycle. Following Haegele et al. (1981), the current practice of herring biologists in B.C. is to assume that negligible mortality occurrs during the first week after spawning (Schweigert and Stocker 1988). This argument assumes that predation from bottom-feeding fish or invertebrates is negligible, an assumption which is questionable, especially since there is no published information on losses of herring eggs in subtidal habitat in British Columbia. Some experienced SCUBA divers report observing few potential predators on herring spawn in Prince William Sound, Alaska, (personal communication, E. Biggs, Division of Commercial Fisheries, ADFG, P.O. Box 669, Cordova, Alaska 99574-0669), but others report observing large numbers of flatfish on herring beds in Bristol Bay (personal communication, M. Stekoll, University of Alaska-Southeast, Juneau, Alaska 99801).

The current practice of ADFG herring biologists in southeast Alaska is to assume that 25% of the eggs are lost to exposure and predation unless extraordinarily high concentrations of birds are observed feeding on the eggs, in which case a predation mortality of 50% is assumed (Blankenbeckler 1987). If the average incubation period herring eggs in southeast Alaska is approximately 21 d, then this is equivalent to assuming a daily predation mortality of 0.014 to 0.033 d^{-1}.

A wide range of estimates of egg mortality due to predation has also been reported for Atlantic herring. Tibbo et al. (1963) reported that densities of winter flounder (Pleuronectes americanus) greater than 1 m^{-2} were observed with SCUBA techniques on egg beds near Blanchard Point in Chaleur Bay, New Brunswick. Their stomachs

contained nothing but herring eggs. The mortality of eggs due to this single species of fish was calculated from their densities and from average number of eggs in their stomachs to be at least 7% over the spawning/incubation period of 50 d or at least 0.0015 d^{-1}. This is almost certainly an underestimate of total predation mortality because large numbers of other species of fish were also observed to be feeding on herring eggs.

Caddy and Iles (1973) reported a similar magnitude of total predation on herring eggs laid on Georges Bank. They observed from a submersible that the eggs had attracted a feeding community of fish and invertebrates, and calculated a mortality rate of 8% for the entire incubation period up to about 1 to 2 d before hatching from the number and the size of holes that predators had made in the egg bed. If we assume a spawning/incubation period of approximately 50 d (Tibbo et al. 1963), then this is equivalent to a Z_e of 0.0017 d^{-1}.

Dragesund and Nakken (1973) estimated that about 40% of the potential herring egg production of the Ona-Grip area off the northern coast of Norway was consumed by haddock (Melanogrammus aeglefinus) and saithe (Pollachius virens). They based this estimate on echo-sounding surveys of fish abundance over the egg beds, and on trawl surveys of the fish community. Eighty percent of the haddock and 15% of the saithe caught by the trawls were found to have herring eggs in their stomachs. If the incubation period of the eggs is approximately 25 d as it is in Lindaaspollene, western Norway (Johannessen 1986), then Z_e = 0.020 d^{-1}.

Johannessen (1986) reported that the rates of egg loss from herring egg beds in a fjord on the western coast of Norway ranged from 20 to 60% (mean = 34%) during the first 2 wk after spawning, for a range of Z_e of 0.009 to 0.037 d^{-1} (mean = 0.017 d^{-1}). The loss rates were assumed to result entirely from predation by bottom-feeding invertebrates and fish and by diving ducks. Losses from wave action and strong currents were assumed to be negligible.

Predation mortality of demersal eggs of fish species other than herring has also been measured. Frank and Leggett (1984) reported that mortality of capelin (Mallotus villosus) eggs deposited in the beach of Conception Bay, Newfoundland, from predation by winter flounder (Pseudopleuronectes americanus) ranged from 1.9 to 5.0% (mean = 3.0%, n = 3) over an incubation period of 40 d, which is equivalent to a Z_e of 0.0005 to 0.0013 d^{-1} (mean = 0.0008 d^{-1}).

In summary, Pacific herring eggs laid in the subtidal zone may have a negligible risk of death from exposure and bird predation, but they almost certainly have a significant risk of death from predation by bottom-feeding fish and invertebrates. Almost all of the

herring eggs laid in Port Moller are deposited in subtidal habitat. The range of Z_e of demersal fish eggs that has actually been measured is 0.0008 to 0.017 d^{-1} (Tibbo et al. 1963, Caddy and Iles 1973, Dragesund and Nakken 1973, Frank and Leggett 1984, Johannessen 1986). Therefore, since the egg incubation period in Moller Bay in early June 1989 was 100%/7.02% d^{-1} or 14.2 d, s_1 has an expected range of 0.79 to 0.99.

Fraction of eggs that hatch (s_2)

Alderdice and Velsen (1971) reported an equation that predicts the percent hatch of Pacific herring eggs from the temperature and salinity of their incubation water. If the average temperature (9.89°C) and salinity (20.62 ppt) of the surface water of upper Moller Bay measured over the period June 11 to 14 was similar to the temperatures and salinities that the eggs encountered during their incubation, then their equation predicts a total hatch of 93.7%. This is the maximum percent hatch that could possibly have occurred because Alderdice and Velsen (1971) incubated their eggs under ideal conditions; only one layer of eggs was spawned and this layer was continually perfused with oxygenated seawater. Natural spawns usually consist of several layers of eggs and most studies on this subject have shown that multiple egg layers leads to restriction of the flow of oxygen to eggs in the inner layers and increased mortality of those eggs due to asphyxiation (Taylor 1971, Galkina 1971, Johannessen 1986). Therefore, in order to obtain a realistic value for s_2 we must refer to those reports which have measured the percent hatch of natural herring spawn.

It is generally concluded from the appearance of natural herring spawn that egg survival is high during incubation. Baxter (1971) and Hempel and Hempel (1971) reported that an average of 95.8% and 96.1 to 94.3% of North Sea and Clyde Sea Atlantic herring eggs, respectively, were alive. Haegele et al. (1981) reported that they have rarely ever seen natural Pacific herring spawn from British Columbia which contained less than 90% live eggs. Johannessen (1986) reported similar results for Atlantic herring spawn from Lindaaspollene in western Norway.

These high survival rates do not persist through the hatching period either because the appearance of eggs is a poor index of their actual viability or because the act of hatching is so stressful that it leads to substantial mortality. Hourston et al. (1984) measured the percent total hatch and percent viable hatch of 50 batches of Pacific herring eggs spawned onto 14 different species of vegetation at 5 different spawning intensities. They reported that percent hatch was highly variable ranging from 16 to 100% and that it tended to decrease as spawning intensity increased. The intensity at which percent hatching fell off abruptly varied with the substrate tested, but it was generally low (mean = 30%, SD = 19, n = 21) for all cases of heavy intensity, arbitrarily defined by Hourston et al. (1984) as greater than 250 eggs per linear in of

eelgrass (98 eggs cm^{-1}) or greater than 500 eggs in^{-2} of kelp (775,194 eggs m^{-2}). The mean percent hatch for all cases was 54% (SD = 28, n = 50), and the mean for all cases of very light, light and medium egg intensity was 71% (SD = 19, n = 29).

Similar results were reported by Johannessen (1986) for natural Atlantic herring spawn that had been laid in Lindaspollene, western Norway. Percent hatching of 22 samples of spawn ranged from 17.2 to 84.4% with mean percent hatch decreasing from a maximum of 50.5% (n = 13) for light egg densities (<250,000 eggs m^{-2}) to 27.7% (n = 3) for heavy egg densities (500,000 to 1 million eggs m^{-2}). The mean percent hatch for all samples was 42.8%.

In the absence of any data on the density of herring spawn in Port Moller, the average density recorded for other stocks of herring must be used to guide the choice of an appropriate hatching success. The largest set of data on Pacific herring spawn intensity is a 30 yr long time series that has been collected by herring biologists in British Columbia (Hay 1985, Hay and Kronlund 1987). In general, the density of Pacific herring eggs laid in southern British Columbia ranges between 200,000 and 1 million eggs m^{-2} and rarely exceeds 4 million eggs m^{-2}. Similar densities are found among other Pacific and Atlantic herring stocks, although densities as high as 6 million m^{-2} have occasionally been recorded. Thus, s_2 is assigned a range of values from 0.30 to 0.71.

Fraction of newly-hatched larvae that are viable (s_3)

Hourston et al. (1984) defined viability of newly-hatched Pacific herring larvae as the absence of a bent body axis or retarded or abnormal development. Presumably, larvae defined as non-viable would not survive long enough to enter the population of feeding larvae. Indeed, no deformed larvae were ever observed in the samples taken from Port Moller. Hourston et al. (1984) reported that viability was usually over 80% and that it was not related to type of substrate or to spawning intensity. Therefore, a single mean percent viability was calculated, 83% (SD = 15, n = 50), and s_3 was assigned a value of 0.83.

If one assumes that s_1 = 0.79 to 0.99, s_2 = 0.30 to 0.71, and s_3 = 0.83, then 20 to 58% of the herring eggs laid in Port Moller are expected to hatch into viable larvae.

Relative fecundity (F_r)

Following the arguments presented in section 4.1.6, F_r of Port Moller herring was assumed to be 200 eggs g^{-1}.

Larval Mortality (Z/β)

The mortality rate measured from cohort 2 herring larvae in Moller Bay was assumed to apply to the larvae of both cohorts 1 and 2 in both Moller and Herendeen Bays. This estimate of mortality was one of the few parameters that was measured directly from the larvae of Port Moller, and it was calculated using a method that removed bias due to transport of the larvae out of the sampling area. However, some uncertainty exists concerning the correct way in which to extrapolate from a mortality rate measured at an average age of 5 d to an average age of 0 d or 14 d. Was the mortality rate constant with age? or did it decrease with age as is suggested by the slightly better fit of equation (16b) than equation (16a) to the density data of cohort 2 larvae in Moller Bay? A comparison of Z from Moller Bay with estimates of Z from the published literature

Z (d^{-1})	Age (d)	Location	Author
0.25	1-23	Barkley Sound, B.C.	Stevenson (1962)
0.40	1-27	Queen Cove, B.C.	Stevenson (1962)
0.09	1-48	Akkeshi Bay, Japan	Iizuka (1966)
0.12	1-30	Akkeshi Bay, Japan	Iizuka (1966)
0.02	5-55	Bamfield Inlet, B.C.	McGurk (1989a)
0.16	1-37	Bamfield Inlet, B.C.	McGurk (1989a)
0.53	3-8	Moller Bay, Alaska	this study

shows that the Z from Port Moller is the highest ever measured for Pacific herring larvae, but that it is also an estimate for the shortest and earliest age span. This suggests that one explanation for the high Z of Port Moller larvae is that it was measured for relatively young larvae, and that mortality of Pacific herring larvae may decrease with age according to some Pareto-type function. This argument is supported by Hewitt et al.'s (1985) report that mortality of young jack mackerel, Trachurus symmetricus, larvae decreased exponentially with age from rates as high as 0.9 d^{-1} for 1 d old fish, and by McGurk's (1986) suggestion that exponential declines in mortality rate with age may occur in pelagic eggs and very young larvae of many species of marine fish due to predation on patches of eggs and newly-hatched larvae.

However, this data must be interpreted with caution because of the many factors involved in their estimation. Also, as will be shown in section 4.4.2 below, the use of Pareto-type mortality to back-calculate the number of newly-hatched herring larvae in Port Moller leads to predictions of spawning biomass of cohort 2 that are much too high to be accepted. Therefore, in this study stock biomass was back-calculated using both Z and β, and the mortality function that predicted the most reasonable stock biomass was accepted as the best predictor of mortality in the immediate post-hatching ages.

4.4.2 Estimates of spawning biomass

Table 8 shows an example of the calculations used to back-calculate spawning biomass from density of larvae in Port Moller. Table 9 shows the biomasses of cohort 1 and 2 back-calculated under the assumptions of constant mortality and Pareto-type mortality, and for the two extremes of the range of likely values of s_1 and s_2. Spawning biomass of cohort 1 was calculated to range from 5,101 to 26,214 MT. Spawning biomass of cohort 2 ranged from 1,788 to 30,791 MT.

The fact that biomasses of cohort 1 fish of the magnitude shown in Table 9 have never been seen in or near Port Moller indicates that all of the biomass estimates for cohort 1 are too large to be realistic. They should not be used for any stock management purpose.

The biomasses of cohort 2 that were estimated using a Pareto-type mortality are also much too large to be realistic, but the biomasses calculated under the assumptions of a constant mortality rate (Z) of 0.5279 d^{-1}, a range of egg survival rates (s_1) of 0.79 to 0.99, and a fractional hatching success (s_2) of 0.71 are reasonable because they are only 1 to 27% times higher than the spawning biomass estimated from aerial surveys in 1989.

This analysis shows that the application of a mortality rate measured from 5 d old cohort 2 larvae to 14 d old cohort 1 larvae leads to unrealistic estimates of spawning biomass. It also shows that the use of a Pareto-type mortality to back-calculate spawning biomass also leads to unrealistically high estimates of biomass. Only when mortality is measured relatively close in time to the spawning date, and mortality is assumed to be constant over the early larval period, is a realistic estimate of spawning biomass produced.

One way of assessing the validity of the calculations shown in Tables 8 and 9 is to calculate the mortality rates that would have been required to produce the number of cohort 2 larvae measured in Port Moller, if the spawning biomass that was observed by aerial surveys was an accurate estimate of true spawning biomass. If survival during incubation and hatching is assumed to range from 0.20 (s_1 s_2 s_3 = 0.79 0.30 0.83) to 0.58

Table 8. Spawning biomass of herring in Port Moller.

Site	x (m)	Area of section (m^2) sub-tidal	inter-tidal	total	Depth of section (m) sub-tidal	inter-tidal	Volume of section (m^3) sub-tidal	inter-tidal	total	Cohort 1 Estimated density of larvae (m^-3)	total number of larvae	Cohort 2 Estimated density of larvae (m^-3)	total number of larvae
A	7980	28917525	48498450	77415975	4.4	1.5	127237110	72747675	199984785	0.4863	97251845	13.95010	2789806752
B	14763	21526050	34234200	55760250	6.0	1.5	129156300	51351300	180507600	0.2881	51999430	7.88844	1423923779
C	19870	28074637	10438838	38513475	5.6	1.5	157217967	15658257	172876224	0.1580	27322433	4.10323	709351024
D	25935	24184387	19256725	43441125	6.4	1.5	154780077	28885088	183665164	0.0616	11305891	1.46982	269954851
E	30962	49017150	9077250	58094400	6.1	1.5	299004615	13615875	312620490	0.0233	7289227	0.51076	159675197
F	36069	95246287	972563	96218850	8.2	1.5	781019553	1458845	782478398	0.0073	5708521	0.14415	112792613
G	48358	216946275	0	216946275	17.2	1.5	3731475930	0	3731475930	0.0002	804553	0.00312	11628815
H	45805	75730200	0	75730200	8.0	1.5	605841600	0	605841600	0.0005	295390	0.00758	4590250
I	57935	35660625	0	35660625	9.6	1.5	342342000	0	342342000	0.0000	2331	0.00007	24794
J	36149	68727750	56473462	125201212	5.6	1.5	384875400	84710193	469585593	0.0072	3359307	0.14110	66259884
K	24100	58548262	69440962	127989225	6.0	1.5	351289572	104161443	455451015	0.0630	28693414	0.17316	78866879
L	18035	26907562	34623225	61530787	3.8	1.5	102248736	51934838	154183573	0.0630	9713565	0.47172	72731107
M	11252	37929937	4733137	42663075	16.4	1.5	622050967	7099706	629150672	0.0630	39636492	1.02805	646795529
N	4389	8234362	778050	9012412	45.4	1.5	247030860	1167075	248197935	0.0630	15636470	1.56614	388713892
O	1676	6548587	324187	6872775	33.9	1.5	196457610	486281	196943891	0.0630	12407465	1.67053	329001640
TOTAL											311426334		7064117006
Parameters: Z											0.528		0.528
t											13.700		5.100
Number new larvae											430797242581		104304867264
s1											0.990		0.990
s2											0.710		0.710
s3											0.830		0.830
Number new eggs											7.38416E+11		1.78786E+11
Fr											200.000		200.000
Spawning biomass (MT)											7384.16		1787.86

Notes:

1. Mean depth of water above mean LLT was calculated from all sampling times.
2. Depths of stations N and O were restricted to 30 m for the purpose of calculating volumes.

Table 9. Estimates of the number of herring eggs and larvae and of spawning biomass.

	constant mortality (Z = 0.5279)				exponential mortality (beta = 2.6218)			
	s1=0.79		s1=0.99		s1=0.79		s1=0.99	
	s2=0.3	s2=0.71	s2=0.3	s2=0.71	s2=0.3	s2=0.71	s2=0.3	s2=0.71
				Cohort 1				
Nt	3.1143x10^8							
N0	4.3080x10^11				2.9758x10^11			
Ne	21.9001x10^11	9.2536x10^11	17.4758x10^11	7.3842x10^11	18.1078x10^11	7.6512x10^11	12.0719x10^11	5.1008x10^11
B	21,900	9,254	17,476	7,384	18,108	7,651	12,072	5,101
				Cohort 2				
Nt	7.0641x10^9							
N0	1.0430x10^11				5.0602x10^11			
Ne	5.3025x10^11	2.2405x10^11	4.2313x10^11	1.7879x10^11	30.7909x10^11	13.0102x10^11	20.5272x10^11	8.6735x10^11
B	5,302	2,241	4,231	1,788	30,791	13,010	20,527	8,673

Notes:

Nt = number of larvae at age t;

N0 = number of larvae at hatch (t=0);

Ne = number of eggs spawned; and

B = spawning biomass (MT).

(s_1 s_2 s_3 = 0.99 0.71 0.83), then $3.528x10^{10}$ to $1.023x10^{11}$ viable cohort 2 larvae would have been produced from $1.764x10^{11}$ newly-laid eggs. This leads to expected instantaneous larval mortality rates of 0.31 to 0.53 d^{-1} over the first 5 d after hatch. These are high rates of larval mortality compared to those that have been reported in the literature for this species (section 4.4.1), and so they support the validity of the high rate of larval mortality measured in this study.

If larval mortality is assumed to have been constant at 0.5279 d^{-1} over the first 5 d after hatch, then 59% [= $100(1.0430x10^{11}/1.764x10^{11})$], of the eggs of cohort 2 are expected to have hatched viable larvae, i.e. s_1 s_2 s_3 = 0.59. If a range of egg survivals (s_1) of 79 to 99% is assumed, then 72 to 90% of the surviving eggs must have survived the stress of hatching. A hatching success of this magnitude is within the range reported for light intensities of natural herring spawn, implying that the eggs were laid in Port Moller at densities less than approximately 500,000 eggs m^{-2}. In this regard, it is interesting to note that eelgrass, Zostera, was the only substrate tested by Hourston et al. (1984) to have 100% hatch. Eelgrass is the major herring pawning substrate in Port Moller.

4.4.3 Perturbation analysis

The relative importance of the parameters used to calculate spawning biomass can be obtained by combining equations (10), (11), (12) and (14a) to give

$$(20) \quad B = \frac{2N_t \exp(Z_e t_e + Zt)}{10^6 s_2 s_3 F_r}$$

and then perturbing each of the parameters in equation (20) by $\pm$5% and $\pm$25%. Table 10 shows that spawning biomass is most sensitive larval mortality, Z, and to the average age of capture of the larvae, t. Spawning biomass was least sensitive to egg mortality, Z_e, and egg incubation time, t_e. Perturbations of the other four parameters result in changes of only -25.0 to +33.3% in the back-calculated spawning biomass. Table 10 also shows that the response of biomass to perturbations in Z and t is approximately twice as great for overestimates of Z and t as it is for underestimates of the two parameters. Asymmetrical responses are also observed for Z_e, t_e, s_2, s_3 and F_r, but with lower magnitudes.

This analysis indicates that correct ageing of the larvae is as important to the back-calculation of spawning biomass as is obtaining a correct estimate of larval mortality rate. It also implies that the accuracy of back-calculated stock biomass would be maximized if the densities of herring larvae were measured as close to the date of hatch as is practical.

Table 10. Response of equation (20) to perturbation of its parameters.

Parameter	Perturbation -25%	-5%	+5%	+25%
Nt	-25.0	-5.0	5.0	25.0
Ze	-3.1	-0.6	0.6	3.3
te	-3.1	-0.6	0.6	3.3
Z	-49.0	-12.6	14.3	96.0
t	-49.0	-12.6	14.3	96.0
s2	33.3	5.3	4.8	-20.0
s3	33.3	5.3	4.8	-20.0
Fr	33.3	5.3	4.8	-20.0

Note:
1. Initial parameter values taken from cohort 2.

4.5 Location of spawning habitat

4.5.1 Distribution of intertidal vegetation

Extensive beds of eelgrass were observed at four locations in Moller Bay (Fig. 12A, B):

(1) on the western and eastern shores of Deer Island;

(2) on the tidal flats opposite Harbor Point;

(3) inside Harbor Point; and

(4) off an unnamed bluff that defines the western edge of Right Head.

Narrow strips of eelgrass were observed along the shore between Egg Island and the entrance to Left Head, and scattered bands of Fucus were observed on rocky reefs along the shore of upper Moller Bay opposite Entrance Point and below the bluffs that separate Left and Right Heads.

No vegetation was observed along the Bering Sea coast from Entrance Point to the mouth of Bear River (Fig. 12B).

Scattered bands of eelgrass were observed at three locations in Herendeen bay (Fig. 12C):

(1) along the western shore between Village Spit and Buck Valley;

(2) around Midway Reef between Bluff and Crow Points; and

(3) along the southern shores opposite Grass and Lawrence Valleys.

Scattered Fucus was also seen on rocky substrate below Bluff, Crow and Gull Points. No vegetation was observed in Mud Bay or Nelson Lagoon or along the eastern or western shores of upper Herendeen Bay.

4.5.2 Traditional herring spawning beaches

According to Warren Johnson spawning occurs at six sites in the Port Moller complex each year (Fig. 13A, B, and C). These "consistent" sites are:

(1) the beds of Fucus along the shore of lower Moller Bay opposite Entrance Point;

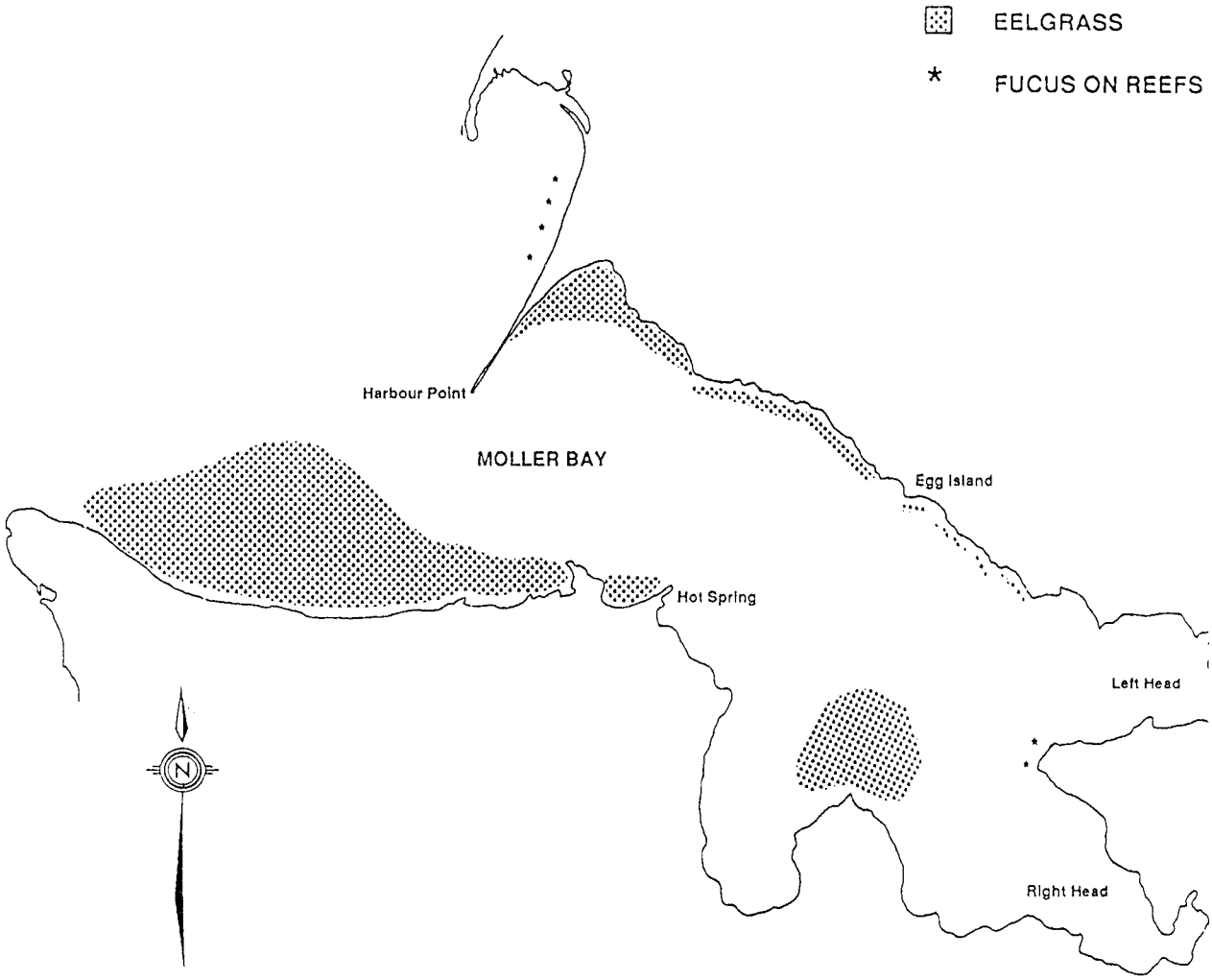


Fig. 12A. Map of intertidal and subtidal vegetation.

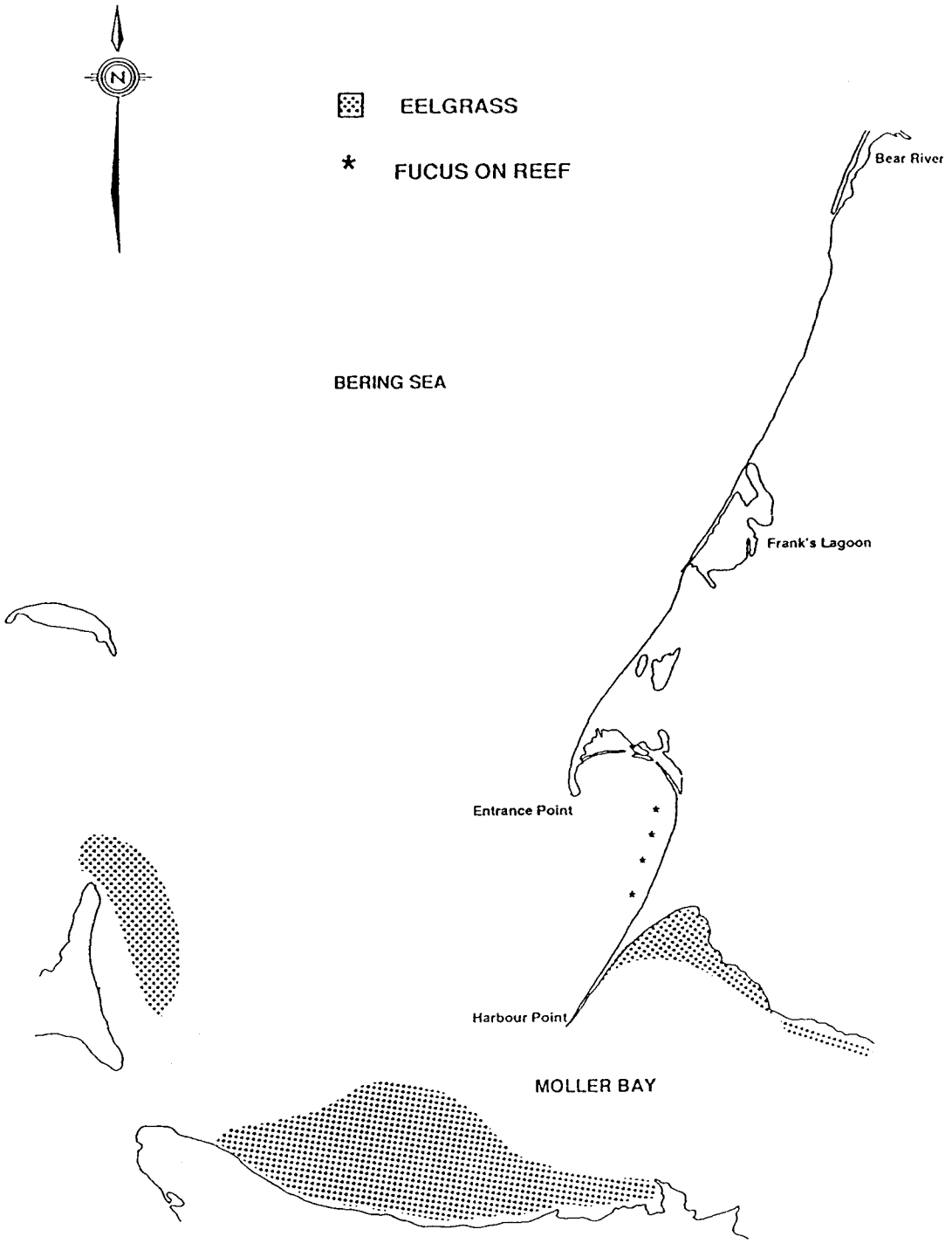


Fig. 12B. Map of intertidal and subtidal vegetation.

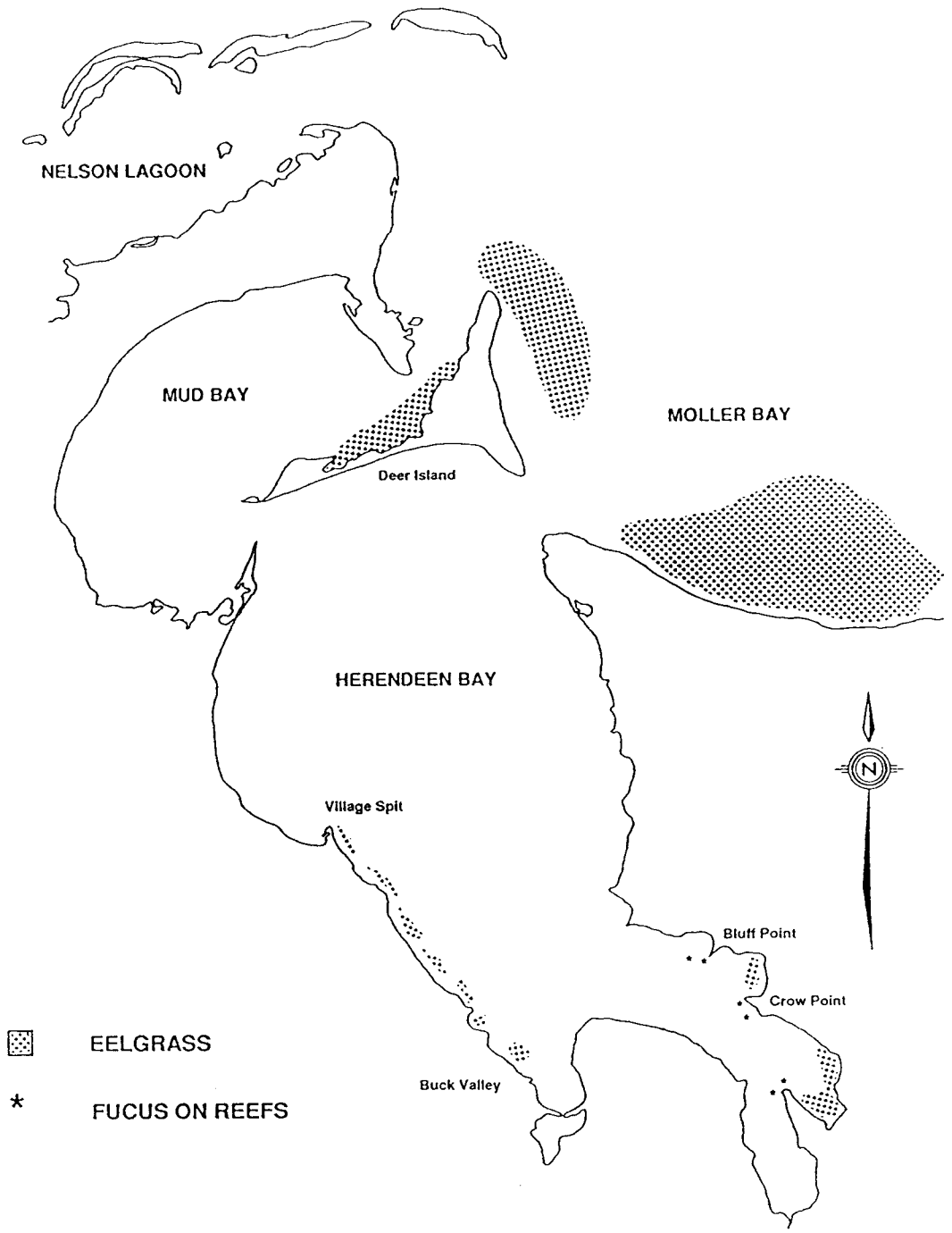


Fig. 12C. Map of intertidal and subtidal vegetation.

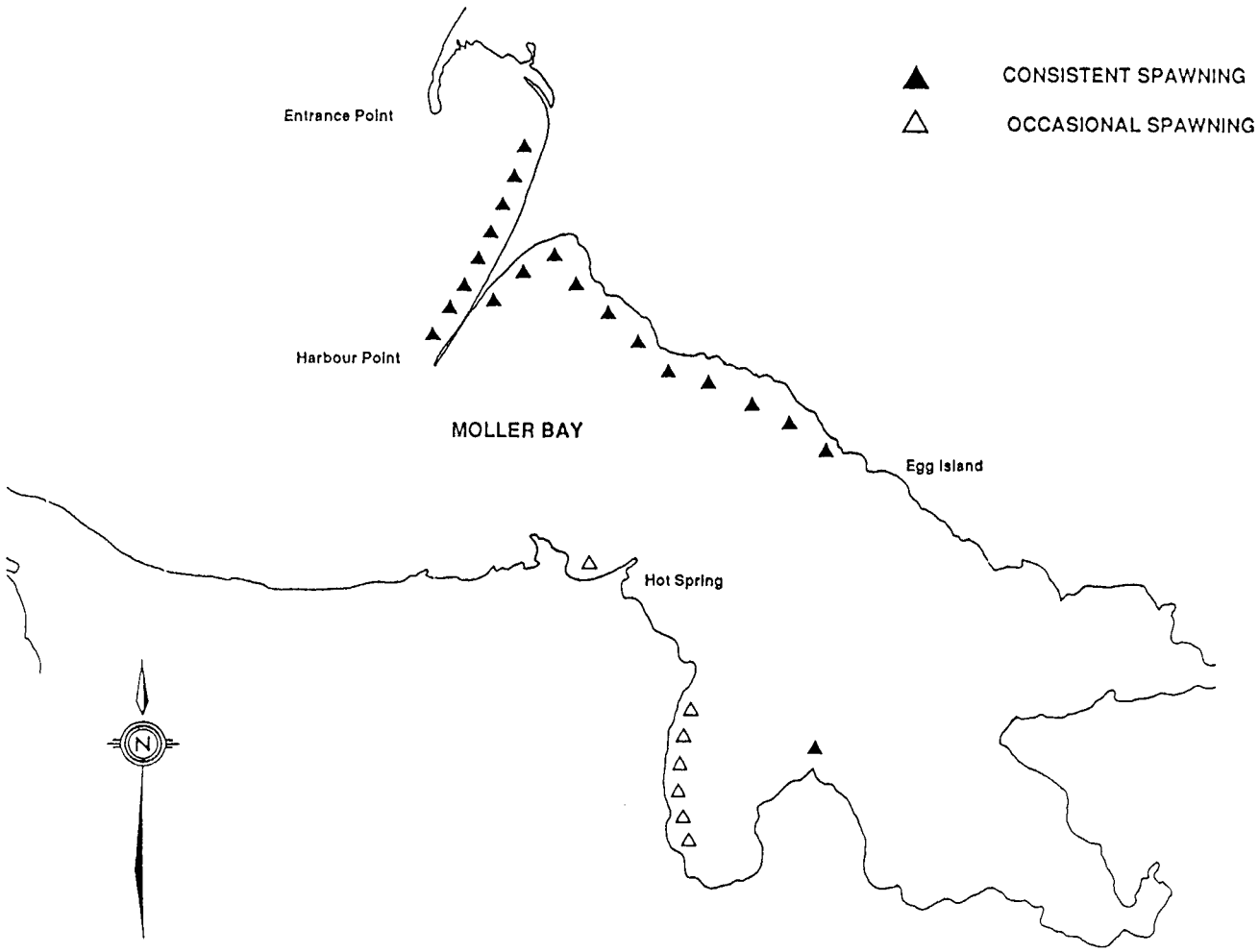


Fig. 13A. Map of herring spawning sites.

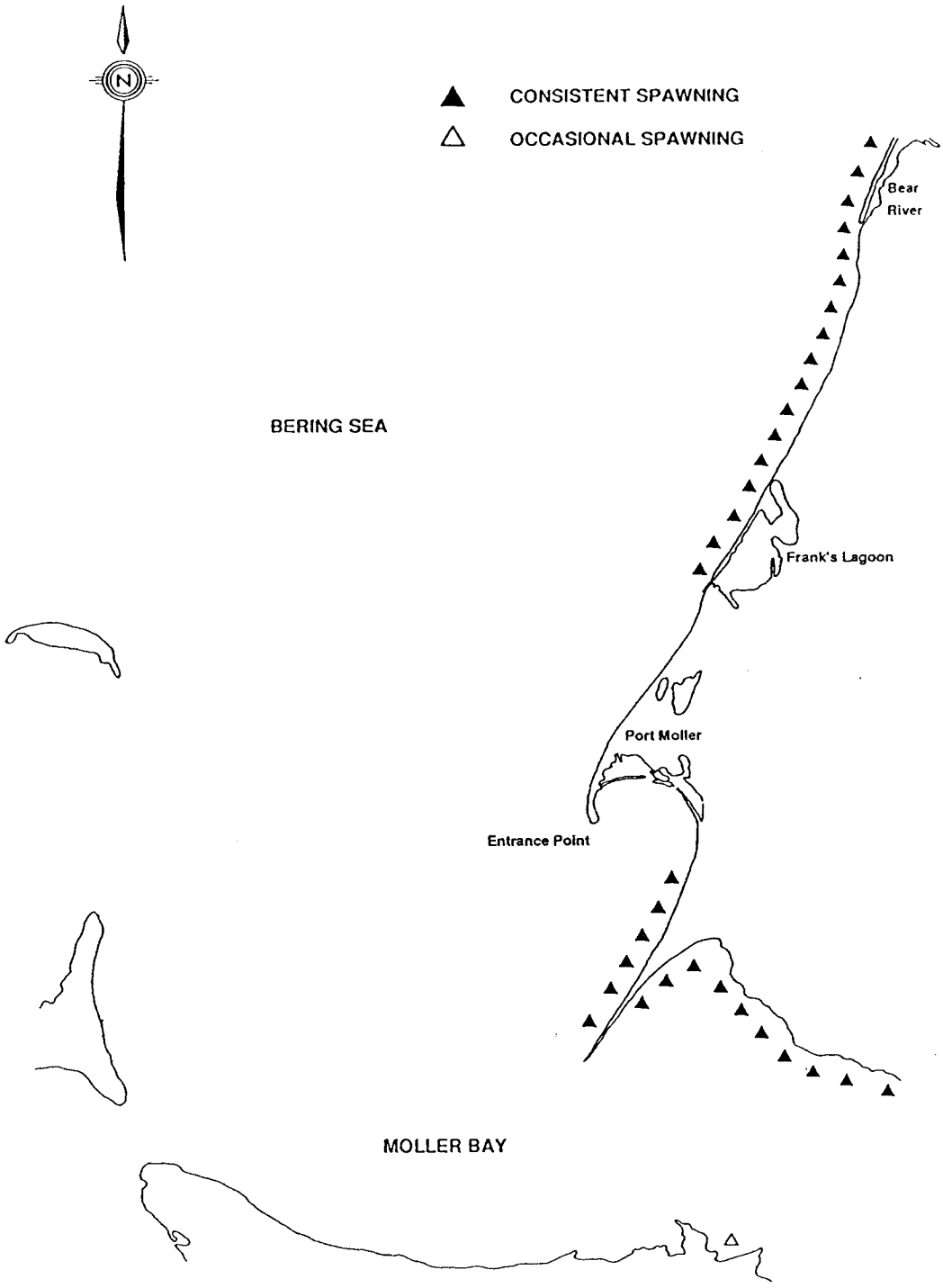


Fig. 13B. Map of herring spawning sites.

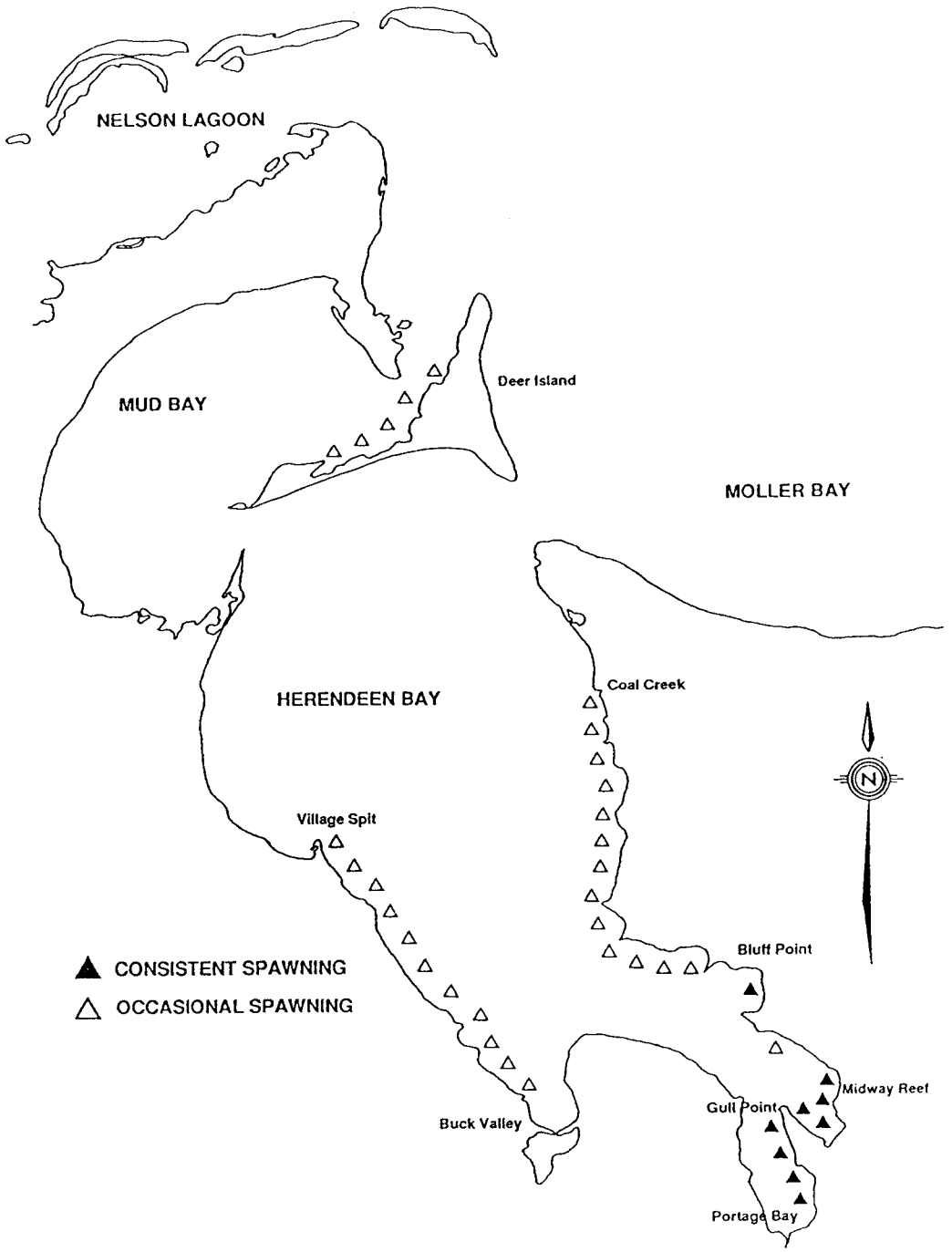


Fig. 13C. Map of herring spawning sites.

(2) the beds of eelgrass inside Harbor Point and extending southeast as far as Egg Island;

(3) the large eelgrass bed off the shore of the unnamed bluff that defines the western edge of Right Head in upper Moller Bay;

(4) the Bering Sea shore from Frank's Lagoon to the mouth of the Bear River;

(5) the eastern shore of Portage Bay and the shoreline of the adjacent Bay to the east; and

(6) the shore just south of Bluff Point.

The site opposite Entrance Point is usually the first to receive spawn. In Moller Bay, the sites of heaviest spawning are inside Harbor Point and opposite the unnamed bluff west of Right Head. In Herendeen Bay, the most concentrated spawning occurs in the southernmost embayments: Portage Bay and the adjacent eastern bay.

Occasional spawning, arbitrarily defined as once every 4 yr, was reported to occur at four sites:

(1) along the shore north and south of Hot Spring;

(2) on the northwestern shore of Deer Island;

(3) on the western shore of Herendeen bay between Village Spit and Buck Valley; and

(4) on the eastern shore of Herendeen Bay between Coal Creek and Bluff Point.

Len Schwarz states that spawning has also been observed on the eastern shore of the peninsula that separates Left and Right Heads of Moller Bay and on the western shore of Portage Bay. It is not known whether these sites are "consistent" or "occasional".

Spawning does not occur often, if it occurs at all, in Left and Right Heads of Moller Bay, even though pre-spawning adults have been seen there. Warren Johnson states that the adults usually aggregate there before moving on to the large eelgrass beds just west of Right Head to spawn. No spawning has been known to occur on the extensive beds of eelgrass along the shore of Moller Bay several kilometers west of Hot Spring, on the Bering Sea shore between Entrance Point and Frank's Lagoon, on the western shore of upper Herendeen Bay, on the southern shore of Deer Island, in Mud Bay, or in Nelson Lagoon.

5. Discussion

5.1 Stock structure

The spawn timing reported in this review falls within the range reported by Rounsefell (1930), Wespestad and Barton (1979) and Barton and Wespestad (1980) [see also the review by Hay (1985)]. These authors report that Pacific herring spawn on the north shore of the Alaska Peninsula and in Bristol Bay from early May to mid-June.

The existence of at least 2 separate spawning runs in the same location has been reported in Pacific herring from British Columbia (Hay 1985), and in Atlantic herring from the eastern coast of North America and from the North Sea (Lambert 1984, 1987). Its ubiquity indicates that it is a basic feature of herring stock structure.

Both Lambert (1987) and Hay (1985) report that the runs represent separate age classes, with the oldest fish, usually 5+, spawning first and younger fish spawning in later runs. They report that the number of days between spawning runs ranges from 17 to 25 d, which is very close to the period of time, 18 to 24 d, separating the 2 runs in Port Moller in 1987. This suggests that the spawners observed in June 1987 and June 1989 may have been younger age classses of the same stock as the spawners that were observed in May 1987 and May 1989, respectively, rather than a separate stock.

The age structure of Port Moller herring supports the idea that the 2 groups of spawners in 1987 and 1989 came from the same spawning stock, that older fish spawned first in May, and that younger fish spawned in June. A trend of decreasing modal age of spawners as the spawning season progresses has also been observed in herring from Togiak and Norton Sound (Fried et al. 1982, 1983, Lebida et al. 1986).

The fact that the age structures of both the May and June spawners are similar, apart from the increased proportion of recruit spawners in June, does not support the hypothesis that the 2 spawning runs represent 2 different spawning stocks, unless one assumes that all spawning stocks in the eastern Bering Sea have synchronous year-class strengths, and that different stocks spawn in the same areas. The hypothesis of one stock and age-dependent run timing is the most parsimonious expanation for the origin of multiple spawning runs in Port Moller.

The observation that a June spawning run only occurs about every second year has three explanations. First, it may occur every year but not be reported because: biological data is not collected after the fishery is closed, which usually occurs in May; aerial surveys are unreliable because of the poor 'seeing' conditions in Port Moller; and the June spawning run is too small to be observed except during years in which very

strong year-classes are passing through the 3 to 5 year old age classes. Two corollaries of this explanation is that the fish which hatched in 1983 produced a strong year-class which appeared as 4 yr olds in 1987, and that the 1988 and 1989 spawning population should have been dominated by 5 and 6 year old fish, respectively. Fig. 5 supports the second prediction, but not the first.

The alternate explanation for the apparent absence of a June spawning run in 1983, 1984, and 1986 is that the run does not occur every year for reasons that are unknown. The first explanation is the most parsimonious one, and it also takes into account the difficulty involved in collecting reliable information from a stock of fish that spawns in one of the most remote locations in Alaska.

The controversy concerning the stock structure of Port Moller herring has obvious relevance for the management of the stock. It is also important for an understanding of the dynamics of the egg and larval stages because the timing of production of larvae in relation to the food production cycle, their spatial distribution within the Port Moller estuary, and the viability of the eggs and larvae are affected by the age, size, and relative abundance of the spawners. For example, recruit spawners produce smaller eggs than 5+ spawners (Kingston 1983), and they spawn several weeks after the older fish at a time (June) when the spring plankton bloom is usually subsiding. Both factors may reduce the survival rate of the larvae that hatch from these eggs.

5.2 Spawning biomass

The biomass of the spawners that produced the cohort 2 larvae was at least 1,764 MT but less than 2,241 MT. Since this group of fish was only the second of three spawning waves, the total size of the Port Moller stock, excluding immature fish, probably close to 3,000 MT.

To my knowledge, this report is the first attempt to compare spawning biomasses of Pacific herring calculated from aerial surveys and larval surveys. The comparison shows that spawning biomass can be estimated from a larval survey, but that the method is so sensitive to the mortality rates of the eggs and young larvae that it can only be used under special circumstances. These include complete spatial coverage of the larvae or at least sufficient coverage to calculate reliable rates of dispersal; temporal coverage sufficient to calculate reliable estimates of larval mortality; accurate ageing of the larvae; and accurate information on the average density of egg deposition.

Larval surveys are impractical for realtime management of a stock because they require too much time to analyse the data.

Despite these restrictions, larval surveys may be useful in assessing spawning biomass in areas such as Port Moller where other techniques of stock assessment are impractical or fail too often to be relied upon. This report is the first review of the information requirements of the larval survey method for Pacific herring. It identifies likely values

of important population parameters for Bering Sea herring. Whether or not these parameter values can be applied to other populations can only be known after future studies of this kind have been performed.

5.3 Location of spawning sites

Most of the major herring spawning sites of the Port Moller complex coincide with observed beds of eelgrass and Fucus. The probable sites of spawning identified by the distribution of herring larvae also coincide with these beds. The most likely spawning sites for both cohorts 1 and 2 are the eelgrass beds off Right Head in Moller Bay, and the eelgrass beds south of Bluff Point in Herendeen Bay.

The two exceptions to this pattern are the presence of spawning on the Bering Sea coast between Frank's Lagoon and Bear River despite the absence of vegetation, and the absence of spawning on the shores opposite Harbor Point despite the presence of extensive eelgrass beds.

5.4 Comparison of larval abundance with Auke Bay

The results of this reconnaissance show that the herring that utilize Port Moller are at least one magnitude more abundant than the herring that spawned in Auke Bay in 1988. This is demonstrated by a comparison of larval densities between the two sites:

	Number of herring larvae				Density (m^{-3}) of herring larvae			
Site	mean	SD	n	range	mean	SD	n	range
Port Moller	453	751	25	0-3,165	2.577	4.284	25	0.000-15.146
Auke Bay	13	15	98	0-8	0.168	0.332	98	0.000- 1.914

and a comparison of spawning biomasses:

	Spawning biomass (MT)	
Site	cohort 2	cohort 3
Port Moller	1,788 - 2,241	-
Auke Bay	13	6

6. Recommendations

1. There is sufficient density of herring larvae in Port Moller to make a study of their population dynamics feasible.

2. Future studies of the early life history stages of Port Moller herring must begin on May 1 and run to at least July 15 because herring in Port Moller spawn in at least three waves beginning in mid-May and running to mid-June.

3. Future studies must extend over all parts of Moller and Herendeen Bays because both Bays support separate groups of larvae. The studies should also extend at least as far north as the mouth of the Bear River, since consistent spawning is reported to occur on the coast between Frank's Lagoon and Bear River.

4. Future studies involving plankton sampling must filter more than 187 m^3 of water in each tow in order to be able to reliably detect the presence of herring larvae that are older than 14 d.

5. Future studies should be designed to locate egg beds within Port Moller, identify their relative use by successive waves of spawners, and measure the dynamics of the egg stage because these are important subjects of basic research. They are important not only for assessing the possible impacts of oil development on herring resources in Port Moller, but for measuring the size and structure of the Port Moller herring stock and for testing and refining techniques of stock assessment that may be employed for other herring stocks that spawn in sub-tidal areas of Alaska.

6. The plan for the physical/biological population model of herring larvae in Port Moller should incorporate techniques for measuring daily changes in the magnitude of population parameters. This is especially important for testing the hypothesis that mortality of newly-hatched herring larvae declines exponentially with age, and for measuring the rate of change of mortality as accurately as possible.

7. The causes of the break in coastal current patterns that has been reported to occur at Bear River should be investigated by those responsible for measuring and modelling the hydrodynamics of the Port Moller complex because this may be relevant to the retention of herring larvae within the Port Moller area.

8. The Alaska Department of Fish and Game should be formally requested to compile, analyse, and publish the information they have collected on Port Moller herring. Special attention should be taken to compare age structures and growth curves of separate spawning waves with each other and with those of adjacent stocks in Bristol Bay and the Aleutian Islands in order to test the hypothesis that the Port Moller fish consist of only one stock, and that it is separate from all others in the Bering Sea.

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Appendix A. Dates of Pacific herring fishery in Port Moller, Alaska

	Herendeen Bay		Moller Bay		Bear River			
Date	catch (MT)	percent roe yield	catch (MT)	percent roe yield	catch (MT)	percent roe yield	Total catch (MT)	Percent of total catch
31-May-82	-	-	-	-	42	-	42	9.0
2-Jun-82	60	-	-	-	-	-	60	12.8
8-Jun-82	-	-	164	-	-	-	164	35.1
10-Jun-82	92	-	-	-	-	-	92	19.7
12-Jun-82	109	-	-	-	-	-	109	23.3
	261		164		42		467	100.0
9-May-83	257	-	-	-	-	-	257	44.4
10-May-83	43	-	-	-	-	-	43	7.4
14-May-83	2	-	-	-	-	-	2	0.3
17-May-83	112	-	-	-	-	-	112	19.3
18-May-83	59	-	-	-	-	-	59	10.2
19-May-83	-	-	55	-	-	-	55	9.5
20-May-83	-	-	49	-	-	-	49	8.5
21-May-83	-	-	1	-	-	-	1	0.2
29-May-83	-	-	1	-	-	-	1	0.2
	473		106		0		579	100.0
24-May-84	-	-	149	-	-	-	149	38.0
25-May-84	87	-	68	-	-	-	155	39.5
27-May-84	22	-	-	-	-	-	22	5.6
28-May-84	1	-	-	-	-	-	1	0.3
31-May-84	18	-	-	-	-	-	18	4.6
1-Jun-84	29	-	-	-	-	-	29	7.4
4-Jun-84	7	-	-	-	-	-	7	1.8
8-Jun-84	-	-	11	-	-	-	11	2.8
	164		228		0		392	100.0
24-May-85	15	-	-		-	-	15	2.3
25-May-85	16	-	-		-	-	16	2.5
26-May-85	27	-	-		-	-	27	4.2
27-May-85	11	-	18		-	-	29	4.5
29-May-85	-	-	-		261	-	261	40.2
30-May-85	-	-	40		-	-	40	6.2
1-Jun-85	-	-	174		-	-	174	26.8

Appendix A. Dates of Pacific herring fishery in Port Moller, Alaska

	Herendeen Bay		Moller Bay		Bear River			
Date	catch (MT)	percent roe yield	catch (MT)	percent roe yield	catch (MT)	percent roe yield	Total catch (MT)	Percent of total catch
4-Jun-85	87	-	-		-	-	87	13.4
	156		232		261		649	100.0
18-May-86	-	-	3	-	-	-	3	0.4
19-May-86	-	-	31	-	-	-	31	3.8
20-May-86	102	-	10	-	-	-	112	13.8
21-May-86	-	-	-	-	64	-	64	7.9
22-May-86	-	-	-	-	-	-	0	0.0
23-May-86	-	-	1	-	-	-	1	0.1
24-May-86	-	-	14	-	41	-	55	6.8
25-May-86	4	-	10	-	21	-	35	4.3
26-May-86	34	-	169	-	19	-	222	27.4
27-May-86	-	-	1	-	-	-	1	0.1
28-May-86	-	-	-	-	-	-	0	0.0
29-May-86	-	-	-	-	217	-	217	26.8
30-May-86	-	-	-	-	68	-	68	8.4
	140		239		430		809	100.0
9-May-87	-	-	18	7.12	-	-	18	3.9
10-May-87	109	10.44	17	12.62	7	12.04	133	28.5
11-May-87	37	9.31	18	8.99	-	-	55	11.8
19-May-87	-	-	48	6.90	-	-	48	10.3
2-Jun-87	-	-	103	12.51	-	-	103	22.1
4-Jun-87	-	-	83	12.23	-	-	83	17.8
5-Jun-87	-	-	26	9.77	-	-	26	5.6
	146		313		7		466	100.0
28-May-88	4	9.00	-	-	-	-	4	1.5
6-Jun-88	3	7.20	-	-	-	-	3	1.1
9-Jun-88	-	-	61	7.30	-	-	61	22.8
10-Jun-88	-	-	6	5.70	-	-	6	2.2
12-Jun-88	-	-	6	8.60	-	-	6	2.2
16-Jun-88	-	-	124	8.50	-	-	124	46.4
17-Jun-88	-	-	63	9.00	-	-	63	23.6
	7		260		-		267	100.0

Appendix A. Dates of Pacific herring fishery in Port Moller, Alaska

Date	Herendeen Bay catch (MT)	Herendeen Bay percent roe yield	Moller Bay catch (MT)	Moller Bay percent roe yield	Bear River catch (MT)	Bear River percent roe yield	Total catch (MT)	Percent of total catch
29-May-89	-	-	284	9.80	-	-	284	63.1
16-Jun-89	28	9.40	-	-	-	-	28	6.2
17-Jun-89	33	8.70	80	8.60	-	-	113	25.1
23-Jun-89	-	-	25	10.00	-	-	25	5.6
	62		389		-		450	100.0

Notes:

1. Catches are processed herring boxed weights.
2. Dashes indicate data not taken or recorded.

Appendix B. Biomass (MT) of spawning herring in Port Moller estimated by aerial surveys by the Alaska Department of Fish and Game.

Date	Deer Island	Herendeen Bay	Moller Bay	Bear River	Total	Survey Rating
6-May-83	-	0	82	-	82	-
4-May-84	-	0	0	0	0	-
10-May-84	-	0	0	-	0	-
16-May-84	-	0	0	0	0	-
19-May-84	-	0	0	-	0	-
22-May-84	-	454	-	-	454	-
23-May-84	-	0	36	4	40	-
25-May-84	-	120	402	0	522	-
26-May-84	-	136	80	-	216	-
27-May-84	-	187	60	0	247	-
30-May-84	-	82	71	0	153	-
6-Jun-84	-	61	0	0	61	-
7-Jun-84	-	123	0	-	123	-
14-Jun-84	-	0	-	-	0	-
18/30-May-86	no major biomass sightings					
6-May-87	-	0	-	-	0	-
7-May-87	-	0	-	-	0	-
10-May-87	-	0	0	-	0	-
11-May-87	-	0	0	0	0	-
15-May-87	-	0	15	-	15	-
16-May-87	-	0	0	-	0	-
17-May-87	-	-	-	0	0	-
19-May-87	-	-	0	-	0	-
24-May-87	-	0	-	-	0	-
30-May-87	-	-	-	0	0	-
31-May-87	-	-	-	0	0	-
1-Jun-87	-	0	0	-	0	-
2-Jun-87	-	0	5000	2	5002	-
3-Jun-87	-	0	110	0	110	-
17-May-88	0	18	0	0	18	1.5
19-May-88	0	12	0	0	12	2.5
23-May-88	0	354	204	0	558	2.0

Appendix B. Biomass (MT) of spawning herring in Port Moller estimated by aerial surveys by the Alaska Department of Fish and Game.

Date	Deer Island	Herendeen Bay	Moller Bay	Bear River	Total	Survey Rating
26-May-88	91	0	-	-	91	2.0
27-May-88	6	44	0	0	50	2.5
28-May-88	0	0	0	-	0	2.3
29-May-88	7	105	0	0	112	2.3
30-May-88	21	359	0	0	380	2.8
31-May-88	-	-	0	0	0	2.5
1-Jun-88	0	634	0	0	634	2.8
3-Jun-88	0	709	197	0	906	1.5
6-Jun-88	0	0	0	0	0	2.0
9-Jun-88	-	0	0	-	0	3.0
10-Jun-88	-	-	0	7	7	2.0
11-Jun-88	0	-	0	-	0	2.0
15-Jun-88	0	-		-	0	3.0
19-May-89	0	0	-	-	0	4.0
22-May-89	0	0	0	0	0	3.5
23-May-89	0	0	0	-	0	2.7
25-May-89	0	0	0	0	0	2.5
29-May-89	-	-	0	1182	1182	2.0
29-May-89	-	-	0	726	726	2.0
30-May-89	14	1002	157	0	1173	2.0
30-May-89	0	14	748	0	762	2.0
31-May-89	0	0	7	0	7	2.8
2-Jun-89	0	0	7	0	7	2.3
13-Jun-89	0	42	259	-	301	2.3
15-Jun-89	-	-	154	-	154	2.0
16-Jun-89	-	-	332	-	332	2.0

Notes:

1. Dashes indicate no data.
2. Survey rating:
   1 = excellent (calm, no glare)
   2 = good (light ripple, uneven lighting, easy to spot schools)
   3 = fair (light chop, some glare or shadows, relatively easy to spot schools)
   4 = poor (rough seas, strong glare, difficult to spot schools)
   5 = unsatisfactory

Appendix C. Age structure of Port Moller herring.

Date	Age	Moller Bay inner	Moller Bay outer	Moller Bay total	Herendeen Bay	Bear River	Total	Percent of total
May/June-76	3	-	-	-	28	-	28	14.7
	4	-	-	-	120	-	120	63.2
	5	-	-	-	30	-	30	15.8
	6	-	-	-	9	-	9	4.7
	7	-	-	-	2	-	2	1.1
	8	-	-	-	0	-	0	0.0
	9	-	-	-	1	-	1	0.5
	10	-	-	-	0	-	0	0.0
	11	-	-	-	0	-	0	0.0
Total		-	-	-	190	-	190	100.0
May-81	3	-	-	2	14	-	16	5.7
	4	-	-	134	72	-	206	72.8
	5	-	-	22	14	-	36	12.7
	6	-	-	5	6	-	11	3.9
	7	-	-	4	5	-	9	3.2
	8	-	-	2	2	-	4	1.4
	9	-	-	1	0	-	1	0.4
	10	-	-	0	0	-	0	0.0
	11	-	-	0	0	-	0	0.0
Total		-	-	170	113	-	283	100.0
May-82	3	-	-	15	-	-	15	2.8
	4	-	-	115	-	-	115	21.5
	5	-	-	275	-	-	275	51.4
	6	-	-	41	-	-	41	7.7
	7	-	-	9	-	-	9	1.7
	8	-	-	41	-	-	41	7.7
	9	-	-	29	-	-	29	5.4
	10	-	-	10	-	-	10	1.9
	11	-	-	0	-	-	0	0.0
Total		-	-	535	-	-	535	100.0

Appendix C. Age structure of Port Moller herring.

Date	Age	Moller Bay inner	outer	total	Herendeen Bay	Bear River	Total	Percent of total
9/29-May-83	3	-	-	0	6	-	6	0.5
	4	-	-	16	26	-	42	3.6
	5	-	-	109	212	-	321	27.3
	6	-	-	167	524	-	691	58.7
	7	-	-	12	52	-	64	5.4
	8	-	-	4	12	-	16	1.4
	9	-	-	3	19	-	22	1.9
	10	-	-	3	6	-	9	0.8
	11	-	-	0	6	-	6	0.5
Total		-	-	314	863	0	1177	100.0
May 24/June 1-85	3	6	23	29	0	0	29	3.1
	4	59	297	356	4	7	367	39.8
	5	42	120	162	4	29	195	21.1
	6	75	77	152	6	57	215	23.3
	7	168	26	194	7	57	258	28.0
	8	137	15	152	5	65	222	24.1
	9	12	0	12	0	3	15	1.6
	10	1	2	3	0	2	5	0.5
	11	10	1	11	1	2	14	1.5
		110	562	672	27	223	922	100.0
18/29-May-86	3	4	0	4	5	1	10	1.1
	4	20	0	20	39	9	68	7.2
	5	58	5	63	100	76	239	25.2
	6	33	7	40	53	39	132	13.9
	7	50	15	65	40	61	166	17.5
	8	55	21	76	28	63	167	17.6
	9	57	15	72	35	51	158	16.6
	10	2	0	2	1	3	6	0.6
	11	3	0	3	0	0	3	0.3
Total		282	63	345	301	303	949	100.0

Appendix C. Age structure of Port Moller herring.

Date		Age	Moller Bay inner	outer	total	Herendeen Bay	Bear River	Total	Percent of total
	10-May-87	3	1	0	1	4	0	5	1.4
		4	2	0	2	7	1	10	2.7
		5	14	2	16	40	0	56	15.3
		6	37	3	40	44	5	89	24.4
		7	15	3	18	31	3	52	14.2
		8	15	7	22	24	12	58	15.9
		9	27	17	44	18	3	65	17.8
		10	11	1	12	11	3	26	7.1
		11	0	0	0	4	0	4	1.1
Total			122	33	155	183	27	365	100.0
	19-May-87	3	5	-	5	-	-	5	2.8
		4	21	-	21	-	-	21	11.8
		5	35	-	35	-	-	35	19.7
		6	34	-	34	-	-	34	19.1
		7	27	-	27	-	-	27	15.2
		8	11	-	11	-	-	11	6.2
		9	20	-	20	-	-	20	11.2
		10	25	-	25	-	-	25	14.0
		11	0	-	0	-	-	0	0.0
Total			178	-	178	-	-	178	100.0
	4-Jun-87	3	1	1	2	-	-	2	1.1
		4	20	48	68	-	-	68	36.8
		5	2	9	11	-	-	11	5.9
		6	15	14	29	-	-	29	15.7
		7	5	5	10	-	-	10	5.4
		8	18	11	29	-	-	29	15.7
		9	20	8	28	-	-	28	15.1
		10	5	3	8	-	-	8	4.3
		11	0	0	0	-	-	0	0.0
Total			86	99	185	-	-	185	100.0

Appendix C. Age structure of Port Moller herring.

Date	Age	Moller Bay inner	Moller Bay outer	Moller Bay total	Herendeen Bay	Bear River	Total	Percent of total
Total		86	99	185	-	-	185	100.0
May 28/June 6-88	3	-	-	-	6	-	6	2.8
	4	-	-	-	48	-	48	22.6
	5	-	-	-	63	-	63	29.7
	6	-	-	-	47	-	47	22.2
	7	-	-	-	19	-	19	9.0
	8	-	-	-	8	-	8	3.8
	9	-	-	-	7	-	7	3.3
	10	-	-	-	7	-	7	3.3
	11	-	-	-	7	-	7	3.3
		-	-	-	212	-	212	100.0
June 9/16-88	3	3	-	3	-	-	3	0.9
	4	99	-	99	-	-	99	29.8
	5	96	-	96	-	-	96	28.9
	6	39	-	39	-	-	39	11.7
	7	20	-	20	-	-	20	6.0
	8	16	-	16	-	-	16	4.8
	9	16	-	16	-	-	16	4.8
	10	25	-	25	-	-	25	7.5
	11	18	-	18	-	-	18	5.4
		332	-	332	-	-	332	100.0

Notes:

1. Dashes indicate no data.
2. Herendeen Bay includes catches taken near Deer Island.
3. Bear River includes all catches taken north of Frank's Lagoon.
4. Data for 1976 from Warner and Shafford (1979).
5. Data for 1981-1989 from annual reports by the Alaska Department of Fish and Game, Kodiak.

Appendix D. Temperature, salinity and conductivity profiles of Port Moller.

Date	Site code	Time	Depth (m)	Temp (degC)	conduct. (mmho/cm)	salinity (ppt)
10-Jun-89	D	1115	0	8.22	-	-
10-Jun-89	D	1115	2	8.20	-	-
10-Jun-89	D	1115	0	8.22	-	-
10-Jun-89	D	1115	2	8.20	-	-
10-Jun-89	D	1115	4	8.28	-	-
10-Jun-89	D	1115	6	8.21	-	-
10-Jun-89	D	1115	8	8.30	-	-
10-Jun-89	D	1115	10	8.25	-	-
10-Jun-89	D	1115	12	8.22	-	-
10-Jun-89	D	1115	14	8.09	-	-
10-Jun-89	D	1115	16	8.21	-	-
10-Jun-89	D	1115	18	8.00	-	-
10-Jun-89	D	1115	20	8.11	-	-
			MEAN	8.19		-
			SD	0.09		-
			N	11		-
11-Jun-89	D	0945	0	8.24	27.66	25.84
11-Jun-89	D	0945	2	8.15	27.65	25.83
11-Jun-89	D	0945	4	8.23	27.66	25.77
11-Jun-89	D	0945	6	8.19	27.66	25.74
11-Jun-89	D	0945	8	8.32	27.70	25.72
11-Jun-89	D	0945	10	8.23	27.77	25.79
11-Jun-89	D	0945	12	8.19	27.72	25.98
11-Jun-89	D	0945	14	8.15	27.73	25.88
11-Jun-89	D	0945	16	8.47	27.75	25.60
11-Jun-89	D	0945	18	9.05	27.82	26.59
11-Jun-89	D	0945	20	8.10	27.78	25.72
11-Jun-89	D	0945	22	8.90	27.80	25.54
11-Jun-89	D	0945	24	8.60	27.75	25.80
11-Jun-89	D	0945	26	8.20	27.78	26.00
11-Jun-89	D	0945	28	8.32	27.79	25.84
11-Jun-89	D	0945	30	8.20	27.78	26.10
			MEAN	8.346		25.859
			SD	0.28		0.24
			N	16		16

Appendix D. Temperature, salinity and conductivity profiles of Port Moller.

Date	Site code	Time	Depth (m)	Temp (degC)	conduct. (mmho/cm)	salinity (ppt)
11-Jun-89	A	1200	4	9.15	25.38	22.90
11-Jun-89	A	1200	6	9.18	25.43	22.90
11-Jun-89	A	1200	8	9.15	25.44	22.98
11-Jun-89	A	1200	10	9.04	25.42	22.74
11-Jun-89	A	1200	12	9.14	25.44	22.98
			MEAN	9.153		22.513
			SD	0.06		0.70
			N	7		7
11-Jun-89	F	1555	0	8.49	27.93	26.00
11-Jun-89	F	1555	2	8.16	27.85	26.06
11-Jun-89	F	1555	4	8.00	27.88	26.31
11-Jun-89	F	1555	6	7.94	27.90	26.41
11-Jun-89	F	1555	8	7.82	27.92	26.50
11-Jun-89	F	1555	10	7.70	27.90	26.50
11-Jun-89	F	1555	12	7.87	27.92	26.30
11-Jun-89	F	1555	14	7.70	27.97	26.51
11-Jun-89	F	1555	16	7.64	27.97	26.54
11-Jun-89	F	1555	18	7.74	27.97	26.60
			MEAN	7.906		26.373
			SD	0.26		0.20
			N	10		10
12-Jun-89	H	925	0	7.60	27.92	26.81
12-Jun-89	H	925	2	7.25	28.02	27.11
12-Jun-89	H	925	4	7.14	28.00	27.11
12-Jun-89	H	925	6	7.05	27.96	27.20
12-Jun-89	H	925	8	7.16	27.94	27.20
12-Jun-89	H	925	10	7.14	27.96	27.19
12-Jun-89	H	925	12	7.06	27.88	27.18
			MEAN	7.2		27.114
			SD	0.19		0.14
			N	7		7
12-Jun-89	I	1000	0	7.27	27.37	26.35
12-Jun-89	I	1000	2	6.96	27.84	26.87
12-Jun-89	I	1000	4	6.68	27.77	27.06

Appendix D. Temperature, salinity and conductivity profiles of Port Moller.

Date	Site code	Time	Depth (m)	Temp (degC)	conduct. (mmho/cm)	salinity (ppt)
12-Jun-89	I	1000	6	6.60	27.77	27.24
12-Jun-89	I	1000	8	6.52	27.73	27.24
12-Jun-89	I	1000	10	6.33	27.64	27.25
12-Jun-89	I	1000	12	5.94	27.34	27.41
			MEAN	6.614		27.060
			SD	0.43		0.36
			N	7		7
12-Jun-89	G	1125	0	7.77	27.83	26.49
12-Jun-89	G	1125	2	7.44	27.73	26.48
12-Jun-89	G	1125	4	7.37	27.70	26.64
12-Jun-89	G	1125	6	7.25	27.68	26.70
12-Jun-89	G	1125	8	7.22	27.67	26.77
12-Jun-89	G	1125	10	7.19	27.67	26.77
12-Jun-89	G	1125	12	7.17	27.69	26.84
			MEAN	7.344		26.670
			SD	0.21		0.14
			N	7		7
12-Jun-89	K	1300	0	8.98	28.40	26.20
12-Jun-89	K	1300	2	8.70	28.34	26.20
12-Jun-89	K	1300	4	8.77	28.60	26.60
12-Jun-89	K	1300	6	8.86	28.51	28.35
12-Jun-89	K	1300	8	8.74	28.65	26.49
12-Jun-89	K	1300	10	8.72	28.61	26.65
12-Jun-89	K	1300	12	8.59	28.58	26.62
12-Jun-89	K	1300	14	8.78	28.60	26.72
12-Jun-89	K	1300	16	8.47	28.56	26.72
12-Jun-89	K	1300	18	8.53	28.52	26.46
12-Jun-89	K	1300	20	8.46	28.40	26.50
12-Jun-89	K	1300	22	8.54	28.53	26.64
12-Jun-89	K	1300	24	8.42	28.38	26.51
12-Jun-89	K	1300	26	8.45	28.35	26.50
12-Jun-89	K	1300	28	8.42	28.35	26.61
12-Jun-89	K	1300	30	8.34	28.35	26.58
			MEAN	8.611		26.647
			SD	0.19		0.48

Appendix D. Temperature, salinity and conductivity profiles of Port Moller.

Date	Site code	Time	Depth (m)	Temp (degC)	conduct. (mmho/cm)	salinity (ppt)
			N	16		16
12-Jun-89	O	1500	0	8.64	25.42	23.37
12-Jun-89	O	1500	2	8.26	25.82	24.15
12-Jun-89	O	1500	4	7.97	26.12	24.54
12-Jun-89	O	1500	6	6.85	25.66	24.37
12-Jun-89	O	1500	8	6.75	25.75	24.54
12-Jun-89	O	1500	10	6.72	25.78	24.64
12-Jun-89	O	1500	12	6.68	25.73	24.87
12-Jun-89	O	1500	14	6.72	25.73	24.82
12-Jun-89	O	1500	16	6.55	25.68	24.86
12-Jun-89	O	1500	18	6.38	25.64	25.00
12-Jun-89	O	1500	20	6.32	25.55	24.89
12-Jun-89	O	1500	22	6.50	25.54	25.02
12-Jun-89	O	1500	24	6.16	25.39	25.00
12-Jun-89	O	1500	26	6.24	25.32	24.94
12-Jun-89	O	1500	28	5.65	25.18	25.00
12-Jun-89	O	1500	30	5.30	25.04	25.20
			MEAN	6.731		24.701
			SD	0.88		0.45
			N	16		16
12-Jun-89	M	1610	0	9.30	27.09	24.30
12-Jun-89	M	1610	2	9.17	27.11	24.60
12-Jun-89	M	1610	4	8.30	27.20	25.41
12-Jun-89	M	1610	6	7.80	27.07	25.51
12-Jun-89	M	1610	8	7.51	27.01	25.59
12-Jun-89	M	1610	10	7.54	27.01	25.59
12-Jun-89	M	1610	12	7.46	26.98	25.55
12-Jun-89	M	1610	14	7.24	26.82	25.67
12-Jun-89	M	1610	16	7.10	26.77	25.71
12-Jun-89	M	1610	18	6.98	26.71	25.55
12-Jun-89	M	1610	20	6.65	26.53	25.55
12-Jun-89	M	1610	22	6.48	26.36	25.75
12-Jun-89	M	1610	24	6.22	26.33	26.03
12-Jun-89	M	1610	26	6.13	26.18	25.86
12-Jun-89	M	1610	28	6.42	24.25	23.20

Appendix D. Temperature, salinity and conductivity profiles of Port Moller.

Date	Site code	Time	Depth (m)	Temp (degC)	conduct. (mmho/cm)	salinity (ppt)
			MEAN	7.353		25.325
			SD	0.98		0.74
			N	15		15
13-Jun-89	D	0911	0	8.88	28.37	26.10
13-Jun-89	D	0911	2	8.87	28.39	26.10
13-Jun-89	D	0911	4	8.86	28.43	26.12
13-Jun-89	D	0911	6	8.86	28.42	26.08
13-Jun-89	D	0911	8	8.82	28.45	26.28
13-Jun-89	D	0911	10	8.68	28.48	26.25
13-Jun-89	D	0911	12	8.70	28.48	26.35
13-Jun-89	D	0911	14	8.70	28.48	26.40
13-Jun-89	D	0911	16	8.76	28.48	26.32
13-Jun-89	D	0911	18	8.74	28.46	26.35
13-Jun-89	D	0911	20	8.78	28.46	26.28
13-Jun-89	D	0911	22	8.81	28.48	26.30
13-Jun-89	D	0911	24	8.67	28.48	26.28
13-Jun-89	D	0911	26	8.78	28.46	26.37
13-Jun-89	D	0911	28	8.81	28.46	26.24
13-Jun-89	D	0911	30	8.73	28.46	26.26
			MEAN	8.778		26.255
			SD	0.07		0.10
			N	16		16
13-Jun-89	C	1435	0	10.78	10.58	8.60
13-Jun-89	C	1435	2	10.43	11.32	9.34
13-Jun-89	C	1435	4	10.52	21.39	18.30
13-Jun-89	C	1435	6	10.28	24.36	21.33
13-Jun-89	C	1435	8	10.00	26.33	23.34
13-Jun-89	C	1435	10	9.89	25.99	22.99
13-Jun-89	C	1435	12	9.85	24.02	21.30
13-Jun-89	C	1435	14	10.00	18.150	15.59
			MEAN	10.22		17.599
			SD	0.34		5.90
			N	8		8
13-Jun-89	A	1520	0	11.30	26.58	22.78

Appendix D. Temperature, salinity and conductivity profiles of Port Moller.

Date	Site code	Time	Depth (m)	Temp (degC)	conduct. (mmho/cm)	salinity (ppt)
13-Jun-89	A	1520	2	11.29	26.66	22.87
13-Jun-89	A	1520	4	11.25	26.66	22.99
13-Jun-89	A	1520	6	10.84	26.50	23.16
13-Jun-89	A	1520	8	10.75	26.60	23.20
13-Jun-89	A	1520	10	10.79	26.67	23.31
13-Jun-89	A	1520	12	10.96	27.00	23.39
13-Jun-89	A	1520	14	10.83	27.13	23.66
13-Jun-89	A	1520	16	11.03	27.13	23.61
			MEAN	11		23.219
			SD	0.22		0.31
			N	9		9
13-Jun-89	D	1640	0	9.75	27.67	24.83
13-Jun-89	D	1640	2	9.60	27.62	24.77
13-Jun-89	D	1640	4	9.49	27.64	24.90
13-Jun-89	D	1640	6	9.42	27.65	25.01
13-Jun-89	D	1640	8	9.34	27.67	24.86
13-Jun-89	D	1640	10	9.50	27.62	25.02
			MEAN	9.517		24.898
			SD	0.14		0.10
			N	6		6
13-Jun-89	E	1725	0	9.08	28.70	26.31
13-Jun-89	E	1725	2	9.08	28.71	26.30
13-Jun-89	E	1725	4	8.98	28.71	26.22
13-Jun-89	E	1725	6	9.11	28.68	26.37
13-Jun-89	E	1725	8	8.97	28.68	26.21
13-Jun-89	E	1725	10	9.06	28.68	26.30
13-Jun-89	E	1725	12	9.10	28.66	26.33
13-Jun-89	E	1725	14	9.10	28.66	26.17
13-Jun-89	E	1725	16	9.09	28.67	26.44
			MEAN	9.063		26.294
			SD	0.06		0.08
			N	9		9
14-Jun-89	F	0810	0	8.24	28.32	26.59
14-Jun-89	F	0810	2	8.14	28.30	26.62

Appendix D. Temperature, salinity and conductivity profiles of Port Moller.

Date	Site code	Time	Depth (m)	Temp (degC)	conduct. (mmho/cm)	salinity (ppt)
14-Jun-89	F	0810	4	8.14	28.27	26.69
14-Jun-89	F	0810	6	8.06	28.27	26.70
14-Jun-89	F	0810	8	8.04	28.24	26.66
14-Jun-89	F	0810	10	8.10	28.25	26.74
14-Jun-89	F	0810	12	8.09	28.25	26.72
14-Jun-89	F	0810	14	8.05	28.24	26.71
14-Jun-89	F	0810	16	8.04	28.24	26.71
14-Jun-89	F	0810	18	8.01	28.24	26.67
			MEAN	8.091		26.681
			SD	0.04		0.05
			N	10		10
14-Jun-89	J	1400	0	9.12	27.98	25.55
14-Jun-89	J	1400	2	9.15	28.03	25.55
14-Jun-89	J	1400	4	9.12	27.93	25.53
14-Jun-89	J	1400	6	9.16	27.93	25.54
14-Jun-89	J	1400	8	9.05	27.93	25.50
			MEAN	9.12		25.534
			SD	0.04		0.02
			N	5		5
14-Jun-89	N	0945	0	8.64	20.70	17.60
14-Jun-89	N	0945	2	9.55	19.71	17.36
14-Jun-89	N	0945	4	9.56	19.89	17.45
14-Jun-89	N	0945	6	9.30	19.80	17.60
14-Jun-89	N	0945	8	8.63	19.90	18.00
14-Jun-89	N	0945	10	7.36	19.28	18.03
14-Jun-89	N	0945	12	7.35	19.37	18.18
14-Jun-89	N	0945	14	7.08	19.17	18.00
14-Jun-89	N	0945	16	6.80	19.03	18.01
14-Jun-89	N	0945	18	6.52	18.86	18.01
14-Jun-89	N	0945	20	6.26	18.69	17.95
14-Jun-89	N	0945	22	6.06	18.60	17.99
14-Jun-89	N	0945	24	5.87	18.52	18.04
14-Jun-89	N	0945	26	5.76	18.48	18.09
14-Jun-89	N	0945	28	5.56	18.35	17.92
14-Jun-89	N	0945	30	5.28	18.12	17.86

Appendix D. Temperature, salinity and conductivity profiles of Port Moller.

Date	Site code	Time	Depth (m)	Temp (degC)	conduct. (mmho/cm)	salinity (ppt)
			MEAN	7.224		17.881
			SD	1.48		0.24
			N	16		16
14-Jun-89	M	1100	0	9.77	24.93	22.10
14-Jun-89	M	1100	2	10.24	26.52	23.43
14-Jun-89	M	1100	4	9.73	26.42	23.74
14-Jun-89	M	1100	6	8.87	26.29	24.16
14-Jun-89	M	1100	8	8.57	26.13	24.37
14-Jun-89	M	1100	10	8.13	26.02	24.53
14-Jun-89	M	1100	12	8.02	26.02	24.40
14-Jun-89	M	1100	14	7.59	25.76	24.54
14-Jun-89	M	1100	16	7.50	25.67	24.54
14-Jun-89	M	1100	18	7.19	25.44	24.42
14-Jun-89	M	1100	20	7.16	25.39	24.57
14-Jun-89	M	1100	22	6.94	25.33	24.64
14-Jun-89	M	1100	24	6.65	25.70	25.22
14-Jun-89	M	1100	26	6.16	25.43	25.61
			MEAN	8.037		24.305
			SD	1.25		0.83
			N	14		14
14-Jun-89	L	1155	0	10.28	25.95	22.80
14-Jun-89	L	1155	2	9.00	27.01	24.66
14-Jun-89	L	1155	4	8.95	27.05	24.77
14-Jun-89	L	1155	6	8.89	27.09	24.80
14-Jun-89	L	1155	8	8.86	27.17	24.92
14-Jun-89	L	1155	10	8.85	27.29	25.01
14-Jun-89	L	1155	12	8.87	27.46	25.08
			MEAN	9.1		24.577
			SD	0.52		0.80
			N	7		7
14-Jun-89	K	1325	0	9.20	28.19	25.72
14-Jun-89	K	1325	2	9.19	28.22	25.82
14-Jun-89	K	1325	4	9.21	28.20	25.81
14-Jun-89	K	1325	6	9.14	28.14	25.66

Appendix D. Temperature, salinity and conductivity profiles of Port Moller.

Date	Site code	Time	Depth (m)	Temp (degC)	conduct. (mmho/cm)	salinity (ppt)
14-Jun-89	K	1325	8	9.21	28.18	25.71
14-Jun-89	K	1325	10	9.20	28.12	25.70
14-Jun-89	K	1325	12	9.24	28.14	25.74
14-Jun-89	K	1325	14	9.08	28.21	25.77
14-Jun-89	K	1325	16	9.20	28.21	25.64
14-Jun-89	K	1325	18	9.04	28.21	25.77
14-Jun-89	K	1325	20	9.23	28.21	25.73
14-Jun-89	K	1325	22	9.22	28.21	25.85
14-Jun-89	K	1325	24	9.04	28.24	25.84
14-Jun-89	K	1325	26	9.14	28.24	25.89
14-Jun-89	K	1325	28	9.03	28.19	25.81
14-Jun-89	K	1325	30	9.01	28.22	25.86
			MEAN	9.149		25.770
			SD	0.08		0.07
			N	16		16
14-Jun-89	A	1635	0	11.65	4.79	3.76
14-Jun-89	A	1635	2	11.28	4.95	3.89
14-Jun-89	A	1635	4	11.30	5.43	4.32
14-Jun-89	A	1635	6	11.36	5.54	4.40
14-Jun-89	A	1635	8	11.24	5.65	4.53
14-Jun-89	A	1635	10	11.23	5.66	4.52
14-Jun-89	A	1635	12	11.26	5.69	4.52
			MEAN	11.33		4.277
			SD	0.15		0.32
			N	7		7
14-Jun-89	B	1717	0	10.50	26.96	23.67
14-Jun-89	B	1717	2	10.45	27.00	23.64
14-Jun-89	B	1717	4	10.34	27.00	23.71
14-Jun-89	B	1717	6	10.32	27.00	23.74
14-Jun-89	B	1717	8	10.30	27.01	23.79
14-Jun-89	B	1717	10	10.31	27.01	23.80
14-Jun-89	B	1717	12	10.28	27.01	23.80
14-Jun-89	B	1717	14	10.21	27.01	23.70
14-Jun-89	B	1717	16	10.18	27.01	23.81
14-Jun-89	B	1717	18	10.36	26.99	23.88

Appendix D. Temperature, salinity and conductivity profiles of Port Moller.

Date	Site code	Time	Depth (m)	Temp (degC)	conduct. (mmho/cm)	salinity (ppt)
			MEAN	10.33		23.754
			SD	0.10		0.07
			N	10		10
14-Jun-89	C	1755	0	10.45	27.80	24.41
14-Jun-89	C	1755	2	10.12	27.89	24.62
14-Jun-89	C	1755	4	9.83	27.89	24.98
14-Jun-89	C	1755	6	9.83	27.91	24.86
14-Jun-89	C	1755	8	9.84	27.91	24.98
14-Jun-89	C	1755	10	9.98	27.91	24.84
14-Jun-89	C	1755	12	9.77	27.87	24.88
14-Jun-89	C	1755	14	9.86	27.87	24.94
14-Jun-89	C	1755	16	9.88	27.89	25.05
14-Jun-89	C	1755	18	9.73	27.89	24.92
			MEAN	9.929		24.848
			SD	0.21		0.19
			N	10		10
14-Jun-89	D	1840	0	9.74	27.96	25.10
14-Jun-89	D	1840	2	9.73	28.01	25.15
14-Jun-89	D	1840	4	9.65	28.01	25.20
14-Jun-89	D	1840	6	9.73	28.02	25.32
14-Jun-89	D	1840	8	9.72	28.04	25.20
14-Jun-89	D	1840	10	9.60	28.04	25.29
14-Jun-89	D	1840	12	9.72	28.04	25.14
14-Jun-89	D	1840	14	9.63	28.04	25.17
14-Jun-89	D	1840	16	9.63	28.04	25.16
14-Jun-89	D	1840	18	9.77	28.04	25.19
14-Jun-89	D	1840	20	9.64	28.04	25.21
14-Jun-89	D	1840	22	9.64	28.04	25.33
14-Jun-89	D	1840	24	9.67	28.04	25.16
			MEAN	9.682		25.202
			SD	0.05		0.07
			N	13		13

Notes:

1. All measurements made with a conductivity-temperature-salinity meter.
2. Dashes indicate no measurements made.

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
11-Jun-89	1	D	2	5	1	7.0	8.1
11-Jun-89	1	D	2	9	2	7.2	8.3
11-Jun-89	1	D	2	61	1	7.3	8.4
11-Jun-89	1	D	2	44	2	7.3	8.4
11-Jun-89	1	D	2	27	1	7.3	8.4
11-Jun-89	1	D	2	15	1	7.5	8.5
11-Jun-89	1	D	2	23	1	7.5	8.5
11-Jun-89	1	D	2	60	1	7.6	8.6
11-Jun-89	1	D	2	52	1	7.6	8.6
11-Jun-89	1	D	2	2	1	7.6	8.6
11-Jun-89	1	D	2	47	1	7.8	8.8
11-Jun-89	1	D	2	48	2	7.8	8.8
11-Jun-89	1	D	2	43	2	7.9	8.9
11-Jun-89	1	D	2	49	2	7.9	8.9
11-Jun-89	1	D	2	57	1	7.9	8.9
11-Jun-89	1	D	2	62	2	8.1	9.0
11-Jun-89	1	D	2	10	1	8.1	9.0
11-Jun-89	1	D	2	28	1	8.1	9.0
11-Jun-89	1	D	2	14	1	8.1	9.0
11-Jun-89	1	D	2	30	1	8.1	9.0
11-Jun-89	1	D	2	54	1	8.2	9.1
11-Jun-89	1	D	2	36	1	8.2	9.1
11-Jun-89	1	D	2	12	2	8.2	9.1
11-Jun-89	1	D	2	46	2	8.2	9.1
11-Jun-89	1	D	2	37	2	8.4	9.3
11-Jun-89	1	D	2	59	2	8.4	9.3
11-Jun-89	1	D	2	41	2	8.4	9.3
11-Jun-89	1	D	2	32	2	8.5	9.4
11-Jun-89	1	D	2	19	2	8.5	9.4
11-Jun-89	1	D	2	34	2	8.5	9.4
11-Jun-89	1	D	2	17	2	8.5	9.4
11-Jun-89	1	D	2	25	2	8.5	9.4
11-Jun-89	1	D	2	50	2	8.7	9.6
11-Jun-89	1	D	2	56	2	8.7	9.6
11-Jun-89	1	D	2	38	2	8.7	9.6

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
11-Jun-89	1	D	2	8	2	8.7	9.6
11-Jun-89	1	D	2	26	2	8.8	9.7
11-Jun-89	1	D	2	45	2	8.8	9.7
11-Jun-89	1	D	2	7	2	9.0	9.8
11-Jun-89	1	D	2	40	2	9.0	9.8
11-Jun-89	1	D	2	21	2	9.0	9.8
11-Jun-89	1	D	2	35	2	9.0	9.8
11-Jun-89	1	D	2	18	2	9.1	9.9
11-Jun-89	1	D	2	1	2	9.1	9.9
11-Jun-89	1	D	2	58	2	9.1	9.9
11-Jun-89	1	D	2	39	2	9.1	9.9
11-Jun-89	1	D	2	53	2	9.1	9.9
11-Jun-89	1	D	2	11	2	9.3	10.1
11-Jun-89	1	D	2	16	1	9.3	10.1
11-Jun-89	1	D	2	22	2	9.3	10.1
11-Jun-89	1	D	2	4	2	9.4	10.2
11-Jun-89	1	D	2	31	2	9.4	10.2
11-Jun-89	1	D	2	29	2	9.6	10.3
11-Jun-89	1	D	2	24	2	9.6	10.3
11-Jun-89	1	D	2	3	2	9.6	10.3
11-Jun-89	1	D	2	20	2	9.6	10.3
11-Jun-89	1	D	2	51	2	9.6	10.3
11-Jun-89	1	D	2	55	2	9.7	10.4
11-Jun-89	1	D	2	63	2	9.9	10.6
						---	---
					MEAN	8.5	9.4
					SD	0.7	0.6
					N	59	59
11-Jun-89	1	D	1	13	2	11.2	11.8
11-Jun-89	1	D	1	42	2	11.2	11.8
11-Jun-89	1	D	1	6	2	11.5	12.0
11-Jun-89	1	D	1	33	2	11.8	12.3
						---	---
					MEAN	11.4	12.0

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
					SD	0.3	0.3
					N	4	4
11-Jun-89	2	D	2	58	1	6.7	7.9
11-Jun-89	2	D	2	15	2	7.2	8.3
11-Jun-89	2	D	2	96	1	7.3	8.4
11-Jun-89	2	D	2	48	2	7.3	8.4
11-Jun-89	2	D	2	75	2	7.3	8.4
11-Jun-89	2	D	2	66	1	7.3	8.4
11-Jun-89	2	D	2	18	2	7.5	8.5
11-Jun-89	2	D	2	11	2	7.5	8.5
11-Jun-89	2	D	2	22	1	7.5	8.5
11-Jun-89	2	D	2	36	1	7.5	8.5
11-Jun-89	2	D	2	67	2	7.5	8.5
11-Jun-89	2	D	2	78	2	7.5	8.5
11-Jun-89	2	D	2	74	2	7.5	8.5
11-Jun-89	2	D	2	69	1	7.6	8.6
11-Jun-89	2	D	2	60	2	7.6	8.6
11-Jun-89	2	D	2	52	1	7.6	8.6
11-Jun-89	2	D	2	82	1	7.6	8.6
11-Jun-89	2	D	2	100	1	7.6	8.6
11-Jun-89	2	D	2	7	1	7.6	8.6
11-Jun-89	2	D	2	90	1	7.8	8.8
11-Jun-89	2	D	2	99	1	7.8	8.8
11-Jun-89	2	D	2	42	1	7.8	8.8
11-Jun-89	2	D	2	63	2	7.8	8.8
11-Jun-89	2	D	2	14	1	7.9	8.9
11-Jun-89	2	D	2	45	2	7.9	8.9
11-Jun-89	2	D	2	13	1	7.9	8.9
11-Jun-89	2	D	2	88	2	7.9	8.9
11-Jun-89	2	D	2	93	2	7.9	8.9
11-Jun-89	2	D	2	53	1	7.9	8.9
11-Jun-89	2	D	2	64	1	7.9	8.9
11-Jun-89	2	D	2	38	1	7.9	8.9
11-Jun-89	2	D	2	51	2	8.1	9.0

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
11-Jun-89	2	D	2	19	1	8.1	9.0
11-Jun-89	2	D	2	33	2	8.1	9.0
11-Jun-89	2	D	2	54	1	8.1	9.0
11-Jun-89	2	D	2	43	2	8.1	9.0
11-Jun-89	2	D	2	40	2	8.1	9.0
11-Jun-89	2	D	2	16	1	8.1	9.0
11-Jun-89	2	D	2	1	1	8.1	9.0
11-Jun-89	2	D	2	31	1	8.1	9.0
11-Jun-89	2	D	2	92	1	8.1	9.0
11-Jun-89	2	D	2	3	2	8.2	9.1
11-Jun-89	2	D	2	9	2	8.2	9.1
11-Jun-89	2	D	2	94	2	8.2	9.1
11-Jun-89	2	D	2	25	1	8.2	9.1
11-Jun-89	2	D	2	23	2	8.2	9.1
11-Jun-89	2	D	2	5	2	8.2	9.1
11-Jun-89	2	D	2	32	1	8.2	9.1
11-Jun-89	2	D	2	49	2	8.4	9.3
11-Jun-89	2	D	2	46	2	8.4	9.3
11-Jun-89	2	D	2	6	2	8.4	9.3
11-Jun-89	2	D	2	95	1	8.4	9.3
11-Jun-89	2	D	2	98	2	8.4	9.3
11-Jun-89	2	D	2	10	2	8.4	9.3
11-Jun-89	2	D	2	89	2	8.4	9.3
11-Jun-89	2	D	2	8	2	8.4	9.3
11-Jun-89	2	D	2	29	1	8.5	9.4
11-Jun-89	2	D	2	2	2	8.5	9.4
11-Jun-89	2	D	2	65	2	8.5	9.4
11-Jun-89	2	D	2	39	2	8.5	9.4
11-Jun-89	2	D	2	34	2	8.5	9.4
11-Jun-89	2	D	2	26	2	8.5	9.4
11-Jun-89	2	D	2	97	2	8.7	9.6
11-Jun-89	2	D	2	84	2	8.7	9.6
11-Jun-89	2	D	2	87	2	8.7	9.6
11-Jun-89	2	D	2	41	2	8.7	9.6
11-Jun-89	2	D	2	83	2	8.7	9.6

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
11-Jun-89	2	D	2	20	2	8.7	9.6
11-Jun-89	2	D	2	80	2	8.7	9.6
11-Jun-89	2	D	2	70	2	8.8	9.7
11-Jun-89	2	D	2	35	2	8.8	9.7
11-Jun-89	2	D	2	50	2	8.8	9.7
11-Jun-89	2	D	2	73	2	8.8	9.7
11-Jun-89	2	D	2	86	2	8.8	9.7
11-Jun-89	2	D	2	91	2	8.8	9.7
11-Jun-89	2	D	2	62	2	9.0	9.8
11-Jun-89	2	D	2	71	2	9.0	9.8
11-Jun-89	2	D	2	24	2	9.0	9.8
11-Jun-89	2	D	2	55	2	9.0	9.8
11-Jun-89	2	D	2	85	2	9.0	9.8
11-Jun-89	2	D	2	17	2	9.0	9.8
11-Jun-89	2	D	2	4	2	9.1	9.9
11-Jun-89	2	D	2	28	2	9.1	9.9
11-Jun-89	2	D	2	47	2	9.1	9.9
11-Jun-89	2	D	2	79	2	9.1	9.9
11-Jun-89	2	D	2	77	2	9.1	9.9
11-Jun-89	2	D	2	72	2	9.1	9.9
11-Jun-89	2	D	2	44	2	9.3	10.1
11-Jun-89	2	D	2	68	2	9.4	10.2
11-Jun-89	2	D	2	81	2	9.4	10.2
11-Jun-89	2	D	2	57	2	9.4	10.2
11-Jun-89	2	D	2	37	2	9.4	10.2
11-Jun-89	2	D	2	12	2	9.4	10.2
11-Jun-89	2	D	2	21	2	9.4	10.2
11-Jun-89	2	D	2	30	2	9.4	10.2
11-Jun-89	2	D	2	56	2	9.4	10.2
11-Jun-89	2	D	2	61	2	9.6	10.3
11-Jun-89	2	D	2	76	2	9.7	10.4
11-Jun-89	2	D	2	27	2	9.7	10.4
						---	---
					MEAN	8.4	9.3
					SD	0.7	0.6

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
					N	99	99
11-Jun-89	2	D	1	59	2	10.2	10.9
					MEAN	10.2	10.9
					SD	-	-
					N	1	1
11-Jun-89	3	A	2	61	2	6.1	7.3
11-Jun-89	3	A	2	97	1	6.1	7.3
11-Jun-89	3	A	2	9	1	6.3	7.5
11-Jun-89	3	A	2	75	2	6.4	7.6
11-Jun-89	3	A	2	99	1	6.7	7.9
11-Jun-89	3	A	2	16	2	6.7	7.9
11-Jun-89	3	A	2	12	1	6.9	8.0
11-Jun-89	3	A	2	39	1	6.9	8.0
11-Jun-89	3	A	2	1	1	6.9	8.0
11-Jun-89	3	A	2	79	1	6.9	8.0
11-Jun-89	3	A	2	98	1	7.0	8.1
11-Jun-89	3	A	2	47	2	7.0	8.1
11-Jun-89	3	A	2	92	1	7.0	8.1
11-Jun-89	3	A	2	87	2	7.0	8.1
11-Jun-89	3	A	2	89	1	7.0	8.1
11-Jun-89	3	A	2	43	1	7.2	8.3
11-Jun-89	3	A	2	52	1	7.2	8.3
11-Jun-89	3	A	2	3	1	7.2	8.3
11-Jun-89	3	A	2	46	1	7.2	8.3
11-Jun-89	3	A	2	81	2	7.2	8.3
11-Jun-89	3	A	2	95	1	7.2	8.3
11-Jun-89	3	A	2	57	1	7.3	8.4
11-Jun-89	3	A	2	36	2	7.3	8.4
11-Jun-89	3	A	2	91	1	7.3	8.4
11-Jun-89	3	A	2	86	1	7.3	8.4
11-Jun-89	3	A	2	32	1	7.5	8.5
11-Jun-89	3	A	2	100	1	7.5	8.5

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
11-Jun-89	3	A	2	64	2	7.5	8.5
11-Jun-89	3	A	2	41	2	7.5	8.5
11-Jun-89	3	A	2	10	2	7.5	8.5
11-Jun-89	3	A	2	35	1	7.6	8.6
11-Jun-89	3	A	2	54	1	7.6	8.6
11-Jun-89	3	A	2	67	1	7.6	8.6
11-Jun-89	3	A	2	71	2	7.6	8.6
11-Jun-89	3	A	2	13	1	7.6	8.6
11-Jun-89	3	A	2	62	2	7.6	8.6
11-Jun-89	3	A	2	93	1	7.6	8.6
11-Jun-89	3	A	2	70	1	7.6	8.6
11-Jun-89	3	A	2	27	1	7.8	8.8
11-Jun-89	3	A	2	83	2	7.8	8.8
11-Jun-89	3	A	2	88	2	7.8	8.8
11-Jun-89	3	A	2	4	2	7.8	8.8
11-Jun-89	3	A	2	28	2	7.8	8.8
11-Jun-89	3	A	2	49	1	7.8	8.8
11-Jun-89	3	A	2	72	2	7.8	8.8
11-Jun-89	3	A	2	50	2	7.8	8.8
11-Jun-89	3	A	2	31	2	7.8	8.8
11-Jun-89	3	A	2	65	1	7.8	8.8
11-Jun-89	3	A	2	77	2	7.8	8.8
11-Jun-89	3	A	2	2	2	7.8	8.8
11-Jun-89	3	A	2	94	2	7.9	8.9
11-Jun-89	3	A	2	90	2	7.9	8.9
11-Jun-89	3	A	2	20	2	7.9	8.9
11-Jun-89	3	A	2	96	1	7.9	8.9
11-Jun-89	3	A	2	76	2	7.9	8.9
11-Jun-89	3	A	2	7	1	7.9	8.9
11-Jun-89	3	A	2	21	1	7.9	8.9
11-Jun-89	3	A	2	78	1	7.9	8.9
11-Jun-89	3	A	2	17	2	7.9	8.9
11-Jun-89	3	A	2	18	2	7.9	8.9
11-Jun-89	3	A	2	30	1	8.1	9.0
11-Jun-89	3	A	2	60	2	8.1	9.0

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
11-Jun-89	3	A	2	44	2	8.2	9.1
11-Jun-89	3	A	2	69	2	8.2	9.1
11-Jun-89	3	A	2	24	1	8.2	9.1
11-Jun-89	3	A	2	55	2	8.2	9.1
11-Jun-89	3	A	2	5	2	8.2	9.1
11-Jun-89	3	A	2	66	2	8.2	9.1
11-Jun-89	3	A	2	11	2	8.2	9.1
11-Jun-89	3	A	2	14	2	8.2	9.1
11-Jun-89	3	A	2	25	2	8.4	9.3
11-Jun-89	3	A	2	58	2	8.4	9.3
11-Jun-89	3	A	2	82	2	8.4	9.3
11-Jun-89	3	A	2	38	1	8.4	9.3
11-Jun-89	3	A	2	56	2	8.4	9.3
11-Jun-89	3	A	2	53	2	8.4	9.3
11-Jun-89	3	A	2	84	2	8.5	9.4
11-Jun-89	3	A	2	15	2	8.5	9.4
11-Jun-89	3	A	2	37	2	8.5	9.4
11-Jun-89	3	A	2	80	2	8.7	9.6
11-Jun-89	3	A	2	85	2	8.7	9.6
11-Jun-89	3	A	2	23	2	8.7	9.6
11-Jun-89	3	A	2	45	2	8.7	9.6
11-Jun-89	3	A	2	68	2	8.7	9.6
11-Jun-89	3	A	2	74	2	8.7	9.6
11-Jun-89	3	A	2	51	2	8.8	9.7
11-Jun-89	3	A	2	73	2	9.0	9.8
11-Jun-89	3	A	2	48	2	9.0	9.8
11-Jun-89	3	A	2	63	2	9.3	10.1
11-Jun-89	3	A	2	42	2	9.7	10.4
						---	---
					MEAN	7.8	8.8
					SD	0.7	0.6
					N	90	90
11-Jun-89	3	A	1	40	2	10.6	11.2
11-Jun-89	3	A	1	29	2	10.8	11.4

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
11-Jun-89	3	A	1	22	2	10.8	11.4
11-Jun-89	3	A	1	19	2	11.2	11.8
11-Jun-89	3	A	1	26	2	11.7	12.2
11-Jun-89	3	A	1	59	2	12.0	12.5
11-Jun-89	3	A	1	33	2	12.1	12.6
11-Jun-89	3	A	1	6	2	12.1	12.6
11-Jun-89	3	A	1	8	2	12.7	13.1
						---	---
					MEAN	11.6	12.1
					SD	0.7	0.7
					N	9	9
11-Jun-89	4	F	2	4	1	7.6	8.6
11-Jun-89	4	F	2	5	2	7.8	8.8
11-Jun-89	4	F	2	2	2	8.7	9.6
11-Jun-89	4	F	2	6	2	9.1	9.9
11-Jun-89	4	F	2	3	2	9.1	9.9
11-Jun-89	4	F	2	7	2	9.6	10.3
11-Jun-89	4	F	2	8	2	9.7	10.4
11-Jun-89	4	F	2	1	2	9.9	10.6
						---	---
					MEAN	8.9	9.8
					SD	0.9	0.7
					N	8	8
			2	GRAND	MEAN	8.3	9.2
					SD	0.7	0.6
					N	256	256
			1	GRAND	MEAN	11.4	12.0
					SD	0.7	0.6
					N	14	14
12-Jun-89	5	H	2	1	2	9.4	10.2
						---	---

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
					MEAN	9.4	10.2
					SD	-	-
					N	1	1
12-Jun-89	6	I	-	-	-	-	-
12-Jun-89	7	G	-	-	-	-	-
12-Jun-89	8	K	2	3	1	7.0	8.1
12-Jun-89	8	K	2	1	1	8.1	9.0
12-Jun-89	8	K	2	2	2	8.2	9.1
						---	---
					MEAN	7.8	8.8
					SD	0.7	0.6
					N	3	3
12-Jun-89	9	O	2	37	2	6.7	7.9
12-Jun-89	9	O	2	74	2	6.9	8.0
12-Jun-89	9	O	2	62	2	7.2	8.3
12-Jun-89	9	O	2	58	2	7.3	8.4
12-Jun-89	9	O	2	46	2	7.3	8.4
12-Jun-89	9	O	2	87	2	7.3	8.4
12-Jun-89	9	O	2	70	2	7.5	8.5
12-Jun-89	9	O	2	32	1	7.5	8.5
12-Jun-89	9	O	2	83	1	7.5	8.5
12-Jun-89	9	O	2	36	2	7.5	8.5
12-Jun-89	9	O	2	6	1	7.5	8.5
12-Jun-89	9	O	2	54	2	7.5	8.5
12-Jun-89	9	O	2	96	1	7.5	8.5
12-Jun-89	9	O	2	27	2	7.5	8.5
12-Jun-89	9	O	2	89	2	7.6	8.6
12-Jun-89	9	O	2	52	2	7.6	8.6
12-Jun-89	9	O	2	11	1	7.6	8.6
12-Jun-89	9	O	2	34	2	7.6	8.6
12-Jun-89	9	O	2	39	2	7.6	8.6

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
12-Jun-89	9	O	2	24	2	7.6	8.6
12-Jun-89	9	O	2	21	2	7.6	8.6
12-Jun-89	9	O	2	23	2	7.8	8.8
12-Jun-89	9	O	2	14	1	7.8	8.8
12-Jun-89	9	O	2	65	1	7.8	8.8
12-Jun-89	9	O	2	15	2	7.8	8.8
12-Jun-89	9	O	2	29	2	7.8	8.8
12-Jun-89	9	O	2	5	2	7.8	8.8
12-Jun-89	9	O	2	69	1	7.8	8.8
12-Jun-89	9	O	2	100	2	7.8	8.8
12-Jun-89	9	O	2	47	2	7.8	8.8
12-Jun-89	9	O	2	67	2	7.9	8.9
12-Jun-89	9	O	2	13	2	7.9	8.9
12-Jun-89	9	O	2	31	1	7.9	8.9
12-Jun-89	9	O	2	95	2	7.9	8.9
12-Jun-89	9	O	2	72	1	7.9	8.9
12-Jun-89	9	O	2	28	2	7.9	8.9
12-Jun-89	9	O	2	17	2	7.9	8.9
12-Jun-89	9	O	2	63	2	7.9	8.9
12-Jun-89	9	O	2	82	2	8.1	9.0
12-Jun-89	9	O	2	25	2	8.1	9.0
12-Jun-89	9	O	2	91	2	8.1	9.0
12-Jun-89	9	O	2	84	2	8.1	9.0
12-Jun-89	9	O	2	90	2	8.1	9.0
12-Jun-89	9	O	2	68	2	8.1	9.0
12-Jun-89	9	O	2	51	2	8.2	9.1
12-Jun-89	9	O	2	26	2	8.2	9.1
12-Jun-89	9	O	2	18	2	8.2	9.1
12-Jun-89	9	O	2	8	2	8.2	9.1
12-Jun-89	9	O	2	71	2	8.2	9.1
12-Jun-89	9	O	2	80	2	8.2	9.1
12-Jun-89	9	O	2	50	2	8.2	9.1
12-Jun-89	9	O	2	56	2	8.2	9.1
12-Jun-89	9	O	2	43	2	8.2	9.1
12-Jun-89	9	O	2	57	2	8.2	9.1

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
12-Jun-89	9	O	2	45	2	8.2	9.1
12-Jun-89	9	O	2	44	2	8.2	9.1
12-Jun-89	9	O	2	99	2	8.2	9.1
12-Jun-89	9	O	2	41	2	8.2	9.1
12-Jun-89	9	O	2	97	2	8.4	9.3
12-Jun-89	9	O	2	78	2	8.4	9.3
12-Jun-89	9	O	2	88	2	8.4	9.3
12-Jun-89	9	O	2	92	2	8.4	9.3
12-Jun-89	9	O	2	7	2	8.4	9.3
12-Jun-89	9	O	2	38	2	8.4	9.3
12-Jun-89	9	O	2	53	2	8.4	9.3
12-Jun-89	9	O	2	35	2	8.4	9.3
12-Jun-89	9	O	2	49	2	8.4	9.3
12-Jun-89	9	O	2	81	2	8.4	9.3
12-Jun-89	9	O	2	4	2	8.4	9.3
12-Jun-89	9	O	2	9	2	8.4	9.3
12-Jun-89	9	O	2	86	2	8.4	9.3
12-Jun-89	9	O	2	93	2	8.5	9.4
12-Jun-89	9	O	2	16	2	8.5	9.4
12-Jun-89	9	O	2	94	2	8.5	9.4
12-Jun-89	9	O	2	75	2	8.5	9.4
12-Jun-89	9	O	2	30	2	8.5	9.4
12-Jun-89	9	O	2	40	2	8.5	9.4
12-Jun-89	9	O	2	64	2	8.7	9.6
12-Jun-89	9	O	2	76	2	8.7	9.6
12-Jun-89	9	O	2	55	2	8.7	9.6
12-Jun-89	9	O	2	22	2	8.7	9.6
12-Jun-89	9	O	2	42	2	8.7	9.6
12-Jun-89	9	O	2	61	2	8.7	9.6
12-Jun-89	9	O	2	10	2	8.7	9.6
12-Jun-89	9	O	2	79	2	8.7	9.6
12-Jun-89	9	O	2	2	2	8.7	9.6
12-Jun-89	9	O	2	73	2	8.8	9.7
12-Jun-89	9	O	2	85	2	8.8	9.7
12-Jun-89	9	O	2	60	2	8.8	9.7

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
12-Jun-89	9	O	2	3	2	9.0	9.8
12-Jun-89	9	O	2	59	2	9.0	9.8
12-Jun-89	9	O	2	98	2	9.0	9.8
12-Jun-89	9	O	2	33	2	9.0	9.8
12-Jun-89	9	O	2	66	2	9.1	9.9
12-Jun-89	9	O	2	48	2	9.1	9.9
12-Jun-89	9	O	2	19	2	9.1	9.9
12-Jun-89	9	O	2	77	2	9.1	9.9
12-Jun-89	9	O	2	12	2	9.3	10.1
12-Jun-89	9	O	2	20	2	9.3	10.1
12-Jun-89	9	O	2	1	2	9.4	10.2
						---	---
					MEAN	8.2	9.1
					SD	0.6	0.5
					N	100	100
12-Jun-89	10	M	2	15	2	6.9	8.0
12-Jun-89	10	M	2	16	1	6.9	8.0
12-Jun-89	10	M	2	14	1	6.9	8.0
12-Jun-89	10	M	2	74	1	6.9	8.0
12-Jun-89	10	M	2	70	1	6.9	8.0
12-Jun-89	10	M	2	53	1	6.9	8.0
12-Jun-89	10	M	2	40	1	6.9	8.0
12-Jun-89	10	M	2	54	2	6.9	8.0
12-Jun-89	10	M	2	75	1	6.9	8.0
12-Jun-89	10	M	2	30	1	7.0	8.1
12-Jun-89	10	M	2	7	1	7.0	8.1
12-Jun-89	10	M	2	26	2	7.0	8.1
12-Jun-89	10	M	2	81	1	7.0	8.1
12-Jun-89	10	M	2	1	2	7.0	8.1
12-Jun-89	10	M	2	44	1	7.0	8.1
12-Jun-89	10	M	2	47	1	7.0	8.1
12-Jun-89	10	M	2	79	1	7.2	8.3
12-Jun-89	10	M	2	3	1	7.2	8.3
12-Jun-89	10	M	2	68	1	7.2	8.3

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
12-Jun-89	10	M	2	11	2	7.2	8.3
12-Jun-89	10	M	2	24	1	7.2	8.3
12-Jun-89	10	M	2	63	1	7.2	8.3
12-Jun-89	10	M	2	80	1	7.2	8.3
12-Jun-89	10	M	2	61	1	7.2	8.3
12-Jun-89	10	M	2	28	1	7.2	8.3
12-Jun-89	10	M	2	87	1	7.3	8.4
12-Jun-89	10	M	2	38	1	7.3	8.4
12-Jun-89	10	M	2	8	1	7.3	8.4
12-Jun-89	10	M	2	51	2	7.5	8.5
12-Jun-89	10	M	2	62	2	7.5	8.5
12-Jun-89	10	M	2	46	1	7.5	8.5
12-Jun-89	10	M	2	60	1	7.5	8.5
12-Jun-89	10	M	2	77	2	7.5	8.5
12-Jun-89	10	M	2	39	1	7.5	8.5
12-Jun-89	10	M	2	10	1	7.5	8.5
12-Jun-89	10	M	2	20	1	7.5	8.5
12-Jun-89	10	M	2	64	1	7.5	8.5
12-Jun-89	10	M	2	49	1	7.5	8.5
12-Jun-89	10	M	2	76	2	7.5	8.5
12-Jun-89	10	M	2	94	1	7.5	8.5
12-Jun-89	10	M	2	71	1	7.5	8.5
12-Jun-89	10	M	2	22	1	7.5	8.5
12-Jun-89	10	M	2	65	1	7.6	8.6
12-Jun-89	10	M	2	36	1	7.6	8.6
12-Jun-89	10	M	2	35	2	7.6	8.6
12-Jun-89	10	M	2	89	1	7.6	8.6
12-Jun-89	10	M	2	98	1	7.6	8.6
12-Jun-89	10	M	2	17	1	7.6	8.6
12-Jun-89	10	M	2	48	1	7.6	8.6
12-Jun-89	10	M	2	19	1	7.6	8.6
12-Jun-89	10	M	2	33	1	7.6	8.6
12-Jun-89	10	M	2	18	1	7.6	8.6
12-Jun-89	10	M	2	23	1	7.6	8.6
12-Jun-89	10	M	2	99	2	7.6	8.6

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
12-Jun-89	10	M	2	73	2	7.6	8.6
12-Jun-89	10	M	2	2	1	7.6	8.6
12-Jun-89	10	M	2	58	1	7.8	8.8
12-Jun-89	10	M	2	32	1	7.8	8.8
12-Jun-89	10	M	2	84	2	7.8	8.8
12-Jun-89	10	M	2	50	1	7.8	8.8
12-Jun-89	10	M	2	4	2	7.8	8.8
12-Jun-89	10	M	2	67	1	7.8	8.8
12-Jun-89	10	M	2	69	1	7.8	8.8
12-Jun-89	10	M	2	97	2	7.8	8.8
12-Jun-89	10	M	2	83	1	7.8	8.8
12-Jun-89	10	M	2	6	1	7.9	8.9
12-Jun-89	10	M	2	55	1	7.9	8.9
12-Jun-89	10	M	2	31	1	7.9	8.9
12-Jun-89	10	M	2	88	1	7.9	8.9
12-Jun-89	10	M	2	93	1	7.9	8.9
12-Jun-89	10	M	2	72	1	8.1	9.0
12-Jun-89	10	M	2	86	1	8.1	9.0
12-Jun-89	10	M	2	57	1	8.1	9.0
12-Jun-89	10	M	2	27	1	8.1	9.0
12-Jun-89	10	M	2	42	1	8.1	9.0
12-Jun-89	10	M	2	34	1	8.1	9.0
12-Jun-89	10	M	2	29	1	8.1	9.0
12-Jun-89	10	M	2	56	2	8.2	9.1
12-Jun-89	10	M	2	92	2	8.2	9.1
12-Jun-89	10	M	2	12	2	8.2	9.1
12-Jun-89	10	M	2	66	2	8.2	9.1
12-Jun-89	10	M	2	78	2	8.2	9.1
12-Jun-89	10	M	2	5	1	8.2	9.1
12-Jun-89	10	M	2	41	2	8.2	9.1
12-Jun-89	10	M	2	52	1	8.2	9.1
12-Jun-89	10	M	2	90	1	8.4	9.3
12-Jun-89	10	M	2	43	2	8.4	9.3
12-Jun-89	10	M	2	100	2	8.4	9.3
12-Jun-89	10	M	2	82	2	8.5	9.4

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
12-Jun-89	10	M	2	13	2	8.5	9.4
12-Jun-89	10	M	2	37	2	8.5	9.4
12-Jun-89	10	M	2	91	1	8.5	9.4
12-Jun-89	10	M	2	9	2	8.5	9.4
12-Jun-89	10	M	2	45	2	8.7	9.6
12-Jun-89	10	M	2	59	2	8.7	9.6
12-Jun-89	10	M	2	25	2	8.7	9.6
12-Jun-89	10	M	2	85	2	8.7	9.6
12-Jun-89	10	M	2	95	2	8.8	9.7
12-Jun-89	10	M	2	96	2	9.0	9.8
12-Jun-89	10	M	2	21	2	9.1	9.9
						---	---
					MEAN	7.7	8.7
					SD	0.5	0.5
					N	100	100
			2	GRAND	MEAN	7.9	8.9
					SD	0.6	0.5
					N	204	204
			1	GRAND	MEAN	-	-
					SD	-	-
					N	-	-
13-Jun-89	11	D	2	91	2	7.2	8.3
13-Jun-89	11	D	2	63	1	7.3	8.4
13-Jun-89	11	D	2	95	2	7.3	8.4
13-Jun-89	11	D	2	51	1	7.5	8.5
13-Jun-89	11	D	2	32	1	7.5	8.5
13-Jun-89	11	D	2	41	2	7.5	8.5
13-Jun-89	11	D	2	36	1	7.5	8.5
13-Jun-89	11	D	2	49	2	7.5	8.5
13-Jun-89	11	D	2	87	1	7.5	8.5
13-Jun-89	11	D	2	10	1	7.5	8.5
13-Jun-89	11	D	2	79	2	7.5	8.5

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	11	D	2	60	2	7.5	8.5
13-Jun-89	11	D	2	7	2	7.6	8.6
13-Jun-89	11	D	2	78	1	7.6	8.6
13-Jun-89	11	D	2	13	2	7.6	8.6
13-Jun-89	11	D	2	9	2	7.6	8.6
13-Jun-89	11	D	2	20	2	7.6	8.6
13-Jun-89	11	D	2	82	1	7.6	8.6
13-Jun-89	11	D	2	45	2	7.6	8.6
13-Jun-89	11	D	2	56	2	7.6	8.6
13-Jun-89	11	D	2	26	1	7.6	8.6
13-Jun-89	11	D	2	15	1	7.8	8.8
13-Jun-89	11	D	2	46	1	7.8	8.8
13-Jun-89	11	D	2	94	2	7.8	8.8
13-Jun-89	11	D	2	31	2	7.8	8.8
13-Jun-89	11	D	2	24	2	7.8	8.8
13-Jun-89	11	D	2	35	2	7.8	8.8
13-Jun-89	11	D	2	33	1	7.9	8.9
13-Jun-89	11	D	2	44	1	7.9	8.9
13-Jun-89	11	D	2	21	2	7.9	8.9
13-Jun-89	11	D	2	74	2	7.9	8.9
13-Jun-89	11	D	2	25	1	7.9	8.9
13-Jun-89	11	D	2	89	1	7.9	8.9
13-Jun-89	11	D	2	54	2	7.9	8.9
13-Jun-89	11	D	2	67	1	7.9	8.9
13-Jun-89	11	D	2	40	1	7.9	8.9
13-Jun-89	11	D	2	42	2	7.9	8.9
13-Jun-89	11	D	2	16	2	8.1	9.0
13-Jun-89	11	D	2	98	1	8.1	9.0
13-Jun-89	11	D	2	71	1	8.1	9.0
13-Jun-89	11	D	2	38	2	8.1	9.0
13-Jun-89	11	D	2	52	2	8.1	9.0
13-Jun-89	11	D	2	37	2	8.1	9.0
13-Jun-89	11	D	2	50	1	8.1	9.0
13-Jun-89	11	D	2	39	2	8.1	9.0
13-Jun-89	11	D	2	84	1	8.1	9.0

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	11	D	2	93	2	8.1	9.0
13-Jun-89	11	D	2	48	1	8.1	9.0
13-Jun-89	11	D	2	2	1	8.2	9.1
13-Jun-89	11	D	2	83	2	8.2	9.1
13-Jun-89	11	D	2	76	1	8.2	9.1
13-Jun-89	11	D	2	80	1	8.2	9.1
13-Jun-89	11	D	2	14	2	8.2	9.1
13-Jun-89	11	D	2	69	1	8.2	9.1
13-Jun-89	11	D	2	6	1	8.2	9.1
13-Jun-89	11	D	2	72	1	8.2	9.1
13-Jun-89	11	D	2	88	2	8.2	9.1
13-Jun-89	11	D	2	43	1	8.2	9.1
13-Jun-89	11	D	2	53	1	8.4	9.3
13-Jun-89	11	D	2	3	1	8.4	9.3
13-Jun-89	11	D	2	70	2	8.4	9.3
13-Jun-89	11	D	2	68	2	8.4	9.3
13-Jun-89	11	D	2	73	1	8.4	9.3
13-Jun-89	11	D	2	34	1	8.4	9.3
13-Jun-89	11	D	2	64	2	8.4	9.3
13-Jun-89	11	D	2	62	1	8.4	9.3
13-Jun-89	11	D	2	59	1	8.4	9.3
13-Jun-89	11	D	2	55	1	8.4	9.3
13-Jun-89	11	D	2	4	1	8.4	9.3
13-Jun-89	11	D	2	58	1	8.4	9.3
13-Jun-89	11	D	2	97	1	8.4	9.3
13-Jun-89	11	D	2	1	2	8.4	9.3
13-Jun-89	11	D	2	61	2	8.5	9.4
13-Jun-89	11	D	2	81	2	8.5	9.4
13-Jun-89	11	D	2	28	2	8.5	9.4
13-Jun-89	11	D	2	85	1	8.5	9.4
13-Jun-89	11	D	2	12	1	8.5	9.4
13-Jun-89	11	D	2	29	1	8.7	9.6
13-Jun-89	11	D	2	27	2	8.7	9.6
13-Jun-89	11	D	2	17	2	8.7	9.6
13-Jun-89	11	D	2	77	2	8.7	9.6

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	11	D	2	57	2	8.7	9.6
13-Jun-89	11	D	2	96	2	8.7	9.6
13-Jun-89	11	D	2	8	1	8.7	9.6
13-Jun-89	11	D	2	19	1	8.7	9.6
13-Jun-89	11	D	2	30	1	8.7	9.6
13-Jun-89	11	D	2	90	2	8.8	9.7
13-Jun-89	11	D	2	66	1	8.8	9.7
13-Jun-89	11	D	2	100	1	8.8	9.7
13-Jun-89	11	D	2	18	2	8.8	9.7
13-Jun-89	11	D	2	99	1	9.0	9.8
13-Jun-89	11	D	2	47	1	9.0	9.8
13-Jun-89	11	D	2	75	2	9.0	9.8
13-Jun-89	11	D	2	92	2	9.0	9.8
13-Jun-89	11	D	2	86	2	9.0	9.8
13-Jun-89	11	D	2	11	2	9.1	9.9
13-Jun-89	11	D	2	22	2	9.1	9.9
13-Jun-89	11	D	2	23	2	9.4	10.2
13-Jun-89	11	D	2	5	2	9.7	10.4
13-Jun-89	11	D	2	65	2	9.9	10.6
						---	---
					MEAN	8.2	9.1
					SD	0.5	0.5
					N	100	100
13-Jun-89	12	C	2	59	2	6.4	7.6
13-Jun-89	12	C	2	51	2	6.7	7.9
13-Jun-89	12	C	2	17	1	7.0	8.1
13-Jun-89	12	C	2	73	1	7.3	8.4
13-Jun-89	12	C	2	10	2	7.3	8.4
13-Jun-89	12	C	2	14	1	7.6	8.6
13-Jun-89	12	C	2	40	1	7.6	8.6
13-Jun-89	12	C	2	6	1	7.6	8.6
13-Jun-89	12	C	2	46	2	7.6	8.6
13-Jun-89	12	C	2	64	2	7.8	8.8
13-Jun-89	12	C	2	69	2	7.8	8.8

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	12	C	2	3	1	7.8	8.8
13-Jun-89	12	C	2	35	2	7.8	8.8
13-Jun-89	12	C	2	98	2	7.8	8.8
13-Jun-89	12	C	2	19	2	7.9	8.9
13-Jun-89	12	C	2	99	1	7.9	8.9
13-Jun-89	12	C	2	1	2	7.9	8.9
13-Jun-89	12	C	2	83	2	7.9	8.9
13-Jun-89	12	C	2	41	2	7.9	8.9
13-Jun-89	12	C	2	49	2	7.9	8.9
13-Jun-89	12	C	2	48	2	8.1	9.0
13-Jun-89	12	C	2	20	1	8.1	9.0
13-Jun-89	12	C	2	90	2	8.1	9.0
13-Jun-89	12	C	2	4	2	8.1	9.0
13-Jun-89	12	C	2	44	1	8.1	9.0
13-Jun-89	12	C	2	96	2	8.1	9.0
13-Jun-89	12	C	2	77	1	8.1	9.0
13-Jun-89	12	C	2	74	2	8.2	9.1
13-Jun-89	12	C	2	25	2	8.2	9.1
13-Jun-89	12	C	2	24	1	8.2	9.1
13-Jun-89	12	C	2	31	2	8.2	9.1
13-Jun-89	12	C	2	70	2	8.2	9.1
13-Jun-89	12	C	2	86	2	8.2	9.1
13-Jun-89	12	C	2	58	2	8.2	9.1
13-Jun-89	12	C	2	30	2	8.2	9.1
13-Jun-89	12	C	2	27	2	8.2	9.1
13-Jun-89	12	C	2	63	2	8.2	9.1
13-Jun-89	12	C	2	2	2	8.2	9.1
13-Jun-89	12	C	2	29	1	8.4	9.3
13-Jun-89	12	C	2	22	2	8.4	9.3
13-Jun-89	12	C	2	72	2	8.4	9.3
13-Jun-89	12	C	2	80	1	8.4	9.3
13-Jun-89	12	C	2	43	2	8.4	9.3
13-Jun-89	12	C	2	18	2	8.4	9.3
13-Jun-89	12	C	2	28	2	8.4	9.3
13-Jun-89	12	C	2	12	2	8.4	9.3

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	12	C	2	60	2	8.4	9.3
13-Jun-89	12	C	2	9	1	8.4	9.3
13-Jun-89	12	C	2	54	1	8.4	9.3
13-Jun-89	12	C	2	34	2	8.4	9.3
13-Jun-89	12	C	2	76	2	8.4	9.3
13-Jun-89	12	C	2	7	2	8.4	9.3
13-Jun-89	12	C	2	52	2	8.5	9.4
13-Jun-89	12	C	2	82	2	8.5	9.4
13-Jun-89	12	C	2	21	2	8.5	9.4
13-Jun-89	12	C	2	5	1	8.5	9.4
13-Jun-89	12	C	2	65	2	8.5	9.4
13-Jun-89	12	C	2	53	2	8.5	9.4
13-Jun-89	12	C	2	66	2	8.5	9.4
13-Jun-89	12	C	2	84	2	8.5	9.4
13-Jun-89	12	C	2	67	2	8.5	9.4
13-Jun-89	12	C	2	62	1	8.5	9.4
13-Jun-89	12	C	2	39	1	8.5	9.4
13-Jun-89	12	C	2	95	1	8.5	9.4
13-Jun-89	12	C	2	26	2	8.5	9.4
13-Jun-89	12	C	2	61	2	8.5	9.4
13-Jun-89	12	C	2	13	1	8.5	9.4
13-Jun-89	12	C	2	71	2	8.5	9.4
13-Jun-89	12	C	2	32	2	8.5	9.4
13-Jun-89	12	C	2	78	2	8.7	9.6
13-Jun-89	12	C	2	45	2	8.7	9.6
13-Jun-89	12	C	2	88	2	8.7	9.6
13-Jun-89	12	C	2	100	1	8.7	9.6
13-Jun-89	12	C	2	79	2	8.7	9.6
13-Jun-89	12	C	2	75	2	8.7	9.6
13-Jun-89	12	C	2	94	2	8.7	9.6
13-Jun-89	12	C	2	89	2	8.7	9.6
13-Jun-89	12	C	2	38	2	8.7	9.6
13-Jun-89	12	C	2	93	2	8.7	9.6
13-Jun-89	12	C	2	81	2	8.7	9.6
13-Jun-89	12	C	2	16	2	8.8	9.7

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	12	C	2	11	2	8.8	9.7
13-Jun-89	12	C	2	92	2	8.8	9.7
13-Jun-89	12	C	2	47	2	8.8	9.7
13-Jun-89	12	C	2	85	2	8.8	9.7
13-Jun-89	12	C	2	36	2	8.8	9.7
13-Jun-89	12	C	2	8	1	8.8	9.7
13-Jun-89	12	C	2	87	2	8.8	9.7
13-Jun-89	12	C	2	50	2	8.8	9.7
13-Jun-89	12	C	2	23	2	9.0	9.8
13-Jun-89	12	C	2	15	2	9.1	9.9
13-Jun-89	12	C	2	37	1	9.1	9.9
13-Jun-89	12	C	2	97	2	9.3	10.1
13-Jun-89	12	C	2	42	2	9.3	10.1
13-Jun-89	12	C	2	55	2	9.3	10.1
13-Jun-89	12	C	2	91	2	9.3	10.1
13-Jun-89	12	C	2	33	2	9.4	10.2
13-Jun-89	12	C	2	57	2	9.7	10.4
13-Jun-89	12	C	2	56	2	10.3	11.0
						---	---
					MEAN	8.4	9.3
					SD	0.6	0.5
					N	99	99
13-Jun-89	13	A	2	64	2	7.3	8.4
13-Jun-89	13	A	2	23	2	7.3	8.4
13-Jun-89	13	A	2	86	1	7.6	8.6
13-Jun-89	13	A	2	71	2	7.6	8.6
13-Jun-89	13	A	2	1	1	7.6	8.6
13-Jun-89	13	A	2	77	2	7.6	8.6
13-Jun-89	13	A	2	46	2	7.8	8.8
13-Jun-89	13	A	2	39	2	7.8	8.8
13-Jun-89	13	A	2	94	2	7.8	8.8
13-Jun-89	13	A	2	43	2	7.8	8.8
13-Jun-89	13	A	2	25	2	7.8	8.8
13-Jun-89	13	A	2	87	2	7.9	8.9

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	13	A	2	45	2	7.9	8.9
13-Jun-89	13	A	2	40	1	8.1	9.0
13-Jun-89	13	A	2	66	2	8.2	9.1
13-Jun-89	13	A	2	91	2	8.2	9.1
13-Jun-89	13	A	2	13	2	8.2	9.1
13-Jun-89	13	A	2	47	2	8.2	9.1
13-Jun-89	13	A	2	69	2	8.2	9.1
13-Jun-89	13	A	2	2	2	8.2	9.1
13-Jun-89	13	A	2	93	2	8.2	9.1
13-Jun-89	13	A	2	14	2	8.2	9.1
13-Jun-89	13	A	2	76	2	8.4	9.3
13-Jun-89	13	A	2	95	2	8.4	9.3
13-Jun-89	13	A	2	21	2	8.4	9.3
13-Jun-89	13	A	2	33	2	8.4	9.3
13-Jun-89	13	A	2	52	2	8.4	9.3
13-Jun-89	13	A	2	31	2	8.4	9.3
13-Jun-89	13	A	2	62	2	8.4	9.3
13-Jun-89	13	A	2	92	2	8.4	9.3
13-Jun-89	13	A	2	16	2	8.4	9.3
13-Jun-89	13	A	2	34	2	8.4	9.3
13-Jun-89	13	A	2	51	2	8.5	9.4
13-Jun-89	13	A	2	30	2	8.5	9.4
13-Jun-89	13	A	2	78	2	8.5	9.4
13-Jun-89	13	A	2	96	2	8.5	9.4
13-Jun-89	13	A	2	17	2	8.5	9.4
13-Jun-89	13	A	2	37	2	8.5	9.4
13-Jun-89	13	A	2	72	1	8.5	9.4
13-Jun-89	13	A	2	27	2	8.5	9.4
13-Jun-89	13	A	2	89	2	8.5	9.4
13-Jun-89	13	A	2	19	2	8.5	9.4
13-Jun-89	13	A	2	26	2	8.5	9.4
13-Jun-89	13	A	2	12	2	8.7	9.6
13-Jun-89	13	A	2	32	2	8.7	9.6
13-Jun-89	13	A	2	10	2	8.7	9.6
13-Jun-89	13	A	2	28	2	8.7	9.6

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	13	A	2	18	2	8.7	9.6
13-Jun-89	13	A	2	68	2	8.7	9.6
13-Jun-89	13	A	2	15	2	8.7	9.6
13-Jun-89	13	A	2	57	2	8.7	9.6
13-Jun-89	13	A	2	7	2	8.7	9.6
13-Jun-89	13	A	2	67	2	8.8	9.7
13-Jun-89	13	A	2	41	2	8.8	9.7
13-Jun-89	13	A	2	36	2	8.8	9.7
13-Jun-89	13	A	2	44	2	8.8	9.7
13-Jun-89	13	A	2	38	2	8.8	9.7
13-Jun-89	13	A	2	3	2	8.8	9.7
13-Jun-89	13	A	2	82	2	8.8	9.7
13-Jun-89	13	A	2	59	2	8.8	9.7
13-Jun-89	13	A	2	81	2	8.8	9.7
13-Jun-89	13	A	2	98	2	8.8	9.7
13-Jun-89	13	A	2	6	2	8.8	9.7
13-Jun-89	13	A	2	100	2	8.8	9.7
13-Jun-89	13	A	2	11	2	8.8	9.7
13-Jun-89	13	A	2	54	1	9.0	9.8
13-Jun-89	13	A	2	80	2	9.0	9.8
13-Jun-89	13	A	2	79	2	9.0	9.8
13-Jun-89	13	A	2	84	2	9.0	9.8
13-Jun-89	13	A	2	55	2	9.0	9.8
13-Jun-89	13	A	2	70	2	9.0	9.8
13-Jun-89	13	A	2	24	2	9.0	9.8
13-Jun-89	13	A	2	9	2	9.0	9.8
13-Jun-89	13	A	2	99	2	9.0	9.8
13-Jun-89	13	A	2	75	2	9.1	9.9
13-Jun-89	13	A	2	73	2	9.1	9.9
13-Jun-89	13	A	2	60	2	9.1	9.9
13-Jun-89	13	A	2	20	2	9.1	9.9
13-Jun-89	13	A	2	49	2	9.1	9.9
13-Jun-89	13	A	2	42	2	9.3	10.1
13-Jun-89	13	A	2	74	2	9.3	10.1
13-Jun-89	13	A	2	83	2	9.4	10.2

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	13	A	2	35	2	9.4	10.2
13-Jun-89	13	A	2	22	2	9.4	10.2
13-Jun-89	13	A	2	8	2	9.4	10.2
13-Jun-89	13	A	2	53	2	9.4	10.2
13-Jun-89	13	A	2	61	2	9.6	10.3
13-Jun-89	13	A	2	90	2	9.6	10.3
13-Jun-89	13	A	2	97	2	9.6	10.3
13-Jun-89	13	A	2	58	2	9.7	10.4
13-Jun-89	13	A	2	65	2	9.7	10.4
13-Jun-89	13	A	2	50	2	9.7	10.4
13-Jun-89	13	A	2	5	2	9.9	10.6
13-Jun-89	13	A	2	88	2	9.9	10.6
13-Jun-89	13	A	2	63	2	10.0	10.7
13-Jun-89	13	A	2	56	2	10.0	10.7
13-Jun-89	13	A	2	85	2	10.2	10.9
13-Jun-89	13	A	2	48	2	10.5	11.1
13-Jun-89	13	A	2	29	2	10.6	11.2
						---	---
					MEAN	8.7	9.6
					SD	0.7	0.6
					N	99	99
13-Jun-89	13	A	1	4	2	12.6	13.0
						---	---
					MEAN	12.6	13.0
					SD	-	-
					N	1	1
13-Jun-89	14	C	2	45	1	6.6	7.8
13-Jun-89	14	C	2	10	1	6.7	7.9
13-Jun-89	14	C	2	43	1	7.0	8.1
13-Jun-89	14	C	2	3	2	7.0	8.1
13-Jun-89	14	C	2	34	1	7.0	8.1
13-Jun-89	14	C	2	51	2	7.2	8.3
13-Jun-89	14	C	2	26	1	7.2	8.3

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	14	C	2	18	1	7.2	8.3
13-Jun-89	14	C	2	66	1	7.2	8.3
13-Jun-89	14	C	2	57	1	7.2	8.3
13-Jun-89	14	C	2	55	2	7.3	8.4
13-Jun-89	14	C	2	40	2	7.3	8.4
13-Jun-89	14	C	2	60	1	7.3	8.4
13-Jun-89	14	C	2	48	1	7.5	8.5
13-Jun-89	14	C	2	6	1	7.5	8.5
13-Jun-89	14	C	2	86	2	7.5	8.5
13-Jun-89	14	C	2	35	2	7.5	8.5
13-Jun-89	14	C	2	62	1	7.5	8.5
13-Jun-89	14	C	2	49	1	7.5	8.5
13-Jun-89	14	C	2	98	1	7.5	8.5
13-Jun-89	14	C	2	31	1	7.5	8.5
13-Jun-89	14	C	2	54	1	7.6	8.6
13-Jun-89	14	C	2	96	2	7.6	8.6
13-Jun-89	14	C	2	30	2	7.6	8.6
13-Jun-89	14	C	2	67	2	7.6	8.6
13-Jun-89	14	C	2	87	2	7.8	8.8
13-Jun-89	14	C	2	36	2	7.8	8.8
13-Jun-89	14	C	2	82	1	7.8	8.8
13-Jun-89	14	C	2	88	2	7.8	8.8
13-Jun-89	14	C	2	44	1	7.8	8.8
13-Jun-89	14	C	2	70	1	7.9	8.9
13-Jun-89	14	C	2	68	2	7.9	8.9
13-Jun-89	14	C	2	22	2	7.9	8.9
13-Jun-89	14	C	2	24	2	7.9	8.9
13-Jun-89	14	C	2	56	2	8.1	9.0
13-Jun-89	14	C	2	94	2	8.1	9.0
13-Jun-89	14	C	2	77	1	8.1	9.0
13-Jun-89	14	C	2	50	2	8.1	9.0
13-Jun-89	14	C	2	14	2	8.1	9.0
13-Jun-89	14	C	2	20	1	8.1	9.0
13-Jun-89	14	C	2	15	1	8.1	9.0
13-Jun-89	14	C	2	46	2	8.1	9.0

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	14	C	2	17	2	8.2	9.1
13-Jun-89	14	C	2	25	2	8.2	9.1
13-Jun-89	14	C	2	93	2	8.2	9.1
13-Jun-89	14	C	2	8	2	8.2	9.1
13-Jun-89	14	C	2	28	1	8.2	9.1
13-Jun-89	14	C	2	74	2	8.2	9.1
13-Jun-89	14	C	2	81	2	8.2	9.1
13-Jun-89	14	C	2	78	2	8.2	9.1
13-Jun-89	14	C	2	83	2	8.2	9.1
13-Jun-89	14	C	2	52	2	8.4	9.3
13-Jun-89	14	C	2	13	1	8.4	9.3
13-Jun-89	14	C	2	53	2	8.4	9.3
13-Jun-89	14	C	2	76	2	8.4	9.3
13-Jun-89	14	C	2	95	2	8.4	9.3
13-Jun-89	14	C	2	19	2	8.4	9.3
13-Jun-89	14	C	2	69	2	8.4	9.3
13-Jun-89	14	C	2	61	2	8.4	9.3
13-Jun-89	14	C	2	63	2	8.5	9.4
13-Jun-89	14	C	2	84	1	8.5	9.4
13-Jun-89	14	C	2	9	2	8.5	9.4
13-Jun-89	14	C	2	47	2	8.5	9.4
13-Jun-89	14	C	2	58	2	8.5	9.4
13-Jun-89	14	C	2	41	2	8.5	9.4
13-Jun-89	14	C	2	97	2	8.5	9.4
13-Jun-89	14	C	2	38	2	8.5	9.4
13-Jun-89	14	C	2	92	2	8.5	9.4
13-Jun-89	14	C	2	90	2	8.5	9.4
13-Jun-89	14	C	2	7	2	8.7	9.6
13-Jun-89	14	C	2	59	2	8.7	9.6
13-Jun-89	14	C	2	65	2	8.7	9.6
13-Jun-89	14	C	2	85	2	8.7	9.6
13-Jun-89	14	C	2	80	2	8.7	9.6
13-Jun-89	14	C	2	32	2	8.7	9.6
13-Jun-89	14	C	2	42	2	8.7	9.6
13-Jun-89	14	C	2	23	2	8.7	9.6

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	14	C	2	4	2	8.7	9.6
13-Jun-89	14	C	2	75	2	8.8	9.7
13-Jun-89	14	C	2	21	2	8.8	9.7
13-Jun-89	14	C	2	5	2	8.8	9.7
13-Jun-89	14	C	2	11	2	8.8	9.7
13-Jun-89	14	C	2	39	2	8.8	9.7
13-Jun-89	14	C	2	64	1	8.8	9.7
13-Jun-89	14	C	2	100	1	8.8	9.7
13-Jun-89	14	C	2	72	2	9.0	9.8
13-Jun-89	14	C	2	33	2	9.0	9.8
13-Jun-89	14	C	2	99	2	9.0	9.8
13-Jun-89	14	C	2	12	2	9.1	9.9
13-Jun-89	14	C	2	29	2	9.1	9.9
13-Jun-89	14	C	2	91	2	9.1	9.9
13-Jun-89	14	C	2	79	2	9.1	9.9
13-Jun-89	14	C	2	16	2	9.3	10.1
13-Jun-89	14	C	2	37	2	9.3	10.1
13-Jun-89	14	C	2	1	2	9.4	10.2
13-Jun-89	14	C	2	89	2	9.4	10.2
13-Jun-89	14	C	2	27	2	9.4	10.2
13-Jun-89	14	C	2	71	2	9.6	10.3
13-Jun-89	14	C	2	73	2	9.6	10.3
13-Jun-89	14	C	2	2	2	9.7	10.4
						---	---
					MEAN	8.2	9.2
					SD	0.7	0.6
					N	100	100
13-Jun-89	17	E	2	24	1	6.9	8.0
13-Jun-89	17	E	2	37	2	7.5	8.5
13-Jun-89	17	E	2	61	2	7.5	8.5
13-Jun-89	17	E	2	63	2	7.5	8.5
13-Jun-89	17	E	2	21	2	7.5	8.5
13-Jun-89	17	E	2	41	1	7.5	8.5
13-Jun-89	17	E	2	45	2	7.6	8.6

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	17	E	2	32	2	7.8	8.8
13-Jun-89	17	E	2	59	2	7.8	8.8
13-Jun-89	17	E	2	36	2	7.9	8.9
13-Jun-89	17	E	2	11	2	7.9	8.9
13-Jun-89	17	E	2	12	2	7.9	8.9
13-Jun-89	17	E	2	62	2	7.9	8.9
13-Jun-89	17	E	2	68	2	7.9	8.9
13-Jun-89	17	E	2	44	2	8.1	9.0
13-Jun-89	17	E	2	13	2	8.1	9.0
13-Jun-89	17	E	2	30	2	8.1	9.0
13-Jun-89	17	E	2	18	2	8.1	9.0
13-Jun-89	17	E	2	15	1	8.1	9.0
13-Jun-89	17	E	2	27	2	8.1	9.0
13-Jun-89	17	E	2	23	2	8.2	9.1
13-Jun-89	17	E	2	33	2	8.2	9.1
13-Jun-89	17	E	2	66	2	8.2	9.1
13-Jun-89	17	E	2	56	2	8.2	9.1
13-Jun-89	17	E	2	55	2	8.2	9.1
13-Jun-89	17	E	2	58	1	8.2	9.1
13-Jun-89	17	E	2	2	2	8.2	9.1
13-Jun-89	17	E	2	1	2	8.4	9.3
13-Jun-89	17	E	2	20	2	8.4	9.3
13-Jun-89	17	E	2	46	2	8.4	9.3
13-Jun-89	17	E	2	31	2	8.4	9.3
13-Jun-89	17	E	2	50	1	8.4	9.3
13-Jun-89	17	E	2	10	2	8.4	9.3
13-Jun-89	17	E	2	47	2	8.4	9.3
13-Jun-89	17	E	2	67	2	8.4	9.3
13-Jun-89	17	E	2	3	1	8.5	9.4
13-Jun-89	17	E	2	9	1	8.5	9.4
13-Jun-89	17	E	2	19	2	8.5	9.4
13-Jun-89	17	E	2	34	2	8.5	9.4
13-Jun-89	17	E	2	14	1	8.5	9.4
13-Jun-89	17	E	2	60	2	8.5	9.4
13-Jun-89	17	E	2	17	2	8.5	9.4

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
13-Jun-89	17	E	2	39	2	8.5	9.4
13-Jun-89	17	E	2	49	2	8.7	9.6
13-Jun-89	17	E	2	6	2	8.7	9.6
13-Jun-89	17	E	2	26	2	8.7	9.6
13-Jun-89	17	E	2	38	2	8.7	9.6
13-Jun-89	17	E	2	48	1	8.8	9.7
13-Jun-89	17	E	2	4	2	8.8	9.7
13-Jun-89	17	E	2	16	2	8.8	9.7
13-Jun-89	17	E	2	42	2	8.8	9.7
13-Jun-89	17	E	2	65	2	8.8	9.7
13-Jun-89	17	E	2	53	2	8.8	9.7
13-Jun-89	17	E	2	52	2	8.8	9.7
13-Jun-89	17	E	2	22	2	8.8	9.7
13-Jun-89	17	E	2	57	2	8.8	9.7
13-Jun-89	17	E	2	5	2	9.0	9.8
13-Jun-89	17	E	2	64	2	9.0	9.8
13-Jun-89	17	E	2	7	2	9.0	9.8
13-Jun-89	17	E	2	35	2	9.1	9.9
13-Jun-89	17	E	2	43	2	9.1	9.9
13-Jun-89	17	E	2	51	2	9.1	9.9
13-Jun-89	17	E	2	8	2	9.4	10.2
13-Jun-89	17	E	2	28	2	9.6	10.3
13-Jun-89	17	E	2	29	2	9.6	10.3
13-Jun-89	17	E	2	40	2	10.2	10.9
13-Jun-89	17	E	2	54	2	10.5	11.1
					MEAN	8.4	9.3
					SD	0.6	0.5
					N	67	67
			2	GRAND	MEAN	8.4	9.3
					SD	0.6	0.5
					N	465	465
			1	GRAND	MEAN	12.6	13.0

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
					SD	-	-
					N	1	1
14-Jun-89	15	F	-	-	-	-	-
					MEAN	-	-
					SD	-	-
					N	-	-
14-Jun-89	16	J	2	13	2	7.6	8.6
14-Jun-89	16	J	2	12	2	7.8	8.8
14-Jun-89	16	J	2	10	2	7.9	8.9
14-Jun-89	16	J	2	4	2	8.2	9.1
14-Jun-89	16	J	2	1	2	8.4	9.3
14-Jun-89	16	J	2	14	2	8.4	9.3
14-Jun-89	16	J	2	8	2	8.5	9.4
14-Jun-89	16	J	2	5	2	8.5	9.4
14-Jun-89	16	J	2	15	2	8.5	9.4
14-Jun-89	16	J	2	2	2	8.7	9.6
14-Jun-89	16	J	2	7	2	8.8	9.7
14-Jun-89	16	J	2	6	2	8.8	9.7
14-Jun-89	16	J	2	3	2	9.1	9.9
14-Jun-89	16	J	2	9	2	9.3	10.1
					MEAN	8.5	9.4
					SD	0.5	0.4
					N	14	14
14-Jun-89	16	J	1	11	2	11.1	11.7
					MEAN	11.1	11.7
					SD	-	-
					N	1	1
14-Jun-89	18	N	2	90	2	6.7	7.9

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	18	N	2	22	2	7.0	8.1
14-Jun-89	18	N	2	57	2	7.2	8.3
14-Jun-89	18	N	2	87	2	7.2	8.3
14-Jun-89	18	N	2	83	2	7.3	8.4
14-Jun-89	18	N	2	25	1	7.3	8.4
14-Jun-89	18	N	2	46	2	7.5	8.5
14-Jun-89	18	N	2	94	2	7.5	8.5
14-Jun-89	18	N	2	14	2	7.5	8.5
14-Jun-89	18	N	2	37	2	7.6	8.6
14-Jun-89	18	N	2	64	2	7.6	8.6
14-Jun-89	18	N	2	40	2	7.6	8.6
14-Jun-89	18	N	2	98	2	7.6	8.6
14-Jun-89	18	N	2	52	2	7.6	8.6
14-Jun-89	18	N	2	29	2	7.8	8.8
14-Jun-89	18	N	2	58	2	7.8	8.8
14-Jun-89	18	N	2	41	2	7.8	8.8
14-Jun-89	18	N	2	34	2	7.9	8.9
14-Jun-89	18	N	2	89	2	7.9	8.9
14-Jun-89	18	N	2	8	2	7.9	8.9
14-Jun-89	18	N	2	93	2	7.9	8.9
14-Jun-89	18	N	2	99	2	8.1	9.0
14-Jun-89	18	N	2	50	2	8.1	9.0
14-Jun-89	18	N	2	36	1	8.1	9.0
14-Jun-89	18	N	2	60	2	8.2	9.1
14-Jun-89	18	N	2	30	2	8.2	9.1
14-Jun-89	18	N	2	38	2	8.2	9.1
14-Jun-89	18	N	2	16	1	8.2	9.1
14-Jun-89	18	N	2	62	2	8.2	9.1
14-Jun-89	18	N	2	67	2	8.2	9.1
14-Jun-89	18	N	2	20	2	8.2	9.1
14-Jun-89	18	N	2	1	2	8.2	9.1
14-Jun-89	18	N	2	55	2	8.2	9.1
14-Jun-89	18	N	2	7	2	8.4	9.3
14-Jun-89	18	N	2	19	2	8.4	9.3
14-Jun-89	18	N	2	75	2	8.4	9.3

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	18	N	2	17	2	8.4	9.3
14-Jun-89	18	N	2	95	2	8.4	9.3
14-Jun-89	18	N	2	74	2	8.4	9.3
14-Jun-89	18	N	2	3	2	8.4	9.3
14-Jun-89	18	N	2	78	2	8.5	9.4
14-Jun-89	18	N	2	47	2	8.5	9.4
14-Jun-89	18	N	2	70	2	8.5	9.4
14-Jun-89	18	N	2	73	2	8.5	9.4
14-Jun-89	18	N	2	84	2	8.5	9.4
14-Jun-89	18	N	2	39	2	8.5	9.4
14-Jun-89	18	N	2	4	2	8.5	9.4
14-Jun-89	18	N	2	91	2	8.5	9.4
14-Jun-89	18	N	2	59	2	8.5	9.4
14-Jun-89	18	N	2	72	2	8.5	9.4
14-Jun-89	18	N	2	48	2	8.7	9.6
14-Jun-89	18	N	2	56	2	8.7	9.6
14-Jun-89	18	N	2	100	2	8.7	9.6
14-Jun-89	18	N	2	71	2	8.7	9.6
14-Jun-89	18	N	2	45	2	8.7	9.6
14-Jun-89	18	N	2	2	2	8.7	9.6
14-Jun-89	18	N	2	35	2	8.7	9.6
14-Jun-89	18	N	2	5	2	8.7	9.6
14-Jun-89	18	N	2	28	2	8.7	9.6
14-Jun-89	18	N	2	79	2	8.8	9.7
14-Jun-89	18	N	2	24	2	8.8	9.7
14-Jun-89	18	N	2	10	2	8.8	9.7
14-Jun-89	18	N	2	88	2	8.8	9.7
14-Jun-89	18	N	2	32	2	8.8	9.7
14-Jun-89	18	N	2	23	2	8.8	9.7
14-Jun-89	18	N	2	51	2	9.0	9.8
14-Jun-89	18	N	2	65	2	9.0	9.8
14-Jun-89	18	N	2	43	2	9.0	9.8
14-Jun-89	18	N	2	44	2	9.0	9.8
14-Jun-89	18	N	2	92	2	9.1	9.9
14-Jun-89	18	N	2	18	2	9.1	9.9

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	18	N	2	82	2	9.1	9.9
14-Jun-89	18	N	2	85	2	9.1	9.9
14-Jun-89	18	N	2	80	2	9.1	9.9
14-Jun-89	18	N	2	86	2	9.3	10.1
14-Jun-89	18	N	2	69	2	9.3	10.1
14-Jun-89	18	N	2	61	2	9.3	10.1
14-Jun-89	18	N	2	76	2	9.3	10.1
14-Jun-89	18	N	2	96	2	9.3	10.1
14-Jun-89	18	N	2	33	2	9.4	10.2
14-Jun-89	18	N	2	54	2	9.4	10.2
14-Jun-89	18	N	2	27	2	9.4	10.2
14-Jun-89	18	N	2	26	2	9.4	10.2
14-Jun-89	18	N	2	42	2	9.4	10.2
14-Jun-89	18	N	2	6	2	9.4	10.2
14-Jun-89	18	N	2	15	2	9.4	10.2
14-Jun-89	18	N	2	21	2	9.6	10.3
14-Jun-89	18	N	2	77	2	9.6	10.3
14-Jun-89	18	N	2	63	2	9.6	10.3
14-Jun-89	18	N	2	66	2	9.6	10.3
14-Jun-89	18	N	2	11	2	9.6	10.3
14-Jun-89	18	N	2	9	2	9.6	10.3
14-Jun-89	18	N	2	53	2	9.6	10.3
14-Jun-89	18	N	2	81	2	9.7	10.4
14-Jun-89	18	N	2	49	2	9.7	10.4
14-Jun-89	18	N	2	68	2	9.7	10.4
14-Jun-89	18	N	2	13	2	9.9	10.6
14-Jun-89	18	N	2	31	2	9.9	10.6
14-Jun-89	18	N	2	97	2	10.3	11.0
14-Jun-89	18	N	2	12	2	10.6	11.2
						---	---
					MEAN	8.6	9.5
					SD	0.8	0.7
					N	100	100
14-Jun-89	19	M	2	74	1	6.6	7.8

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	19	M	2	29	1	6.6	7.8
14-Jun-89	19	M	2	81	2	6.9	8.0
14-Jun-89	19	M	2	3	1	6.9	8.0
14-Jun-89	19	M	2	16	2	6.9	8.0
14-Jun-89	19	M	2	37	2	6.9	8.0
14-Jun-89	19	M	2	84	2	7.0	8.1
14-Jun-89	19	M	2	49	2	7.0	8.1
14-Jun-89	19	M	2	9	1	7.2	8.3
14-Jun-89	19	M	2	70	2	7.3	8.4
14-Jun-89	19	M	2	4	1	7.3	8.4
14-Jun-89	19	M	2	12	2	7.5	8.5
14-Jun-89	19	M	2	10	2	7.5	8.5
14-Jun-89	19	M	2	42	2	7.5	8.5
14-Jun-89	19	M	2	15	2	7.5	8.5
14-Jun-89	19	M	2	85	2	7.5	8.5
14-Jun-89	19	M	2	17	2	7.5	8.5
14-Jun-89	19	M	2	40	2	7.6	8.6
14-Jun-89	19	M	2	92	2	7.6	8.6
14-Jun-89	19	M	2	32	1	7.6	8.6
14-Jun-89	19	M	2	87	2	7.6	8.6
14-Jun-89	19	M	2	55	2	7.6	8.6
14-Jun-89	19	M	2	93	2	7.8	8.8
14-Jun-89	19	M	2	38	1	7.8	8.8
14-Jun-89	19	M	2	65	2	7.8	8.8
14-Jun-89	19	M	2	18	2	7.8	8.8
14-Jun-89	19	M	2	53	2	7.8	8.8
14-Jun-89	19	M	2	79	2	7.8	8.8
14-Jun-89	19	M	2	50	2	7.8	8.8
14-Jun-89	19	M	2	73	2	7.9	8.9
14-Jun-89	19	M	2	100	2	7.9	8.9
14-Jun-89	19	M	2	20	2	7.9	8.9
14-Jun-89	19	M	2	68	2	7.9	8.9
14-Jun-89	19	M	2	24	2	7.9	8.9
14-Jun-89	19	M	2	72	2	8.1	9.0
14-Jun-89	19	M	2	62	2	8.1	9.0

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	19	M	2	33	2	8.1	9.0
14-Jun-89	19	M	2	48	1	8.1	9.0
14-Jun-89	19	M	2	34	2	8.1	9.0
14-Jun-89	19	M	2	95	1	8.1	9.0
14-Jun-89	19	M	2	76	2	8.1	9.0
14-Jun-89	19	M	2	21	1	8.1	9.0
14-Jun-89	19	M	2	97	2	8.2	9.1
14-Jun-89	19	M	2	14	1	8.2	9.1
14-Jun-89	19	M	2	26	2	8.2	9.1
14-Jun-89	19	M	2	57	2	8.2	9.1
14-Jun-89	19	M	2	69	2	8.2	9.1
14-Jun-89	19	M	2	11	2	8.4	9.3
14-Jun-89	19	M	2	66	2	8.4	9.3
14-Jun-89	19	M	2	22	2	8.4	9.3
14-Jun-89	19	M	2	28	2	8.4	9.3
14-Jun-89	19	M	2	39	1	8.5	9.4
14-Jun-89	19	M	2	77	2	8.5	9.4
14-Jun-89	19	M	2	90	2	8.5	9.4
14-Jun-89	19	M	2	44	2	8.5	9.4
14-Jun-89	19	M	2	80	2	8.5	9.4
14-Jun-89	19	M	2	5	1	8.5	9.4
14-Jun-89	19	M	2	63	2	8.5	9.4
14-Jun-89	19	M	2	88	2	8.7	9.6
14-Jun-89	19	M	2	30	2	8.7	9.6
14-Jun-89	19	M	2	86	2	8.7	9.6
14-Jun-89	19	M	2	1	2	8.7	9.6
14-Jun-89	19	M	2	45	2	8.7	9.6
14-Jun-89	19	M	2	94	2	8.8	9.7
14-Jun-89	19	M	2	13	2	8.8	9.7
14-Jun-89	19	M	2	54	2	8.8	9.7
14-Jun-89	19	M	2	67	2	9.0	9.8
14-Jun-89	19	M	2	25	2	9.0	9.8
14-Jun-89	19	M	2	8	2	9.0	9.8
14-Jun-89	19	M	2	52	2	9.0	9.8
14-Jun-89	19	M	2	58	2	9.0	9.8

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	19	M	2	82	2	9.1	9.9
14-Jun-89	19	M	2	99	2	9.1	9.9
14-Jun-89	19	M	2	61	2	9.1	9.9
14-Jun-89	19	M	2	47	2	9.1	9.9
14-Jun-89	19	M	2	46	2	9.1	9.9
14-Jun-89	19	M	2	51	2	9.3	10.1
14-Jun-89	19	M	2	6	2	9.3	10.1
14-Jun-89	19	M	2	59	2	9.3	10.1
14-Jun-89	19	M	2	36	2	9.3	10.1
14-Jun-89	19	M	2	31	2	9.4	10.2
14-Jun-89	19	M	2	27	2	9.6	10.3
14-Jun-89	19	M	2	98	2	9.6	10.3
14-Jun-89	19	M	2	2	2	9.6	10.3
14-Jun-89	19	M	2	91	2	9.6	10.3
14-Jun-89	19	M	2	89	2	9.7	10.4
14-Jun-89	19	M	2	78	2	9.7	10.4
14-Jun-89	19	M	2	71	2	9.7	10.4
14-Jun-89	19	M	2	83	2	9.7	10.4
14-Jun-89	19	M	2	41	2	9.7	10.4
14-Jun-89	19	M	2	23	2	9.9	10.6
14-Jun-89	19	M	2	7	2	10.0	10.7
14-Jun-89	19	M	2	64	2	10.0	10.7
14-Jun-89	19	M	2	96	2	10.3	11.0
14-Jun-89	19	M	2	19	2	10.3	11.0
14-Jun-89	19	M	2	60	2	10.6	11.2
14-Jun-89	19	M	2	43	2	10.9	11.5
						---	---
				MEAN		8.4	9.3
				SD		0.9	0.8
				N		97	97
14-Jun-89	19	M	1	35	2	11.1	11.7
14-Jun-89	19	M	1	75	2	11.1	11.7
14-Jun-89	19	M	1	56	2	12.1	12.6
						---	---

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
					MEAN	11.4	12.0
					SD	0.6	0.5
					N	3	3
14-Jun-89	20	L	2	18	2	7.8	8.8
14-Jun-89	20	L	2	2	2	7.8	8.8
14-Jun-89	20	L	2	19	2	7.8	8.8
14-Jun-89	20	L	2	8	2	8.1	9.0
14-Jun-89	20	L	2	13	2	8.1	9.0
14-Jun-89	20	L	2	5	2	8.2	9.1
14-Jun-89	20	L	2	16	2	8.4	9.3
14-Jun-89	20	L	2	4	2	8.4	9.3
14-Jun-89	20	L	2	11	2	8.5	9.4
14-Jun-89	20	L	2	12	2	8.5	9.4
14-Jun-89	20	L	2	6	2	8.5	9.4
14-Jun-89	20	L	2	9	2	8.5	9.4
14-Jun-89	20	L	2	14	2	8.7	9.6
14-Jun-89	20	L	2	10	2	8.8	9.7
14-Jun-89	20	L	2	7	2	8.8	9.7
14-Jun-89	20	L	2	3	2	8.8	9.7
14-Jun-89	20	L	2	15	2	9.0	9.8
14-Jun-89	20	L	2	1	2	9.7	10.4
						---	---
					MEAN	8.5	9.4
					SD	0.5	0.4
					N	18	18
14-Jun-89	21	K	2	27	2	6.6	7.8
14-Jun-89	21	K	2	24	2	7.2	8.3
14-Jun-89	21	K	2	19	2	7.2	8.3
14-Jun-89	21	K	2	25	2	7.5	8.5
14-Jun-89	21	K	2	23	2	7.8	8.8
14-Jun-89	21	K	2	16	2	7.8	8.8
14-Jun-89	21	K	2	20	2	7.8	8.8

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	21	K	2	22	2	7.9	8.9
14-Jun-89	21	K	2	12	1	7.9	8.9
14-Jun-89	21	K	2	11	2	8.1	9.0
14-Jun-89	21	K	2	15	2	8.2	9.1
14-Jun-89	21	K	2	18	2	8.2	9.1
14-Jun-89	21	K	2	26	2	8.2	9.1
14-Jun-89	21	K	2	4	2	8.4	9.3
14-Jun-89	21	K	2	14	2	8.4	9.3
14-Jun-89	21	K	2	2	2	8.4	9.3
14-Jun-89	21	K	2	10	2	8.4	9.3
14-Jun-89	21	K	2	9	2	8.5	9.4
14-Jun-89	21	K	2	21	2	8.5	9.4
14-Jun-89	21	K	2	8	2	8.7	9.6
14-Jun-89	21	K	2	6	2	8.8	9.7
14-Jun-89	21	K	2	7	2	9.0	9.8
14-Jun-89	21	K	2	17	2	9.0	9.8
14-Jun-89	21	K	2	3	2	9.4	10.2
						---	---
					MEAN	8.2	9.1
					SD	0.6	0.5
					N	24	24
14-Jun-89	21	K	1	5	2	11.1	11.7
14-Jun-89	21	K	1	1	2	12.7	13.1
						---	---
					MEAN	11.9	12.4
					SD	1.1	1.0
					N	2	2
14-Jun-89	22	A	2	57	1	7.3	8.4
14-Jun-89	22	A	2	44	1	7.3	8.4
14-Jun-89	22	A	2	60	1	7.5	8.5
14-Jun-89	22	A	2	94	1	7.6	8.6
14-Jun-89	22	A	2	21	2	7.8	8.8
14-Jun-89	22	A	2	2	2	7.9	8.9

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	22	A	2	38	1	7.9	8.9
14-Jun-89	22	A	2	99	2	8.1	9.0
14-Jun-89	22	A	2	79	2	8.1	9.0
14-Jun-89	22	A	2	69	1	8.1	9.0
14-Jun-89	22	A	2	100	2	8.2	9.1
14-Jun-89	22	A	2	65	2	8.2	9.1
14-Jun-89	22	A	2	17	1	8.2	9.1
14-Jun-89	22	A	2	78	2	8.2	9.1
14-Jun-89	22	A	2	43	1	8.2	9.1
14-Jun-89	22	A	2	72	2	8.2	9.1
14-Jun-89	22	A	2	47	2	8.4	9.3
14-Jun-89	22	A	2	27	2	8.4	9.3
14-Jun-89	22	A	2	90	2	8.4	9.3
14-Jun-89	22	A	2	6	1	8.4	9.3
14-Jun-89	22	A	2	93	1	8.4	9.3
14-Jun-89	22	A	2	11	1	8.4	9.3
14-Jun-89	22	A	2	62	2	8.4	9.3
14-Jun-89	22	A	2	96	1	8.4	9.3
14-Jun-89	22	A	2	46	2	8.5	9.4
14-Jun-89	22	A	2	23	2	8.5	9.4
14-Jun-89	22	A	2	8	2	8.5	9.4
14-Jun-89	22	A	2	52	2	8.5	9.4
14-Jun-89	22	A	2	59	1	8.7	9.6
14-Jun-89	22	A	2	28	1	8.7	9.6
14-Jun-89	22	A	2	80	2	8.7	9.6
14-Jun-89	22	A	2	89	2	8.7	9.6
14-Jun-89	22	A	2	24	2	8.7	9.6
14-Jun-89	22	A	2	50	2	8.7	9.6
14-Jun-89	22	A	2	29	2	8.7	9.6
14-Jun-89	22	A	2	25	2	8.8	9.7
14-Jun-89	22	A	2	64	2	8.8	9.7
14-Jun-89	22	A	2	14	2	8.8	9.7
14-Jun-89	22	A	2	7	2	8.8	9.7
14-Jun-89	22	A	2	53	2	8.8	9.7
14-Jun-89	22	A	2	10	2	8.8	9.7

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	22	A	2	81	2	8.8	9.7
14-Jun-89	22	A	2	77	1	8.8	9.7
14-Jun-89	22	A	2	67	2	8.8	9.7
14-Jun-89	22	A	2	48	2	8.8	9.7
14-Jun-89	22	A	2	82	2	8.8	9.7
14-Jun-89	22	A	2	61	2	9.0	9.8
14-Jun-89	22	A	2	70	2	9.0	9.8
14-Jun-89	22	A	2	19	2	9.0	9.8
14-Jun-89	22	A	2	71	2	9.0	9.8
14-Jun-89	22	A	2	34	2	9.0	9.8
14-Jun-89	22	A	2	76	2	9.0	9.8
14-Jun-89	22	A	2	32	2	9.0	9.8
14-Jun-89	22	A	2	98	2	9.0	9.8
14-Jun-89	22	A	2	33	2	9.0	9.8
14-Jun-89	22	A	2	68	2	9.0	9.8
14-Jun-89	22	A	2	91	2	9.1	9.9
14-Jun-89	22	A	2	75	2	9.1	9.9
14-Jun-89	22	A	2	58	2	9.1	9.9
14-Jun-89	22	A	2	55	2	9.1	9.9
14-Jun-89	22	A	2	54	2	9.1	9.9
14-Jun-89	22	A	2	87	2	9.1	9.9
14-Jun-89	22	A	2	84	2	9.1	9.9
14-Jun-89	22	A	2	95	2	9.1	9.9
14-Jun-89	22	A	2	20	2	9.1	9.9
14-Jun-89	22	A	2	40	2	9.1	9.9
14-Jun-89	22	A	2	39	2	9.3	10.1
14-Jun-89	22	A	2	92	2	9.3	10.1
14-Jun-89	22	A	2	31	2	9.3	10.1
14-Jun-89	22	A	2	86	2	9.3	10.1
14-Jun-89	22	A	2	88	2	9.3	10.1
14-Jun-89	22	A	2	26	2	9.3	10.1
14-Jun-89	22	A	2	9	2	9.3	10.1
14-Jun-89	22	A	2	3	2	9.3	10.1
14-Jun-89	22	A	2	66	2	9.3	10.1
14-Jun-89	22	A	2	42	2	9.3	10.1

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	22	A	2	36	2	9.4	10.2
14-Jun-89	22	A	2	74	2	9.4	10.2
14-Jun-89	22	A	2	35	2	9.4	10.2
14-Jun-89	22	A	2	85	2	9.4	10.2
14-Jun-89	22	A	2	30	2	9.4	10.2
14-Jun-89	22	A	2	5	2	9.4	10.2
14-Jun-89	22	A	2	13	2	9.4	10.2
14-Jun-89	22	A	2	12	2	9.4	10.2
14-Jun-89	22	A	2	15	2	9.6	10.3
14-Jun-89	22	A	2	56	2	9.6	10.3
14-Jun-89	22	A	2	45	2	9.6	10.3
14-Jun-89	22	A	2	49	2	9.6	10.3
14-Jun-89	22	A	2	1	2	9.6	10.3
14-Jun-89	22	A	2	97	2	9.6	10.3
14-Jun-89	22	A	2	51	2	9.7	10.4
14-Jun-89	22	A	2	63	2	9.7	10.4
14-Jun-89	22	A	2	4	2	9.7	10.4
14-Jun-89	22	A	2	41	2	9.7	10.4
14-Jun-89	22	A	2	18	2	9.9	10.6
14-Jun-89	22	A	2	37	2	10.2	10.9
14-Jun-89	22	A	2	22	2	10.2	10.9
14-Jun-89	22	A	2	16	2	10.2	10.9
14-Jun-89	22	A	2	73	1	10.3	11.0
14-Jun-89	22	A	2	83	2	10.5	11.1
						---	---
					MEAN	8.9	9.8
					SD	0.6	0.6
					N	100	100
14-Jun-89	23	B	2	88	2	6.4	7.6
14-Jun-89	23	B	2	87	2	6.7	7.9
14-Jun-89	23	B	2	23	1	6.9	8.0
14-Jun-89	23	B	2	39	1	6.9	8.0
14-Jun-89	23	B	2	51	2	7.2	8.3
14-Jun-89	23	B	2	57	1	7.2	8.3

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	23	B	2	83	1	7.3	8.4
14-Jun-89	23	B	2	56	2	7.3	8.4
14-Jun-89	23	B	2	71	2	7.5	8.5
14-Jun-89	23	B	2	98	1	7.5	8.5
14-Jun-89	23	B	2	45	1	7.5	8.5
14-Jun-89	23	B	2	36	1	7.5	8.5
14-Jun-89	23	B	2	3	1	7.5	8.5
14-Jun-89	23	B	2	92	1	7.5	8.5
14-Jun-89	23	B	2	40	2	7.5	8.5
14-Jun-89	23	B	2	6	2	7.6	8.6
14-Jun-89	23	B	2	84	1	7.6	8.6
14-Jun-89	23	B	2	15	2	7.6	8.6
14-Jun-89	23	B	2	30	1	7.6	8.6
14-Jun-89	23	B	2	82	1	7.6	8.6
14-Jun-89	23	B	2	100	1	7.8	8.8
14-Jun-89	23	B	2	79	2	7.8	8.8
14-Jun-89	23	B	2	89	2	7.8	8.8
14-Jun-89	23	B	2	81	2	7.8	8.8
14-Jun-89	23	B	2	69	1	7.9	8.9
14-Jun-89	23	B	2	68	2	7.9	8.9
14-Jun-89	23	B	2	99	2	7.9	8.9
14-Jun-89	23	B	2	54	2	7.9	8.9
14-Jun-89	23	B	2	18	2	8.1	9.0
14-Jun-89	23	B	2	32	1	8.1	9.0
14-Jun-89	23	B	2	4	2	8.1	9.0
14-Jun-89	23	B	2	55	1	8.1	9.0
14-Jun-89	23	B	2	43	2	8.1	9.0
14-Jun-89	23	B	2	49	2	8.2	9.1
14-Jun-89	23	B	2	28	2	8.2	9.1
14-Jun-89	23	B	2	62	1	8.2	9.1
14-Jun-89	23	B	2	96	2	8.2	9.1
14-Jun-89	23	B	2	47	1	8.2	9.1
14-Jun-89	23	B	2	86	1	8.2	9.1
14-Jun-89	23	B	2	42	2	8.4	9.3
14-Jun-89	23	B	2	91	2	8.4	9.3

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	23	B	2	50	2	8.4	9.3
14-Jun-89	23	B	2	33	1	8.4	9.3
14-Jun-89	23	B	2	73	1	8.4	9.3
14-Jun-89	23	B	2	65	2	8.4	9.3
14-Jun-89	23	B	2	12	2	8.5	9.4
14-Jun-89	23	B	2	27	2	8.5	9.4
14-Jun-89	23	B	2	46	2	8.5	9.4
14-Jun-89	23	B	2	61	2	8.5	9.4
14-Jun-89	23	B	2	22	2	8.5	9.4
14-Jun-89	23	B	2	64	2	8.5	9.4
14-Jun-89	23	B	2	63	2	8.7	9.6
14-Jun-89	23	B	2	59	2	8.7	9.6
14-Jun-89	23	B	2	10	2	8.7	9.6
14-Jun-89	23	B	2	16	2	8.7	9.6
14-Jun-89	23	B	2	77	2	8.7	9.6
14-Jun-89	23	B	2	78	2	8.8	9.7
14-Jun-89	23	B	2	21	2	8.8	9.7
14-Jun-89	23	B	2	52	2	8.8	9.7
14-Jun-89	23	B	2	5	2	8.8	9.7
14-Jun-89	23	B	2	11	2	8.8	9.7
14-Jun-89	23	B	2	80	2	8.8	9.7
14-Jun-89	23	B	2	60	2	8.8	9.7
14-Jun-89	23	B	2	17	1	8.8	9.7
14-Jun-89	23	B	2	75	2	8.8	9.7
14-Jun-89	23	B	2	58	2	9.0	9.8
14-Jun-89	23	B	2	90	2	9.0	9.8
14-Jun-89	23	B	2	37	2	9.0	9.8
14-Jun-89	23	B	2	94	2	9.0	9.8
14-Jun-89	23	B	2	85	2	9.0	9.8
14-Jun-89	23	B	2	1	2	9.1	9.9
14-Jun-89	23	B	2	26	2	9.1	9.9
14-Jun-89	23	B	2	13	1	9.1	9.9
14-Jun-89	23	B	2	29	2	9.3	10.1
14-Jun-89	23	B	2	41	2	9.3	10.1
14-Jun-89	23	B	2	9	2	9.3	10.1

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	23	B	2	95	1	9.3	10.1
14-Jun-89	23	B	2	66	2	9.3	10.1
14-Jun-89	23	B	2	2	2	9.3	10.1
14-Jun-89	23	B	2	8	2	9.4	10.2
14-Jun-89	23	B	2	24	2	9.4	10.2
14-Jun-89	23	B	2	72	2	9.4	10.2
14-Jun-89	23	B	2	44	2	9.4	10.2
14-Jun-89	23	B	2	31	2	9.6	10.3
14-Jun-89	23	B	2	97	2	9.6	10.3
14-Jun-89	23	B	2	7	2	9.6	10.3
14-Jun-89	23	B	2	20	2	9.7	10.4
14-Jun-89	23	B	2	14	1	9.7	10.4
14-Jun-89	23	B	2	70	2	9.7	10.4
14-Jun-89	23	B	2	76	1	9.9	10.6
14-Jun-89	23	B	2	74	1	10.5	11.1
14-Jun-89	23	B	2	35	1	10.5	11.1
14-Jun-89	23	B	2	25	2	10.5	11.1
14-Jun-89	23	B	2	48	2	10.6	11.2
14-Jun-89	23	B	2	93	2	10.6	11.2
14-Jun-89	23	B	2	38	2	10.8	11.4
14-Jun-89	23	B	2	67	2	10.8	11.4
14-Jun-89	23	B	2	34	1	10.8	11.4
14-Jun-89	23	B	2	53	2	10.9	11.5
						---	---
					MEAN	8.6	9.5
					SD	1.0	0.9
					N	99	99
14-Jun-89	23	B	1	19	2	11.5	12.0
						---	---
					MEAN	11.5	12.0
					SD	-	-
					N	1	1
14-Jun-89	24	C	2	62	2	7.3	8.4

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	24	C	2	20	1	7.5	8.5
14-Jun-89	24	C	2	10	1	7.5	8.5
14-Jun-89	24	C	2	32	1	7.6	8.6
14-Jun-89	24	C	2	48	1	7.8	8.8
14-Jun-89	24	C	2	12	1	7.8	8.8
14-Jun-89	24	C	2	18	1	7.8	8.8
14-Jun-89	24	C	2	55	1	7.8	8.8
14-Jun-89	24	C	2	90	2	7.9	8.9
14-Jun-89	24	C	2	8	2	7.9	8.9
14-Jun-89	24	C	2	39	2	7.9	8.9
14-Jun-89	24	C	2	74	2	7.9	8.9
14-Jun-89	24	C	2	28	2	7.9	8.9
14-Jun-89	24	C	2	47	2	8.1	9.0
14-Jun-89	24	C	2	91	2	8.1	9.0
14-Jun-89	24	C	2	83	2	8.1	9.0
14-Jun-89	24	C	2	5	2	8.1	9.0
14-Jun-89	24	C	2	7	2	8.1	9.0
14-Jun-89	24	C	2	66	2	8.2	9.1
14-Jun-89	24	C	2	50	2	8.2	9.1
14-Jun-89	24	C	2	53	2	8.2	9.1
14-Jun-89	24	C	2	69	2	8.2	9.1
14-Jun-89	24	C	2	49	2	8.2	9.1
14-Jun-89	24	C	2	96	2	8.2	9.1
14-Jun-89	24	C	2	31	2	8.2	9.1
14-Jun-89	24	C	2	4	2	8.2	9.1
14-Jun-89	24	C	2	6	2	8.4	9.3
14-Jun-89	24	C	2	15	2	8.4	9.3
14-Jun-89	24	C	2	73	2	8.4	9.3
14-Jun-89	24	C	2	67	2	8.4	9.3
14-Jun-89	24	C	2	95	2	8.4	9.3
14-Jun-89	24	C	2	79	1	8.4	9.3
14-Jun-89	24	C	2	37	1	8.4	9.3
14-Jun-89	24	C	2	64	2	8.4	9.3
14-Jun-89	24	C	2	26	2	8.4	9.3
14-Jun-89	24	C	2	9	2	8.4	9.3

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	24	C	2	43	2	8.5	9.4
14-Jun-89	24	C	2	59	2	8.5	9.4
14-Jun-89	24	C	2	17	2	8.5	9.4
14-Jun-89	24	C	2	16	2	8.5	9.4
14-Jun-89	24	C	2	89	2	8.5	9.4
14-Jun-89	24	C	2	30	2	8.5	9.4
14-Jun-89	24	C	2	27	2	8.5	9.4
14-Jun-89	24	C	2	3	2	8.5	9.4
14-Jun-89	24	C	2	88	1	8.5	9.4
14-Jun-89	24	C	2	35	2	8.7	9.6
14-Jun-89	24	C	2	78	1	8.7	9.6
14-Jun-89	24	C	2	65	2	8.7	9.6
14-Jun-89	24	C	2	45	2	8.7	9.6
14-Jun-89	24	C	2	34	2	8.7	9.6
14-Jun-89	24	C	2	41	2	8.7	9.6
14-Jun-89	24	C	2	11	2	8.7	9.6
14-Jun-89	24	C	2	71	2	8.7	9.6
14-Jun-89	24	C	2	57	2	8.7	9.6
14-Jun-89	24	C	2	52	2	8.8	9.7
14-Jun-89	24	C	2	46	2	8.8	9.7
14-Jun-89	24	C	2	80	2	8.8	9.7
14-Jun-89	24	C	2	87	2	8.8	9.7
14-Jun-89	24	C	2	24	2	8.8	9.7
14-Jun-89	24	C	2	33	1	8.8	9.7
14-Jun-89	24	C	2	58	2	8.8	9.7
14-Jun-89	24	C	2	75	2	8.8	9.7
14-Jun-89	24	C	2	68	2	8.8	9.7
14-Jun-89	24	C	2	36	2	9.0	9.8
14-Jun-89	24	C	2	23	2	9.0	9.8
14-Jun-89	24	C	2	60	2	9.0	9.8
14-Jun-89	24	C	2	93	2	9.0	9.8
14-Jun-89	24	C	2	77	2	9.0	9.8
14-Jun-89	24	C	2	85	2	9.0	9.8
14-Jun-89	24	C	2	86	2	9.1	9.9
14-Jun-89	24	C	2	76	2	9.1	9.9

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	24	C	2	22	2	9.1	9.9
14-Jun-89	24	C	2	82	2	9.1	9.9
14-Jun-89	24	C	2	29	2	9.1	9.9
14-Jun-89	24	C	2	94	2	9.1	9.9
14-Jun-89	24	C	2	14	2	9.1	9.9
14-Jun-89	24	C	2	72	2	9.1	9.9
14-Jun-89	24	C	2	42	2	9.1	9.9
14-Jun-89	24	C	2	51	2	9.3	10.1
14-Jun-89	24	C	2	44	2	9.3	10.1
14-Jun-89	24	C	2	97	2	9.3	10.1
14-Jun-89	24	C	2	19	2	9.3	10.1
14-Jun-89	24	C	2	40	2	9.4	10.2
14-Jun-89	24	C	2	92	2	9.4	10.2
14-Jun-89	24	C	2	56	2	9.4	10.2
14-Jun-89	24	C	2	25	2	9.4	10.2
14-Jun-89	24	C	2	61	2	9.4	10.2
14-Jun-89	24	C	2	2	2	9.4	10.2
14-Jun-89	24	C	2	63	2	9.4	10.2
14-Jun-89	24	C	2	54	2	9.4	10.2
14-Jun-89	24	C	2	21	2	9.6	10.3
14-Jun-89	24	C	2	38	2	9.6	10.3
14-Jun-89	24	C	2	84	2	9.6	10.3
14-Jun-89	24	C	2	13	2	9.7	10.4
						---	---
					MEAN	8.6	9.5
					SD	0.5	0.5
					N	94	94
14-Jun-89	24	C	1	1	2	11.5	12.0
						---	---
					MEAN	11.5	12.0
					SD	-	-
					N	1	1
14-Jun-89	25	D	2	17	2	7.0	8.1

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Fish Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	25	D	2	63	1	7.0	8.1
14-Jun-89	25	D	2	16	2	7.2	8.3
14-Jun-89	25	D	2	41	2	7.3	8.4
14-Jun-89	25	D	2	27	2	7.3	8.4
14-Jun-89	25	D	2	9	2	7.3	8.4
14-Jun-89	25	D	2	45	1	7.3	8.4
14-Jun-89	25	D	2	2	1	7.5	8.5
14-Jun-89	25	D	2	67	2	7.5	8.5
14-Jun-89	25	D	2	71	1	7.5	8.5
14-Jun-89	25	D	2	55	2	7.5	8.5
14-Jun-89	25	D	2	29	2	7.6	8.6
14-Jun-89	25	D	2	94	1	7.6	8.6
14-Jun-89	25	D	2	60	2	7.6	8.6
14-Jun-89	25	D	2	100	2	7.6	8.6
14-Jun-89	25	D	2	80	2	7.6	8.6
14-Jun-89	25	D	2	54	2	7.8	8.8
14-Jun-89	25	D	2	85	2	7.8	8.8
14-Jun-89	25	D	2	26	2	7.8	8.8
14-Jun-89	25	D	2	61	2	7.9	8.9
14-Jun-89	25	D	2	62	1	7.9	8.9
14-Jun-89	25	D	2	93	2	7.9	8.9
14-Jun-89	25	D	2	50	1	7.9	8.9
14-Jun-89	25	D	2	87	2	8.1	9.0
14-Jun-89	25	D	2	99	1	8.1	9.0
14-Jun-89	25	D	2	15	2	8.2	9.1
14-Jun-89	25	D	2	78	2	8.2	9.1
14-Jun-89	25	D	2	58	2	8.2	9.1
14-Jun-89	25	D	2	13	2	8.2	9.1
14-Jun-89	25	D	2	35	2	8.2	9.1
14-Jun-89	25	D	2	21	2	8.2	9.1
14-Jun-89	25	D	2	8	2	8.2	9.1
14-Jun-89	25	D	2	42	2	8.2	9.1
14-Jun-89	25	D	2	44	2	8.4	9.3
14-Jun-89	25	D	2	83	2	8.4	9.3
14-Jun-89	25	D	2	4	2	8.4	9.3

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	25	D	2	84	2	8.4	9.3
14-Jun-89	25	D	2	76	2	8.4	9.3
14-Jun-89	25	D	2	82	2	8.4	9.3
14-Jun-89	25	D	2	91	2	8.4	9.3
14-Jun-89	25	D	2	53	2	8.4	9.3
14-Jun-89	25	D	2	39	2	8.5	9.4
14-Jun-89	25	D	2	10	2	8.5	9.4
14-Jun-89	25	D	2	72	2	8.5	9.4
14-Jun-89	25	D	2	70	2	8.5	9.4
14-Jun-89	25	D	2	68	2	8.5	9.4
14-Jun-89	25	D	2	30	2	8.5	9.4
14-Jun-89	25	D	2	34	2	8.7	9.6
14-Jun-89	25	D	2	56	2	8.7	9.6
14-Jun-89	25	D	2	64	2	8.7	9.6
14-Jun-89	25	D	2	57	2	8.7	9.6
14-Jun-89	25	D	2	1	2	8.7	9.6
14-Jun-89	25	D	2	22	2	8.7	9.6
14-Jun-89	25	D	2	81	2	8.7	9.6
14-Jun-89	25	D	2	20	2	8.7	9.6
14-Jun-89	25	D	2	31	2	8.7	9.6
14-Jun-89	25	D	2	3	2	8.7	9.6
14-Jun-89	25	D	2	88	2	8.7	9.6
14-Jun-89	25	D	2	47	2	8.7	9.6
14-Jun-89	25	D	2	90	2	8.7	9.6
14-Jun-89	25	D	2	12	2	8.7	9.6
14-Jun-89	25	D	2	89	1	8.8	9.7
14-Jun-89	25	D	2	24	2	8.8	9.7
14-Jun-89	25	D	2	96	2	8.8	9.7
14-Jun-89	25	D	2	32	2	8.8	9.7
14-Jun-89	25	D	2	77	2	8.8	9.7
14-Jun-89	25	D	2	11	2	8.8	9.7
14-Jun-89	25	D	2	7	2	8.8	9.7
14-Jun-89	25	D	2	38	2	8.8	9.7
14-Jun-89	25	D	2	33	2	8.8	9.7
14-Jun-89	25	D	2	19	2	9.0	9.8

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
14-Jun-89	25	D	2	69	2	9.0	9.8
14-Jun-89	25	D	2	86	2	9.0	9.8
14-Jun-89	25	D	2	36	2	9.0	9.8
14-Jun-89	25	D	2	74	2	9.0	9.8
14-Jun-89	25	D	2	40	2	9.0	9.8
14-Jun-89	25	D	2	95	2	9.0	9.8
14-Jun-89	25	D	2	75	2	9.0	9.8
14-Jun-89	25	D	2	49	1	9.0	9.8
14-Jun-89	25	D	2	65	2	9.0	9.8
14-Jun-89	25	D	2	51	2	9.1	9.9
14-Jun-89	25	D	2	28	2	9.1	9.9
14-Jun-89	25	D	2	37	2	9.1	9.9
14-Jun-89	25	D	2	5	2	9.1	9.9
14-Jun-89	25	D	2	23	2	9.1	9.9
14-Jun-89	25	D	2	43	2	9.1	9.9
14-Jun-89	25	D	2	98	2	9.1	9.9
14-Jun-89	25	D	2	6	2	9.3	10.1
14-Jun-89	25	D	2	48	2	9.3	10.1
14-Jun-89	25	D	2	46	2	9.3	10.1
14-Jun-89	25	D	2	59	2	9.4	10.2
14-Jun-89	25	D	2	97	2	9.6	10.3
14-Jun-89	25	D	2	66	2	9.7	10.4
14-Jun-89	25	D	2	25	2	9.9	10.6
14-Jun-89	25	D	2	52	2	10.0	10.7
14-Jun-89	25	D	2	79	2	10.3	11.0
14-Jun-89	25	D	2	18	2	10.8	11.4
14-Jun-89	25	D	2	73	2	10.9	11.5
14-Jun-89	25	D	2	14	2	10.9	11.5
						---	---
					MEAN	8.6	9.4
					SD	0.8	0.7
					N	99	99
14-Jun-89	25	D	1	92	2	12.0	12.5
						---	---

Appendix E. Lengths of herring larvae in Port Moller, 1989.

Date	Sample number	Site	Cohort	Fish number	Yolk	Measured length (mm)	Capture-corrected length (mm)
					MEAN	12.0	12.5
					SD	-	-
					N	1	1
				2 GRAND	MEAN	8.6	9.5
					SD	0.7	0.6
					N	645	645
				1 GRAND	MEAN	11.6	12.1
					SD	0.6	0.5
					N	9	9

Notes:

1. Yolk: 1 = yolk sac, 2 = no yolk sac.
2. Site codes from Table 1.
3. Fish number refers to the order in which the fish were randomly chosen for measurement.
4. Corrected length = measured L*EXP(0.91*EXP(-0.26*measured L)).
5. Fish were assigned to a cohort based on their corrected length:

	cohort 2	cohort 1
June 11	6.5-10.7	>10.7
June 12	7.9-11.0	>11.0
June 13	6.9-11.3	>11.3
June 14	7.7-11.6	>11.6

This appendix reviews three methods of correcting measured densities of Pacific herring larvae for the probability of capture by a towed plankton net.

The most widely used method is to calculate the ratio of the density of fish larvae caught at night to the density of larvae caught during the day. The densities measured at night are assumed to approximate true densities because larvae are less able to detect and evade the net during the night than during the day. Three sets of night/day catch ratios of herring larvae have been reported in the literature. McGurk (1989a) reported the only set of night/day ratios that are currently available for Pacific herring larvae. They were measured with a 40 cm diameter bongo net equipped with a 1.5 m long net with a mesh width of 471 μm. The net was towed at about 2 to 3 kn. Brander and Thompson (1989) reported night/day catch ratios of Atlantic herring larvae captured by high-speed tow nets in the North Sea during the International Herring Larval Surveys. The net was a modified Gulf III sampler with a mouth diameter of 20 cm and a mesh width of 270 μm. It was towed at a speed of 5 kn. Heath et al. (1987) reported a single night/day ratio for Atlantic herring larvae of an average length of 11 mm captured off the north coast of Scotland. The efficiency of a 1 m diameter ring net with a mesh width of 250 μm was 3.14 times higher at night than during the day. The net was towed at a speed of 2 to 3 kn.

In order to compare the three data sets, the lengths of the Atlantic herring larvae were corrected for shrinkage due to capture in a towed net using McGurk's (1985) correction equation. The lengths of McGurk's (1989a) larvae were already corrected using the same equation. A covariance analysis showed that all three sets of data had the same intercept, but that Brander and Thompson's (1989) catch ratios increased with length at a significantly ($P<0.01$) lower rate than either McGurk's (1989a) or Heath et al.'s (1987) catch ratios (Fig. F1). Therefore, a separate highly significant ($P<0.001$) regression was fit to Brander and Thompson's (1989) data (Table F1). The difference in slopes is probably due to the difference in towing speeds; larvae were less able to evade the high-speed net used in the International Herring Larvae Surveys than the lower-speed nets used by Heath et al. (1987) and McGurk (1989a). Since a low-speed net was used to sample the plankton of Port Moller, McGurk's (1989a) equation was most applicable to this study.

The major assumption of the night/day catch ratio method is that the catch efficiency of the night tows is 100%. However, McGurk (1989a) reported that this assumption was not correct for Pacific herring larvae longer than about 18 mm in length. At that size the burst speeds of the fish may be great enough to enable them to evade a towed net even when their reaction distance to the net is reduced by darkness. The critical length

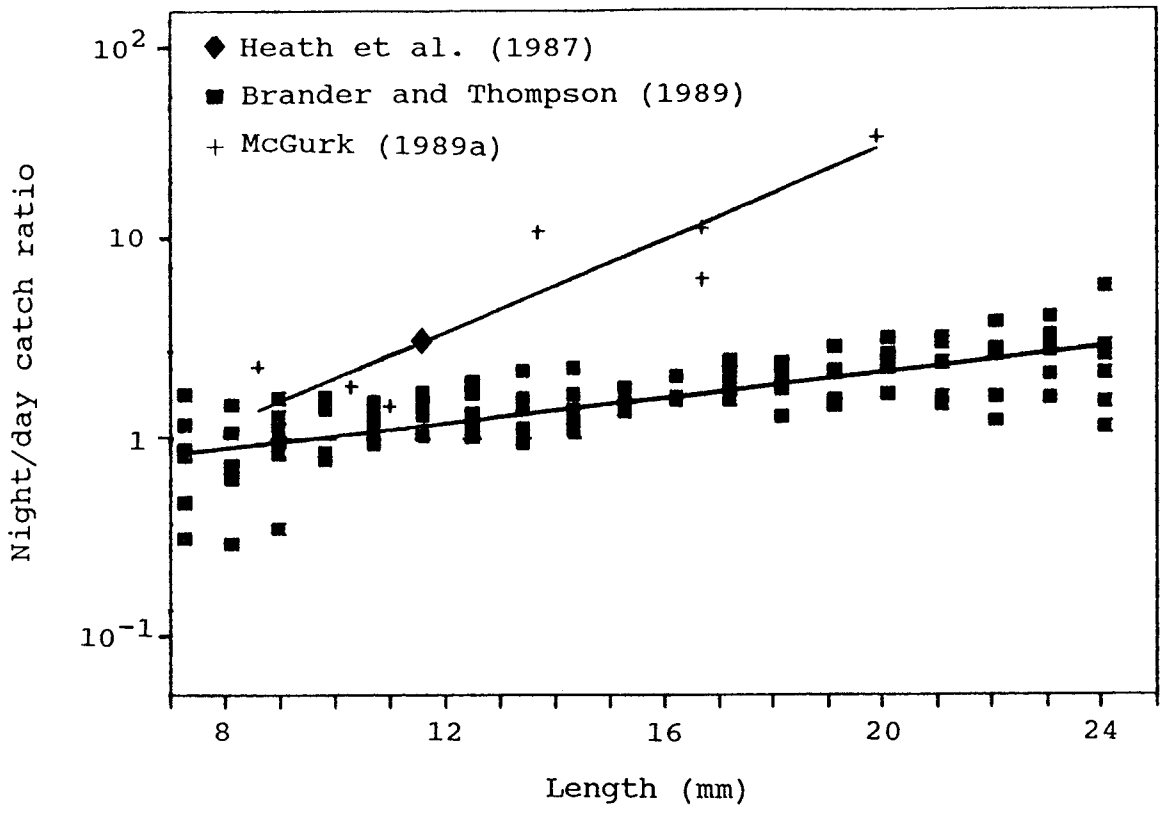

Fig. F1. Ratios of larval density measured at night to density measured during the day for herring larvae captured with low-speed towed nets (Heath et al. 1987, McGurk 1989a) and with high-speed nets (Brander and Thompson 1989).

is less than 18 mm in other species; for example Houde (1977a) reported that the night/day catch ratios for round herring, Etrumeus teres, larvae increased over the length range of 3 to 13 mm, but then declined in fish longer than 13 mm. The declining right-hand limb of this curve was presumably due to the evasion of the towed net at night. Therefore, the other two methods of correcting catches for net evasion are examined below in order to assess their usefulness compared to night/day catch ratios.

The second method of measuring catch efficiency is to compare two different types of sampling gear. Murphy and Clutter's (1972) study is the best example available. They compared catches of Hawaiian anchovy, Stolephorus purpureus, larvae taken with a 1 m diameter towed plankton net (333 μm mesh width) with catches taken by a plankton purse seine (333 μm mesh width) at the same site and time. The ratios of purse seine to tow net catches showed that the day plankton net catches underestimated the density of anchovy larvae in all length classes greater than 3.5 mm. The ratios of catches taken at night showed that the night plankton net catches also underestimated the density of anchovy larvae, but only in length classes greater than 19.5 mm. Murphy and Clutter's (1972) estimates of the catch efficiency of a towed plankton net were used by Yamashita et al. (1985) and Leak and Houde (1987) to correct the measured densities of Japanese sand eel, Ammodytes personatus, and bay anchovy, Anchoa mitchilli, respectively, for net evasion. Therefore, their study is reviewed in detail in this section of the report.

Murphy and Clutter's (1972) method is based on the assumptions that the catch efficiency of a plankton purse seine is 100%, and that the daytime tows of the towed plankton net were conducted using standard methods. However, a comparison of their night/day ratios for the towed net and their purse seine/tow-net ratios with the night/day ratios of towed nets reported by other authors suggests that the second assumption may not have been valid. Table F1 tabulates the regressions of ln(night/day ratios) on length for 10 species of fish larvae. It shows that the slope of the regression of ln(purse seine/tow net) on length, 0.4947 mm^{-1}, for Hawaiian anchovy is the highest slope that has yet been measured. It is 40% higher than the next highest slope of 0.3533 mm^{-1} for northern anchovy, Engraulis mordax, larvae, and it is 289% higher than the mean slope of 0.1712 mm^{-1} for the 9 species of fish other than Hawaiian anchovy. The regression calculated from Murphy and Clutter's (1972) data predicts that only 9.6% of 8 mm long herring larvae and 0.3% of 15 mm long herring larvae would be captured by a towed plankton net.

If correct, Murphy and Clutter's (1972) data indicates that most reported densities of fish larvae underestimate the true densities by as much as an order of magnitude. However, an examination of the ratios of night to day catches of Murphy and Clutter's (1972) towed net suggests that these results may also have been due to unusually low

Table F1. Regressions of ln-transformed ratios of night/day catches or purse seine/tow-net catches of fish larvae on length of larvae.

Species	Type of ratio	Length range (mm)	n	intercept	slope (SE)	r^2	P	Author	Comments
Sardinops sagax	N/D	4.75-21.25	15	0.1564	0.1264 (0.0145)	0.85	<0.01	Ahlstrom (1954)	data from 1940-41 and 1950-51; all data used
Sardinops sagax	N/D	2.50-21.20	17	-0.5318	0.1381 (0.0185)	0.79	<0.01	Lenarz (1973)	data from 1951-60; all data used
Stolephorus purpureus	N/D	3.50-14.50	12	-3.5328	0.6546 (0.0624)	0.92	<0.01	Murphy and Clutter (1972)	all data used
Stolephorus purpureus	PS/TN	1.50-14.50	14	-1.6205	0.4947 (0.0537)	0.87	<0.01	Murphy and Clutter (1972)	all data used
Merluccius productus	N/D	2.00-18.10	26	0.2974	0.0212 (0.0249)	0.03	>0.05	Lenarz (1973)	data from 1966; all data used
Trachurus symmetricus	N/D	2.00- 5.50	8	-0.6099	0.1886 (0.0431)	0.76	<0.01	Lenarz (1973)	data from 1966; data truncated at L=5.5 mm
Engraulis mordax	N/D	3.00-10.75	8	-1.8357	0.3533 (0.0255)	0.97	<0.01	Lenarz (1973)	data from 1951-60; data truncated at L=10.75 mm
Etrumeus teres	N/D	3.00-13.00	6	-0.5031	0.1381 (0.0268)	0.87	<0.01	Houde (1977a)	data truncated at L=13.0 mm
Opisthonema oglinum	N/D	1.50-16.50	16	-1.0894	0.2507 (0.0365)	0.77	<0.01	Houde (1977b)	all data used
Harengula jaguana	N/D	2.00-18.00	9	-0.2160	0.0546 (0.0323)	0.30	>0.05	Houde (1977c)	all data used
Clupea harengus harengus	N/D	6.00-24.00	103	-0.5648	0.0665 (0.0061)	0.54	<0.01	Brander and Thompson (1989)	all data used
Clupea harengus pallasi	N/D	8.00-20.00	7	-1.9990	0.2700 (0.0580)	0.81	<0.01	McGurk (1989a)	all data used

Notes:

1. Only the ascending left-hand limb of the curve of ln(ratio) on length was used.
2. N/D = night/day ratios, PS/TN = purse seine/tow-net ratios.

catches of anchovy larvae in day plankton-net tows. Table F1 shows that the slope of the regression of ln(night/day catches) on length for Hawaiian anchovy larvae is 0.6546 mm^{-1}, which is 185% higher than the second highest night/day slope, and 382% higher than mean night/day slope. Such an unusually high slope suggests that the day plankton-net tows were performed in a non-standard method. At the very least, this analysis indicates that using night/day catch ratios or purse seine/tow net catch ratios from one species to correct densities of fish larvae of another species may lead to very large errors in estimating the true abundance of fish larvae.

The third method of correcting the density of fish larvae for net evasion is a mathematical model that relates the probability of capture to the radius of the towed net, to the size and burst swimming speed of a larva, and to water temperature. This model was developed by Clutter and Anraku (1968) and extended to Atlantic mackerel, Scomber scombrus, larvae by Ware and Lambert (1985). Its major assumption concerns the dependence of burst swimming speed on the length of a fish larva and on water temperature. Clutter and Anraku (1968) proposed that the probability of capture of a larva is determined by

$$(1) \quad p = 1 - \frac{1}{\pi R^2}\left[a\left(R^2 - \frac{a^2}{4}\right)^{0.5} + 2R^2 \sin^{-1}\left(\frac{a}{2R}\right)\right]$$

where p = probability of capture, R = radius of net (cm), and a = the distance (cm) larvae move between the time they react to the net and the time that the net reaches their plane. The distance moved in time T_r is

$$(2) \quad a = QL^b$$

where $Q = f T_r$, f = a temperature-dependent coefficient (s^{-1}), L = length (cm) of fish larva, and b = a coefficient with a value of approximately 2.42 [see Ware and Lambert (1985) for reasons supporting the choice of this exponent and other parameter values]. Since p approaches zero as a approaches the diameter of the net, 2R, then equation (2) can be rearranged to obtain

$$L_{max} = \frac{2R^{0.41}}{Q}$$

where L_{max} = the longest larva that can be captured. Thus, Q can be estimated from

$$(3) \quad Q = \frac{2R}{L_{max}^{2.42}}$$

Q is adjusted for the effects of water temperature by assuming a Q_{10} of 2, i.e. it doubles for every 10^0C change in temperature.

The applicability of this model to Pacific herring larvae was examined by calculating the change in catch ratio (= 1/p) with length for the herring larvae of Bamfield Inlet, B.C., that were studied by McGurk (1989a), and comparing it with the night/day catch ratios he reported. The radius of a bongo net was assumed to be 20 cm because the two ring nets that comprise the bongo net are assumed to fish independently of each other. L_{max} was estimated to be 2.3 cm from the catch curve for larva caught by day plankton net tows (McGurk 1989a: Fig. 1). Thus, Q = 5.33 at an median water temperature of 11^0C. Fig. F2 shows that the envelope of modelled catch ratios for the temperature range of 8 to 14^0C coincides with the average night/day ratio at the extremes of the range of fish lengths: 8 mm and 20 to 24 mm, but that the envelope underestimates the catch ratio between these extremes.

In summary, McGurk's (1989a) night/day catch ratios appear to be the most reliable method of correcting observed densities of Pacific herring larvae in Port Moller for the effect of net evasion. Murphy and Clutter's (1972) purse seine/plankton net catch ratios are too large to be reasonable, and there is too much unexplained variability between the night/day ratios of other species for their results to be applicable to herring larvae. Although Ware and Lambert's (1985) mathematical model predicts catch ratios of small and large larvae that are very similar to those reported by McGurk (1989a), their model underestimates the catch ratios for mid-size herring larvae.

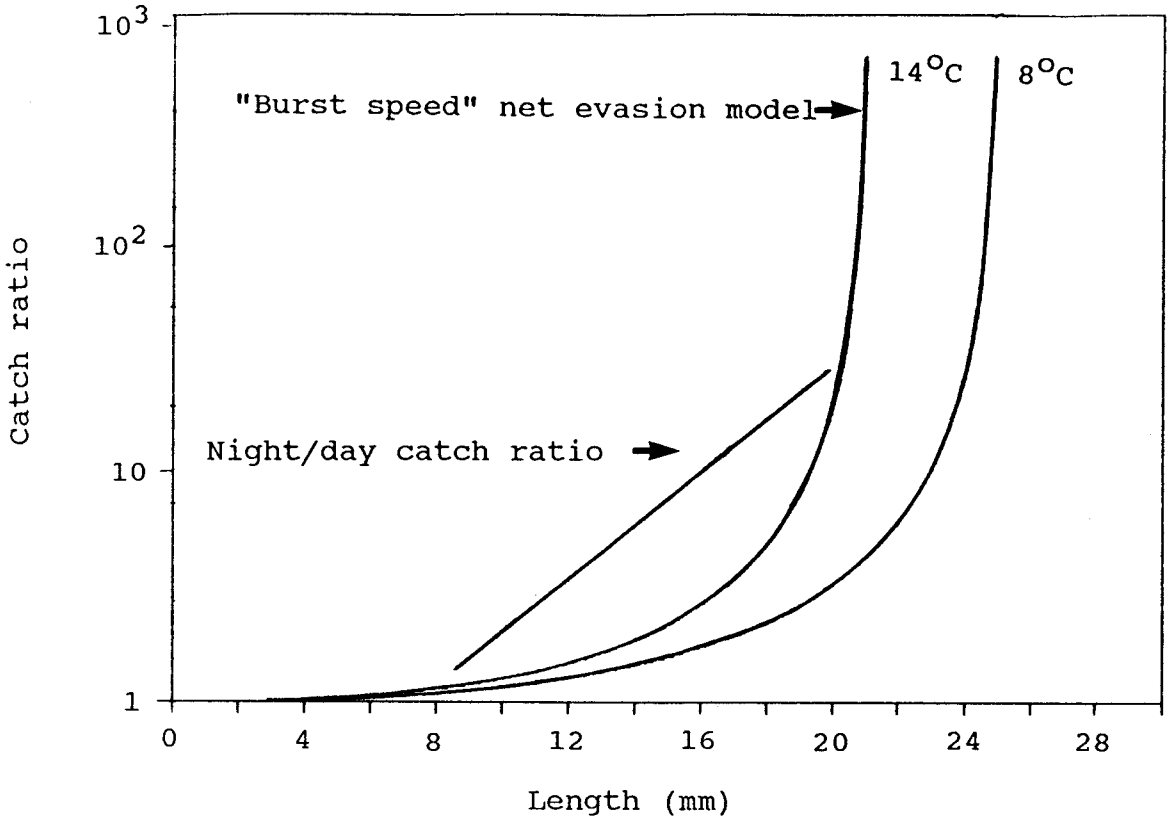

Fig. F2. Size-dependence of catch ratios of Pacific herring larvae calculated from McGurk's (1989a) night/day catch ratios and from Ware and Lambert's (1985) "burst speed" net evasion model (Lmax = 23 mm, R = 200 mm, T = 11°C) over the temperature range of 8 to 14°C.

EFFECTS OF PETROLEUM CONTAMINATED WATERWAYS ON SPAWNING MIGRATION OF PACIFIC SALMON PHASE I. LABORATORY STUDIES

by

W. H. Pearson
D. L. Woodruff
Battelle/Marine Research Laboratory
439 West Sequim Bay Road
Sequim, Washington 98382

and

P. B. Johnsen
U.S. Department of Agriculture
Agricultural Research Service
Southern Regional Research Center
New Orleans, Louisiana 10179

Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 681

July 1987

ACKNOWLEDGMENTS

We thank M. Fleischmann, P. Wilkinson, S. L. Kiesser, and J. Coley for their technical support. We also thank R. B. Lucke and J. M. Gurtisen for performing the chemical analyses.

This study was funded by the Minerals Management Service of the Department of the Interior through an interagency agreement with the National Oceanic and Atmospheric Administration (NOAA), Department of Commerce, as part of the Alaska Outer Continental Shelf Environmental Assessment Program (OCSEAP), under NOAA Contract Number 50-ABNC-6-0075.

SUMMARY

Because oil exposure has been shown to cause chemosensory disruption and behavioral changes in other marine organisms, and because salmon depend on chemosensory detection of chemical cues during the coastal as well as freshwater phase of their spawning migration, there is concern that oil spilled into the path of migrating salmon may disrupt their spawning migration. The general objective of this project was to determine whether exposure to oil-contaminated water would disrupt the ability of adult Pacific salmon to migrate. Phase I of the project consisted of laboratory studies of the effects of oil on salmon chemosensory function. Phase II will consist of field experiments on the effects of petroleum-contaminated waterways on salmon migration. The findings of Phase I are to be used in designing the fieldwork of Phase II. After providing a background on the spawning migration of salmon and the potential effects of oil spills, this report presents the findings to date in the Phase I laboratory work.

Electro-olfactogram (EOG) experiments were used to determine the concentration at which adult male coho salmon detect water-soluble fraction (WSF) of Alaska North Slope (ANS) crude oil. With different protocols of stimulation and experimental treatment of the fish, EOG techniques were also used to examine changes in chemosensory function of adult coho salmon at higher concentrations of the WSF of ANS crude oil and the effects of short-term exposure of adult coho salmon to the WSF of ANS crude oil on detection of an amino acid mixture. There are no techniques for directly measuring motivational state or any adequate physiological assays of early spawning condition. However, examination of how motivation might be influencing the various responses of salmon to petroleum hydrocarbons was attempted through post hoc correlations of olfactory responses observed on a particular date with the hormonal status of that fish measured using radioimmunoassay (RIA) techniques.

Using EOG techniques, adult coho salmon, Oncorhynchus kisutch, were found to have an estimated detection threshold for the WSF of ANS crude oil on the order of $10^{-10\pm1}$ mg/l WSF or about 10^{-7} ppb. At WSF concentrations above 10^{-4} mg/l, the chemosensory response to WSF was degraded but not irreversibly. After short presentation of 10^{-3} mg/l WSF, the ability to detect lower levels of WSF returned within minutes. For the levels tested, exposure to WSF did not appear to impair the ability of salmon to detect biologically relevant cues. For WSF concentrations from 10^{-7} to 10^{-3} mg/l, short-term exposure to WSF did not result in decreased chemosensory responses to amino acids. Exposures at 10^{-5} mg/l for up to 90 min did not impair amino acid detection. The results concerning the relationship between hormone levels and chemosensory function were inconclusive.

These findings suggest that coho salmon can detect the presence of dissolved petroleum hydrocarbons at several orders of magnitude below the levels seen or predicted to cover large areas during oil spills. The salmon have the sensory ability necessary to avoid oil spills, but field studies are necessary to demonstrate whether migrating salmon will actually avoid oil-contaminated areas. The implications of the degradation in WSF detection at higher WSF levels for avoidance of oil spills is less clear. Such degradation suggests that where migrating salmon encounter exposure levels above 10^{-3} mg/l WSF, the fish may have impaired ability to detect and avoid oil-contaminated areas.

The finding of little or no evidence for impairment of biologically relevant cues by WSF up to 10^{-3} mg/l suggests that the salmon can be expected to be able to migrate through these concentrations without becoming disoriented. Levels and durations of WSF exposure above 10^{-3} mg/l have not been tested and need investigation.

The pursuit of field studies is recommended only after more laboratory studies. The findings of Phase I shift the focus of any Phase II field tracking studies from investigation of potential disorientation of migrating

salmon by chemosensory disruption to investigation of avoidance. However, the possibility of disorientation through chemosensory impairment by petroleum exposure above 10^{-3} mg/liter remains open, and because of the logistical problems in applying a field treatment of sufficient magnitude to be a valid test, laboratory studies of the chemosensory effects of exposures above 10^{-3} mg/liter WSF are urged. Addressing questions of avoidance and disorientation above 10^{-3} mg/liter WSF with field tracking appears to be beyond logistical and permitting feasibility, and both questions can be addressed with laboratory studies. If laboratory studies show that the EOG response to WSF becomes increasingly impaired as WSF concentration rises, then one can reasonably expect avoidance to become increasingly unlikely as its sensory foundation is eroded. Similarly, because it is known that migrating salmon that have impaired homing cue detection become disoriented, such disorientation can be expected in the field, should laboratory studies indicate that cue detection is impaired above 10^{-3} mg/liter WSF.

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INTRODUCTION

Extensive offshore oil and gas development is planned for the North Aleutian Shelf and Bristol Bay, Alaska. Such development will occur in an area through which large numbers of several species of Pacific salmon migrate as they return to their home streams to spawn. Because oil exposure has been shown to cause chemosensory disruption and behavioral changes in other marine organisms (snails: Jacobson and Boylan 1973; Hyland and Miller 1979; lobsters: Atema and Stein 1974; crabs: Takahashi and Kittredge 1973; Pearson et al. 1981a; salmon: Maynard and Weber 1981; Weber et al. 1981) and because salmon depend on chemosensory detection of cues from the home stream water during their spawning migration (Johnsen 1986; Døving et al. 1985; Hiyama et al. 1966; and Bertmar and Toft 1969), there is concern that oil spilled into the path of migrating salmon may disrupt their spawning migration. The general objective of this project is to determine whether exposure to oil-contaminated water would disrupt the ability of adult Pacific salmon to migrate.

The project was designed in two phases. Phase I consisted of laboratory studies of the effects of oil on salmon chemosensory function. Phase II will consist of field experiments on the effects of petroleum-contaminated waterways on salmon migration. The findings of Phase I are to be used in designing the fieldwork of Phase II.

After providing a background on the spawning migration of salmon and the potential effects of oil spills, this report presents the findings to date in the Phase I laboratory work. In raising as well as answering questions, the findings of current Phase I work indicate the need for more laboratory work as well as having implications for any fieldwork. The implications of the findings to the design of any fieldwork as well as the need for more laboratory work are discussed here in a concluding section.

BACKGROUND

Salmon Spawning Migration

The migration of salmon from the oceanic feeding grounds to the home stream spawning site involves orientation in open ocean, coastal waters, and streams. Traditionally, the oceanic and stream phases of the migration have been thought to involve different cues and mechanisms (Hasler and Scholz 1983), but chemical signals are now known to be important in both coastal waters and streams (Døving et al. 1985; Hiyama et al. 1966; and Bertmar and Toft 1969).

Sensory impairment studies, demonstrating the requirements of a functioning olfactory system for successful homing in the freshwater phase, have been conducted for many species of salmonids (Oncorhynchus kisutch, Wisby and Hasler 1954; O. nerka, Lorz and Northcote 1965; O. keta, Hiyama et al. 1966; O. tshawytscha, Groves et al. 1968; DeLacy et al. 1969; Salmo clarki, Jahn 1969; and S. trutta, Shearer 1959). In studying the stream phase of homing, Hasler and his coworkers demonstrated that coho salmon, O. kisutch, are attracted by imprinted chemical cues (Scholz et al. 1976) and that these cues are used in the upstream migration (Johnsen and Hasler 1980).

Westerberg (1982), in ultrasonic tracking studies with depth sensing transmitters, showed that the salmon's movement is closely related to the

fine-scale vertical layering of the water. These observations led to the suggestion that vertically stratified hydrographic features may be important for the salmon's orienting movements (Westerberg 1984). In ablation studies, it has been observed that anosmic salmon, i.e., fish with olfactory nerves surgically severed, do not respond to the hydrographic features as do intact fish in the same studies (Westerberg 1982; Døving et al. 1985). This observation and the experiments of Craigie (1926) and Bertmar and Toft (1969) which found that fish released in coastal waters without a sense of olfaction did not enter the home stream as well as controls, suggest that olfaction may be as important in coastal, nearshore migrations as in the stream phase of homing.

To understand how exposure to petroleum hydrocarbons might adversely effect salmon during the spawning migration, an examination of the mechanisms of chemosensory orientation is needed. Unlike other environmental signals, such as light and sound, chemical signals have no directive component and vary only in intensity. This lack of directivity therefore imposes several restrictions on possible mechanisms by which an animal might orient to a stimulus source (Johnsen 1984). Orientation to weak chemical gradients is considered unlikely (Kleerekoper 1982) so that directive information must be obtained from other cues. During the stream phase of the migration, it has been demonstrated that salmon respond to the direction of water currents. If the home stream odor is detected, the animal moves upstream with positive rheotaxis, and if the odor is absent, the fish move down current (Johnsen and Hasler 1980). Several field observations support the hypothesis that rheotaxis may be released through olfaction and thus become the main orienting cue during migration not only within a river system but in the coastal waters as well (Harden-Jones 1965; Nikoyalev 1978; Scholz et al. 1972).

For a fish to orient to a current it must have some reference system to establish its motion relative to the displacement by the water current itself. In a stream, the fish can determine the direction of the current

with respect to the bottom by tactile and/or visual signals and move upstream to the home site. However, when the fish is in open water, this reference system is lost and an alternate reference is required if the fish is to respond to water currents.

Salmon are, however, able to detect the interface between two differentially scented bodies of water. This has been confirmed through behavioral observations (Johnsen and Hasler 1980; Døving et al. 1985) and electrophysiological experiments (Døving et al. 1985). In the nearshore regions, salmon respond to horizontally stratified water masses by vertical zig-zagging at their interface. Westerberg (1984) has suggested that the salmon, after locating the interface between two adjacent water masses, make use of the local sheer currents to derive the necessary directional information needed for oriented movement.

Based on field and laboratory evidence, the following scheme for salmon homing has been proposed. When reaching the nearshore environment, salmon begin to use olfactory cues to distinguish between adjacent water masses. By monitoring sheer currents at the interface, fish can obtain directional information and move toward the home stream. After entering the home stream, the salmon continue to move against the current if the home odor is present. Through a series of simple rheotaxic behaviors related to stimulus distribution, the salmon can arrive at the home site.

This dependence on chemical signals for both the nearshore as well as the stream phases of the homing migration indicates that any change in olfactory acuity would have significant impact on the successful completion of the salmon's life cycle.

Effects of Oil on Chemoreception

Chemosensory disruption by various petroleum hydrocarbons and oil fractions has been reported in snails (Jacobson and Boylan 1973; Hyland and

Miller 1979), lobsters (Atema and Stein 1974), and crabs (Takahashi and Kittredge 1973; Pearson et al. 1981a). In early studies, the exposure regimes were not well enough defined for interpretation (National Academy of Sciences 1975) and were often greater in duration and level than that likely to be actually encountered. Under a more realistic exposure, Pearson et al. (1981a) have found chemosensory impairment in the Dungeness crab, Cancer magister. After exposing crabs in a continuously flowing exposure system to seawater contaminated with Prudhoe Bay crude oil (0.27 ppm) for 24 h and with oil still present, the proportion of crabs showing the antennular flicking response, indicative of food cue detection, was significantly reduced. Within 1 h after return to clean seawater, the chemosensory antennular response recovered. Such rapid recovery indicates that the impairment did not derive from structural damage to the chemoreceptor cells but does not indicate which of several other possibilities was the most likely mechanism. Monoaromatic hydrocarbons predominated in the oil-contaminated seawater and have been implicated elsewhere as agents of anesthesia or reversible narcosis (Crisp et al. 1967; Johnson 1977).

Only one preliminary electrophysiological study of potential chemosensory disruption by petroleum hydrocarbons in juvenile coho salmon has been done previously. After rinsing the nares with synthetic mixture of monoaromatic hydrocarbons (4 ppm) for 20 min, Maynard and Weber (1981) reported no significant difference in the electroencephalogram (EEG) response to the amino acid, L-serine, presented before and after exposure. There was a decreased responsiveness at the most severe exposure, but high variability and small sample size prevents adequate evaluation. Also, the exposure duration (20 min) was rather short compared to the 12 to 24 h predicted for migrating salmon by Thorsteinson and Thorsteinson (1984) under two Bristol Bay oil spill scenarios. (For further details on potential exposures see section entitled Potential Exposures During Oil Spills.)

Several mechanisms by which petroleum hydrocarbons could disrupt chemoreception have been suggested. First, exposure to petroleum

hydrocarbons could cause structural damage to the chemosensory cells. Such damage has been inferred in the shore crab from the long period necessary for two chemosensory behavioral responses to recover after exposure to various oil fractions (Takahashi and Kittredge 1973; Kittredge et al. 1974). Second, petroleum hydrocarbons could anesthetize the chemosensory cells. Many petroleum hydrocarbons produce anesthesia in barnacle larvae (Crisp et al. 1967), and anesthesia of chemosensory cells can be inferred from the rapid recovery of chemosensory response in shore crabs exposed to single monoaromatic hydrocarbons (Takahashi and Kittredge 1973). Third, the odor of oil could mask the odor of other cues. Odor masking by oil was suggested by Atema and Stein (1974) as one possible mechanism behind a longer food finding time in American lobsters. Fourth, oil physically dispersed into the water column by turbulence could coat the chemosensory surfaces and block passage of chemical cues to the chemosensory cells. Fifth, the petroleum hydrocarbons could interact with the chemical cues to deactivate them. Such potential deactivation has been suggested by Stabell (1983) for the relatively insoluble components of oil, which theoretically could extract hydrophobic chemical cues from the water column. As far as we know, the latter mechanism of deactivation of chemical cues has received no experimental study and seems a remoter possibility for chemosensory disruption by oil than the former four mechanisms for which there is some experimental evidence.

Chemosensory disruption by oil has been observed so far only at much higher hydrocarbon concentrations than has chemosensory detection of oil. For example, impairment of food cue detection in the Dungeness crab occurred at 267 ppb of monoaromatics in a continuously flowing system (Pearson et al. 1981a) whereas detection of the water soluble fraction of a crude oil by Dungeness crab occurred at 0.4 ppb, three orders of magnitude lower (Pearson et al. 1980). The blue crab, Callinectes sapidus, detects the WSF of crude oil still lower - at 0.002 ppt (Pearson et al. 1981b). The cod, Gadus morhua, detects the WSF of diesel fuel at 0.030 to 0.300 ppb (Hellstrom and Døving 1983). The observation of saw-toothed detection curves for

hydrocarbons suggests that detection ability is acute at low concentrations but degrades at higher concentrations as a result of some toxic or anesthetic effect of the hydrocarbon (Pearson et al. 1980, 1981b).

In summary, the implications of these observations are that, at concentrations in the ppt to ppb range, marine organisms appear able to detect petroleum hydrocarbons. In the presence of hydrocarbons at higher levels, a reduced ability to detect other chemical cues can be expected, especially in the presence of oil. Anesthetic effects from monoaromatic hydrocarbons appear to have the strongest experimental support for being the mechanism behind this chemosensory disruption.

Potential Exposure During Oil Spills

Much research has been done to develop an understanding of the nature, level, and duration of hydrocarbon contamination likely to occur during and after a spill. Generally, the unique circumstances of each spill govern, in the extreme, the fate and persistence of hydrocarbons (National Academy of Sciences 1975). Once spilled, the oil is immediately subject to a variety of processes that change its physical and chemical characteristics. Spreading, evaporation, dissolution, dispersion, and sinking all act to partition various oil components among the atmosphere, sea surface, water column, and sediments (Manen and Pelto 1984). Following rapid changes in the first hours and days, this partitioning is generally complete within 10 days.

Information concerning potential exposure during oil spills comes from four sources: (1) laboratory studies of effects, (2) field studies of accidental oil spills, (3) field and mesocosm studies of experimental spills, and (4) modelling efforts. From these studies four general patterns emerge. First, the toxicity of oil derives mainly from the aromatic hydrocarbons (Anderson 1979). For chemosensory disruption, the monoaromatic hydrocarbons also seem to be an important agent (Pearson et al. 1981a) (See section entitled Effects of Oil on Chemoreception). Second, whereas the aromatic

hydrocarbons are the most toxic oil component, they are also the most volatile and soluble so that the competing processes of dissolution and evaporation determine their concentration in the water column. Volatile aromatic hydrocarbons are judged unlikely to attain high or long sustained concentrations in the water column because of rapid loss to atmosphere by evaporation (McAuliffe 1977a and b; Manen and Pelto 1984). Third, turbulence can physically disperse oil into the water column to produce higher hydrocarbon concentrations to greater depth than can be attained otherwise. Fourth, where spilled oil reaches shallow coastal waters, concentrations in sediments can become quite high and persistent (Sharp and Appan 1982). Whereas medium and coarse sediments in high energy environments can cleanse rapidly, fine-grained sediments in low energy environments appear to be "sinks" for hydrocarbon contamination (Vandermuelen 1982).

The four sources of information mentioned above also indicate potential levels and durations of exposure. In accidental spills, the concentrations of hydrocarbons in the water column have varied with the circumstances of the spill. During the last 3 days of a 21-day platform spill, McAuliffe et al. (1975) found concentrations of dissolved hydrocarbons ranging from 0.002 ppm to 0.20 ppm and estimated that half of the hydrocarbons were monoaromatics. After a North Sea platform spill, Grahl-Nielsen (1978) found hydrocarbon concentrations in the water up to 0.4 ppm. In spills where turbulence disperses oil into the water column, hydrocarbon concentrations can be higher than 0.2 to 0.4 ppm. During the AMOCO CADIZ spill, Calder and Boehm (1981) found hydrocarbon concentrations over 1.0 ppm in the water entering the Aber Wrac'h estuary and exceeding 0.5 ppm through the water column in the rest of the estuary. The presence of alkanes in subsurface water samples confirmed that the oil in the water column was present as droplets. Following the AMOCO CADIZ spill, oil-in-water concentrations of 2 to 200 ppb were observed in the nearshore zone and 30 to 500 ppb in the estuaries (Grundlach et al. 1983).

In a 10.5-barrel experimental spill, McAuliffe (1977b) found aromatic hydrocarbons to range from 0.002 to 0.050 ppm at 1.5 m after 20 min but detected none after 1 h. In experimental spills of Prudhoe Bay crude oil in mesocosms, Payne et al. (1983) found that the concentration of aromatic hydrocarbons peaked at 0.380 ppm after 12 h and then fell exponentially. For the monoaromatic hydrocarbons, substantial loss by evaporation had occurred after 1 day. For winter experimental runs, the peak concentration (460 ppm) was higher than for summer (360 ppm) (Payne et al. 1984). In a series of experimental spills treated with a chemical dispersant, McAuliffe et al. (1980) found maximum hydrocarbon concentrations in the water column of 3 and 18 ppm depending on the crude oil. After chemical dispersion, evaporation of low molecular weight hydrocarbons proceeded rapidly.

Potential spills of Prudhoe Bay crude oil have been modelled under various scenarios for Bristol Bay, Alaska (Manen and Pelto 1984; Laevastu et al. 1985). These efforts indicate two potential courses of events: either within 100 h most of the volatile oil components will have evaporated or within 48 h the spilled oil will have formed a stable emulsion ("mousse") that retards further partitioning. For 12 h after the spill and a persistent wind of 5 m/s (9.7 knots), hydrocarbon concentrations above 0.01 ppm were estimated to extend 100 m beyond the edges of a 200-m-wide slick and to a depth of 15 m. The maximum concentration was conservatively estimated to be not greater than 0.650 ppm. Modelling of a blowout scenario for the Bering Sea predicted maximum concentrations under an oil slick of 340 ppb (Laevastu et al. 1985). The modelling effort by Laevastu et al. (1985) predicted that the areas covered by oil concentrations above 1 ppb reach maximums of almost 250 km^2 for a tanker accident and 500 km^2 for a blowout. Concentrations above 1 ppb are predicted to continue for about 35 days for the tanker accident and slightly less than 30 days for the blowout.

The sum of these observations and estimates seems to be that maximum hydrocarbon concentrations in the water column can generally be expected to range between 0.2 and 0.65 ppm but can exceed 1.0 ppm where turbulence

physically disperses oil into the water column. For spills treated with chemical dispersants, the maximum concentrations appear to be on the order of 20 ppm. Also, exposures of more than a few days to such water column concentrations, especially for fresh oil, do not seem likely.

Knowledge of salmon spawning migration further limits the potential exposure. First, at least in the Bering Sea, homing salmon appear to be migrating in the top 5 m, the area of highest petroleum hydrocarbons concentrations (Thorsteinson and Thorsteinson 1984). Second, based on their rate of migration and assuming the salmon do not avoid oil-contaminated water, Thorsteinson and Thorsteinson (1984) estimated for two oil spill scenarios within Bristol Bay that salmon on their spawning migrations would be exposed to the widest area of oil contamination for 12 to 24 h. Third, the summer spill scenarios indicate a movement of the slick to the north side of Bristol Bay over a period of 30 days. Because salmon also concentrate on the north side of Bristol Bay (Straty 1981; Thorsteinson and Thorsteinson 1984), exposure of migrating adults is more likely to be to weathered than fresh oil. This higher probability of encountering weathered oil is simply because the volatiles will probably evaporated in 4 days (Manen and Pelto 1984).

Potential Effects of Oil Spills on Salmon Chemoreception and Homing

There are two major ways in which salmon spawning migrations potentially can be disrupted by oil contamination: (1) through loss or degradation of the ability to detect chemical cues used in migration and (2) through avoidance of oil-contaminated areas that lay in the migratory path. These effects could reduce successful return to the home stream.

Chemosensory Disruption

Because salmon depend on the detection of chemical cues in their spawning migrations, loss of the ability to detect those cues could cause

delays in migration. The first report of disruption of a salmon spawning migration was that of Saunders and Sprague (1967) for Atlantic salmon entering a stream contaminated with heavy metals from mining operations. Whereas they explained the downstream movement of salmon as avoidance of high levels of zinc and copper in the river, a reexamination of their observations in light of present knowledge concerning salmon migratory behavior reveals a more likely and simpler explanation than avoidance. As indicated in the behavioral control model shown in Figure 1 (Johnsen 1982), salmon, upon detection of home stream odor, swim upstream against the current. In the absence of detection of home stream odor, salmon move downstream. Simple loss of the ability to detect home stream odor in the presence of the metal contamination would lead to the downstream movement of the salmon observed by Saunders and Sprague (1967). Copper and other heavy metals are known to reduce olfactory response in salmonids (Hara et al. 1976) so that loss of detection ability at the metal levels observed by Saunders and Sprague (1967) was likely.

We postulate that if oil-contaminated waterways are going to disrupt salmon migration, one such disruption will occur though an impairment of the ability to detect chemical cues with a consequent loss of ability to orient properly to current and other hydrographic features. Exposure to petroleum hydrocarbons, especially monoaromatics, has been seen to impair the ability of other marine organisms to detect chemical cues. The ability of hydrocarbons to impair chemosensory detection by salmon has not yet been adequately examined and was one of the first objects of study in this work. We hypothesize that an exposed salmon that had lost its chemosensory detection abilities would act like a surgically anosmic salmon. Such salmon do not show orientation to hydrographic features and fail to return to the home stream (Westerberg 1982; Døving et al. 1985). A salmon with impaired detection ability will show more variability in its responses to hydrographic features and, if still able to home, will do so at a slower rate because the fish is spending time swimming in search of alternate cues. If any loss or impairment of chemosensory function is observed in the laboratory, then

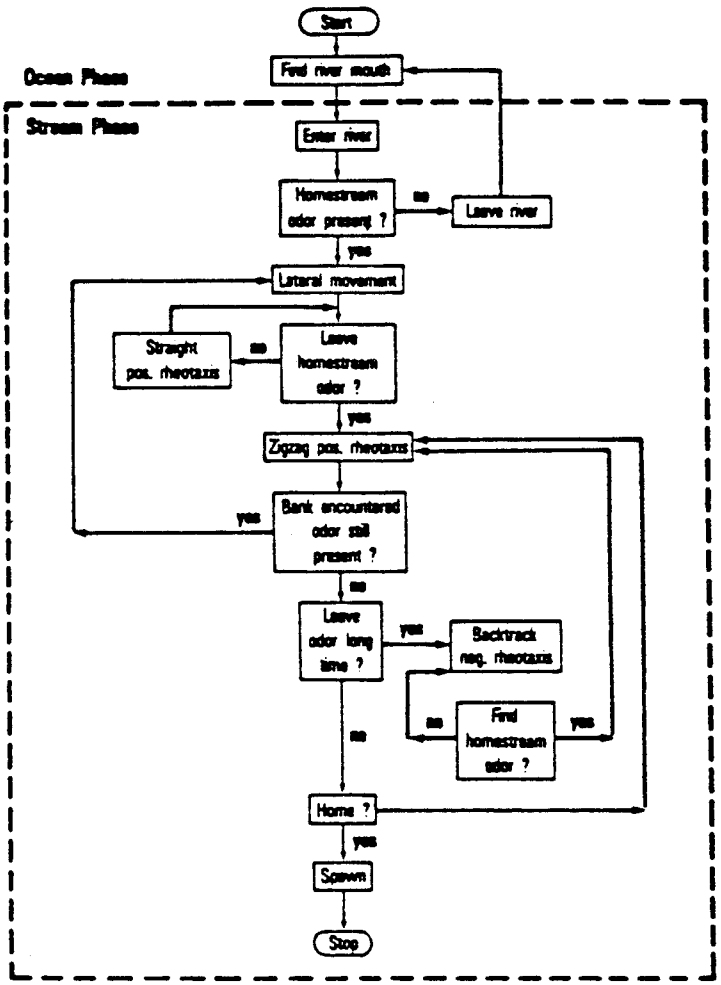

FIGURE 1. Behavioral Control Model for Upstream Movement and Homestream Selection in Migrating Salmonids (From Johnsen 1982)

disruption of orientation in the field is likely. Only if any observed impairment persists after exposure, are field tracking studies of laboratory-exposed salmon likely to observe any consequences for migratory behavior.

Indeed, in three such studies, the homing pond study and the Tulalip Creek study of Malins et al. (1985) and the Big Beef Creek study of Nakatani et al. (1985), no clear and substantial effects were observed in migrating salmon that were captured, exposed to petroleum hydrocarbons in the laboratory, marked, and then, subsequently released to continue their migration to their hatchery. In the homing pond study, the marked fish were released within the freshwater portion of their run. In the Tulalip Creek study, the marked fish were released at marine sites 1.6 and 4.7 km from the mouth of their home stream. Differences in the number of fish returning and the time course of their return were used to assess the effects of petroleum exposure on homing ability. In both studies of Malins et al. (1985), the exposure to hydrocarbons did not significantly reduce the number of returning fish. In both studies, there was time of unspecified length for recovery. In the homing pond study, fish showed no delay in return after exposure to the freshwater soluble fraction of oil up to 40 ppm for 14-18 h or after exposure to an aromatic hydrocarbon mixture up to 2 ppm for 8-22 h.

In the Big Beef Creek study of Nakatani et al. (1985), coho salmon were exposed for 1 h to an oil slick (1.6 ppm measured by IR spectrophotometry), dispersed oil (59 ppm), or dispersant alone and then released in salt water 7 km from the home stream. Of 314 fish released, 62 fish or 19.7% returned successfully with no significant difference observed among the treatment groups. Similarly, speed of return did not differ significantly among the treatment groups.

In contrast, fish in the Tulalip Creek study showed a significant delay in return (a mean of 3 days) after exposure to an aromatic mixture of 1 ppm for 8-22 h and 2 ppm for 8 h. In the Tulalip Creek study, the fish

transported the farthest distance away showed the least delay when comparing exposed fish to controls. The lesser delay could have been due to increased variability in the time for control fish to return or due to increased time for recovery from exposure effects. The actual time to return and its variance was not reported, only the difference between control and exposed fish.

The above three studies suffer from the fact that the fish did not have to pass through an oil-contaminated waterway to reach home. The experimental designs, therefore, do not directly address the question of what the behavior of salmon would be when oil contamination is present between the fish and their home. However, we do note the delayed return following exposure to aromatic hydrocarbons, an observation consistent with the notion that aromatic hydrocarbons impair chemosensory function. Because such chemosensory impairment appears to be transient, it would occur during exposure, if it does, and would be more likely to produce delay in homing rather than its failure. Because behavioral avoidance of noxious odor depends upon detection of the odor, the delay in return seen after exposure to the aromatic hydrocarbons coupled with the demonstrated anesthetic effects of the aromatics provides some evidence that behavioral avoidance of oil spills, at least when the concentrations of aromatics are high, will also be impaired because the underlying chemosensory detection is impaired.

Avoidance

Avoidance of petroleum hydrocarbons has been reported for juvenile and adult coho salmon (Maynard and Weber 1981; Weber et al. 1981). In these studies, the concentrations of a mixture of monoaromatic hydrocarbons avoided ranged from 2 to 4 ppm for juvenile salmon and 3.2 ppm for adult salmon. These concentrations are an order of magnitude higher than the maximum concentrations expected to occur under a oil slick. These high avoidance thresholds would appear to lessen the likelihood that avoidance would be a

mechanism behind delays in salmon migration, however, closer examination of the Chambers Creek study (Weber et al. 1981; Malins et al. 1985) suggests that the observations are compatible with other mechanisms and that whatever the mechanism it may have been acting at lower hydrocarbon levels than the authors' suggest.

In the Chambers Creek study (Weber et al. 1981; Malins et al. 1985), the dam had a fish ladder on each side of the creek. A mixture of monoaromatic hydrocarbons was released into one ladder, and the number of salmon ascending the treated and untreated ladder were counted. Comparisons of the numbers of fish ascending the two ladders were used to estimate that the threshold for "avoidance" of aromatic mixture was 3.2 ppm. The first problem with the study is that the experimental treatment was not confined to the treated ladder. The authors admit that all fish approaching the dam during the test periods could well have encountered the aromatic mixture downstream.

We have reanalyzed the data of the Chambers Creek experiment appearing in Table 46 of Malins et al. (1985) and have found evidence that the total numbers of fish returning to both ladders were reduced when releases of monoaromatic hydrocarbons were high (Figure 2). Regression analysis shows that the total number of returning fish has a significant but negative relation to the calculated hydrocarbon concentration ($F = 8.39$; d.f = 1,10; $p < 0.05$; R-squared = 45.6%). The regression of the total number of returning fish against the measured hydrocarbon concentration is also significant but with more variance (R-squared = 37.9%). In Figure 2, one outlier is evident, and this data point derives from the first day of testing. All others come from a time after hydrocarbons had been introduced into the stream. Multiple regression analysis with time before or after first introduction of the hydrocarbons as a variable again gives a significant regression between total number of returning fish and the two variables, calculated hydrocarbon concentration and time before or after introduction ($F = 18.04$; d.f. = 2,9; $p < 0.01$; R-squared = 80.0%). This reanalysis provides strong circumstantial evidence that the aromatic hydrocarbons released into Chambers Creek were

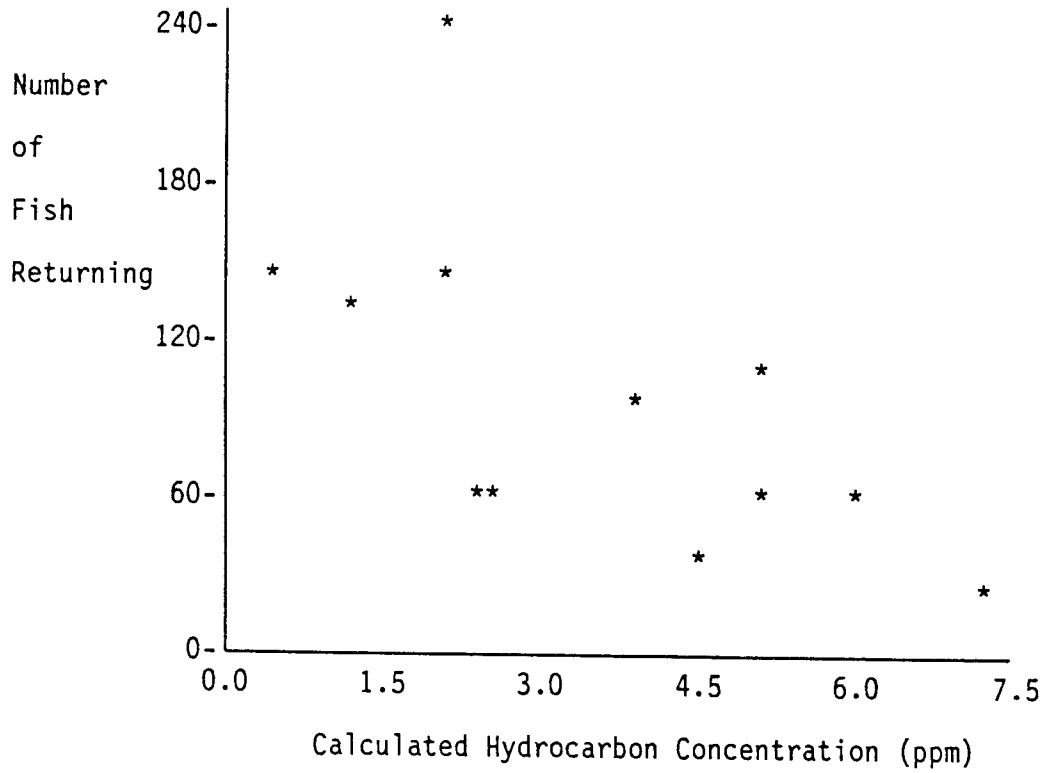

FIGURE 2. The Total Number of Salmon Returning to Both Ladders Versus the Calculated Hydrocarbon Concentration in the Chambers Creek Experiment (Malins et al. 1985)

reducing the overall return of the salmon. The case would be even stronger if information was available on the total number of fish returning on the days when no hydrocarbons were released. Unfortunately, the authors only report the overall return under the no-release conditions rather than the daily returns.

Whereas the authors claim the Chambers Creek results to show that fish avoid a mixture of aromatic hydrocarbons at 3.2 ppm and above, our reanalysis suggests something different. The total number of fish returning to the creek showed a significant negative relationship with the released amount of the mixture of aromatic hydrocarbons. Such observations could be due to behavioral avoidance of the hydrocarbon mixture downstream rather than at the dam or due to impairment of the ability to sense the home stream water. As our well-established behavioral control model (Johnsen 1982; Figure 1 here) indicates, loss of the ability to detect home stream water will lead to downstream movement of salmon, an event that can be misconstrued as "avoidance." Studies with other species demonstrate that monoaromatic hydrocarbons can impair chemosensory function.

In light of this, we suggest an alternative explanation of the Chambers Creek results. On the first day of testing, no aromatic hydrocarbons had been released into the stream so that the normal number of returning fish were at the dam. Upon release of the monoaromatics, those fish on the treated side of the dam where the hydrocarbons were released moved downstream because they lost the ability to detect the home stream odor. Those fish already at the dam on the untreated side continued to detect the stream odor and moved upstream to be counted. Those fish moving upstream well below the dam were encountering some concentration of the aromatic hydrocarbons. Fish encountering a level sufficient to impair detection of home stream odor moved downstream. On the days following the first day of release, the number of fish coming to the dam was reduced to the extent that stream water below the dam contained an aromatic hydrocarbon level sufficient to impair home odor detection. Because the hydrocarbons were probably not evenly distributed

across the stream downstream, some fish were continuing to move upstream to the dam. At the dam, the scenario for the first day was again repeated. The implication of this alternative explanation is that the aromatic hydrocarbons were not acting as noxious odor to which the salmon were exhibiting avoidance behavior but rather were acting as disruptors of the chemosensory detection of home stream odor that, in turn, led to downstream movement of the fish. The point to be remembered from this reanalysis is that an observed change in orientation behavior could have been caused by one of two equally plausible mechanisms: avoidance or chemosensory impairment. Whatever the mechanism, a closer examination of the Chambers Creek results (Weber et al. 1981; Malins et al. 1985) reveals that the released hydrocarbons were apparently active at levels below that indicated by the authors' original interpretation.

Potential Effects of a Delay in Spawning Migration

The concern is that a delay in the spawning migration might adversely affect reproductive success. It is difficult to determine to what extent delays in the spawning migration might influence reproductive success. This difficulty stems largely from the anticipated lag time between the encounter with an environmental disturbance and the actual spawning period. Recent experience in the Mount St. Helens region has demonstrated that salmon are quite flexible in their spawning behavior. When finding their homestream tributary blocked or obliterated by volcanic ash, fish moved to alternate sites and successfully spawned later than normal (Whitman et al. 1982).

In contrast to delays in freshwater, significant delays at sea or in the estuarine regions might have some effects on reproductive success. It appears that the physiological changes that occur upon salmon's entrance into fresh water may also influence the final sexual maturation (Sower and Schreck 1982). When the salmon normally enters freshwater from the ocean, they must undergo osmoregulatory changes; these changes affect, or are affected by, the endocrine system (Woodhead 1975). Thus, if the returning salmon are denied normal entry into freshwater, the endocrine system may not be able to respond

properly. In an experimental study in which fish were retained in seawater during the spawning season, Sower and Schreck (1982) observed modified hormone profiles, dehydrated eggs, small amounts of seminal fluid, incomplete ovulation, low egg survival, and high adult mortality. Such findings suggest that osmoregulatory factors strongly influence the maturational process of salmon and that delays confining migratory salmon to saltwater environments may result in hindered reproductive development.

Although the available information is suggestive, predictions of possible effects on reproductive success cannot be made until the length of the migratory delay is determined. In particular, the hormonal and maturational status of the fish at the time of delay would be an important determinant of reproductive success. Length of delay can be estimated for given exposure levels and durations should chemosensory disruption prove to be the mechanism underlying delay or estimated from time spent in avoidance behavior should avoidance behavior be evident at particular levels of oil contamination. To assess potential effects on reproductive success, effects thresholds must then be related to oil spill scenarios that indicate the level, extent, and duration of oil-contamination of migratory pathways. Comparison of the levels and durations of oil contamination likely to be encountered with the levels and durations producing delays would indicate the expected length of delay. The oil spill scenarios would need to be examined to indicate the likelihood that the delay would occur in saltwater and be of sufficient duration to produce the effects described by Sower and Schreck (1982).

SCENARIOS OF IMPACT FROM OIL SPILLS

What is important to realize is that the studies discussed here rest on the behavioral model developed over many years for the mechanisms in salmonid migration (Johnsen and Hasler 1980; Johnsen 1984; Johnsen 1986) and briefly described above. In the freshwater and nearshore phases of migration, salmon depend on the chemosensory detection of chemical cues to orient their

movements toward and up the home stream (Døving et al. 1985; Hiyama et al. 1966; Bertmar and Toft 1969; Westerberg 1982, 1984; Harden-Jones 1965; Nikoyalev 1978; Scholz et al. 1972). Petroleum has an odor, and, under some circumstances, can disrupt the chemosensory detection of other odors (Hellstrom and Døving 1983; Pearson et al. 1980, 1981a, b). These facts allow the development of several plausible scenarios for the effects of contamination of waterways by petroleum on salmonid spawning migration. The project was intended to provide data to indicate which of the following scenarios are the most likely:

- Detection and avoidance of petroleum

  In this scenario, migrating salmon detect the presence of petroleum and avoid the contaminated area. Consequently, the probability of exposure to petroleum hydrocarbons is decreased, but migration might be delayed. Any delay in migration would be a function of extent of the contaminated area and the time necessary to move around it. The laboratory studies of Phase I addressed the threshold for detection of petroleum hydrocarbons.

- Detection of petroleum hydrocarbons but no avoidance

  Migrating salmon may detect the petroleum contamination but not avoid the contaminated area. If the fish swim through the area, delays in migration would presumably not occur. However, exposure would occur and could increase the probability of acquiring a flavor taint depending on the levels and time duration of exposure. The fieldwork of Phase II is intended to address questions concerning avoidance.

- No detection of petroleum hydrocarbons and, therefore, no avoidance

  Migrating salmon may not detect petroleum hydrocarbons under two conditions: first, when the petroleum hydrocarbons concentrations are

below the detection threshold (the low threshold found in this study will be discussed later) and, second, when the petroleum hydrocarbons concentrations are high enough to disrupt their detection. Should no detection occur, avoidance of the contaminated area appears unlikely. The detection thresholds are quite low so that lack of avoidance of areas with petroleum hydrocarbons concentrations at and below the threshold cause no concern. Lack of avoidance of petroleum hydrocarbons concentrations at which detection is degraded depends on the steepness of the gradient encountered as the fish approaches the contaminated area. It is conceivable that a fish encountering a steep gradient may have only a brief time to detect the petroleum hydrocarbons before its detection ability is depressed. Should the fish not avoid a contaminated area, the questions arising concern the effects of exposure, the extent of which would depend on the exposure level and duration. The laboratory studies of Phase I addressed the question of degradation of chemosensory detection at higher levels of petroleum hydrocarbons.

- Disorientation caused by disruption of the detection of homing cues from exposure to petroleum hydrocarbons

  Because the detection of homing cues is necessary for the appropriate orientation of salmon during migration, degradation of homing cue detection during exposure to petroleum hydrocarbons can be expected to lead to disorientation in the migrating salmon. Should petroleum hydrocarbons impair homing cue detection, delays in migration would be expected, and the degree of delay would depend on the extent of the spill and the duration of disorientation. The laboratory studies of Phase I addressed in part questions concerning the ability of salmon to detect biologically relevant cues under exposure to petroleum hydrocarbons.

OBJECTIVES

The specific research questions addressed in Phase I were the following:

1. Can salmon detect oil?
    a. If so, at what concentration?
    b. If so, is there a degradation of chemosensory detection at high concentrations due to anesthetic or toxic action?
2. Does oil exposure cause loss or impairment of chemosensory detection of other chemical cues?
    a. If so, at what level and duration of exposure?
    b. If so, does the effect occur only in the presence of oil?
    c. If the effect continues after return to clean water, how long does recovery take?

Also, a complementary objective was to determine how "spawning pressure" or motivational state might influence salmon responses to petroleum hydrocarbons. The question of how motivational state is related to spawning condition and migratory behavior can not be directly addressed because there are no techniques for measuring motivational state or any adequate physiological assays of early spawning condition. Our approach to the question of how motivation might be influencing the various responses of salmon was to attempt *post hoc* correlations of olfactory responses observed on a particular date with the hormonal status of that fish measured using radioimmunoassay (RIA) techniques. Another objective of the laboratory work of Phase I was to provide information to design the field tracking studies of Phase II.

Here we report on findings from four areas:

1. The chemosensory detection threshold for the water-soluble fraction (WSF) of Alaska North Slope (ANS) crude oil in adult coho salmon

2. Changes in chemosensory function of adult coho salmon at higher concentrations of the WSF of ANS crude oil

3. Effects of short-term exposure of adult coho salmon to the WSF of ANS crude oil on detection of an amino acid mixture

4. Detection of an amino acid mixture by adult coho salmon during exposure to the WSF of ANS crude oil.

Findings in all four areas derive from use of the same basic EOG technique with different protocols of stimulation and experimental treatment of the fish. Also, we report inconclusive results concerning the relationship between hormone levels and chemosensory function.

MATERIALS AND METHODS

CAPTURE AND HOLDING

Adult male coho salmon, Oncorhynchus kisutch, were captured by hook and line from salt water in the Strait of Juan de Fuca and by seine from the holding basin of the Dungeness Fish Hatchery operated by Washington Department of Fisheries. Some laboratory-reared 2-year-old chinook salmon, O. tshawytscha, were used in the preliminary testing done to modify the EOG apparatus for use with the WSF of crude oil but are not included in the data analysis. The fish were held in 1800-gal circular tanks supplied with aerated well water flowing at a rate of 15 l/min. Coho salmon were not fed during captivity. For transferring fish at various stages in the project, a specially designed sling was used. Unfortunately, the fish captured in salt water were lost through a failure of the water supply to the holding system just at the time when they became no longer available in salt water. Fish weights, capture dates and holding time for the fish used in the experiments are given in Table 1.

PREPARATION OF FISH FOR EOG EXPERIMENTS

For the electrophysiological experiments, the fish were anesthetized with MS-222 (tricainemethane sulphonate, 1:20,000 w/v dilution), immobilized with Flaxedil (gallamine triethiodide, 0.1 mg/100 g body weight) and fastened in a Plexiglas fish holder (Figure 3). Wet sponges, held in position with Velcro straps, were used to keep the fish restrained in the proper position. Aerated well water containing MS-222 was perfused through the mouth over the gills via a recirculating system. Perfusion water was maintained below 5°C with an ice bath. At the end of each day's experimentation, a cardiac

TABLE 1. Biographies of Individual Fish Used in the EOG Experiments. The column entitled RIA provides the results of the radioimmunoassay on circulation hormones estradiol (E2) and testosterone (T). The column entitled IR gives the concentration of total hydrocarbons measured by infrared (IR) spectrophotometry for each WSF batch.

								RIA			
Fish #	Species	Capture Date	Test Date	Wt. (g)	Length (cm)	WSF batch	IR mg/l	E2 pg/ml	T ng/ml	Tests performed	Quality Control Acceptable(Yes/No)
86-1	Chinook	Lab. reared	10-27-86			16	6.9			Threshold WSF 3,2,1 dil.	Prelim. test fish
86-2	Chinook	Lab. reared	10-28-86			16				Threshold WSF 3,2,1 dil., short-term effects	Prelim. test fish
86-3	Coho	9-23-86	10-29-86			17	6.1			Fish died	-----
86-4	Chinook	Lab. reared	10-30-86			17				Threshold WSF 12,9,6 dil.	Prelim. test fish
86-5	Chinook	Lab. reared	10-31-86			18	4.7			Threshold WSF 9,6,3 dil., short-term effects	Prelim. test fish
86-6	Coho	10-31-86	11-1-86	1590	55	18				Fish died	-----
86-7	Coho	10-31-86	11-1-86	1815	60	18				Fish died	-----
86-8	Coho	10-31-86	11-4-86	1472	54	19	4.6			Fish died	-----
86-9	Coho	10-31-86	11-4-86	1557	54	19				Threshold WSF 9,6,3,1 dil.	Yes?
86-10	Coho	10-31-86	11-6-86			19				Threshold WSF 12,9,6,3 dil., short-term effects	No-System contam.
86-11	Coho	10-31-86	11-7-86	1730	58	19				Threshold WSF 12,9,6,3,2,1 dil.	No-System contam.
86-12	Chinook	Lab. reared	11-12-86			20	4.5			Fish died	-----
86-13	Chinook	Lab. reared	11-12-86	132	22	20				Threshold WSF 9,6,3 dil., short-term effects	Prelim. test fish
86-14	Chinook	Lab. reared	11-13-86			20				Fish died	-----
86-15	Chinook	Lab. reared	11-13-86	109	23	20				Threshold WSF 9,6,3,2,1 dil., short-term effects	Prelim. test fish
86-16	Coho	10-31-86	11-14-86	1410	53	20		<.1	28.76	Threshold WSF 9,6,3,2,1 dil., short-term effects	Yes
86-17	Coho	10-31-86	11-18-86	1355	54	21	5.5	0.61	28.12	Threshold WSF 7,6,5,4,3 dil., short-term effects	Yes
86-18	Coho	10-31-86	11-19-86	1190	52	21				Threshold WSF 12,10,8,7 dil.	No-System contam.
86-19	Coho	10-31-86	11-20-86	1780	60	21		<.1	29.28	Threshold WSF 7,6,5,4,3 dil., short-term effects	Yes
86-20	Coho	11-18-86	11-21-86	1628	58	21		<.1	21.08	Threshold WSF 7,6,5,4,3 dil., short-term effects	Yes
86-21A	Coho	11-18-86	12-2-86	2505	64	22	5.4	<.1	30.24	Threshold WSF 7,6,5,4,3 dil., short-term effects	Yes
86-21B	Coho	11-18-86	12-3-86	2060	60	22				Fish died	-----
86-22	Coho	11-18-86	12-4-86	1600	56	22		<.1	33.36	Threshold WSF 7,6,5,4,3 dil.	No-System contam.
86-23	Coho	11-18-86	12-5-86	1485	56	22		<.1	44.36	Threshold WSF 7,6,5,4,3 dil., short-term effects	No-System contam.
86-24	Coho	11-18-86	12-9-86	1455	56	23	3.9	<.1	28.60	Threshold WSF 7,6,5,4,3 dil., short-term effects	Yes

TABLE 1. Continued

Fish #	Species	Capture Date	Test Date	Wt. (g)	Length (cm)	WSF batch	IR mg/l	RIA E2 pg/ml	RIA T ng/ml	Tests performed	Quality Control Acceptable(Yes/No)
86-25	Coho	12-3-86	12-10-86	3200	72	23		<.1	51.32	Exposure effects	Yes
86-26	Coho	12-3-86	12-11-86	2359	64	23		<.1	44.52	Exposure effects	Yes
86-27	Coho	12-3-86	12-12-86	1566	57	23		<.1	47.92	Exposure effects	Yes
86-28	Coho	12-3-86	12-13-86	1555	57	23		<.1	49.52	Exposure effects	Yes
86-29	Coho	12-3-86	12-14-86	1540	56	23		<.1	25.04	Exposure effects	Yes
86-30	Coho	12-3-86	12-15-86	1765	60	23		<.1	23.81	Exposure effects	No-System contam.
86-31	Coho	12-3-86	12-17-86	1455	53	23		<.1	9.84	Exposure effects	Yes

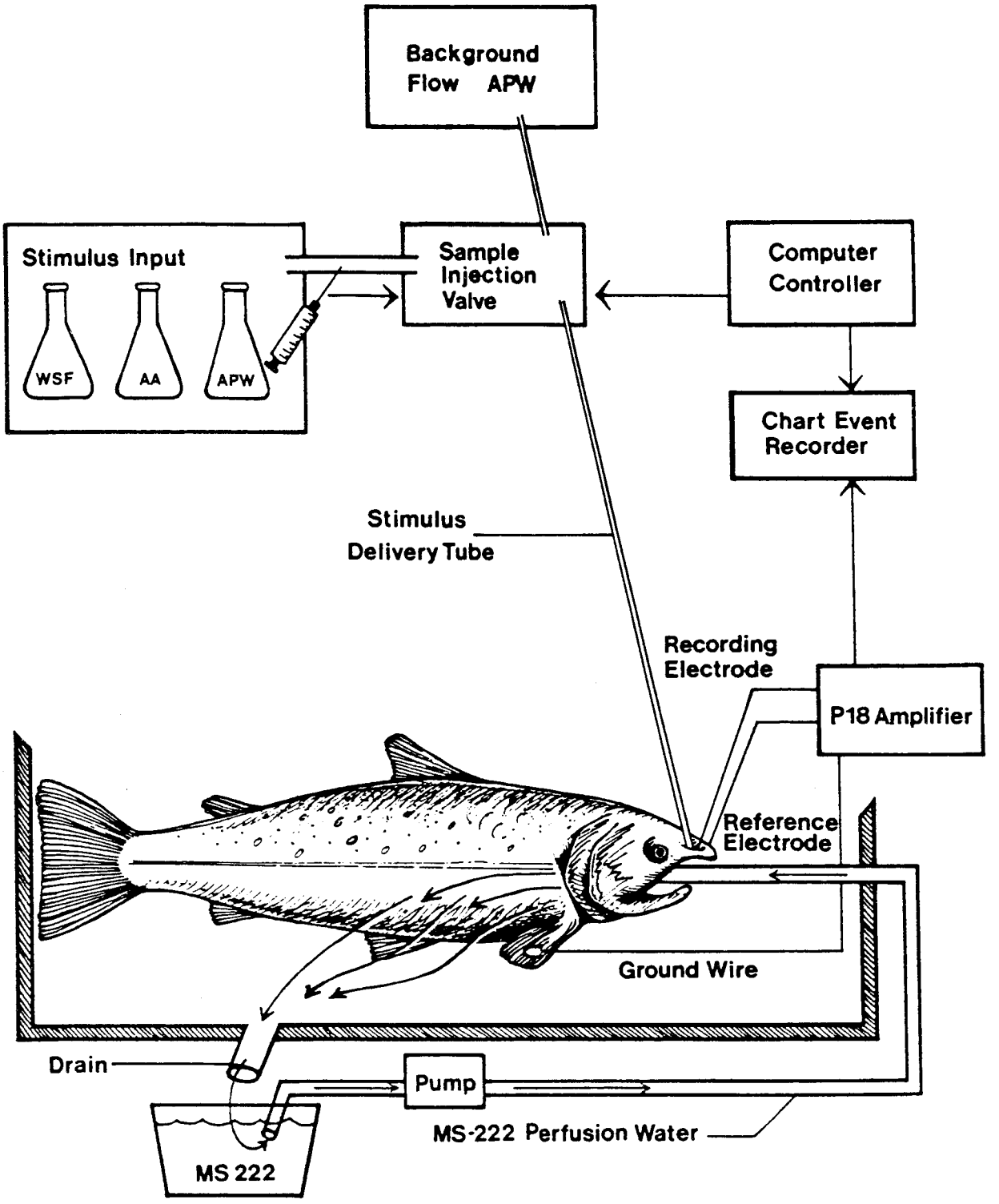

FIGURE 3. The Apparatus for the Electro-Olfactogram (EOG) Experiments with Pacific Salmon

puncture was performed to obtain blood for later RIA analysis for the hormones estradiol and testosterone.

EOG RECORDING TECHNIQUE

To record the EOG response from an individual fish prepared as described above (Figure 3), the olfactory rosette was exposed by removing with ophthalmic scissors the flap of skin forming the incurrent and excurrent nasal pores. The underwater EOG (electro-olfactogram) is a slow potential change in the olfactory mucosa elicited by chemical stimulation (Silver et al. 1976) and was recorded by placing a Ringer-agar filled glass capillary, bridged to a calomel electrode, in the water flowing over the olfactory mucosa. All recordings were made from the center of the rosette along its midline. The reference electrode of similar construction was positioned on the head adjacent to the olfactory capsule. The fish was grounded by an alligator clip to the pectoral fin. The electrodes were dc coupled to a Grass P-18 preamplifier and the signal was displayed on an oscilloscope and Western Graphtec WR7500 pen recorder.

EXPERIMENTAL SOLUTIONS

To maintain control of the ionic and organic constituency of the water flowing over the olfactory mucosa, Artificial Pond Water (APW) (0.3 mM NaCl; 0.02 mM KCl; 0.2 mM $CaCl_2$; 0.2 mM $NaHCO_3$ in distilled deionized water) was used for background flow and to make up all stimuli. The use of freshwater as the background flow does not diminish the applicability of these results to the marine and estuarine situation. First, the olfactory receptor cells are covered with a coating of mucus so that the olfactory cilia and presumptive receptor sites are chemically isolated from the surrounding media (Tucker 1983). In fact, it has been demonstrated that the responses of receptor cells to odor substances are not significantly modified after changes in ion concentrations (Suzuki 1978). Labyrinth cells found in

olfactory mucosa have a chloride cell-like structures that serve as excretory cells for osmo- and ionregulation. In this way, these cells may allow the olfactory organs to function optimally in waters of different salinity (Bertmar 1982). The effect of increased ions in salt water is to shunt the EOG signal (Oshima and Gorbman 1966). Therefore, the conductivity of seawater decreases the absolute amplitude of the recorded signal. However, the signal-to-noise ratio is not degraded in going from freshwater to marine fish. The slope of the olfactory response-concentration curves of marine fishes are similar to those obtained for freshwater fish (Tucker 1983). Additionally, the olfactory responses of Atlantic salmon stimulated with seawater samples (Døving et al. 1985) were similar for the same species stimulated with freshwater samples (Sutterlin and Sutterlin 1971).

The WSF of fresh ANS crude oil was prepared following methods similar to Anderson et al. (1974). Three liters of APW were added to a glass carboy containing a Teflon stir bar and glass siphon tube. An aliquot of 333 ml of oil were carefully added to the surface of the water layer, and the carboy was sealed with a stopper covered with aluminum foil and through which the siphon tube extended to below the oil phase. The mixture was stirred for 20 h at a rate allowing the oil vortex to extend no more than 20% of the distance to the bottom of the bottle. After mixing, the oil and water phases were allowed to separate for 4 h. The water was siphoned from below the oil phase and filtered through a 0.45-micron filter under low pressure to remove any remaining oil droplets. Serial dilutions of WSF were made daily from a half strength stock WSF solution using fresh chilled APW. The WSF dilutions were kept in an ice water bath during use. The stock WSF was analyzed by capillary gas chromatography for diaromatic and triaromatic hydrocarbons (Bean et al. 1980). Monoaromatics were analyzed by gas chromatographic headspace analysis using methods modified from Wylie (1985). Total extractable hydrocarbons were measured from the half strength stock WSF solution using IR spectrophotometry (Bean et al. 1980). Table 2 gives the composition of the WSF of ANS crude oil. The monoaromatic hydrocarbons constituted 97% of those

TABLE 2. The Composition of Stock Solutions of WSF of Alaska North Slope Crude Oil. Sample size was 8 for monoaromatics, 3 for polynuclear aromatics, and 8 for IR spectrophotometry analysis.

Fraction	mean mg/l	S. D.
Monoaromatics		
benzene	7.156	0.841
toluene	5.163	0.137
ethylbenzene	0.361	0.009
m+p xylene	1.126	0.028
o-xylene	0.529	0.013
1,2,4-trimethyl benzene	0.154	0.004
1,2,3-trimethyl benzene	0.098	0.004
Total	14.588	0.836
Polynuclear aromatics		
naphthalene	0.1938	0.0474
2-methyl naphthalene	0.1011	0.0225
1-methyl naphthalene	0.0657	0.0143
2-6 & 2-7 dimethyl naphthalene	0.0170	0.0042
1-6 dimethylnaphthalene	0.0137	0.0027
1-4 dimethylnaphthalene	0.0081	0.0017
1-5 dimethylnaphthalene	0.0077	0.0019
1-2 dimethylnaphthalene	0.0073	0.0018
1-7 & 1-8 dimethyl naphthalene	0.0011	0.0015
2,3,5-dimethylnaphthalene	0.0056	0.0015
phenanthrene	0.0039	0.0004
2-methylphenanthrene	0.0000	0.0000
1-methylphenanthrene	0.0004	0.0002
3,6-dimethylphenanthrene	0.0000	0.0000
Total	0.4253	0.0956
TOTAL HYDROCARBONS	15.0131	0.9312
IR analysis (Total extractable hydrocarbons)	5.9	0.91

measured by GC. Saturate hydrocarbons were not analyzed because their concentrations would have been less than detectable. The stock solutions averaged 5.9 mg/l as measured by IR and 15.0 mg/l as measured by glass capillary GC and GC headspace analysis.

The amino acid stimulus was composed of a mixture of L-serine, L-cysteine, and L-alanine. Stock solutions of 10^{-2} M were made weekly in APW. Test solutions were diluted daily with fresh APW to a 10^{-4} M concentration.

METHOD OF STIMULATION

One ml of each stimulus sample was delivered via a sample injection valve (Rainin Instrument Co., Inc. Model 201-14) to the olfactory capsule. A mariott bottle was used to maintain a constant background flow (6 ml/min) of APW over the olfactory mucosa. For Fish 86-1 to 86-15 (Table 1), the sophisticated automatic injection system originally proposed was used but proved unacceptable because there was bleed-through of the WSF solutions from one presentation to the next as well as interactions between the WSF and system components. For Fish 86-12 and above, a manual injection proved to yield acceptable results. For each sample presentation producing data reported here, the test stimulus was loaded into the sample injection loop by hand using a disposable syringe. A Commodore VIC-20 microcomputer started the pen recorder, delivered the stimulus, and placed an event mark on the chart. The computer maintained the interstimulus interval of 180 sec during which time the nasal capsule was flushed with the background solution.

Using color densitometry, dilution of the stimulus by the background flow was determined. Peak concentrations experienced by the fish were 77% of the injected concentration. Therefore, all concentrations of the amino acid stimulus actually experienced by the fish would presumably be 23% lower than the concentration injected. Besides being diluted by the background flow, the injected WSF suffered additional loss, which was determined by headspace

analysis of samples taken at various points in the delivery system. Peak concentrations of WSF experienced by the fish were reduced by an additional 38±5% of the injected value. The WSF concentrations given in the subsequent figures and tables have been adjusted for loss in the delivery system by multiplying the injected value by the percentage, 47.7%.

PROTOCOLS OF STIMULATION

Different protocols of stimulation were used to address different questions concerning the effects of WSF on the salmon chemosensory function.

For determination of WSF thresholds and changes in detection at higher concentrations, WSF dilutions were presented in an ascending order to coho salmon (Fish 86-16 to 86-24 in Table 1). For Fish 86-17 and 86-19 to 86-24, the series was as follows:

blank
10^{-4} M amino acid
blank
10^{-7} mg/l WSF
blank
10^{-6} mg/l WSF
blank
10^{-5} mg/l WSF
blank
10^{-4} mg/l WSF
blank
10^{-3} mg/l WSF
blank
10^{-4} mg/l WSF
blank
10^{-4} M amino acid
and blank.

Three series were presented to each fish. In each series, an APW blank alternating with the WSF stimulus served as a control while an amino acid mixture served as an internal standard. This standard allowed us to normalize data across fish and through the time course of experiments. This was necessary because the amplitude of the dc EOG response is dependent on the position of the recording electrode relative to the olfactory epithelium. Because decreases in the EOG response were being observed above 10^{-4} mg/l WSF, another 10^{-4} mg/l WSF concentration was presented in the series to determine whether the EOG response to 10^{-4} mg/l WSF was degraded following presentation of 10^{-3} mg/l WSF.

To examine the effects of short-term exposure to WSF on the detection of amino acids, the response to amino acid mixtures following stimulation by WSF was measured. The series was as follows:

blank
10^{-4} M amino acid
10^{-7} mg/l WSF
10^{-4} M amino acid
10^{-6} mg/l WSF
10^{-4} M amino acid
10^{-5} mg/l WSF
10^{-4} M amino acid
10^{-4} mg/l WSF
10^{-4} M amino acid
10^{-3} mg/l WSF
10^{-4} M amino acid
10^{-4} mg/l WSF
10^{-4} M amino acid
and blank.

As in the WSF threshold experiments, increasing concentrations of WSF were presented to the fish. Following the normal rinsing during the interstimulus

interval, amino acids were presented rather than a blank. The amplitude of responses to these stimulations were compared to those presented before the effects trials. A single effects series was presented to each fish at the end of three series of presentations for threshold determination.

The original plans also included using a heart rate conditioning (HRC) system to determine the effects of the presence of petroleum hydrocarbons on chemosensory detection of other biologically significant chemicals. Scaling up the HRC system from designs successfully used with small fish to ones capable of using large adult salmon proved to require more developmental work than the limited availability of the salmon would permit. We were able to successfully condition laboratory-reared 2-year-old chinook salmon and to obtain heart records from adult coho salmon, but we were unable to subject adult coho salmon to the conditioning protocols because of the time limitation on fish availability. To address the questions concerning the effects of WSF exposure on detection of biologically relevant cues, we used the EOG technique.

Using the EOG technique, experiments were conducted to determine if the fish could detect meaningful biological stimuli in the presence of WSF. For Fish 86-25 to 86-31, EOG responses were measured when the background flow over the olfactory mucosa was first, APW, second, 10^{-5} mg/l WSF, and, finally, APW. With APW as background, the EOG response was measured for the following series: blank, 10^{-4} M amino acid, and 10^{-5} mg/l WSF. Following these presentations, the background flow was replaced with a WSF solution equal in concentration to the previously tested solution. After 30 min and still with a background of 10^{-5} mg/l WSF, stimuli were presented in the following series: 10^{-5} mg/l WSF, 10^{-5} mg/l WSF and 10^{-4} M amino acid together, 10^{-4} M amino acid, blank, and 10^{-5} mg/l WSF. The background was then returned to APW, and, after 30 min, stimuli were presented in the series: blank, 10^{-4} M amino acid, and 10^{-5} mg/l WSF. Three trials of each stimulus under each of the three different background flows were conducted. The mean responses during these three stimulation series were then compared.

DATA ANALYSIS

Magnitude of the EOG response was measured from baseline to the peak of the response. Responses are expressed in arbitrary units that may be converted to absolute units (mV) by comparing the size of known calibration signals to the response to chemical stimuli [1 mV = 12 divisions (arbitrary unit)]. Examples of the EOG responses in a stimulus series are shown in Figure 3. Concentration values for the amino acid mixture in Figure 3 are expressed as the concentration presented, without accounting for delivery dilution. Concentration values for the WSF presented in Tables 3 to 6 and Figures 4 to 7 have been adjusted for dilution and loss in the delivery system.

QUALITY ASSURANCE

In addition to the chemical analysis reported elsewhere, two types of tests were performed so that the responses from different fish could be compared. The amino acid solution served as an internal standard calibration reference. All responses are expressed in terms of the individual animal's response to that standard stimulus. In addition, contamination of the test apparatus and the glassware used was evaluated by measuring responses to APW that had been held in glassware to be used in the testing. The EOG responses of fish were examined, and, if abnormally high responses to blanks occurred or no change in response was observed over a wide range of concentrations, the fish was dropped from analysis. Generally, fish used after the switch to manual injection with disposable syringes (at and above Fish 86-16 for coho salmon) yielded acceptable data (Table 1).

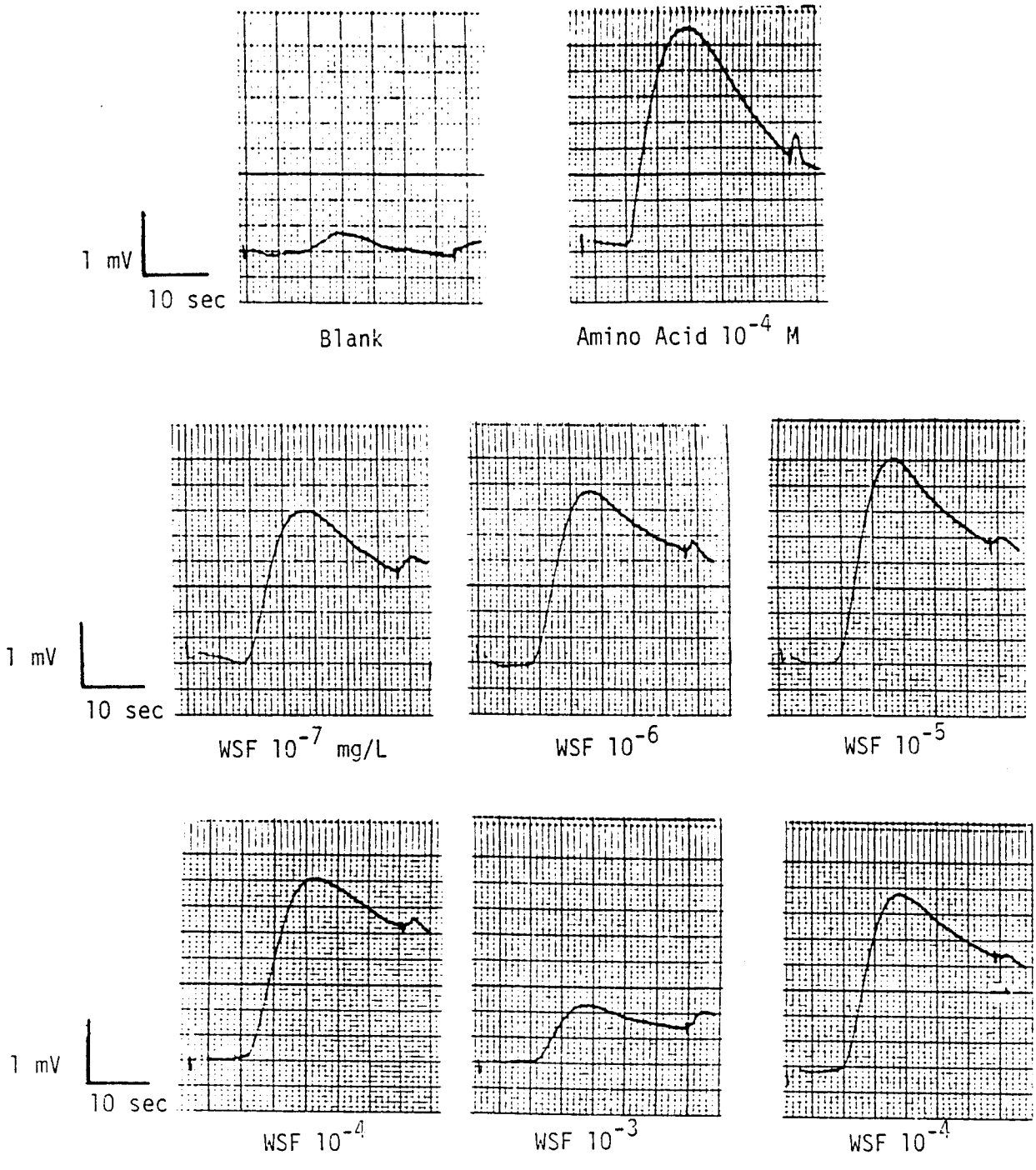

FIGURE 4. EOG Responses to a WSF Concentration Series Presented to Fish #86-20

RESULTS

THRESHOLD FOR DETECTION OF WSF

A primary task was to determine the olfactory detection threshold of WSF using the EOG method with the specific protocols described above. Threshold is defined as that concentration of a stimulus that can be perceived above the ambient noise level. In the EOG recording technique, the noise level is established by measuring the response of the animal to a blank. This blank is the same water in which the stimulus of interest is prepared. Additionally, an ideal blank is as similar to the background flow as possible so that responses to inadvertent contamination are minimized by sensory adaptation.

There exist two common methods to determine the detection threshold. The first involves presenting samples in increasing concentration steps from very low to higher in an attempt to bracket the noise level. Threshold is then determined to be the concentration that elicits a response slightly greater than the background response. Difficulties in this approach are selecting appropriate step sizes and ensuring that the response to background is minimized.

A more common method involves determining the slope of the olfactory response function and calculating the concentration that produces a response equal to that of the background. The existence of a response function over a broad range of concentrations in the peripheral olfactory system is well accepted (Tucker 1983), and a law of logarithmic dependence has been confirmed in fish and for a variety of stimuli (Caprio 1983). The value of having a response function is that one can extrapolate from response points to the limit imposed by noise (control response) for a threshold

concentration determined electrophysiologically. Each stimulus has a particular slope for its linear response function. This slope is determined by measuring responses to a relatively few concentrations of the stimulus and using linear regression of logarithmically transformed responses and concentrations to calculate the equation of the line. This approach has the advantage that fewer concentrations need to be presented and one does not need to have an estimate of the threshold in order to make the appropriate dilutions to bracket the threshold.

Using the extrapolation approach, we presented a series of WSF dilutions chosen in the lower concentration range of known olfactory stimuli for salmonids. For each fish, mean responses to three replicate presentations of each concentration were measured and normalized by expressing responses as percentage of the amino acid response (Table 3). After logarithmic transformation of the variables, linear regressions were calculated for both individual fish means as well as the population mean of individual means.

It is observed from these data that calculated thresholds for individual fish and the population as a whole give extremely low values; calculated thresholds ranged from 11 to 33 log dilutions of the stock WSF solution. Obviously the lower estimates are unrealistic values. A 10^{15} dilution of WSF would have less than 10 hydrocarbon molecules of the molecular weight of naphthalene in the olfactory capsule. Examination of the plots of the concentration-response curves indicates that, unlike previously studied stimuli, the response function does not follow the law of logarithmic dependence (Figures 5 and 6). This deviation will be discussed in greater detail below in the section where the responses to the higher concentrations are considered.

Estimates of the detection threshold can be made on the basis of a number of observations. The most effective known chemical stimuli for fish and for salmonids in particular include amino acids and bile acids. Tucker (1983), in reviewing the physiology of fish chemoreception, observed

TABLE 3. EOG Responses of Coho Salmon to Three Replicate Presentations of a Series of WSF Concentrations.

EOG RESPONSE

FISH #86-17	Presentation Series 1	2	3	MEAN	LOG MEAN	% LOG MEAN AA
BLK				2.2	0.34	28
AA	16	21	14	17.0	1.23	100
-7	11	7	11	9.7	0.99	80
-6	21	25	19	21.7	1.34	109
-5	30	24	19	24.3	1.39	113
-4	29	27	28	28.0	1.45	118
-3		13	14	13.5	1.13	92
-4		22	23	22.5	1.35	110
FISH #86-19						
BLK				1.1	0.04	3
AA	34	26	29	29.7	1.47	100
-7	22	24	24	23.3	1.37	93
-6	24	26	26	25.3	1.40	95
-5	28	28	26	27.3	1.44	98
-4	22	25	23	23.3	1.37	93
-3	8	8	9	8.3	0.92	63
-4	20	24	30	24.7	1.39	95
FISH #86-20						
BLK				2.6	0.41	25
AA	45	43	43	43.7	1.64	100
-7	30	31	23	28.0	1.45	88
-6	34	37	31	34.0	1.53	93
-5	40	43	28	37.0	1.57	96
-4	35	40	33	36.0	1.56	95
-3	11	13	13	12.3	1.09	67
-4	35	47	26	36.0	1.56	95
FISH #86-21A						
BLK				1.5	0.18	10
AA	70	78	65	71.0	1.85	100
-7	32	32	37	33.7	1.53	83
-6	31	42	45	39.3	1.59	86
-5	37	53	47	45.7	1.66	90
-4	41	42	50	44.3	1.65	89
-3	24	28	37	29.7	1.47	80
-4	40	33	50	41.0	1.61	87

EOG RESPONSE

FISH #86-22	Presentation Series 1	2	3	MEAN	LOG MEAN	% LOG MEAN AA
BLK				3.5	0.54	43
AA	18	19	20	19.0	1.28	100
-7	29	37	38	34.7	1.54	120
-6	35	55	53	47.7	1.68	131
-5	31	41	42	38.0	1.58	124
-4	37	42	50	43.0	1.63	128
-3	27	18	33	26.0	1.41	111
-4	37	50	55	47.3	1.68	131
FISH #86-23						
BLK				13.6	1.13	60
AA	80	88	64	77.3	1.89	100
-7	88	112	100	100.0	2.00	106
-6	90	78	72	80.0	1.90	101
-5	85	82	86	84.3	1.93	102
-4	80	88	82	83.3	1.92	102
-3	90	82	72	81.3	1.91	101
-4	83	72	72	75.7	1.88	99
FISH #86-24						
BLK				3.4	0.53	31
AA	49	44	62	51.7	1.71	100
-7	50	51	61	54.0	1.73	101
-6	51	52	69	57.3	1.76	103
-5	48	48	80	58.7	1.77	103
-4	54	41	56	50.3	1.70	100
-3	27	33	34	31.3	1.50	87
-4	41	39	56	45.3	1.66	97

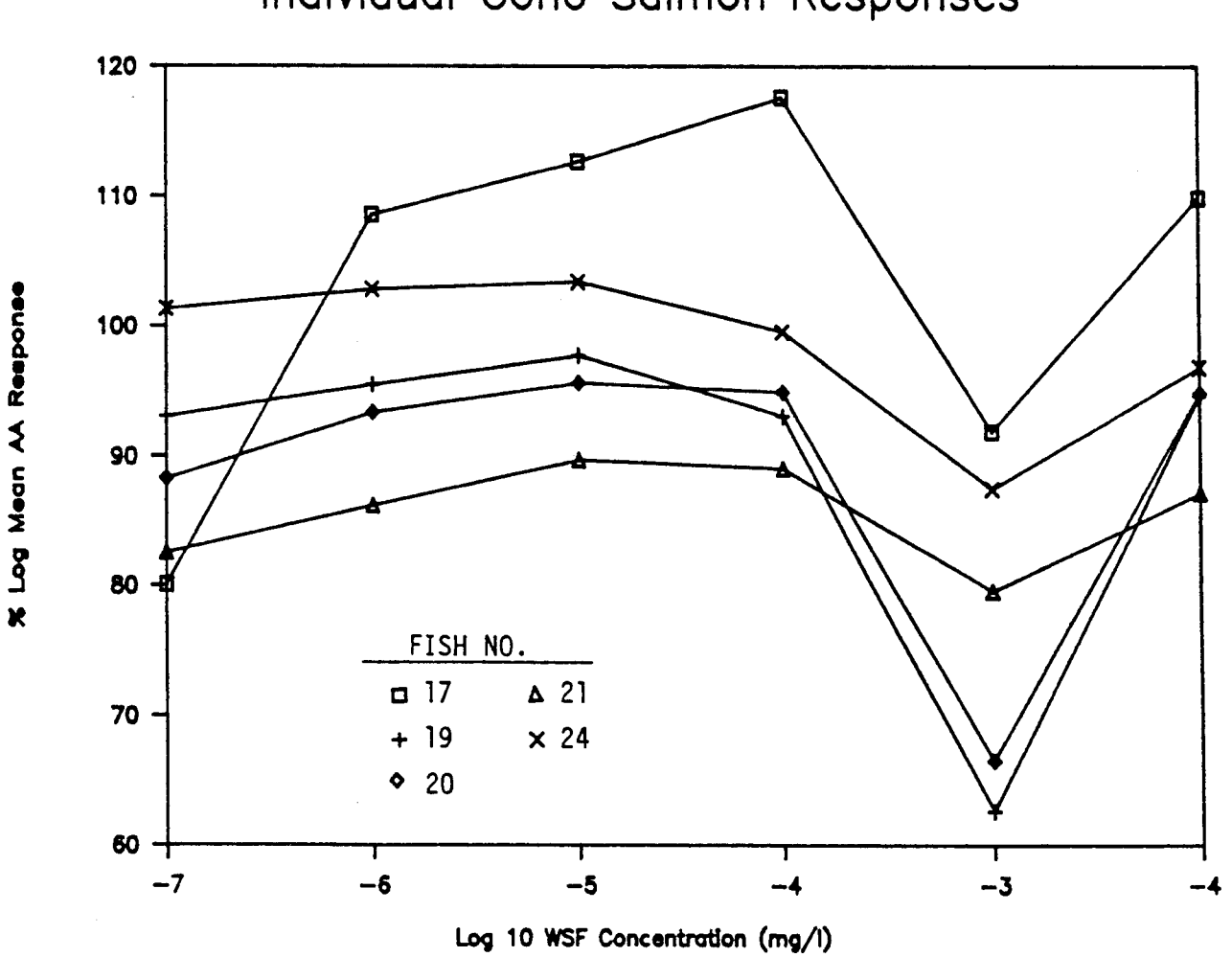

FIGURE 5. The Percentage of the Logarithm of the Mean EOG Response to an Amino Acid Mixture by Five Individual Coho Salmon as a Function of the Logarithm of the WSF Concentrations (mg/l)

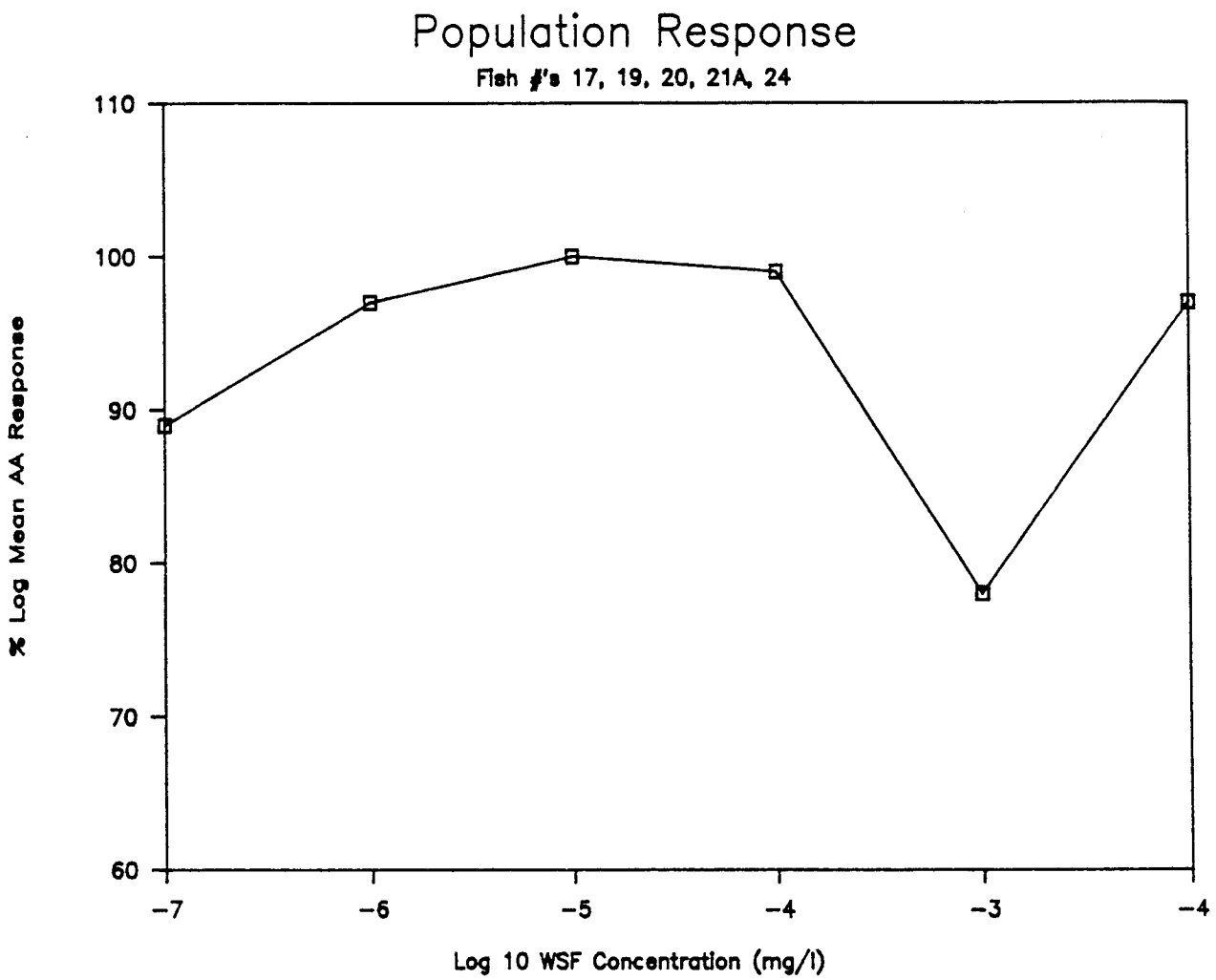

FIGURE 6. The Percentage of the Logarithm of the Mean EOG Response to an Amino Acid Mixture by the Test Population of Coho Salmon as a Function of the Logarithm of the WSF Concentrations (mg/l)

detection thresholds ranging down to 1 X 10^{-9} M for amino acids. Thresholds for bile acids in salmonids are at least the same and may be somewhat lower (Døving et al. 1980). Thus, the robust responses observed at 10^{-7} WSF would indicate that detection thresholds for WSF are comparable to amino and bile acids. Whether the detection threshold could be appreciably lower is debatable. At dilutions below 11 or 12 log steps, most compounds no longer behave in simple ways, and the creation of uniform dilutions is no longer possible. At these levels, a significant percentage of the stimulus compounds begins to interact with the surface of the glassware. This causes nonuniform stimulus strength and inconsistent responses. Therefore, it is unlikely that thresholds for WSF calculated to be below 10^{-12} mg/l WSF are real. The data, however, indicates a threshold below 10^{-9} mg/l WSF. Fish 86-16 still showed a EOG response above the blank response down to the lowest WSF dilution presented, 10^{-9} mg/l WSF (Table 4), and other coho salmon showed substantial EOG responses at 10^{-7} mg/l WSF (Table 5). Thus, for practical purposes, the detection threshold of WSF by coho salmon may be estimated at 4 X $10^{-10\pm1}$ mg/l. This concentration value was derived from the EOG data of Tables 3 and 4 and the chemical data of Table 2 measured by GC and corrected for dilution and loss in the delivery system.

RESPONSES AT HIGHER CONCENTRATIONS

Quite apparent from the response curves presented in Figures 5 and 6 and Table 5 is the degraded response at the 10^{-3} mg/l WSF. This reduction in response is observed in some fish at 10^{-4} mg/l WSF. In fact, the very flat response functions observed for these fish may be caused by an increasing degradation of response as the concentration increases. For other stimuli, there is an exponential increase in response through this range of concentrations (Caprio 1983). A plausible mechanism for our observations involves possible narcotic effects of WSF on cellular elements of the olfactory epithelium. It has been demonstrated that transport and access of stimuli to receptor sites in salmonids is not through passive circulation. Active transport is required and is achieved by a continuous unidirectional

TABLE 4. Responses in Arbitrary Units of Coho Salmon (Fish 86-16) to WSF and Amino Acid Stimulation.

Log 10 Concentration of WSF	Mean Response	% Log Mean Amino Acid Response
-9	7.0	62
-6	17.0	90
-3	34.0	113
-2	23.0	100
-1	24.0	101
Blank	3.7	43
Amino Acid	23.0	100

TABLE 5. Responses in Arbitrary Units of Coho Salmon to WSF And Amino Acid Stimulation.

		Fish #								
		17	19	20	21A	22	23	24	Pop. Mean	Pop. Mean less fish 22 & 23
Mean Response	BLK	2.2	1.1	2.8	1.5	3.5	13.8	3.4	4.0	2.16
	AA	17.0	29.7	43.7	71.0	19.0	77.3	51.7	44.2	42.8
Log 10 concentrations of WSF										
	-7	9.7	23.3	28.0	33.7	34.7	100.0	54.0	40.5	29.7
	-6	21.7	25.3	34.0	39.3	47.7	80.0	57.3	43.6	35.5
	-5	24.3	27.3	37.0	45.7	38.0	84.3	58.7	45.0	38.6
	-4	28.0	23.3	36.0	44.3	43.0	83.3	50.3	44.0	36.4
	-3	13.5	8.3	12.3	29.7	26.0	81.3	31.3	28.9	19.0
	-4	22.5	24.7	36.0	41.0	47.3	75.7	45.3	41.8	33.9
Log Mean Response	BLK	0.34	0.04	0.41	0.18	0.54	1.13	0.53	0.45	0.30
	AA	1.23	1.47	1.64	1.85	1.28	1.89	1.71	1.58	1.58
Log 10 concentrations of WSF										
	-7	0.99	1.37	1.45	1.53	1.54	2.00	1.73	1.51	1.41
	-6	1.34	1.40	1.53	1.59	1.68	1.90	1.78	1.60	1.52
	-5	1.39	1.44	1.57	1.66	1.58	1.93	1.77	1.62	1.56
	-4	1.45	1.37	1.56	1.65	1.63	1.92	1.70	1.61	1.54
	-3	1.13	0.92	1.09	1.47	1.41	1.91	1.50	1.35	1.22
	-4	1.35	1.39	1.56	1.61	1.68	1.88	1.66	1.59	1.51
% Log Mean AA Resp.	BLK	28	3	25	10	43	60	31	28	19
	AA	100	100	100	100	100	100	100	100	100
Log 10 concentrations of WSF										
	-7	80	93	88	83	120	108	101	96	89
	-6	109	95	93	86	131	101	103	103	97
	-5	113	98	96	90	124	102	103	104	100
	-4	118	93	95	89	128	102	100	103	99
	-3	92	63	67	80	111	101	87	86	78
	-4	110	95	95	87	131	99	97	102	97

Mean AA responses following a WSF concentration series expressed as % of pre-WSF exposure AA responses.

	Fish #						
	17	19	20	21A	22	23	24
% Mean Response	9.9	97.8	105.4	89.0	---	101.0	104.7

flow propelled by ciliary action (Døving et al. 1977). Therefore, if ciliary activity is inhibited, stimulus access to receptor sites is restricted, fewer stimulus-receptor interactions take place, and the summed response measured by the EOG technique is reduced. The monoaromatic hydrocarbons that comprised 97% of the WSF used here have been implicated as anesthetic or narcotic agents elsewhere (Crisp et al. 1967; Johnson 1977). The rapid recovery following rinsing indicates that no long-term inhibition or damage is caused by short duration presentations of WSF at these concentrations.

EFFECTS OF SHORT-TERM WSF EXPOSURE ON DETECTION OF AMINO ACIDS

To examine the effects of short-term exposure to WSF on the detection of amino acids, the response to amino acid mixtures following stimulation by WSF was measured. Lasting effects from WSF exposure would result in decreased responses to the amino acid stimulation. At all concentrations of WSF tested, 10^{-7} to 10^{-3} mg/l WSF, no change from the preexposure response amplitudes were observed (Bottom of Table 5). An additional observation made during the threshold experiments supports this conclusion. No significant differences among the first, second, or third presentation series were noted. Whereas these exposures are relatively short in duration, approximately 30 sec, exposures of 60 to 90 min caused no lasting effects to the responses to amino acid and WSF stimuli in subsequent testing.

DETECTION OF AMINO ACIDS DURING EXPOSURE TO WSF

To determine if salmon could detect meaningful biological stimuli in the presence of WSF, EOG responses to amino acids before, during, and after exposure to WSF were measured. Three presentations of blank, amino acids and 10^{-5} mg/l WSF were presented to the fish in a background flow of APW. Following this series, the background flow was switched to 10^{-5} mg/l WSF. After at least 30 min of exposure, the stimulus series was again presented with the addition of fourth stimulus, an amino acid mixture made in the WSF of background flow. At the conclusion of three presentation series, the

background flow was returned to APW, and the first presentation series of three stimuli was again repeated three times per fish. Responses to amino acid solutions at this concentration of WSF were no different from pre- and postexposure trials (Table 6). These experiments indicate that exposures to 10^{-5} mg/l WSF for up to 90 min, the duration of the experiment, do not impair detection of amino acids.

EOG RESPONSES AND SPAWNING PRESSURE

A strong relationship between the EOG responses and the level of circulating hormones taken as an index of spawning pressure was not evident. Figure 7 plots the EOG response normalized to the amino acid response for coho salmon presented with 10^{-7} mg/l WSF against the testosterone level of the fish. This EOG response is to a WSF level below those where the responses began to degrade and shows no significant correlation with the testosterone level ($r = 0.627$, $t = 2.06$, $p > 0.05$). Examination of the testosterone levels for the fish in the threshold experiment (Table 1) shows that the hormone levels were within the range of 21 to 44 ng/ml. This range is above levels measured by Hasler and Scholz (1983), who found ranges of 7 to 19 ng/ml testosterone in coho salmon during the open water phase of migration and 12 to 25 ng/ml in ripe males during the upstream phase.

Examination of Figure 5 shows that Fish 86-17 was somewhat different in its EOG responses than the other fish in the threshold experiment. Fish 86-17 was also somewhat different in that it showed an estradiol titer of 0.61 pg/ml whereas all the others had undetectable levels. The data, however, is too sparse to draw any conclusions concerning chemosensory function and spawning pressure as indicated by hormonal levels.

TABLE 6. Mean Responses in Arbitrary Units of Coho Salmon to WSF and AA Stimulation Presented in APW or WSF Background Flow.

	Fish #						Population Mean	Mean % of AA response
	25	26	27	28	29	31		
APW background flow								
BLK	5.5	7.3	6.3	7.8	4.3	6.7	6.3	9.4
AA	42.3	32.0	65.3	72.7	76.7	112.7	67.0	100
WSF 10 -5	15.0	7.0	21.3	10.0	11.7	18.3	13.9	20.7
WSF background flow								
BLK	2.0	6.0	8.0	4.5	0.0	10.5	5.2	7.9
AA	52.3	32.5	110.0	75.7	37.7	86.0	65.7	100
WSF 10 -5	3.2	20.0	20.8	9.0	4.2	11.7	11.5	1.75
AA in WSF 10 -5	---	40.3	151.7	79.7	44.0	99.7	69.2	126.5
APW background flow								
BLK	9.3	5.3	12.3	3.5	4.3	5.0	6.6	9.4
AA	78.0	25.3	74.3	100.0	56.3	91.0	70.8	100
WSF 10 -5	21.0	24.3	27.7	17.7	34.3	13.0	23.0	32.5

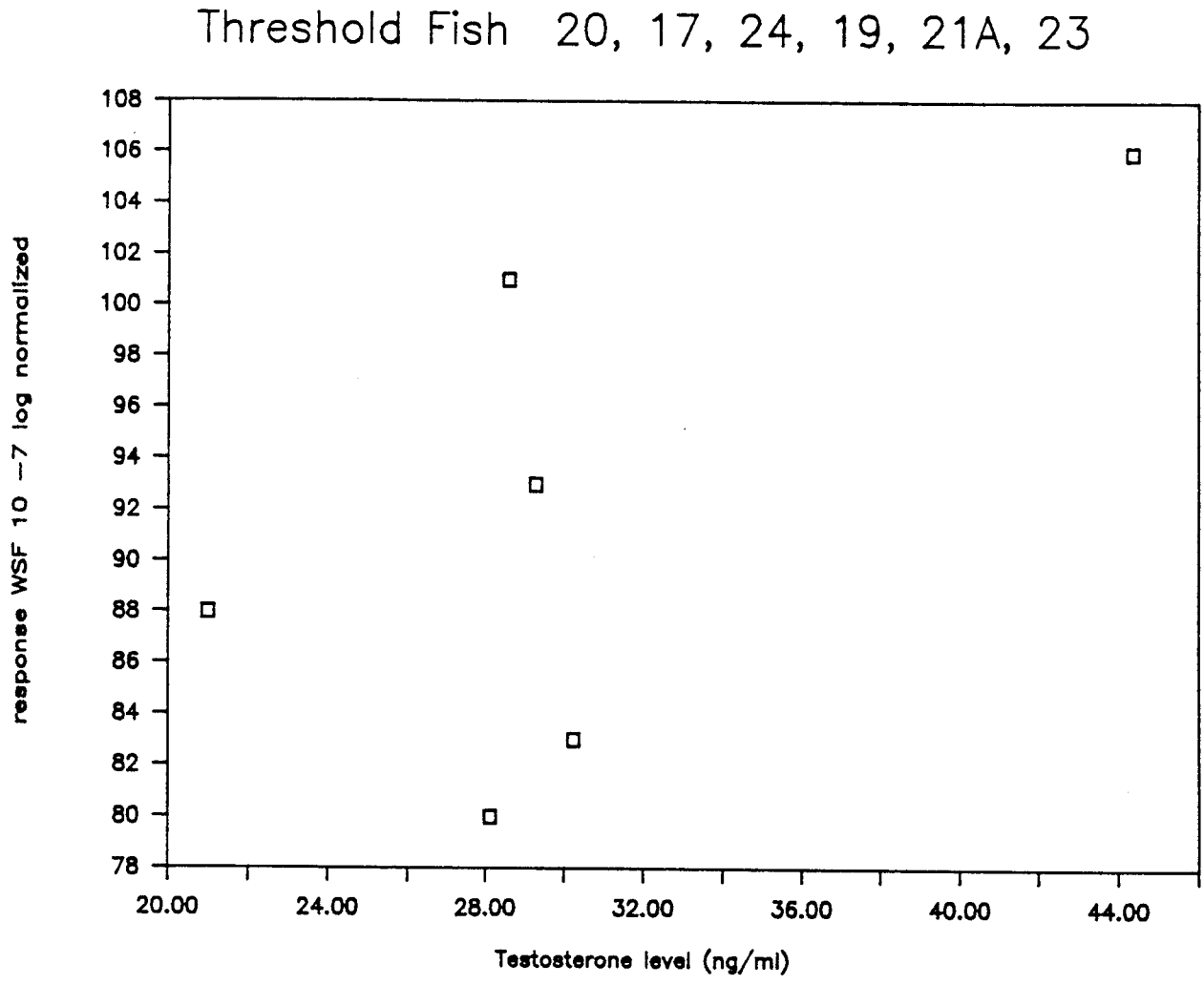

FIGURE 7. The Logarithmically Normalized EOG Response to 10^{-7} mg/l WSF as a Function of the Testosterone Level (ng/ml) in Coho Salmon

DISCUSSION

THRESHOLDS FOR WSF IN SALMON AND OTHER ORGANISMS

The ability of salmon to detect the WSF of crude oil at 10^{-10} mg/l is greater than those reported for other organisms. Hellstrom and Døving (1983) used behavioral criteria to determine that the cod, Gadus morhua, detects the WSF of light diesel fuel at 3 to 30 x 10^{-6} mg/l. Also using behavioral criteria, Dungeness crab, Cancer magister, and blue crab, Callinectes sapidus, were found to detect the WSF of Prudhoe Bay crude oil at 10^{-4} and 10^{-6} mg/l, respectively (Pearson et al. 1980, 1981b).

RELATIONSHIP OF LABORATORY FINDINGS TO OIL SPILL SCENARIOS

The threshold of 10^{-10} mg/l (equivalent to 10^{-7} ppb) found for the detection of WSF by the coho salmon indicates that the fish can detect the presence of hydrocarbons at concentrations 7 to 9 orders of magnitude below levels observed or predicted for accidental oil spills. In accidental spills, the concentrations of hydrocarbons in the water column have varied with the circumstances of the spill. The sum of the observations and estimates discussed in the background section on potential exposure seems to be that maximum hydrocarbon concentrations in the water column can generally be expected to range between 0.2 and 0.65 ppm but can exceed 1.0 ppm where turbulence physically disperses oil into the water column. For spills treated with chemical dispersants, the maximum concentrations appear to be on the order of 20 ppm. Although modelling efforts for Bering Sea oil spill scenarios suggest that the maximum concentrations will not cover large areas or endure long, the modelling effort by Laevastu et al. (1985) predicted that the areas covered by oil concentrations above 1 ppb reach maximums of almost 250 km^2 for a tanker accident and 500 km^2 for a blowout. Concentrations

above 1 ppb are predicted to continue for about 35 days for the tanker accident and slightly less than 30 days for the blowout.

Based on the above information on the concentrations observed and predicted for oil spills, the implications of our laboratory findings are that in spill situations the salmon are likely to encounter WSF concentrations that the fish can detect over a large area. Also, it is clear that oil concentrations are likely in spill situations that are of the same levels (1 ppb and above) as those found by us to cause decreased chemosensory response to WSF. Because the laboratory tests used a WSF that is predominantly monoaromatic hydrocarbons that are rapidly lost in the weathering of oil slicks, it is not clear whether the salmon can detect weathered oil as well as fresh oil or, more importantly, whether the weathered oil would degrade the chemosensory detection of hydrocarbons. Monoaromatics have been implicated elsewhere as agents of anesthesia or reversible narcosis (Crisp et al. 1967; Johnson 1977) so that their loss through evaporation presumably could eliminate the observed degradation on chemosensory detection of WSF.

While the laboratory findings indicate that the salmon can detect WSF of crude oil at low enough concentrations to avoid a spill, they do not demonstrate that salmon will indeed avoid oil-contaminated water. First, avoidance behavior can be expected to occur at levels several orders of magnitude above the detection threshold. Further, the observed degradation in chemosensory response seen above 10^{-4} mg/l (0.1 ppb) WSF suggests that salmon entering a steep gradient of oil contamination may not avoid it because the fish's ability to detect it may be quickly lost. The circumstances of the spill will determine the gradients of contamination.

The laboratory findings lessen concern that WSF exposure could disorient migrating salmon through impairment of homing cue detection. The laboratory findings provide no evidence that detection of biologically relevant cues was impaired by 90-min exposures of 10^{-5} mg/l WSF and short-term exposures up to

10^{-3} mg/l WSF. The rapid recovery of the EOG response to lower levels of WSF after exposure to higher levels suggests that any effects are reversible. WSF levels above 10^{-3} mg/l were not tested so that potential disruption of amino acid detection at higher levels and durations cannot yet be discounted. Present evidence confirms our original conception that any such chemosensory impairment would be evident only in the presence of the WSF and therefore would be transient.

PHASE I FINDINGS, FIELD TRACKING STUDIES AND OTHER LABORATORY STUDIES

The findings indicate that the focus of any field tracking studies should be shifted from investigation of potential disorientation by WSF to avoidance of WSF-contaminated areas. The lack of impairment of amino acid detection by WSF up to 10^{-3} mg/l, and the rapid recovery of WSF detection of lower concentrations after exposure to 10^{-3} mg/l WSF indicates that the likelihood of lasting effects from WSF exposure on homing cues appears small. The successful return without significant delay of coho salmon exposed to crude oil slicks and dispersed oil by Nakatani et al. (1985) also supports the notion that any chemosensory effects from WSF will occur in its presence and not persist after return to uncontaminated water. In light of these findings, we do not recommend the field tracking of laboratory-exposed salmon as originally proposed.

For Phase II, therefore, we recommend field tracking studies that aim to determine whether migrating coho salmon will avoid areas of the water column contaminated with WSF at concentrations which proved detectable in the laboratory. A target concentration of 10^{-5} mg/l WSF will be 5 orders of magnitude above the detection threshold and below the point where the degradation of WSF response was observed. For a target concentration of 10^{-5} mg/l, one would need 90 liters or about 22 gallons of WSF at a full-strength concentration of 15 mg/l to cover a portion of the water column 15 m deep by 30 m wide and 300 m long. Such a target concentration is appropriate for testing avoidance because it is 5 orders of magnitude above the detection

threshold, is at a point where the laboratory observations showed no impairment of detection of biological stimuli, and appears feasible from the logistical and permitting viewpoint. To examine avoidance at a target concentration of 10^{-3} mg/l, where the chemosensory response was impaired, would require, for a single fish and the same volume of water, 2200 gallons of WSF. This latter amount appears beyond logistical and permitting feasibility.

There are two remaining questions not covered then by the present laboratory work and the Phase II fieldwork for which we recommend investigation:

(1) Will the salmon avoid oil-contaminated areas with WSF concentrations above 10^{-3} mg/l WSF where the chemosensory response begins to be degraded?

(2) If salmon are exposed to WSF above 10^{-3} mg/l, will the fish become disoriented through impairment of cue detection?

Also, the observed suppression of olfactory responses to WSF in the mid to higher concentrations tested did not allow us to properly calculate a detection threshold. Without knowing the slope of the response function at lower concentrations, we do not know if there is steep decline in response below 10^{-7} mg/l WSF and, thus, a higher threshold than suggested to date. To address these questions, we recommend further laboratory work in two areas:

(1) Evaluation of olfactory response functions at the lower concentrations not fully tested in Phase I and at the higher concentrations above 10^{-4} mg/l WSF where the function appears to degrade

(2) Evaluation of olfactory response to biologically relevant cues under exposure to WSF at levels above 10^{-3} mg/l.

To determine more accurately the nature of the response function, careful measures of responses of stimuli at concentrations lower than 10^{-5} mg/l and higher than 10^{-3} mg/l are needed. To accomplish this important task, particular care must be given to minimizing system contamination so that background noise is reduced. Presentations of stimuli down to 10^{-10} mg/l WSF should be given in an attempt to bracket the threshold and reduce the complications associated with the response suppression observed at higher concentration.

The sharp decrease in responses observed with WSF concentrations greater than or equal to 10^{-4} mg/l WSF must be investigated. At these concentrations, olfactory function may be impaired by continued exposure and even abolished at higher concentrations. To determine if this is the case, WSF concentrations should be presented several log steps higher than those tested to date. Ideally, the highest should correspond to the highest possible concentration that might be encountered in an oil spill (500 ppb).

No impairment of the salmon's ability to detect other biological stimuli has been observed at the concentrations of WSF tested. However, the strong degradation of response to WSF at higher concentrations indicates that this may be possible. To examine this possibility requires an exposure experiment in which the ability of the fish to detect amino acids in the presence of high levels of WSF is measured.

CONCLUSIONS AND RECOMMENDATIONS

Coho salmon can detect remarkably low levels of petroleum contamination. The electrophysiological evidence indicates that coho salmon have an estimated detection threshold for the water-soluble fraction (WSF) of Alaska North Slope crude oil on the order of $10^{-10\pm1}$ mg/l WSF or about 10^{-7} ppb.

At levels of oil contamination orders of magnitude above the estimated detection threshold, the ability of salmon to detect petroleum hydrocarbons is degraded. At WSF concentrations above 10^{-4} mg/l, the chemosensory response to WSF is degraded but not irreversibly. After short presentation of 10^{-3} mg/l WSF, the ability to detect lower levels of WSF returns within minutes.

For the levels tested, exposure to WSF does not appear to impair the ability of salmon to detect biologically relevant cues. For WSF concentrations from 10^{-7} to 10^{-3} mg/l, short-term exposure to WSF did not result in decreased chemosensory responses to amino acids. Exposures at 10^{-5} mg/l for up to 90 min did not impair amino acid detection.

These findings suggest that coho salmon can detect the presence of dissolved petroleum hydrocarbons at orders of magnitude below the levels seen or predicted to cover large areas during oil spills. The salmon have the sensory ability necessary to avoid oil spills, but field studies are necessary to demonstrate whether migrating salmon will actually avoid oil-contaminated areas.

The implications of the degradation in WSF detection at higher WSF levels for avoidance of oil spills is less clear. Such degradation suggests that where migrating salmon encounter steep gradients to exposure levels

above 10^{-3} mg/l WSF, the fish may have impaired ability to detect and avoid oil-contaminated areas.

The finding of little or no evidence for impairment of biologically relevant cues by WSF up to 10^{-3} mg/l suggests that the salmon can be expected to be able to migrate through these concentrations without becoming disoriented. Levels and durations of WSF exposure above that have not been tested and need investigation.

Based on the laboratory findings of Phase I, we recommend the following:

- Extension of the laboratory studies to include two efforts
  - Evaluation of olfactory response functions at lower concentrations not fully tested in Phase I and at concentrations above 10^{-4} mg/l WSF where the function appears to be degraded
  - Evaluation of olfactory response to biologically relevant cues under exposure to WSF at levels above 10^{-3} mg/l.
- Field tracking studies that concentrate on determining whether salmon avoid WSF concentrations above the detection threshold and below the point at which chemosensory response degrades.

We do not recommend the pursuit of field studies without more laboratory studies. The findings of Phase I shift the focus of Phase II field tracking studies from investigation of potential disorientation of migrating salmon by chemosensory disruption to investigation of avoidance. However, the possibility of disorientation through chemosensory impairment by petroleum remains open, and because of the logistical problems in applying a field treatment of sufficient magnitude to be a valid test, we urge that these be studied in the laboratory. Addressing questions of avoidance and

disorientation above 10^{-3} mg/l WSF with field tracking appears beyond logistical and permitting feasibility, and both questions can be addressed with laboratory studies. If laboratory studies show that the EOG response to WSF becomes increasingly impaired as WSF concentration raises, then one can reasonably expect that avoidance also becomes increasingly unlikely as its sensory foundation is eroded. Similarly, because we know that migrating salmon that have impaired homing cue detection become disoriented, we can expect such disorientation in the field should laboratory studies indicate that cue detection is impaired above 10^{-3} mg/l WSF.

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EFFECTS OF PETROLEUM CONTAMINATED WATERWAYS ON MIGRATORY BEHAVIOR OF ADULT PINK SALMON

by

Douglas J. Martin, Clifford J. Whitmus, and Lon A. Brocklehurst
Pacific Environmental Technologies, Inc.
170 W. Dayton, Suite 201
Edmonds, Washington 98020

Ahmad E. Nevissi
Laboratory of Radiation Ecology
University of Washington
Seattle, Washington 98195

Jeffrey M. Cox and Keith Kurrus
Evans-Hamilton, Inc.
731 N. Northlake Way, Suite 201
Seattle, Washington 98103

Final Report
Outer Continental Shelf Environmental Assessment Program
Research Unit 702

September 1989

ACKNOWLEDGMENTS

This investigation would not have been successful without the ideas and efforts of many individuals and organizations. We wish to thank the following: Ms. Louisa Rand, Alaska Division of Governmental Coordination, for her assistance and guidance in obtaining the necessary environmental permits for this project; Dr. Clayton McAuliffe for his assistance with the formulation of the hydrocarbon cocktail; Mr. David Erikson, Dames & Moore, for his assistance in the field operations; Mr. Ray McClain and graduate students of the University of Washington for assistance in the field and for the hydrocarbon analysis; Ms. Sandy Brocklehurst for her assistance in the field and for making a video record of the field operations; Mr. David Reitz, Real Time Control Corporation, for assisting in development of an algorithm to compute fish position; and Mr. Bob Radek and Ms. Elaine Wedell, Dames & Moore, for technical illustration and word processing services. We are especially grateful to Dr. Jim Payne, Scientific Application International Corporation, for his generous assistance in evaluating the effects of an accidental oil spill in the project area. Special thanks also goes to Mr. Lyman Thorsteinson, NOAA Contract Officer Technical Representative, for his assistance during all phases of the study and Mr. Russel Gaegel, NOAA Kasitsna Bay Station, for providing logistic support and assistance in the field.

This study was funded in part by the Minerals Management Service, Department of the Interior, through an interagency agreement with the National Oceanic and Atmospheric Administration, Department of Commerce, as part of the Alaska Outer Continental Shelf Environmental Assessment Program.

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INTRODUCTION

1.1 BACKGROUND

The North Aleutian Basin including Bristol Bay has the most valuable concentration of salmon in North America. All five species of Pacific salmon (sockeye, pink, chum, coho, and chinook) pass through this region enroute to their home streams for spawning. Fishery management agencies are concerned that oil and gas development in this region could have significant impacts on salmon. An issue of particular concern is that an accidental oil spill in the path of migrating salmon may disrupt their spawning migration. The response of migrating adult salmon during exposure to oil in coastal or open ocean water has never been investigated. Therefore, resource management agencies requested information that would be needed before decisions could be made concerning oil development in the North Aleutian Basin.

In 1986, the National Oceanic and Atmospheric Administration (NOAA) and the Minerals Management Service (MMS) initiated a two-phased project to investigate the effects of petroleum contaminated waterways on spawning migration of Pacific salmon. Phase I consisted of laboratory studies to determine the chemosensory detection threshold for oil by adult salmon and the effects of oil on salmon chemosensory function. Phase II, this study, consisted of field experiments to determine if the migration of adult salmon would be disrupted by exposure to oil contaminated waters at concentrations near or above the chemosensory detection threshold.

The laboratory studies of Phase I were conducted by Pearson et al. (1987). They exposed adult coho salmon held in a freshwater aquarium to the water-soluble fraction (WSF) of crude oil and measured the electrophysiological response of the olfactory mucosa. They found that adult coho salmon have a chemosensory detection threshold of 10^{-7} μg/L (ppb). At concentrations of 0.1 to 1.0 ppb of WSF, the chemosensory response was degraded but not irreversibly. A return of the chemosensory detection response at lower levels of WSF suggested to the investigators that high hydrocarbon levels were causing a temporary narcosis. Exposures to WSF concentrations less than 0.1 ppb did not impair the ability of salmon to detect biologically relevant cues.

Based on the laboratory findings of Phase I, Pearson et al. (1987), concluded that:

- Coho salmon have the sensory ability necessary to avoid oil contaminated waters;
- The degradation of the chemosensory response at exposure levels above 1 ppb suggests that if salmon encounter high exposure levels they may have impaired ability to detect and avoid oil-contaminated areas; and
- If salmon encounter oil concentrations less than 1 ppb and do not avoid the oil, they should be able to migrate through the oil-contaminated areas without becoming disoriented.

Based on these conclusions, a field investigation was designed to address the following questions:

1. Will migrating adult salmon avoid oil-contaminated waters at concentrations near or above the chemosensory detection threshold?

2. If adult salmon encounter WSF concentrations above 1.0 ppb, will they become disoriented?

3. If adult salmon avoid or become disoriented by oil contaminated waters, does either response disrupt migration to the home stream?

In order to address these questions it is necessary to understand the mechanism for salmon orientation and migration in nearshore waters. Research has indicated that salmon depend on chemosensory detection of chemical cues for orientation during migration in coastal waters (Bertmar and Toft 1969, Westerberg 1984, and Doving et al. 1985). Westerberg (1983b) and Doving et al. (1985) have shown that salmon movements are closely related to the fine-scale vertical layering of the water, which contain the home stream odorant. Salmon seek these information-giving layers by large-amplitude vertical movements and maintain orientation within these layers by small-amplitude zigzag movements through the interface layer of strong vertical density gradient (Doving et al. 1985). If salmon lose their olfactory sense, which Doving et al. (1985) tested by surgically severing the olfactory nerve, the salmon do not seek specific depths, they swim with larger amplitude movements, and they swim at a greater depth, often following bottom contours. This demonstrates the importance of olfaction during the coastal phase of migration. During the freshwater phase of migration, salmon will seek the home stream cue at tributary junctions by horizontal zigzag movements along the edge of the scented and unscented plume (Johnsen and Hasler 1980). In the presence of the home stream cue, salmon will make straight positive rheotactic movements and in the absence of the home stream cue, they become negatively rheotactic and swim downstream (Johnsen 1982).

This study provides observations of adult salmon behavior during migration through coastal waters to the estuary of their home stream. Observations of fish movements through coastal waters with and without oil contamination are compared in order to identify behavioral responses to oil exposure. The results of this investigation coupled with our knowledge of salmon migration behavior have lead us to believe that migrating salmon become disoriented when exposed to oil contaminated waters.

1.2 OBJECTIVES

Specific objectives addressed in Phase II were to:

1. Identify the behavior of migrating adult salmon exposed to oil contaminated waters at concentrations ranging from the chemosensory detection threshold to greater than 1.0 ppb,

2. Determine if avoidance or disorientation by adult salmon to oil contaminated waters will disrupt migration to their home stream, and

3. Relate the documented avoidance, non-avoidance, or disorientation by salmon of oil-contaminated waterways to possible effects of oil spill toxicity, tainting, and disruptions in migration.

2. METHODS

2.1 DESCRIPTION OF THE STUDY AREA

Field experiments were conducted in Jakolof Bay, which is located on the south side of Kachemak Bay near Seldovia, Alaska (Figure 2-1). Jakolof Bay is approximately 3.5 km long, 0.5 km wide, and ranges from 1 m to 10 m deep at mean lower-low-water (mllw). The shorelines are mostly rocky with some gravel beaches along the southwestern side. The uplands are wooded and undeveloped for the most part. A gravel road runs along the south side to an inoperative sawmill near the head of the bay. A small boat dock that is used for recreational boaters is located on the western shore just inside the mouth of the bay. Freshwater enters Jakolof Bay from Jakolof Creek and several small intermittent streams. Jakolof Creek is a permanent stream approximately 5 km long and enters at the head of the bay. Annual runs of pink and chum salmon to Jakolof Creek range from several hundred to several thousand fish, with a maximum combined run of 12,000 fish (Tom Schroeder, Alaska Department of Fish and Game, Homer, personal communication).

Jakolof Bay was selected for the field investigation because of its geographic location, configuration, and fish resources. Jakolof Bay is located 2 km from NOAA's Kasitna Bay Station (Figure 2-1), which provided laboratory facilities, logistic support facilities, and lodging. The long narrow configuration of Jakolof Bay with Jakolof Creek at the head of the bay provided a confined coastal area along the migratory route of pink and chum salmon. The bay is closed to commercial salmon fishing, which was necessary to preclude the loss of test fish and to minimize disturbance of test equipment. Jakolof Creek has a native run of pink salmon of sufficient number to provide test fish for the study. The shallow, well-mixed characteristics of Jakolof Bay are ideally suited for development of a hydrodynamic model, which is an important component of the study.

2.2 EXPERIMENTAL DESIGN

The response of adult salmon exposed to oil-contaminated waters was studied by tracking pink salmon movements through Jakolof Bay during periods with and without oil contamination. Ultrasonic transmitters were attached to adult salmon, which were captured at the mouth of Jakolof Creek (Figure 2-2). During an ebb tide, the tagged salmon were released from a holding pen located 2 km from Jakolof Creek and their movements were tracked by a fixed array of hydrophones as the fish returned to their home stream (Figure 2-2). The horizontal and vertical position of each fish within a test group was recorded continuously. Fish horizontal and vertical movement patterns, swimming speed, and duration-of-return to the home stream were examined in order to identify behavioral responses to oil exposure.

A solution of aromatic hydrocarbons similar in composition to the WSF of Prudhoe Bay crude oil was injected into the water column from a diffuser located midway between the fish holding pen and the mouth of Jakolof Creek (Figure 2-2). The diffuser was designed to create a vertically mixed hydrocarbon plume, which extended north from the diffuser and along the eastern one-half of the bay. Salmon were released from the holding pen when the hydrocarbon plume had extended approximately 300 m downfield. This enabled the salmon to have an option

of either moving into or around the plume. Hydrocarbon dispersion rate and concentration within the plume were estimated from a hydrodynamic model, which was calibrated by dye dispersion studies. Predicted hydrocarbon concentrations were also verified with analysis of water samples. The hydrodynamic model and diffuser design were developed from oceanographic data that were collected from a reconnaissance survey conducted during April 1988. The salmon tracking experiments were conducted during late July to correspond with the spawning migration of pink salmon to Jakolof Creek. Tracking experiments conducted without hydrocarbon discharge were designated as "controls" and experiments with hydrocarbon discharge were designated as "treatments." Three control experiments and three treatment experiments were conducted on an alternating schedule during the period from July 19 to July 29. One control experiment had to be repeated because of high winds, which affected the performance of the experiment. Experiments were not conducted for a minimum of two days following each treatment run in order to allow time for the hydrocarbon plume to be flushed from the bay.

Prior to the salmon tracking experiments, an accidental discharge of fuel oil occurred from a tugboat moored near the saw mill on the south side of Jakolof Bay. The oil spill, which occurred on July 17, contaminated the beaches and surface waters near the head of Jakolof Bay. There was a concern that the spilled oil would interfere with the salmon tracking studies. Therefore, an investigation was conducted to determine the concentration and composition of the oil-contaminated waters. The results of this investigation are summarized in Section 3.2.1, as they pertain to background conditions, and a complete description of the results from this investigation is provided by Payne et al. (1988).

2.3 PERMITTING

In order to conduct this study, several permits and a public meeting were required by the State of Alaska. All permit requests and reviews were coordinated by the Alaska Division of Governmental Coordination. Section 307 (c) (1) of the Federal Coastal Zone Management Act requires certification that any activity, which may affect land or water uses in Alaska, will comply with the standards of the Alaska Coastal Management Program. Compliance with this program required three agency permits:

1. Alaska Department of Fish and Game (DFG) - Special Use Permit.

2. Alaska Department of Environmental Conservation (DEC) - Oil Discharge Permit for Scientific Purposes.

3. Alaska Department of Natural Resources (DNR) - Land Use Permit.

These permits stipulated measures necessary to prevent significant contamination of the environment, minimize disturbance of aquatic habitat, and minimize interference of public access to the waters of Jakolof Bay. The public meeting was advertised in the local media and was held in Homer, Alaska. The purpose of this meeting was to inform the public about the study and to gather information on public use of the project area and any public concerns. Consideration for potential impacts to public resources were subsequently addressed by the permit stipulations. The time from permit application to final authorization was six months.

2.4 PLUME MODELING

A numerical dispersion model was use to design a diffuser for injection of a hydrocarbon solution into Jakolof bay and for predicting the fate of hydrocarbons in the bay. Different mechanisms dominant the dispersion process in the near-field and far-field; therefore, models were applied to the simulation of plume behavior in each zone. In the near-field, discharge momentum and buoyancy effects are important; in the far-field, advection and large-scale mixing dominate. The far-field begins, by definition, when the plume buoyancy and momentum match the ambient conditions. The diffuser function and initial plume behavior in the near-field were modeled using a three-dimensional plume model. A two-dimensional far-field model was applied to simulate plume behavior under ambient conditions.

2.4.1 Model Descriptions

2.4.1.1 Near-Field Model

The near-field flow dynamics and dispersion were simulated using the EPA Plume series of models (Muellenhoff et al., 1985). The models were designed for National Pollution Discharge Elimination System (NPDES) permitting and are based on the mixing zone concept for positively buoyant plumes. The Plume series of models predict the spatial dimensions and concentrations of an effluent along single or multi-port discharges. Input parameters required are: current velocity, water temperature, and salinity distributions over the depth of the water column; discharge density; and, discharge rate. A self-similar Gaussian distribution of the cross-plume velocity and concentration profiles is assumed in most of the models. The port size, spacing and discharge angle can be varied as required. Output from the models include the plume centerline position, lateral dimensions and flux-averaged concentration.

2.4.1.2 Far-Field Model

The Dames & Moore proprietary hydrodynamic program TIDAL2 and associated water quality program WQUAL2 are finite-difference, depth-averaged models designed to simulate the circulation patterns and the resulting water quality parameter distributions in tidal water bodies (Dames & Moore, 1985). The models integrated finite differences (or nodal point integration) to represent the governing equations. They are solved using a space-staggered, split-time-level, semi-implicit scheme (see Leendertse, 1970). The programs have been used to study a wide variety of problems ranging from the analysis of pollutant discharge in tidal water bodies to the effect of bathymetric modifications on geostrophic or wind-driven current patterns. TIDAL2 is based on shallow-water equations and WQUAL2 uses heat and mass transfer equations (Stoker, 1957). Both models solve the vertically integrated form of the governing equations. Variable grid spacing has been incorporated into the models in order to obtain higher resolution in areas of particular interest.

Far-field water quality modeling of each discharge was performed in two steps. First, the hydrodynamic program TIDAL2 was run to obtain the current patterns in the bay using the tides at the mouth of the bay as the driving mechanism. Second, the values of the current velocity

and water level at each finite difference grid point were stored and then used as input to the water quality program. Source terms for the water quality program (flow rate and concentrations) were input from the near-field program. Output from the program includes printerplots, tabular output and data for plotting.

Data required by the far-field model include the bathymetric, oceanographic and numerical data necessary to run the model. Bathymetry data were obtained from National Ocean Service (NOS) data files, which were used to prepare the NOS navigation charts for Jakolof Bay. Oceanographic data, specifically tides and currents, required to develop boundary conditions and provide data for the calibration phase, were obtained from field measurements (see Section 2.4.2 and the NOS tide tables for Seldovia.

2.4.2 Oceanographic Data Collection

Oceanographic and atmospheric data collected in support of this study were designed to provide input and calibration data for the hydrodynamic model of Jakolof Bay. Oceanographic parameters measured included current speed and direction, tide height, temperature, and salinity. Atmospheric parameters measured consisted of wind and barometric pressure. Measurements were conducted during April (reconnaissance survey) and during the main experiment period in July.

2.4.2.1 Field Methods

Reconnaissance Survey

During the reconnaissance survey currents were measured with drift sticks. Groups of 6 to 8 drift sticks (2.5-cm by 10-cm by 120-cm boards with a weight on the bottom and a flag on the top) were released along a transect across the bay. Positions were determined every 15 to 30 minutes by tracking each drift stick with a small boat equipped with a Motorola Mini-Ranger III. Estimates of the current speed along the bay and variability across the bay were determined from trajectory plots for each drifter.

Currents were recorded for a period of one month at four locations within Jakolof bay (Figure 2-3) using Aanderaa RCM-4 current meters. The meters were configured to measure current speed and direction, water temperature, and conductivity at five minute intervals. A pair of meters, one near surface and another near bottom, were deployed at stations 1 and 2. One meter was deployed near the bottom at stations 3 and 4. During mid-May the meter at station 1 was redeployed for an additional month after discovering that the mooring had moved from its initial location. At times of extremely low tides, the meters at stations 3 and 4 came out of the water. Tide height was recorded by Aanderaa WLR-5 tide gages, which were mounted near the bottom at stations 1 and 2.

A dye tracking study was attempted in order to measure the along-bay and cross-channel dispersion rates of a Rhodamine dye in solution. This study failed, however, because of: an inadequate dye dispersion mechanism, an insufficient instrument capability to rapidly detect and record the narrow dye plume, and poor weather conditions during the field period.

Wind speed was measured with a hand held anemometer and wind direction was estimated visually.

Main Program

Parameters measured during the main experimental program in July were identical to those measured in April-May; however, sampling locations and patterns changed. Three Aanderaa RCM-4 current meters and one Aanderaa WLR-5 tide gage were deployed within a 1 km long study area in Jakolof Bay (Figure 2-3). Meters were mounted near the bottom at all stations and one meter was mounted near the surface at station 2. Tide height was measured at station 2. Wind speed and barometric pressure were measured by recording instruments located on a small island in the center of the study area (Figure 2-3). Wind speed was measured with an R.M. Young wind anemometer and data were recorded with a Campbell Scientific CR10 data logger. Barometric pressure was measured with a pressure sensor but the data from this instrument was inaccurate as a result of equipment malfunction.

Dye tracking studies were conducted in order to predict the distribution and dispersion of the projected hydrocarbon plume in Jakolof Bay. Rhodamine dye was released from the oil discharge diffuser (see Section 2.4.3) during an ebb tide and was tracked by a small boat equipped with a Turner Fluorometer and Mini-Ranger positioning system. Transects were conducted across and along the plume with the fluorometer intake hose placed at 4 m deep. Vertical profiles of the plume were also conducted periodically during each survey. Boat position and Turner fluorometer values were recorded manually once every 30 seconds. A Turner Designs data logger was also used to automatically record data at one-half second intervals; however, this instrument frequently did not operate correctly. Five dye surveys were attempted; however, usable data were obtained from only two surveys. Malfunctions of the automatic data recording system prohibited using data from the other surveys.

In order to determine the vertical density structure of Jakolof Bay during the fish tracking experiments, water temperature and conductivity were sampled at 12 sites located along three transects of the bay (Figure 2-3). Vertical profiles of the water properties were measured at one meter depth intervals from the surface to bottom. The measurements were made using an Aanderaa RCM-4 current meter without vane and station positioning was determined with a Mini-Ranger. This sampling scheme was followed during the second and third pairs of experiments. During the first pair of experiments, vertical profiles were only performed near the hydrocarbon discharge diffuser.

2.4.2.2 Data Processing

April and July field measurements were processed in a similar manner as follows:

1. All Mini-Ranger data were scanned for obviously erroneous points and those points were eliminated, or corrections made if surrounding data permitted interpolation.

2. Positions of all sampling stations and all drifter trajectories were plotted and checked against field maps.

3. Aanderaa current meter recordings were transferred from magnetic tape to disk using an Aanderaa tape reader. The NOAA supplied meter calibration equations were utilized to transpose the recorded Aanderaa units to actual current speed and direction, temperature, conductivity, and pressure readings. Salinity and density were then calculated using a standard computation routine obtained from the University of Washington. Time series plots of each recorded parameter were plotted and obviously bad data points, as well as pre- and post-deployment recordings, were removed. All suspicious data points (e.g., when the current meter at station 1 moved during April or periods when a meter was out of the water) were removed from the data set. In some cases, it also appears that some meters did not rotate freely during their deployment. In these cases, the data were not removed because the current speed appears accurate; however, the directional data are questionable.

4. Time series of wind speed and direction were plotted and edited for bad data.

5. Water property measurements were used to compute the salinity and density of the water. Vertical profiles of salinity were prepared for selected stations along each transect.

6. Dye concentrations were computed from the manually recorded Turner fluorometer voltage outputs, which were based on daily calibrations of the instrument. The calibration curve derived from these tests is shown in Figure 2-4. Measured concentrations of the dye along each survey transect were plotted and contoured.

2.4.3 Diffuser Design

A submerged diffuser was used to introduce the hydrocarbon solution into the water column with the objective of creating a plume of sufficient size and concentration that would intercept and potentially affect salmon migrating through Jakolof Bay. A hydrocarbon plume 10 to 30 m wide and 100 to 150 m long with a concentration of 10 ppb was assumed sufficient given the uncertainties involved (e.g., salmon migratory route, swimming speed, and plume dispersion). Initial calculations indicated that a multi-port diffuser located on the sea bed would be best suited to meet the design criteria. The results of the reconnaissance survey were used in the near-field plume model to develop the final diffuser design.

2.4.3.1 Results of Reconnaissance Survey

Measurements of currents and density structure taken during the reconnaissance survey were used to finalize the design of the diffuser system. The current meters located near the proposed diffuser site (i.e., April stations 2 and 3, Figure 2-3), recorded maximum currents of 0.38 m/s (0.74 knots) and 0.10 m/s (0.19 knots) during the spring tide and neap tide ebb flows, respectively. Water depths at these tides and a typical density profile are shown in Table 2-1.

Table 2-1: Diffuser Operating Conditions

Tide Class	Maximum Current(m/s)	Minimum Depth(m)	Maximum Depth(m)
Spring	0.38	1	8.5
Neap	0.10	3	6.7

Depth (m)	Temperature (Deg C)	Salinity (ppt)
0.0	5.43	28.1
1.0	4.88	30.5
2.0	4.66	31.0
3.0	4.63	31.1

2.4.3.2 Diffuser Parameters

Hydrocarbon dispersion (mixing) in the water is a function of the initial discharge velocity (momentum), the ambient currents, the vertical stratification, and the relative density (buoyancy) of the discharge and the receiving waters. The greater the initial velocity and mass discharged, the further the plume will penetrate into density stratified water. However, the energy required to obtain a particular velocity is proportional to the square of the velocity, so the horsepower of the pump required rapidly increases at higher discharge velocities. Strong density stratification suppresses mixing while strong currents generally enhance mixing.

The variables considered in the diffuser design included the following:

- Length and diameter of diffuser pipe
- Number, size, and spacing of ports
- Angle of the ports relative to the current
- Diffuser exit velocity and hence pumping rate
- Water depth and current velocity
  - Intake water density (depth of intake)
  - Water column density profile

Considering hydrocarbon solubility led to an additional requirement of approximately 400 dilutions in the zone of initial mixing. Approximately 75 runs of the plume models were made in optimizing the diffuser design for the wide range of possible oceanographic operating conditions.

The final design of the diffuser system as built is shown in Figure 2-5. Intake water from approximately 1 m below the surface (to avoid fresh water from Jakolof Creek) was mixed with the hydrocarbon solution using a vacuum inlet and was pumped into the diffuser with an 8 horsepower pump. Hydrocarbon injection rate was regulated with a metering valve to produce an exit concentration of approximately 20 mg/L of the hydrocarbon solution. The diffuser consists of a 10 m long by 7.63 cm (3 inch) diameter pipe, which was oriented perpendicular to the current flow (cross bay). Discharge is through eleven 1.9 cm (3/4 inch) diameter ports at 1 m centers facing vertically upwards. The pump can achieve a flow rate of 757 to 946 L/min resulting in exit velocities of 5.0 to 5.5 m/s. Under most flow conditions the individual port plumes merge within 5 to 10 m of the diffuser to form an initial plume approximately 12 to 15 m wide and 2 to 3 m deep.

2.5 HYDROCARBON COMPONENTS

2.5.1 Hydrocarbon Stock Solution

2.5.1.1 Rationale for Using Hydrocarbon Cocktail

Experiments were conducted with a hydrocarbon solution "cocktail" that was similar in composition to the WSF of Prudhoe Bay crude oil. This cocktail was used instead of WSF because it provided a test solution with a known chemical composition and concentration that could consistently be replicated for each treatment. WSF produced by batch equilibration is not stable and can vary in concentration. Therefore, the WSF could not be prepared in advance of the field study. The hydrocarbon cocktail could be prepared in advance and could be stored indefinitely. The large volumes of WSF required to create a target concentration of 10 ppb in the far-field plume (see Section 2.4.3 Diffuser Design) was logistically not possible for this study. During the field experiments, 20 ml/min of cocktail added to a water flow of approximately 1000 L/min resulted in a concentration of 20 ppm in the diffuser discharge. If WSF were used, its preparation could be achieved either by batch equilibration of crude oil with water (Nakatani et al. 1985), which yields about 20 ppm WSF/L of water, or by use of continuous-flow devices (Moles et al. 1985), which yields about 2-3 ppm WSF/L of water. The concentration of WSF at equilibrium with sea water is about 20 ppm, or 0.02 ml of WSF/L of sea water. This equilibrium concentration could have been produced with a crude oil to water ratio of 1:100. To produce 20 ml/min of pure WSF, a flow of 1,000 L/min of water in equilibrium with 10 L of crude oil would have been needed. During a 3-hour hydrocarbon release, the volume of water and the volume of crude oil would have been 1.8×10^5 L and 1,800 L, respectively. On the other hand, if a continuous-flow device operating at 3 ppm (or 15% of equilibrium) were used, the volume of crude oil per experiment would have been 12,000 L and the rate of pumping water to the diffuser

would have been 6,666 L/min. The elaborate logistics needed to set up extraction facilities to produce this much WSF in the field and to dispose of the waste crude oil were beyond the capabilities of this study. Additional permitting requirements for this work would likely have postponed the research in 1988.

2.5.1.2 Composition of Hydrocarbon Cocktail

The WSF of crude oil is defined as a single phase, homogeneous mixture of hydrocarbons passed through a 0.45-*um* filter to eliminate colloidal dispersions and oil-in-water emulsions (National Research Council 1985). A water-soluble fraction produced in the laboratory is an artificial mixture and cannot be used to simulate precisely the conditions of hydrocarbon composition and concentration that occur when oil is spilled in the marine environment (National Research Council 1985). Equilibration conditions in the real world are quite different from the laboratory conditions under which the WSF is produced. The WSF produced in the laboratory represents a compromise, a means of generating a highly reproducible and relatively stable oil-in-water mixture.

The WSFs of crude oil prepared and used by different investigators do not necessarily follow the above definition and may differ widely in composition of hydrocarbons. This may be partly due to instability of WSF under nonequilibrium conditions and partly due to analytical difficulties in measuring the highly volatile components of the WSF. For these reasons, only the nonvolatile components of WSF, mainly aromatics and long chain aliphatics, are usually referred to as the major components of the WSF. For example, Pearson et al. (1987) prepared WSF by equilibrating Alaskan North Slope crude oil with artificial pond water. This WSF was composed of 97% monoaromatic and 3% polyaromatic hydrocarbons. Moles et al. (1985) extracted WSF with a flow-through device and reported that 96.5% of the measured hydrocarbons were monoaromatics (i.e., benzene, toluene, and xylenes) and 3.5% were polyaromatics. The National Research Council (1985) reported the WSF composition of five reference oils as containing 94 to 99% monoaromatics, 1 to 4% di- and tri-aromatics, and 0.4 to 1.9% n-paraffins (C_{12} to C_{24}). Light n-paraffins and cycloparaffins (C_1 to C_{10}) are usually not measured in the WSF because of their high volatility, although these compounds can constitute a large proportion of the WSF.

The composition of the cocktail used in this study (Table 2-2) was made as close as possible to the composition of WSF of Prudhoe Bay crude oil, but differed widely from the WSF reported above. Research at the University of Washington (Nakatani et al. 1985) found the WSF of Prudhoe Bay Crude Oil was composed of 54.9% aromatics, 6.8% cycloalkanes, and 38.2% alkanes. These results indicate a much lower proportion of aromatics than was reported by other analyses. This discrepancy between analyses is thought to be due to differences in analytical measurement technique. The former analyses most likely exclude the volatile components of the WSF.

Table 2-2. Composition of the hydrocarbon (cocktail) mixture used compared with the water-soluble fraction (WSF) of Prudhoe Bay crude oil.

Hydrocarbon	WSF[a] (% Weight)	Cocktail Mixture (ml)	(g)	(% Weight)
Methane	0.87	--	--	--
Ethane	7.33	--	--	--
Propane	14.45	--	--	--
Isobutane	2.12	--	--	--
n-Butane	8.02	--	--	--
Isopentane	1.71	750	470	15.8
n-Pentane	2.27	930	580	19.5
2,2-Dimethylbutane	0.03	--	--	--
Cyclopentane + 2-methylpentane	1.50	64	42	1.4
3-Methylpentane	0.24	10	7	0.2
n-Hexane	0.54	22	15	0.5
Methylcyclopentane	1.23	--	--	--
Benzene	24.70	844	741	24.9
Cyclohexane	2.24	86	67	2.3
n-Heptane	0.64	56	38	1.3
Methylcyclohexane	0.89	58	45	1.5
Toluene	17.83	617	535	18.0
Octanes or cycloheptanes	0.21	--	--	--
Octanes or cycloheptanes	0.20	--	--	--
Octanes or cycloheptanes	0.36	38[b]	33	1.1
Octanes or cycloteptanes	0.25	--	--	--
Ethylbenzene	1.23	128	111	3.7
m-, p-Xylene	4.59	250[c]	217	7.3
o-Xylene	2.78[c]	--	--	--
Isopropylbenzene	0.39	51	45	
c3 Benzenes (methylbenzenes)	1.11	--	--	--
o-Methylethylbenzene	0.41	--	--	--
1,2,4-Trimethylbenzene	0.73	--	--	--
1,2,3-Trimethylbenzene	0.27	--	--	--
Naphthalene(s)	0.87	26 g	26	0.9
% Total alkanes	38.21	--	--	37.3
% Total cycloalkanes	6.88	--	--	6.3
% Total aromatics	54.90	--	--	56.3

[a] From Nakatani et al. 1985.
[b] Normal octane.
[b] xylenes.

A mixture of hydrocarbons in approximately the same proportions as are present in the WSF of Prudhoe Bay crude oil (Table 2-2) was prepared. Hydrocarbons that were difficult to add to the mixture under normal conditions (e.g., gaseous hydrocarbons, methane, ethane, propane, and butane) and hydrocarbons that were hard to obtain (e.g., 2,2-dimethylbutane, methylcyclopentane, and methylbenzenes) were omitted from the mixture. Hydrocarbons similar to those that were omitted were added to the mixture in order to simulate as closely as possible the dissolved hydrocarbons in equilibrium with the WSF of Prudhoe Bay crude oil. The make-up hydrocarbons were usually in the same class of hydrocarbons immediately higher or lower in carbon number. The largest additions were isopentane and n-pentane, which replaced the gaseous hydrocarbons that were difficult to handle and include in the mixture.

2.5.2 Water Sampling and Hydrocarbon Analysis

2.5.2.1 Sample Collection

Water samples were collected from five locations along Jakolof Bay (Figure 2-6) during the April reconnaissance survey and again prior to the July study for background measurements of hydrocarbons. During the tracking experiments samples were collected at varying depths at locations both up- and down-bay from the diffuser (Figure 2-6).

Water samples were collected by means of a small 12-volt electric pump. A Tygon intake hose was lowered to the sampling depth and the pump was run for a few minutes to rinse the pump and the hose. Sample containers were also rinsed several times with water from the pump prior to the collection of a sample. The boat was kept on station by means of a Miniranger.

Water samples were collected from the intertidal area by hand. A sample bottle capped with aluminum foil was submerged upside down after the surface microlayer was pushed aside to avoid contamination. While submerged, the bottle was turned right side up and filled under the surface.

Water samples for analysis of C_1 to C_{10} hydrocarbons were collected in 500-ml crown-cap bottles. The bottles were pre-cleaned in the laboratory by washing with detergent and hot water, rinsing with dichloromethane (CH_2 to Cl_2), and drying at 200°C. The bottles were capped with aluminum foil and boxed for shipment to the field station. In the field, the bottles were uncapped, rinsed with the water to be sampled, and then completely filled with water to avoid any head-space. Samples were preserved by adding 1 ml of saturated mercuric chloride ($HgCl_2$) and capped. These samples were returned to Seattle for analysis by gas chromatography (GC) using the multiple phase equilibrium technique.

Water samples for hydrocarbon extraction were collected in 20-L glass carboy bottles. The bottles were cleaned at the field station with detergent and sea water, and rinsed with dichloromethane. After collection, these samples were returned to the field station laboratory for extraction and analysis.

2.5.2.2 Hydrocarbon Measurement

Gas Equilibration and GC Analysis

Water-soluble volatile hydrocarbons (C_1 to C_{10}) were measured by GC using a multiple-phase equilibrium technique (McAuliffe 1969, 1971). A 25-ml water sample was drawn into a glass hypodermic syringe from the sample bottle under a helium atmosphere. An equal volume of helium was added and the syringe valve was closed. To establish equilibrium between gas and aqueous phases, the syringe was shaken vigorously for 5 minutes using a shaker. Twenty milliliters of the gas phase was then injected through the sample loop of the GC, and a measured volume was introduced for analysis. Materials, chromatograph, integrator, and calibration procedures are described by McAuliffe (1980).

The total concentration of hydrocarbons found in the water samples was computed by summation of concentrations of each component, minus the C_1 to C_4 hydrocarbons (i.e., methane, ethane, propane, and butane). These compounds were not added to the cocktail, and some of them, especially methane, are produced naturally in the sediment and released to the water column. The total hydrocarbon concentration is a measure of only those hydrocarbons found in the cocktail.

The detection limits of individual components of the cocktail were obtained by successive dilution of a concentrated solution of the cocktail in water (about 76 ppm) until the hydrocarbon in question was no longer detectable (Appendix A). For example, benzene in the concentrated solution was 45.7 ppm; after 20,000 times dilution a concentration of 0.55 ppb was considered the practical detection limit of benzene in the cocktail (Appendix A).

Solvent Extraction and GC Analysis

A GC setup for the analysis of C_{12} to C_{24} n-paraffin hydrocarbons was located at the NOAA Kasitsna Bay Laboratory. The use of this GC was not planned for this study because it did not have the necessary setup for analyzing the volatile hydrocarbons in the cocktail. However, it was used as an emergency measure to evaluate the effects of an accidental oil spill in Jakolof Bay, which occurred just prior to the study (see Section 2.2).

The methodology and the results of the solvent extraction analysis are presented in Appendix B. A more complete description of the analytical procedure and an evaluation of the effects of the oil spill on water quality are given by Payne et al. (1988).

2.6 SALMON TAGGING AND TRACKING

2.6.1 Test Fish And Transmitter Specifications

Adult pink salmon were obtained from the intertidal area at the mouth of Jakolof Creek (Figure 2-2) one to two days prior to each pair of tracking experiments (i.e., control/treatment). Salmon were caught with a 45-m long beach seine during either a low or a high slack tide. Fish were transported to the holding pens (two 3-m x 3-m x 1.5-m deep floating net pens) in several 240-L tanks.

The size of pink salmon used in all the tracking experiments averaged 50 cm and ranged from 41 to 60 cm (Appendix C). The male to female sex ratio for all test fish was 56:44. Sex ratios of each test group were not similar among the tracking experiments (see Appendix C).

Sonic transmitters were attached to the test fish approximately 12 hours before each tracking experiment. Test fish were anesthetized with tricaine methanesulfonate (MS-222) and an external transmitter was attached to the fish beside the dorsal fin. The tag was held in place by two nickel pins that were pushed through the muscle of the fish and the ends were twisted down onto a plastic plate (Petersen disc type) on the opposite side of the fish. The tagging procedure did not injure the fish and did not have any noticeable effects on swimming behavior. Tracking experiments were initiated by allowing the fish to escape through a removable panel on the side of the floating net pen.

Each sonic tag had an individual identification code and pressure sensor. The pressure sensor had a depth precision of ±15 cm. Both the identification code and the pressure sensor information were transmitted as two 8-bit codes by a sonic carrier at frequencies ranging 41 to 45 kilohertz and 71 to 76 kilohertz. Tag size was 59.4 mm long by 12.2 mm in diameter and weighed 15.8 g in air.

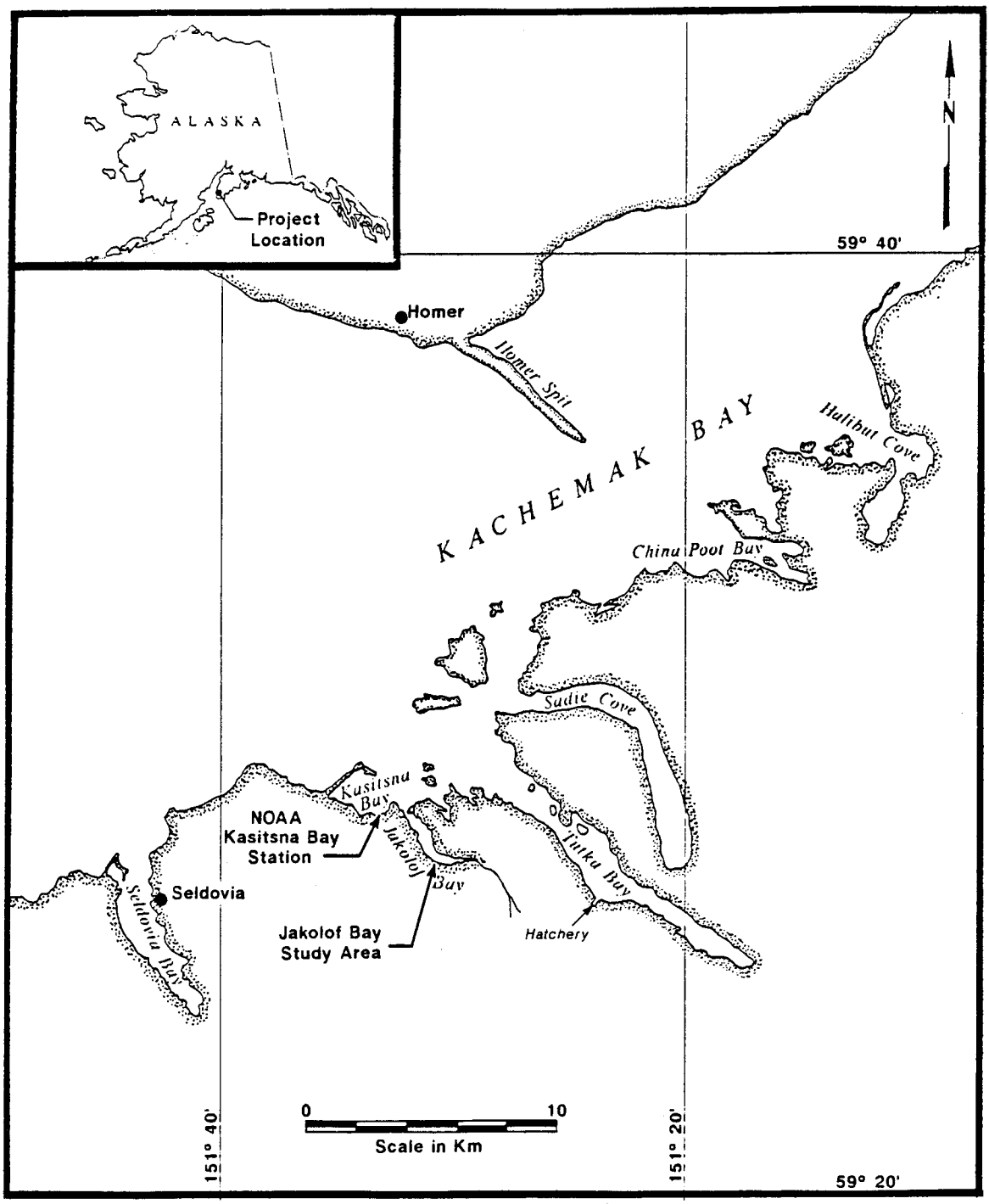
2.6.2 Fish Tracking System

Fish positions were determined by measurements of signal time differences received by a fixed array of tuned hydrophones. Nine omnidirectional hydrophones placed 1 m off the bottom were located over a 1-km reach of Jakolof Bay (Figure 2-2). Each hydrophone was connected by coaxial cable to a sonic receiver station located on a small island at the edge of the hydrophone array. Output from the receiver was recorded on a 14-track recorder, which included time and voice logs. Following the field experiments the data was played back through an analog to digital converter, which was connected to a CRT plotter and a computer. Fish identification number and depth were determined from the plotter. A computer program was used to determine the time difference between time zero (i.e., first hydrophone to receive a tag signal) and delayed time arrivals from a minimum of two other hydrophones. This data was fed into a navigation program, which determined fish position (rectangular coordinates x and y) by solving for the intersection of two or more hyperbolas. Fish positions were determined at time intervals ranging from 0.5 to >10.0 min. Shorter intervals (i.e., 0.5 or 1.0 minutes) were used when the fish were moving fast and longer intervals were used when the fish were moving slow or were inactive.

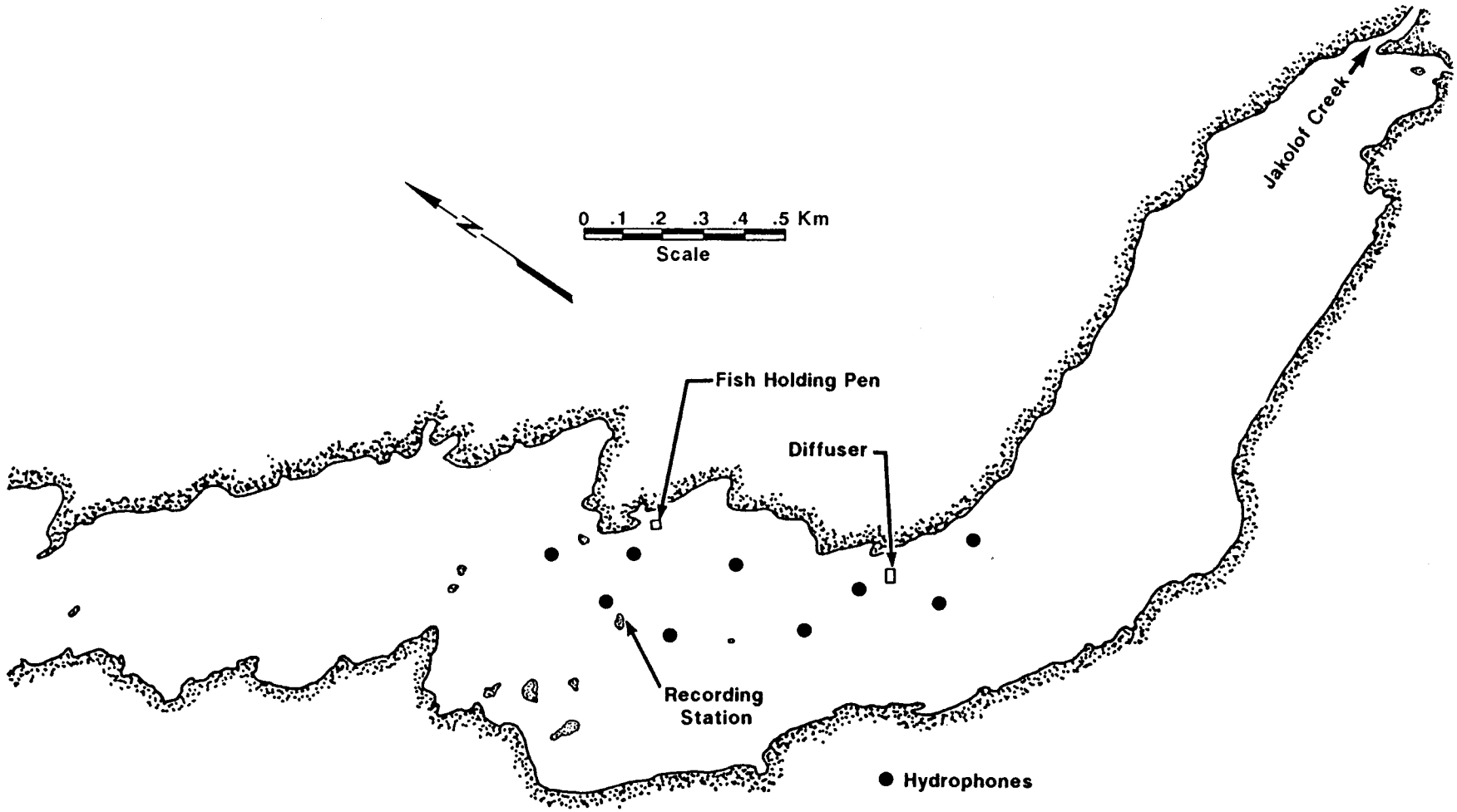
2.6.3 Data Analysis

Movement patterns of pink salmon were determined by individual plots of: fish horizontal position at selected time increments, fish depth versus time, and fish ground speed versus time. Ground speed was computed from the horizontal distance between adjacent fish positions and the time interval. All plots were created from the fish position and time data (Appendix D), which were generated from the fish tracking system. Fish behavior during exposure to the hydrocarbon

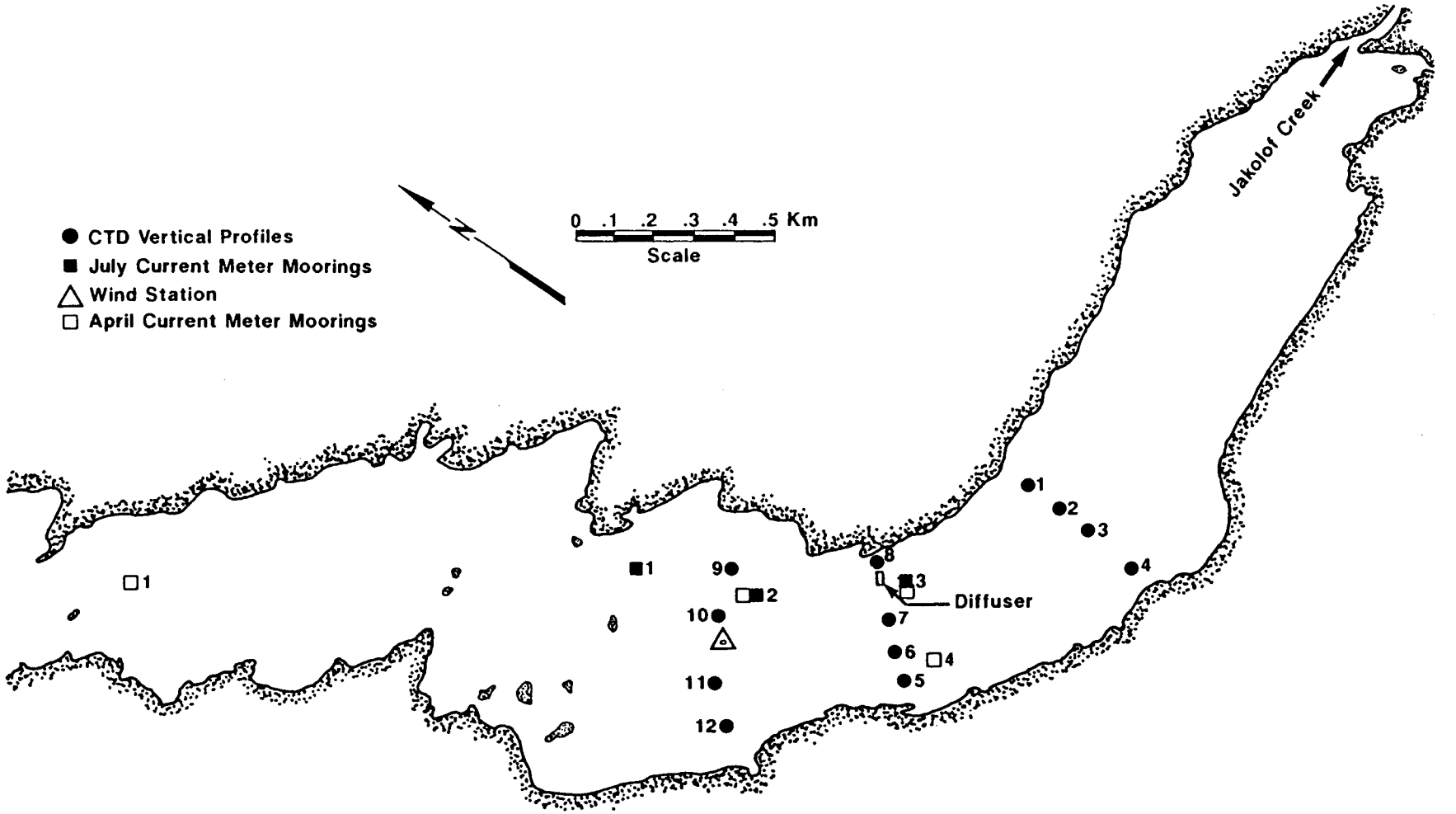
plume was determined from plots of fish horizontal position superimposed on contour plots of the modeled hydrocarbon plume at selected time increments. The duration of fish exposure and the hydrocarbon concentration during exposure were determined from the integration of the fish position data with the hydrocarbon concentration data. The latter data were derived from the output of the plume model. Tests of differences in fish depth, duration-of-return period, and fish speed were performed by the Analysis of Variance procedure.



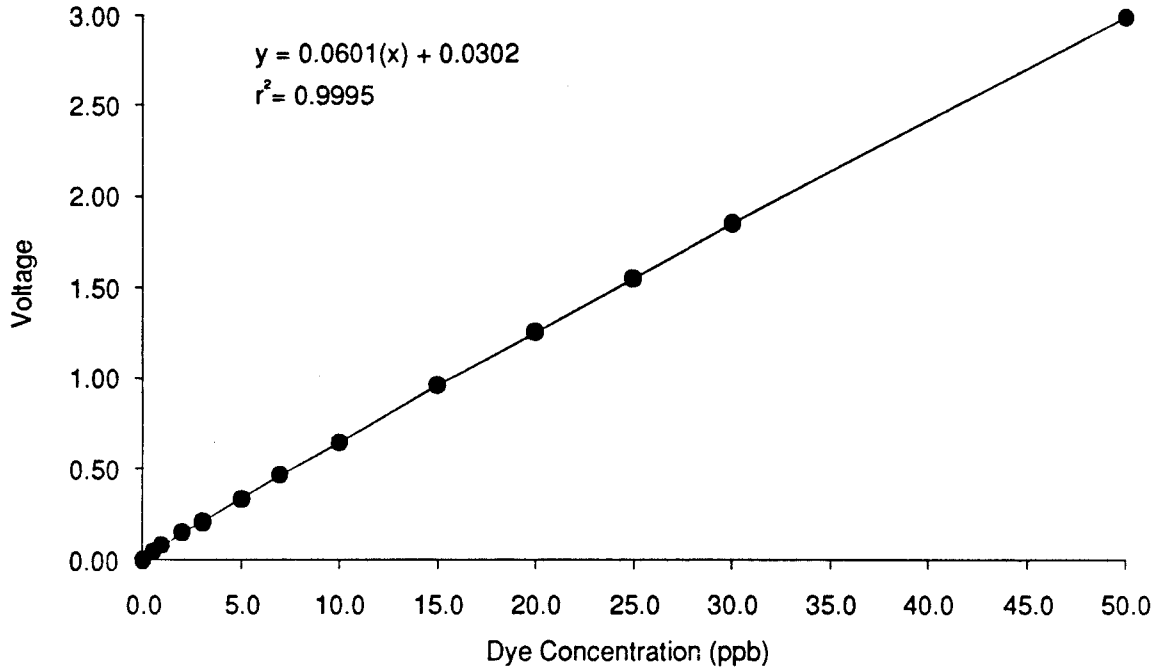
Vicinity Map of Kachemak Bay Showing Location of Jakolof Bay Study Area
Figure 2-1



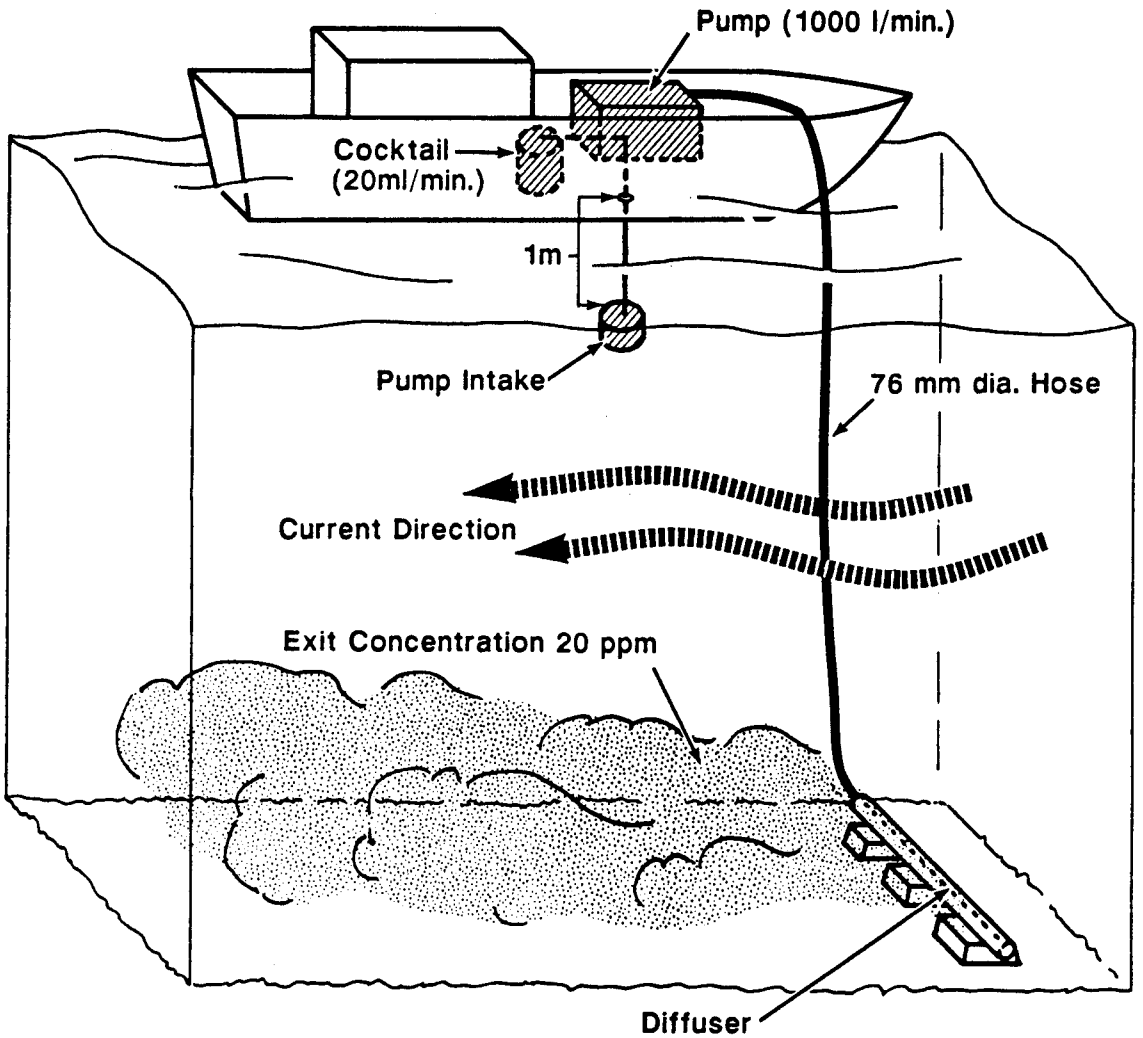
Fish Holding and Fish Tracking Stations in Jakolof Bay
Figure 2-2



Oceanography and Water Property Stations in Jakolof Bay
Figure 2-3

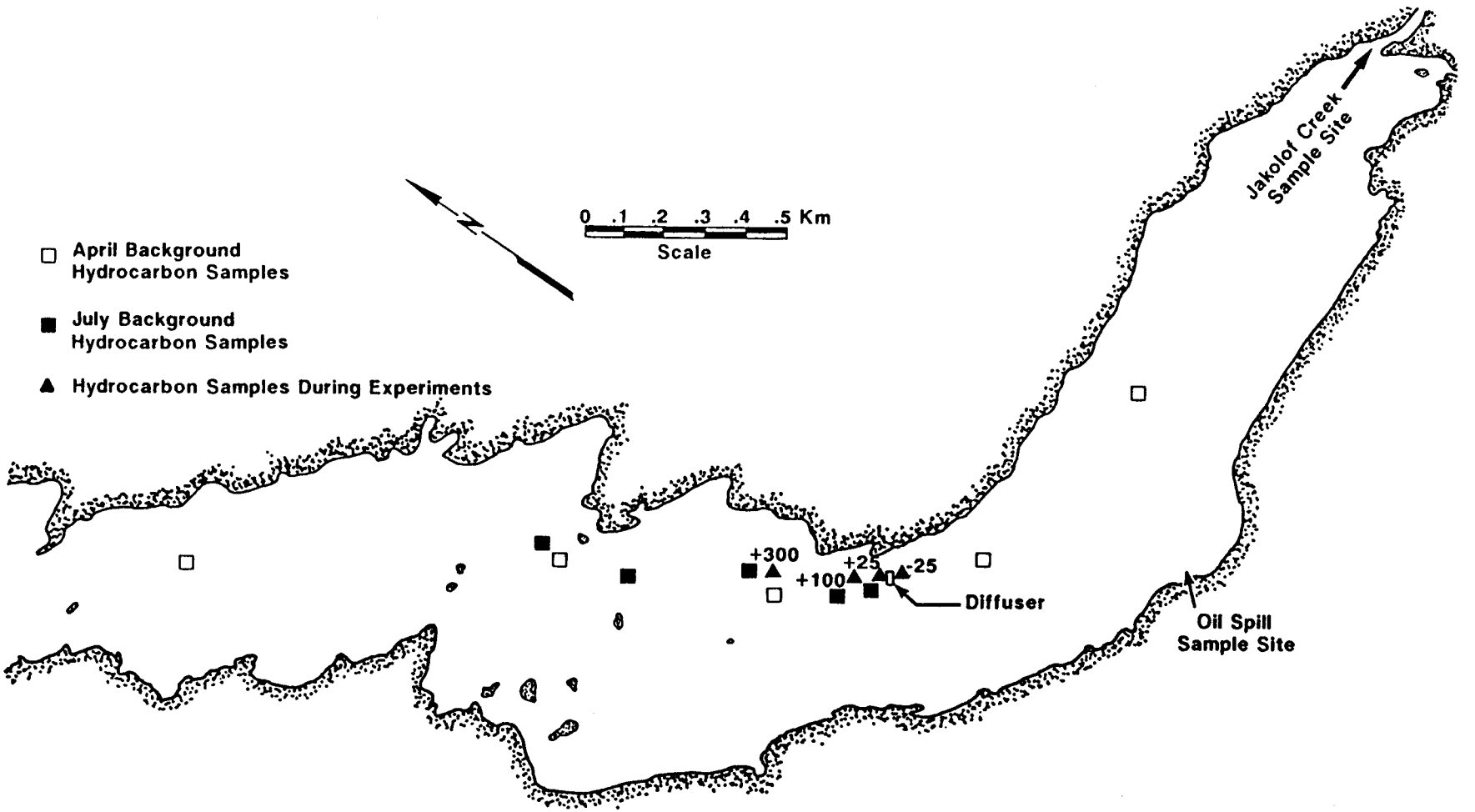


Regression of Fluorometer Voltage and Dye Concentration
Figure 2-4



Length : 10 m
Inside Diameter : 76 mm
Hole Spacing : 1 m
Hole Size : 19 mm

Hydrocarbon Injection System
Figure 2-5



Hydrocarbon Sample Stations in Jakolof Bay
Figure 2-6

3. RESULTS

3.1 OCEANOGRAPHIC CONDITIONS

3.1.1 General Oceanography

Jakolof Bay can be characterized as a very dynamic oceanographic environment due to the combined influences of large semi-diurnal tides and shallow bathymetry. Tidal ranges of up to 8 m are encountered. The bay is approximately 3 km long and 0.5 km wide with average mllw depths less than 3 m over the upper half of the bay and less than 6 m elsewhere. The shallow depths and large tides yield tidal currents of up to 2 knots near the mouth of the bay. Currents are generally less than 3/4 knots in the upper half of the bay. The very shallow depths at the head of the bay result in extensive areas of exposed muds flats during low tides.

A large tidal prism and strong currents generally result in well-mixed conditions and small density gradients. The presence of fresh water from Jakolof Creek can be seen in the upper meter of water, particularly during neap ebb tides. The presence of a fresh water layer is most noticeable in the center of the bay. Radiant heating of surface water contributes to density gradients in the upper meter, particularly in summer conditions.

Winds in the summertime are typified by down slope winds caused by the glaciers to the south east of the bay. These winds flow north-westerly along the axis of the bay and reach speeds of 15 to 20 knots. Conducting tracking experiments was impractical during the latter conditions.

Currents in the bay are principally bidirectional in response to tidal forcing and the long, narrow shape of the bay. Some eddies occur behind the islands on both flood and ebb tides and during extreme neap conditions. A comparison of the tides and currents recorded near the mouth of the bay during the reconnaissance survey is shown in Figure 3-1. As can be seen the currents are strongly bimodal. The weaker outgoing velocities can be attributed to the larger cross-sectional area during flood tide and hence lower velocities during ebb conditions.

3.1.2 Oceanographic Conditions During Experiments

Tide levels during the study period (July 11 to 20th) and during each experiment (bold lines on plot) are shown in Figure 3-2. All experiments took place on ebb tides with the treatment experiments following the control experiments on the same phase of the tide on the following day. A minimum period between treatments of 2.5 days (i.e., 5 tidal cycles) was scheduled to allow flushing of the hydrocarbon solution from the previous experiment. During spring tides it was calculated that two to three tidal cycles were required to flush the oil contaminated waters, while during neap tides the required flushing time increased to five to six cycles.

The tides and currents recorded 1.5 m from the bottom at station 3 near the diffuser site are shown in Figure 3-3. Maximum ebb currents during the three treatment experiments were 0.12m/s, 0.07m/s, and 0.19m/s, respectively. Figure 3-4 shows the water temperature and

salinity recorded from the same meter array. Temperature changes of 1°C and salinity changes of over 1 ppt occur during the tidal cycle. The consistent large spikes in salinity are attributed to the influence of fresh water from Jakolof Creek.

3.2 HYDROCARBON CONCENTRATIONS

3.2.1 Background Conditions

Water samples were collected prior to experimental discharge of the cocktail in order to evaluate the background concentration of hydrocarbons in Jakolof Bay. The sum of individual hydrocarbons C_5 to C_{10} in the samples is given in Table 3-1. Background concentrations in April and July ranged 0.00 to 1.27 ppb and 0.52 to 1.66 ppb, respectively. Toluene was the main component of all the samples except sample No. 3, which contained mainly octanes/cycloheptanes (see Appendix E). Concentrations of hydrocarbons in samples taken during control no. 1 (nos. 11 and 12) were 2.20 ppb and 1.02 ppb (Table 3-1). The hydrocarbon components of sample no. 11 were benzene and toluene, whereas sample no. 12 contained only toluene.

The presence of toluene in the background water samples and the increase in total hydrocarbon concentration between April and May suggests the background hydrocarbons may be coming from anthropogenic sources. In order to answer this question, an analysis of the hydrocarbon composition of gasoline at various dilutions was performed in the laboratory. The results showed that a minute amount of gasoline can contaminate a large volume of water with a number of the cocktail hydrocarbons including benzene, toluene, and xylenes (Appendix F). At extreme dilutions, 770 times the original volume, only benzene, toluene, and m-, p-xylene were measurable. Further dilutions would have probably reduced the number of detectable hydrocarbons to only one or two (i.e., benzene and toluene).

Outboard motors discharge varying amounts of unburned gasoline into water, which is visually observable in calm water behind a boat. Jakolof Bay receives a fair amount of boat traffic during the summer from sport fishermen an recreation boaters. Toluene, which was the most persistent hydrocarbon in the gasoline analysis, was present in all of the July samples and in one of the April samples. For this reason, it is believed that the main contributors to the general background concentration of hydrocarbons in the water column are due to unburned fuel from boat exhaust.

Table 3-1. Total hydrocarbon concentration in Jakolof Bay water samples during background, control, and treatment conditions. Concentrations are the sum of individual cocktail hydrocarbons less C_1-C_4 in ug/L (ppb).

Sample Concentration No.	Experiment	Date	(ADT)[a]	Elapsed Time (min)	time[b] location	Sample (m)	Depth (ppb)
1	Background	4/12/88	09:20	--	c	2	1.10
2	"	"	09:40	--	c	3	0.16
3	"	"	09:55	--	c	3	1.27
4	"	"	10:05	--	c	3	0.00
5	"	"	10:25	--	c	2	0.00
6	Background	7/14/88	09:42	--	c	1	0.77
7	"	"	09:45	--	c	1	1.66
8	"	"	09:45	--	c	1	0.52
9	"	"	09:50	--	c	1	0.73
10	"	"	10:00	--	c	1	0.67
11	Control 1	7/19/88	20:10	--	c	3	2.20
12	"	"	21:00	--	c	3	1.02
13	Treatment 1	7/20/88	21:30	0	-25*e*	4	0.00
14	"	"	21:30	0	-25	1	1.32
15	"	"	21:55	+25	+25	4	57.02
16	"	"	21:55	+25	+25	1	1.59
17	"	"	22:15	+45	+100	4	3.16
18	"	"	22:15	+45	+100	2	2.84
19	"	"	22:35	+65	-25	4	0.75
20	"	"	22:35	+65	-25	1	d
21	"	"	22:55	+85	+100	4	14.93
22	"	"	22.55	+85	+100	2	1.20
23	"	"	23:15	+105	+300	4	43.78
24	"	"	23:15	+105	+300	2	1.53
25	"	"	23:15	+105	+100L[f]	4	d
26	"	"	23:15	+105	+100L	2	8.58
27(1)	Background	7/21/88	12:27	--	c	0.3	0.00

--CONTINUED--

[a] Alaska Daylight Savings Times.
[b] Elapsed time after start of diffuser pump.
[c] See Figure 2-6.
[d] Sample lost.
[e] Distance (m) upbay (-) or downbay (+) from the diffuser, see Figure 2-6.
[e] Sample from 25 to 50m lateral of station.

Table 3-1, Continued

Sample Concentration No.	Experiment	Date	(ADT)	Elapsed Time (min)	time[b] location	Sample (m)	Depth (ppb)
27(2)	Control 2	7/23/88	21:05	-25	-25	4	0.00
28	"	"	21:40	+10	+100	2	d
29	"	"	21:40	+10	+100	4	d
30	"	"	21:50	+20	-25	2	d
31	"	"	21:50	+20	-25	4	0.00
32	"	"	22:10	+40	+100	2	d
33	"	"	22:10	+40	+100	4	0.00
34	"	"	23:10	+60	+300	2	d
35	"	"	23:10	+60	+300	4	d
36	"	"	13:30	0	+100	2	0.96
37	"	"	13:30	0	+100	4	1.15
38	"	"	13:50	+20	-25	1	0.00
39	"	"	13:50	+20	-25	4	1.43
40	"	"	14:30	+40	+100	2	0.00
41	"	"	14:30	+40	+100	4	0.00
42	"	"	14:50	+60	+300	2	0.00
43	"	"	14:50	+60	+300	4	0.00
44	Treatment 2	7/25/88	13:30	0	-25	1	0.00
45	"	"	13:30	0	-25	4	1.01
46	"	"	14:15	+45	+25	2	0.00
47	"	"	14:15	+45	+25	4	64.91
48	"	"	15:00	+90	+100	2	2.52
49	"	"	15:00	+90	+100	4	0.97
50	"	"	15:20	+110	-25	1	2.35
51	"	"	15:20	+110	-25	4	0.67
52	"	"	15:40	+130	+100	2	2.01
53	"	"	15:40	+130	+100	4	0.48
54	"	"	16:00	+150	+300	2	0.81
55	"	"	16:00	+150	+300	4	0.92
56	"	"	15:00	+90	+100L	4	53.48
57	"	"	15:40	+130	100L	4	9.99
58	Background	7/27/88	15:00	--	c	0.3	49.49
59	"	"	15:00	--	c	0.3	30.10
60	Control 3	7/28/88	16:35	0	-25	1	0.00
61	"	"	16:35	0	-25	4	6.82
62	"	"	17:00	+25	+25	2	0.00
63	"	"	17:00	+25	+25	4	0.00
64	"	"	17:00	+25	+25	4	0.76
65	"	"	17:00	+25	+25	4	0.88
66	"	"	17:40	+40	+100	2	0.59
67	"	"	17:40	+40	+100	4	0.00
68	"	"	17:40	+40	+100	4	0.91
69	"	"	17:40	+40	+100	4	0.00
70	"	"	18:00	+60	+300	2	0.00
71	"	"	18:00	+60	+300	4	1.81

Table 3-1, Concluded

Sample Concentration No.	Experiment	Date	(ADT)	Elapsed Time (min)	time[b] location	Sample (m)	Depth (ppb)
72	Treatment 3	7/29/88	16:30	0	-25	1	0.98
73	"	"	16:30	0	-25	4	1.93
74	"	"	16:30	0	+25	4	1.50
75	"	"	16:30	0	+25	4	0.93
76	"	"	16:55	+25	+50	2	0.57
77	"	"	16:55	+25	+50	4	3.76
78	"	"	17:15	+45	+100	2	1.16
79	"	"	17:15	+45	+100	4	0.61
80	"	"	17:35	+65	-25	1	1.09
81	"	"	17:35	+65	-25	4	1.49
82	"	"	17:55	+85	+25	2	0.00
83	"	"	17:55	+85	+25	4	21.85
84	"	"	17:55	+85	+25	4	24.60
85	"	"	17:55	+85	+25	4	7.59
86	"	"	18:15	+105	+100	2	0.60
87	"	"	18:15	+105	+100	4	5.68
88	"	"	18:15	+105	+100	4	6.85
89	"	"	18:15	+105	+100	4	5.68
90	"	"	18:35	+125	+300	2	2.14
91	"	"	18:35	+125	+300	4	4.16
92	"	"	18:35	+125	+300	4	4.61
93	"	"	18:35	+125	+300	4	1.44

The issue of background hydrocarbons in Jakolof Bay waters was further complicated by an oil spill from a tug and barge operation in the area. The spill occurred on July 17 near the upper south side of the bay (Figure 2-6). In order to evaluate the effects of this spill on water quality, a number of samples were collected on July 18 and 19 for background check, and on July 19 during control 1. These samples were processed by solvent extraction and subsequent GC analysis (Appendix B). The concentration of cocktail hydrocarbons in these samples could not be quantified because they are volatilized and lost during the analysis (see Appendix B). However, based on qualitative comparison of chromatograms of these background samples with chromatograms of samples collected at the spill site, it was concluded that the contribution of the spill to background hydrocarbons was minimal, if anything at all. An investigation of the spill by Payne et al. (1988) found that dispersed oil droplets and dissolved components were present along shore at the spill site on July 18. But, samples collected at 2 m deep from near the diffuser on the same day indicated no evidence of dispersed oil. The low concentrations (i.e., 2.2 ppb) measured at 3 m deep during the control experiment on July 19 (Table 3-1), also indicates no significant subsurface contamination.

3.2.2 Conditions During Experimental Discharge

The concentration of hydrocarbons in all samples from the control experiments, except for one sample, ranged from 0.00 to 2.20 ppb (Table 3-1). Toluene was the only detectable hydrocarbon in all samples except for sample No. 11, which also contained benzene (Appendix F). The one exception, sample No. 61, contained 6.82 ppb of toluene. This large difference may be due to contamination, since this sample was taken up bay from the diffuser and was the only sample out of a total of 31 samples collected during the control runs to show a high concentration. The source of contamination may have been from the out board motor on the sample vessel. An analysis of variance test of hydrocarbon concentrations among the background samples and the control samples (i.e., samples 1 to 12, 27 to 43, and 60 to 71, Table 3-1) found no significant difference ($P = 0.41$) among sample periods (Appendix G). These results indicate that the treatment experiments and the oil spill did not increase the background hydrocarbon levels.

The concentration of total hydrocarbons in the treatment samples ranged from 0.00 to 64.91 ppb. The highest concentrations were measured from samples taken at 4 m deep at station +25 m. The concentrations at this station for treatments 1 and 2 were 57.02 and 64.91 ppb, respectively. During treatment 3, three deep water samples were collected at this station and the concentrations ranged from 7.59 to 24.60 ppb. In contrast, the highest concentration measured from samples taken near the surface (i.e., 1 to 2 m deep) was 2.84 ppb. Total hydrocarbon concentrations of the surface samples were generally lower than concentrations of the bottom samples. This indicates the hydrocarbon plume was not completely mixed from the surface to the bottom. Because of the limited number of samples collected during the experiment, it was not possible to detect if a concentration gradient was established downstream from the diffuser.

Toluene was the main or the only component detected in treatment samples with low hydrocarbon concentrations. In treatment samples with relatively high concentration, the main components were toluene and benzene, followed by n-pentane, isopentane, and xylenes. Occasionally, trace amounts of other cocktail hydrocarbons were observed in the samples.

During the course of treatment experiments, three additional background water samples (i.e., sample Nos. 27(1), 58, and 59) were collected from the mouth of Jakolof Creek. Sample No. 27(1), collected on July 21, showed 0.00 ppb hydrocarbon concentration, whereas sample Nos. 58 and 59, collected on July 27, contained 49.49 ppb and 30.10 ppb hydrocarbons, respectively. The large difference between sample No. 27(1) and sample Nos 58 and 59, which were collected 1 and 2 days following a treatment, respectively, suggests the latter samples were contaminated. The source of contamination may have been from the sample boat, which was anchored less than 10 m from the sampling site.

3.3 PLUME STUDIES

The finite-difference grid used in the far-field model studies is shown in Figure 3-5. The greatest grid resolution centers on the region of the diffuser. In order to minimize numerical dispersion and to reduce the amount of computer storage needed, the model grid was oriented

parallel to the long axis of Jakolof Bay (the grid axis is 56.56 degrees west of north). The grid resolution is finest in the region of the diffuser where cell sizes are 12.5 m long. Grid resolution increases to 100 m at the mouth of the bay and 200 m at the head of the bay. A total of 50 cells in the bay axis direction and 34 cells in the cross bay direction were used.

3.3.1 Model Calibration

Before the models were used in a predictive mode, they were each calibrated to known conditions in Jakolof Bay. The hydrodynamic model was calibrated using the current and tide data recorded during the reconnaissance survey. The water quality model was calibrated using the results of the rhodamine dye studies. Model calibration is required to confirm or obtain values for the empirical parameters used in the modeling. Specifically, these parameters are the friction coefficient in the hydrodynamic model and the dispersion coefficient in the water quality model. While typical values have been published in the literature, the range of such parameters is usually a few orders of magnitude. Calibration studies are therefore required to obtain the best fit of these parameters for the unique conditions in Jakolof Bay.

3.3.1.1 Hydrodynamic Model

During the initial calibration of the hydrodynamic model, runs were made using both current and tidal boundary conditions at the mouth of Jakolof Bay. The model grid initially only extended as far as the mllw line. Satisfactory calibration could not be achieved using the full range of friction coefficients from 0.1 to 0.001 and the predicted currents at current meter station 2 (Figure 2-3) were 50% below the recorded currents. The model grid was then extended to include the intertidal area at the head of the bay (see Figure 3-5), adding approximately 25% to the surface area of the model. This modification resulted in dramatic improvement to the hydrodynamic calibration and indicated the importance of the intertidal area in driving the currents at the head of the bay. Sensitivity studies indicated a friction coefficients of 0.007 gave the best calibrations.

A 20 second timestep was used in the simulations because sensitivity studies with 60, 30, 20 and 10 second timesteps indicated a 20 second timestep was required for the spring tide conditions. The high sensitivity of the model under these conditions is due to the rapid propagation of changes in water level in regions of shallow bathymetry and small cell sizes, and the reasonably complex topology.

A comparison of the predicted and measured currents near the mouth of the bay (i.e., station 1) under neap and spring tide conditions are shown in Figure 3-6. As can be seen, the predicted currents are very close to the measured currents except during the ebb tides. These high predictions are due to the change in cross-sectional area of the bay, which occurs during flooding and is not included in the model. While flooding could have been included, computational times are increased by an order of magnitude. The additional expense was not felt to be justified given the generally good calibration. The predicted and actual currents for station 2 are shown in Figure 3-7. The predicted and actual tides inside the bay are almost exact since tides at the mouth of the bay were used to drive the model. There is very little tidal phase shift within the 3-km length of Jakolof Bay.

3.3.1.2 Water Quality Model

The water quality model was calibrated using the results of a rhodamine dye study. Rhodamine dye at a concentration of 1.76 g/L (1.0 L of 20% dye in a 114 L bucket) was introduced into the diffuser at a rate of 1260 ml/min resulting in a discharge concentration of approximately 2345 ppb. A plot of the resulting plume, based on hand recorded data, is shown in Figure 3-8. Data collected by an auto-logger was not usable due an equipment malfunction.

In order to obtain a starting point for the numerical calibration of the water quality model an approximate value was obtained assuming a steady state two-dimensional Gaussian model for the centerline concentrations. The equation for the centerline equation was recast in the form;

$$c = K^{-0.5}(D)\, x$$

where;

c = centerline concentration,
K = constant including discharge rate,
D = dispersion coefficient,
x = downstream distance.

Fitting a one-parameter regression model to the centerline concentrations from Figure 3-8 yielded an approximate dispersion coefficient of 0.09 m^2/sec. This is a low value (Fischer et al. 1979) indicating smooth bottom conditions and hence low turbulence. This finding is consistent with subsurface (divers) and surface observations, which indicate Jakolof Bay has a smooth bottom with a covering of kelp, and the observed absence of surface boiling during the maximum ebb tides.

The water quality model was run using two orders of magnitude of dispersion coefficients approximately centered on the 0.09 value (0.1 to 0.001). A value of 0.001 gave the best fit in terms of the width of the plume; however, the predicted centerline concentrations near the diffuser were approximately 50% low. During the dye studies, it was noted that the plume consistently remained in the bottom 2 meters of water, which is the lower half of the water column. Also, the results of the hydrocarbon sampling indicated concentrations were greater near the bottom. To account for these observation, the discharge concentrations in the model were doubled causing the predicted width and concentrations to match the actual dimensions fairly well. The predicted concentrations are shown in Figure 3-9. Note, that the measured concentrations shown in Figure 3-8 were recorded over a period of two hours, which may explain the counter intuitive widening of the 10 ppb contour in that figure. Figure 3-9, on the other hand, is a snap-shot of the plume 1 hour into the simulation.

3.3.2 Model Estimates of Hydrocarbon Distribution Concentration

The far-field model was run to predict hydrocarbon concentrations for each of the three treatment experiments. Note, that the control experiments were conducted at the same phase of the tidal cycle as the treatment experiments, but on the previous day, in order to match the oceanographic conditions as closely as possible. Table 3-2 shows a comparison of the tidal ranges during the control and treatment experiments.

Table 3-2: Tidal Ranges During Experiments

Experiment	Date	Tides (m) High	Low	Range
Control 1	7/19/88	5.0	1.2	3.8
Treatment 1	7/20/88	4.9	1.3	3.6
Control 2	7/24/88	3.7	2.3	1.4
Treatment 2	7/25/88	4.0	2.2	1.8
Control 3	7/28/88	5.5	0.8	4.7
Treatment 3	7/29/88	5.8	0.4	5.4

Predictions of hydrocarbon concentration were made using the NOS tides for Seldovia as boundary conditions and the actual hydrocarbon release rates as recorded during the experiments (Table 3-3). The time and height differences in the tides between Seldovia and Jakolof Bay are negligible (less than 1 minute and 3 cm respectively).

Table 3-3. Seawater pumping rates and cocktail injection rates during treatment experiments.

Experiment	Date	Start Time (ADT)[a]	Stop Time (ADT)[a]	Pumping Rate (L/min)	Cocktail Injection rate (ml/min)
Treatment 1	7/20/88	21:29	23:52	946[b]	25
Treatment 2	7/25/88	13:30	17:12	946	30-40
Treatment 3	7/29/88	16:30	19:46	946	15-21

[a] Alaska Daylight Savings Time.

[b] At 23:13 the anchorline on the stern broke allowing the boat to swing, which caused the pumping rate to vary from 757 to 946 L/min during remainder of experiment.

3.3.2.1 Treatment 1

High slack tide, before the experiment on July 20, occurred at 19:28. Table 3-2 indicates the 3.6 m tidal range was representative of an intermediate or average tide. The diffuser was turned on two hours after high tide at 21:29 and discharged 25 ml/min of hydrocarbon cocktail into a seawater flow of 946 L/min until 23:52. Salmon were released from the holding pen approximately 2.75 hours after high tide and were tracked for approximately 1.75 hours (i.e., from 22:13 to 23:58).

A vector plot of the currents in the central portion of the bay 3.5 hours into the ebb tide is shown in Figure 3-10. Note the slight ebby in the inlet northwest of the diffuser and the reduction in flow velocity behind the islands. The predicted current speeds at the diffuser were within 5% of the measured currents. The maximum current at the diffuser site during the experiment (i.e., maximum ebb flow) was approximately 0.15 m/s.

The predicted plume position and hydrocarbon concentrations in the water column at half-hour intervals, starting 0.5 hours after the diffuser was turned on, are shown in Figure 3-11. Each figure shows the 10, 5, 1 and 0.5 ppb isolines. The 10 ppb contour defines the center of the plume and the 0.5 ppb contour the outer edge of the plume in each case. These concentrations assume a 0.0 ppb background concentration. Therefore, the actual concentration of C_1 to C_{10} hydrocarbons may be 1 to 2 ppb greater (see Section 3.2.1 for background levels) than the predicted concentrations depending on background hydrocarbon levels at the time of treatment. Predicted hydrocarbon concentrations less than 0.5 ppb are not identified because the level of error, depending on background levels, may range from 0 to 2 ppb.

3.3.2.2 Treatment 2

High slack tide before the treatment experiment on July 25 occurred at 13:03. Neap tide conditions occurred on this day with a tidal range of 1.8 m (Table 3-2). The diffuser was started 0.5 hours after high tide at 13:30 and discharged 30 to 40 ml/min of hydrocarbon cocktail into a seawater flow of 946 L/min until 17:12. The variable discharge rate was due to problems encountered with the vacuum feed to the pump. However, detailed notes of the pumping rate were recorded and used in the simulation. Salmon were released two hours after high tide and tracking occurred for approximately 2.25 hours (i.e., from 14:59 to 17:15).

The predicted plume position and concentrations at half-hour intervals, starting 0.5 hours after the diffuser was turned on, are shown in Figure 3-12. The slow growth of the plume is a result of the neap tide conditions. Maximum currents of 0.07 m/s at the diffuser during the ebb flow were considerably less than in treatment 1.

3.3.2.3 Treatment 3

The tidal range during treatment 3 (i.e., 5.4 m on July 29) was near the maximum range for Jakolof Bay. High slack tide before the treatment experiment occurred at 15:59. The diffuser was turned on 0.5 hours after high tide at 16:30 and discharged from 15 to 21 ml/min of

hydrocarbon cocktail into a seawater flow of 946 L/min until 19:46. The variable discharge rate was due to problems with a valve adjustment on the vacuum feed to the pump. Salmon were released 1.5 hours after high tide and tracking occurred for approximately 2.25 hours (i.e., from 17:33 to 19:46).

The predicted hydrocarbon concentrations during treatment 3 are shown in Figure 3-13. The rapid rate of plume expansion during this experiment is a result of the spring tide conditions and is 25% to 35% faster than during the neap tide conditions of treatment 2. The maximum current during the experiment at the diffuser site was 0.20 m/s. Note, that between 18:30 and 19:00 (Figure 3-13) the area within the 10 ppb isoline contracts, but the area within other isolines continues to grow. This reduction of the 10 ppb contour is due to the enhanced mixing and hence dispersion under high current conditions. The opposite effect can be seen in Treatment 2 under low flow conditions (Figure 3-12 at 15:30), where the area within the 10 ppb isoline makes up 50% of the total plume.

3.4 SALMON MOVEMENT BEHAVIOR

3.4.1 Movement Patterns During No-Discharge Conditions

All but one of the 38 pink salmon released during the three control experiments headed back toward the home stream. One fish from control 2 headed out of the study area immediately after release and was not identified during the remainder of the tracking period. The return route back toward the home stream was similar for all fish within an experiment but differed among experiments. Fish from control 1 all headed up bay immediately after release from the holding pen (e.g., Figure 3-14 and Appendix H, which show fish positions at specific times relative to the diffuser indicated by the 10 isoline). They generally moved along an arc shaped route that first headed south-southwest, turned southeast, and passed within 100 m of the diffuser. The return route for fish from control 2 was not as direct as fish from control 1. Control 2 fish headed across the bay in a westerly direction, at the center of the bay they turned rather sharply to the southeast, and headed up bay passing within 25 to 150 m of the diffuser (e.g., Figure 3-15 and Appendix H). Fish from control 3 returned toward the home stream along the most indirect route of the three experiments (e.g., Figure 3-16 and Appendix H). The return route was characterized by: movement up bay (south) for several hundred meters immediately after release, a sharp turn to the west followed by movement either across the bay or down bay, continued movement toward the west shore and eventually out of tracking range. After a period ranging 12 to 30 minutes, the fish returned to the center of the bay, turned sharply to the southeast, and headed up bay passing within 100 m and in some cases directly over the diffuser. Horizontal movement patterns from all three experiments were generally directed up bay against the ebb tide (positive rheotaxis) with short periods of movement either across or with the current (negative rheotaxis).

The duration-of-return from the time of release at the fish pen to the time of passing the diffuser was substantially different among the three experiments (Table 3-4). The return time for control 1 was the shortest (mean 26.4 minutes) and the return time for control 3 was the longest (mean 65.8 minutes).

Fish that moved toward the home stream exhibited two types of vertical movement patterns. Following an initial dive to 3 to 4 m, the fish moved up and down in the water column over a depth range from 2 to 4 m during their return to the home stream. The amplitude of this vertical movement, however, varied among and within the experiments. During control 1, most fish exhibited a small-amplitude (<0.5 m) vertical movement that continued for the entire return period (e.g., Figure 3-17). During controls 2 and 3, most fish initially exhibit several large-amplitude (1 to 2 m) vertical movements followed by smaller amplitude movements near the end of the return period (e.g., Figures 3-18 and 3-19). The occurrence of the small-amplitude versus the large-amplitude patterns appears to be related to the horizontal movements during the return toward the home stream. When the fish returned along a more direct route, during control 1, they only exhibit small-amplitude vertical movements. But, when the fish returned along a more indirect route, during controls 2 and 3, they exhibited both large- and small-amplitude vertical movements. Large-amplitude movements occurred at a higher frequency during the period when the fish were moving either across the bay or down bay. When the fish were headed along a straight horizontal course toward the home stream, the amplitude of the vertical movements decreased.

Table 3-4. Duration of fish return period and fish depth during control experiments.

Experiment	Number of Fish[a]	Duration[b] (min.)		Depth[c](m)	
		Mean	95% C.I.[d]	Mean	95% C.I.
Control 1	10	26.4	20.1 to 32.6	3.68	3.62 to 3.73
Control 2	9	49.0	43.8 to 54.1	4.01	3.97 to 4.06
Control 3	18	65.8	57.5 to 74.1	3.00	2.96 to 3.04

[a] Only includes fish tracked toward the home stream.
[b] Period from time of fish release to time of movement past disffuser.
[c] Only includes depths during period of straight horizontal movement toward the home stream.
[d] Confidence interval.

The swimming speed of the fish during the return period also varied in association with the horizontal and vertical movement patterns (Figures 3-17 to 3-19). The fish swam slower (mean ground speed ranging 0.22 to 0.36 m/s) during periods of movement either across bay or down bay and during periods of large-amplitude vertical movements (Table 3-5). The fish swam faster (mean ground speed ranging 0.34 to 0.55 m/s) during periods of straight horizontal movements up bay and during periods of small-amplitude vertical movements. The maximum ground speeds during the latter phase ranged up to 1.6 m/s (Table 3-5).

Table 3-5: Swimming speeds (ground speed m/s) of fish during control experiments.[a]

Experiment	Mean	Minimum	Maximum	95% C.I.[d]
		Initial Speed[b]		
Control 1	0.36	0.48	0.69	0.33 to 0.39
Control 2	0.22	0.10	0.44	0.20 to 0.23
Control 3	0.26	0.00	1.23	0.25 to 0.27
All	0.26			
		Final Speed[c]		
Control 1	0.49	0.51	1.23	0.45 to 0.53
Control 2	0.34	0.00	0.79	0.32 to 0.35
Control 3	0.55	0.07	1.61	0.53 to 0.58
All	0.46			

[a] Only includes fish tracked toward the home stream
[b] Only includes data during period when fish are not headed toward the home stream.
[c] Only includes data during period of straight horizontal movement toward the home stream.
[d] Confidence interval.

The average depth of fish during the period of straight horizontal movement toward the home stream was variable among experiments and was associated with the interface between lower salinity surface waters and higher salinity bottom waters. The depth of fish during the final portion of the return period varied little within an experiment but was significantly different ($P < 0.001$) among experiments (Table 3-4 and Appendix G). During controls 2 and 3, the fish headed back toward the home stream at mean depths of 4 and 3 m, respectively. Vertical salinity profiles along the return route (Figures 3-20 and 3-21) indicate that the fish were moving along the interface between the low salinity surface waters and the higher salinity bottom waters. Comparisons of fish depth with hydrographic conditions for control 1 were not possible because vertical profiles of salinity were not taken along the return route.

The movement activity of salmon during the controls indicates two types of movement behavior occur during the return to the home stream. Salmon that returned toward the home stream in the least time were apparently capable of orienting to the home stream very soon after their release. This active movement toward the home stream was characterized by relatively straight horizontal movements against the current (positive rheotaxis), small-amplitude vertical movements with occasional large-amplitude movements, and high swim speed. Salmon that required more time before returning toward the home stream spent more time searching. This searching behavior was characterized by horizontal movements across the current or with the current (negative rheotaxis), a higher frequency of large-amplitude vertical movements, and a low swim speed.

3.4.2 Movement Patterns During Discharge Conditions

Two of the three treatment experiments (i.e., treatments 1 and 2) did not result in a test of fish exposure to oil because the hydrocarbon plume did not intercept the homing fish, except for one case. During treatment 1, six of the ten fish released headed west, across the bay, and moved out of tracking range within 13 to 20 minutes after release (Appendix I). A plot of fish 19 (Figure 3-22), which is typical of this group, shows these fish moved across the bay before the plume reached this area. A survey of the southwestern shore of the bay with a mobil hydrophone after the experiment detected some of these fish in the upper bay, beyond the diffuser. Three other fish followed a similar route, but instead of continuing across the bay, they turned southwest and headed toward the home stream along a route well outside of the plume (e.g., Figure 3-23). These fish also moved too fast to be entrained by the plume. Only fish no. 14, which stopped moving for 55 minutes near the center of the bay, became entrained by the edge of the plume (Figure 3-24). During treatment 2, all of the fish, except one, either moved across the bay out of tracking range (e.g., Figure 3-25) or moved up bay along routes similar to treatment 1 and did not encounter the plume (e.g., Figure 3-26). One fish headed out of the bay ahead of the plume (Figure 3-27). Vertical movements of fish during both treatments were similar to those observed during the control experiments.

The duration-of-return period and fish depth for fish that headed toward the home stream were similar between treatments 1 and 2 (Table 3-6). The average duration-of-return was approximately 40 minutes and the average depth was approximately 3.5 m. A comparison of the duration-of-return period between treatment and control experiment pairs (e.g., treatment 1

versus control 1) indicates no significant difference (P >0.05) for both groups (Appendix G). A test of fish depth indicates no significant (P >0.05) difference between treatment 1 and control 1, but control 2 fish were significantly (P <0.05) deeper than treatment 2 fish (see Tables 3-4 and 3-6). The depth of the latter treatment (i.e., 3.42 m), however, was closely associated with the interface of the vertical salinity gradient (Figure 3-28) as was observed for the control experiments.

Table 3-6. Duration of fish return period and fish depth during treatment experiments.

Experiment	Number of Fish[a]	Duration[b] (min.)		Depth[c](m)	
		Mean	95% C.I.[d]	Mean	95% C.I.
Treatment 1	4	39.7	-29.9 to 109.4	3.67	3.60 to 3.75
Treatment 2	5	43.6	-9.9 to 97.1	3.42	3.27 to 3.58
Treatment 3	18	118.5	115.8 to 121.3	4.41	4.38 to 4.44

[a] Only includes fish tracked toward the home stream.
[b] Period form time of fish release to time of movement past diffuser.
[c] Only includes depths during period of straight horizontal movement toward the home stream.
[d] Confidence interval.

All fish, except one, during treatment 3 headed toward the home stream and were exposed to the hydrocarbon plume. The mean duration of exposure to concentrations ranging 1 to 5 ppb and >5 ppb was 15.6 and 4.8 minutes, respectively (Table 3-7). Several fish were exposed to hydrocarbon concentrations greater than 10 ppb and ranging up to 18.1 ppb (Appendix D).

The horizontal movements of fish after exposure to the plume were different from fish movements observed during the control experiments. During treatment 3, most of the fish headed west across the bay in front of the plume similar to treatments 1 and 2 (e.g., Figures 3-29 and 3-30 at 17:30). Near the center of the bay the fish turn 180° and head back across the bay (Figures 3-29 and 3-30 at 18:00). This initial movement pattern was very similar to the patterns observed for fish during control 3. By the time the fish move back across the bay, the hydrocarbon plume had contaminated the eastern side and the fish move into the plume (Figures 3-29 and 3-30 at 18:30). While in the plume, fish exhibited a variety of horizontal movements.

Table 3-7: Duration of exposure to hydrocarbon concentrations greater than 1.0 ug/L (ppb) during treatment 3.

	Duration of Exposure (min)	
Fish No.	1.0-5.0 (ppb)	>5.0 (ppb)
73	11.5	11.0
74	9.0	10.0
75	14.0	2.0
76	14.0	0.0
77	15.0	0.0
78	9.0	1.0
79	19.0	1.0
80	- -[a]	- -
81	4.0	2.0
82	41.5	3.0
83	13.0	4.0
84	13.0	0.0
85	12.0	0.0
86	21.0	15.0
87	7.0	6.0
88	23.0	6.0
89	18.5	5.0
90	20.0	15.0
91	- -[b]	- -
Mean	15.6	4.8
95% C.I.[c]	11.2 to 19.9	2.1 to 7.4

[a] Fish left study area.
[b] Data deleted due to fish tracking problem.
[c] Confidence interval.

For example: some fish swam slow, turned in the direction of the current, and headed downstream (e.g., Figure 3-30 at 18:30 and 19:00); some fish continued to swim relatively fast, moving in a circular pattern within the plume, and eventually heading downstream (e.g., Figure 3-29 at 18:30 and 19:00); and, one fish conducted several circular movements into and out of the plume before heading downstream (Figure 3-31). Most of the fish that headed downstream moved out of tracking range. After a period of 12 to 19 minutes these fish all returned toward the home stream, traveling a short distance along the outer edge of the plume through hydrocarbon concentrations near 1.0 ppb and the remaining distance outside the plume. During this latter portion of the return, the fish moved along a straight horizontal route similar to fish observed during control 3.

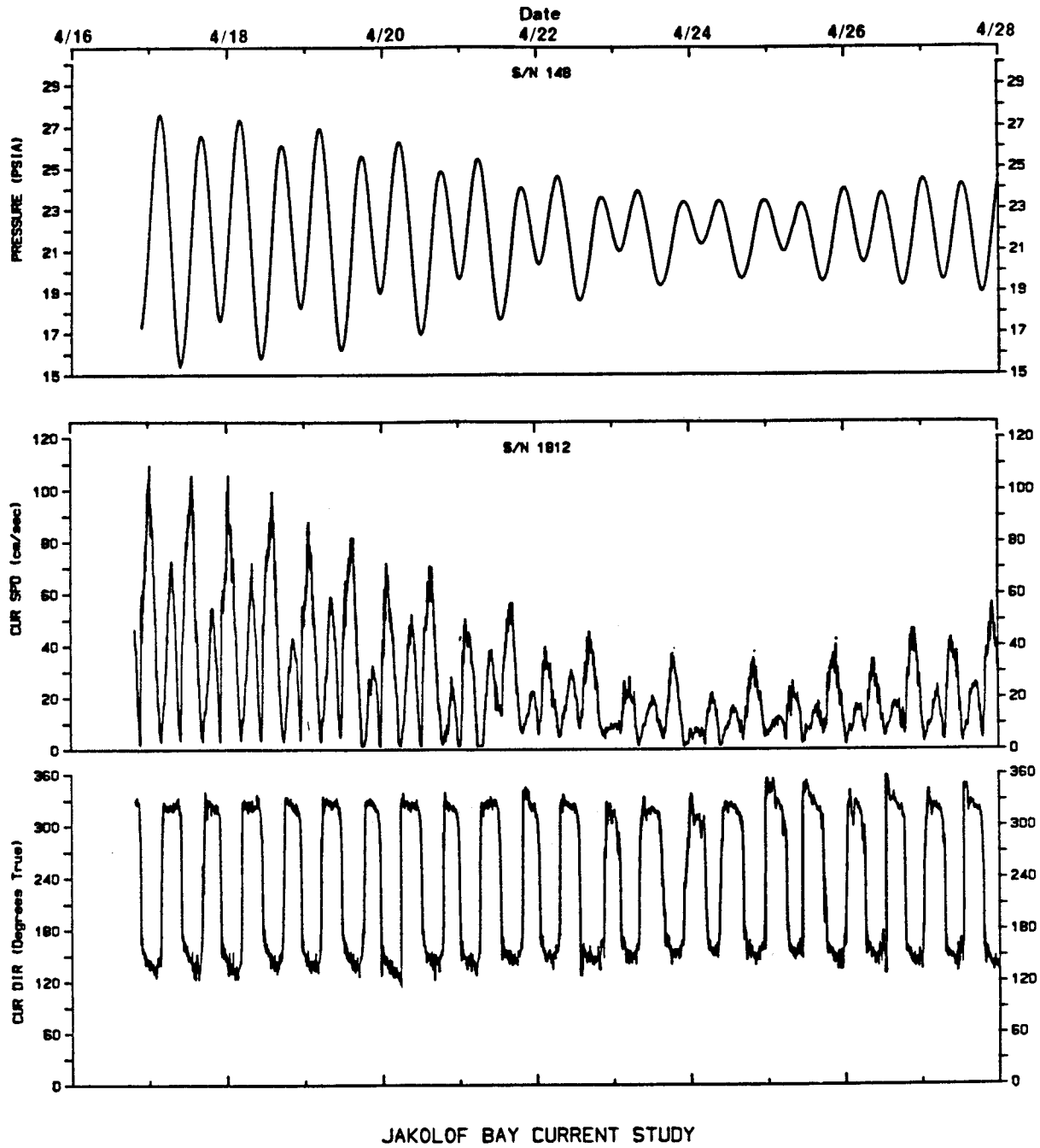
Fish nos. 77 and 82 exhibited a horizontal movement pattern quite different than the others (Figures 3-32 and 3-33). Instead of moving across the bay ahead of the plume, these fish slowly moved to the center of the bay and stopped at approximately 18:00 hours. Between 18:00 and 18:30 both fish became entrained in the hydrocarbon plume. Fish nos. 77 and 82 were exposed to concentrations greater than 1.0 ppb for 15 and 30 minutes, respectively. During this period both fish turned downstream and eventually headed out of the plume (Figures 3-32 at 18:30 and 3-33 at 18:30-19:00). However, the distance each fish moved down bay was different. Fish no. 77 only moved a short distance before turning 180° and headed toward the home stream (Figure 3-32 at 19:00), whereas fish no. 82 continued downstream and headed back into the plume before going out of tracking range (Figure 3-33 at 19:00). During the return toward the home stream fish no. 82 swam through hydrocarbon concentrations >1.0 ppb for at least 200 m before heading outside of the plume. Several other fish also had a short (i.e., <2 minutes) exposure to the plume during the return migration.

The amplitude of vertical movements did not appear to be affected by exposure to the hydrocarbon plume. The pattern of large- and small-amplitude vertical movements that occur prior to exposure generally continue during exposure. Many fish had small-amplitude movements throughout the return period (e.g., Figure 3-34). In many cases the pattern of these movements during the period of swimming downstream was similar to the pattern during the period of straight horizontal movement upstream. Some fish had a mixture of large- and small-amplitude vertical movements (e.g., Figure 3-35, fish no. 73), and some had a high frequency of large-amplitude vertical movements (e.g., Figure 3-35, fish no. 83). During active movement toward the home stream, all fish displayed small-amplitude vertical movements similar to those observed during control experiments.

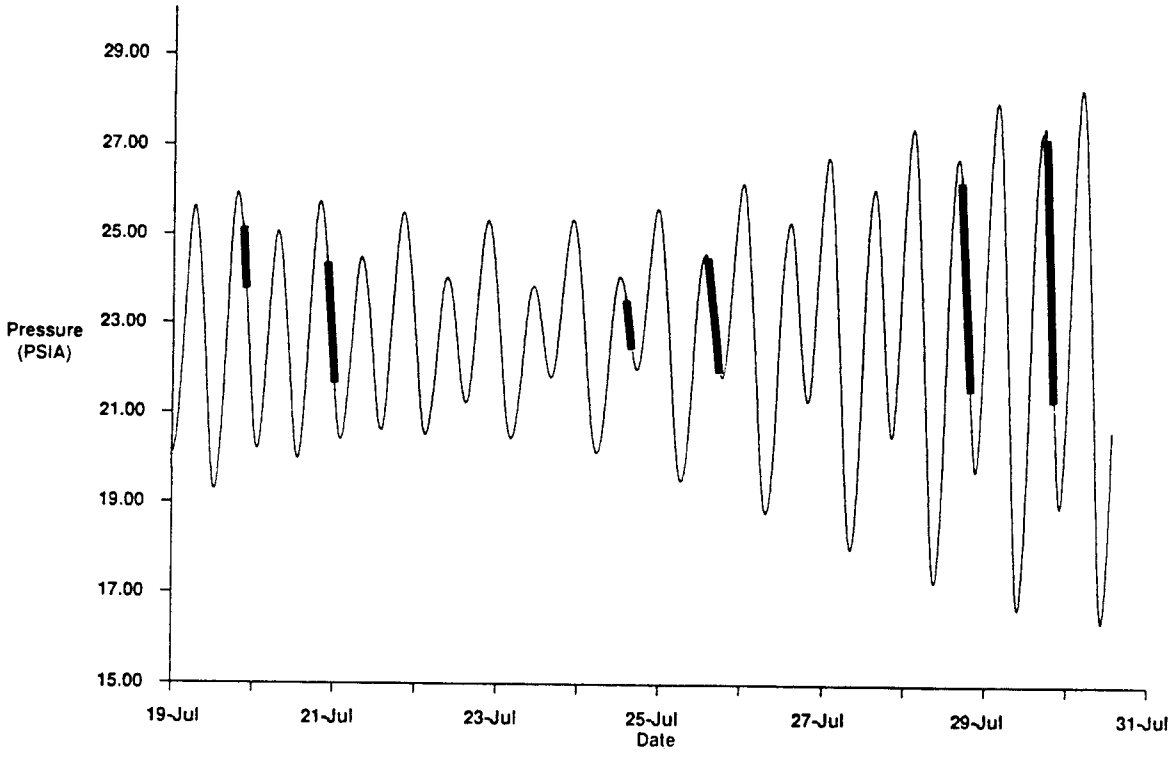
The swimming speed of fish varied significantly during the return period (Figures 3-34 and 3-35). After the initial escape from the holding pen but prior to exposure to the hydrocarbon plume, fish swam very slow (mean ground speed of 0.08 m/s). However, during exposure to the plume swimming speeds increased significantly ($P < 0.001$) to an average ground speed of 0.31 m/s (Appendix G). Swimming speeds were highest (mean ground speed of 0.82 m/s) following exposure to the plume and during the period of straight horizontal movement toward the home stream. This increase in swimming speed from the period of searching to the period of active migration was similar to the pattern observed during the control experiments.

The average depth of treatment 3 fish during the period of straight horizontal movement toward the home stream was significantly ($p < 0.05$) greater than all other experiments (Appendix G) and was not associated with the interface of the vertical salinity gradient. All fish heading toward the home stream swam at an average depth of 4.4 m (Table 3-6), which was approximately 3 m deeper than the interface between the low salinity surface waters and the higher salinity bottom waters (Figure 3-36). Water depth was just over 6 m as indicated by the depth of the salinity profiles, therefore the fish were swimming less than 2 m above the bottom.

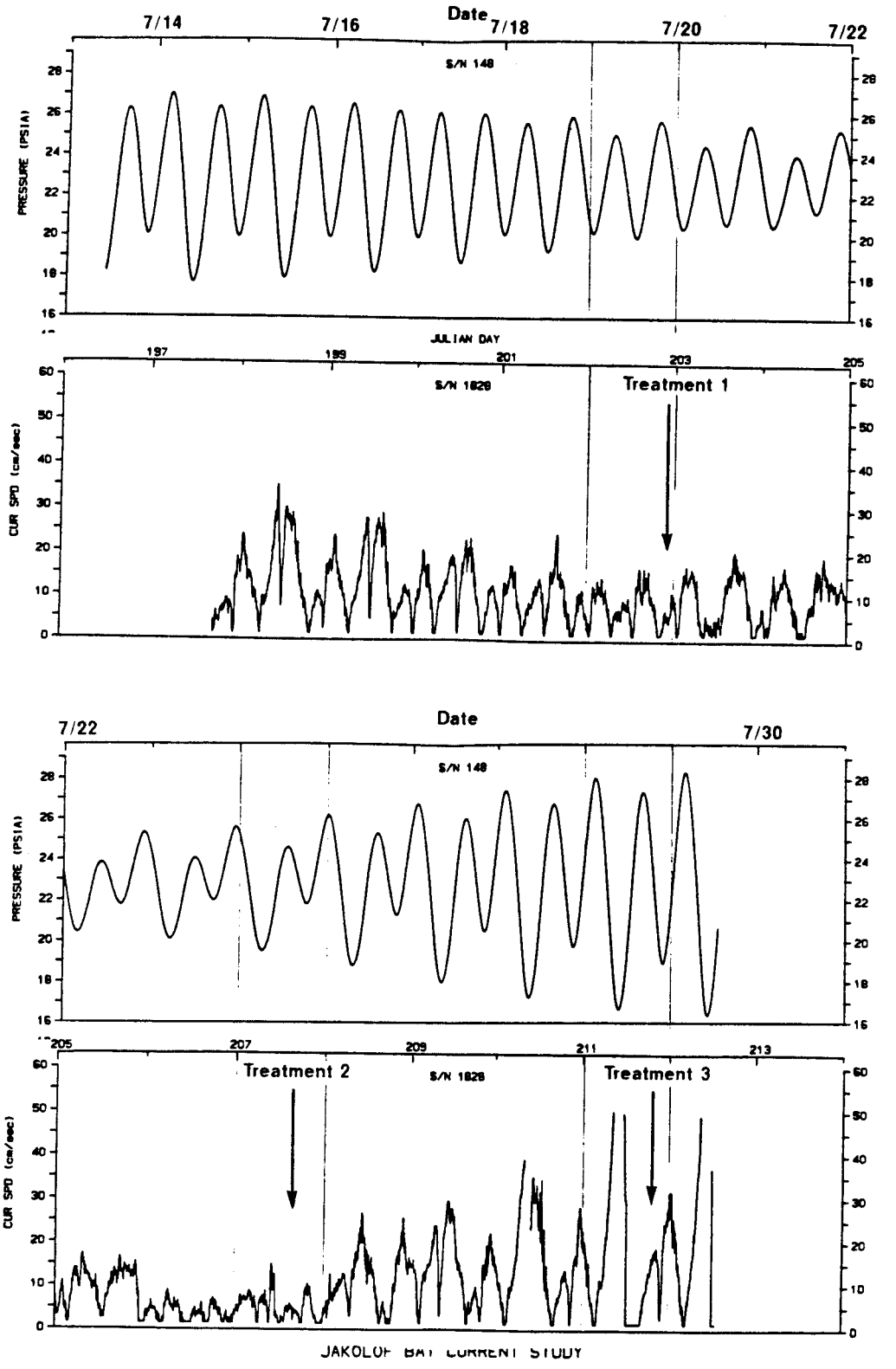
The duration-of-return period during treatment 3 averaged 118.5 minutes (Table 3-6) and was significantly ($P < 0.001$) longer than all the control experiments (Table 3-6 and Appendix G). The longer duration-of-return was due to the longer duration of searching by fish prior to active movement toward the home stream.



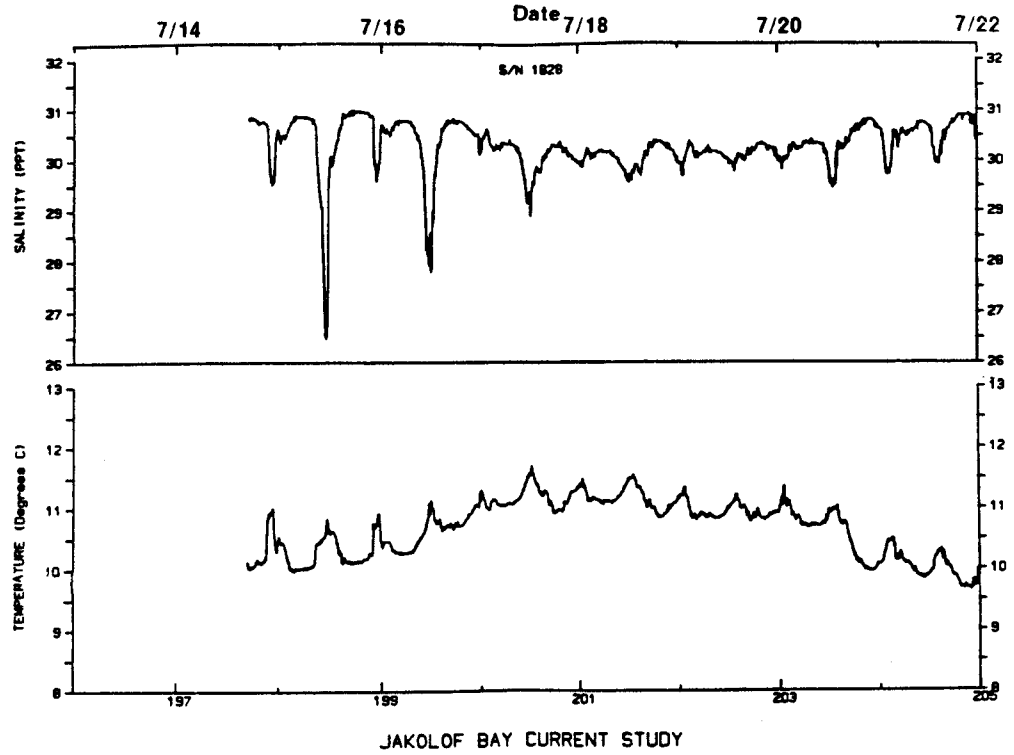
Tides and Currents At Mouth of Jakolof Bay During Reconnaissance Survey
Figure 3-1

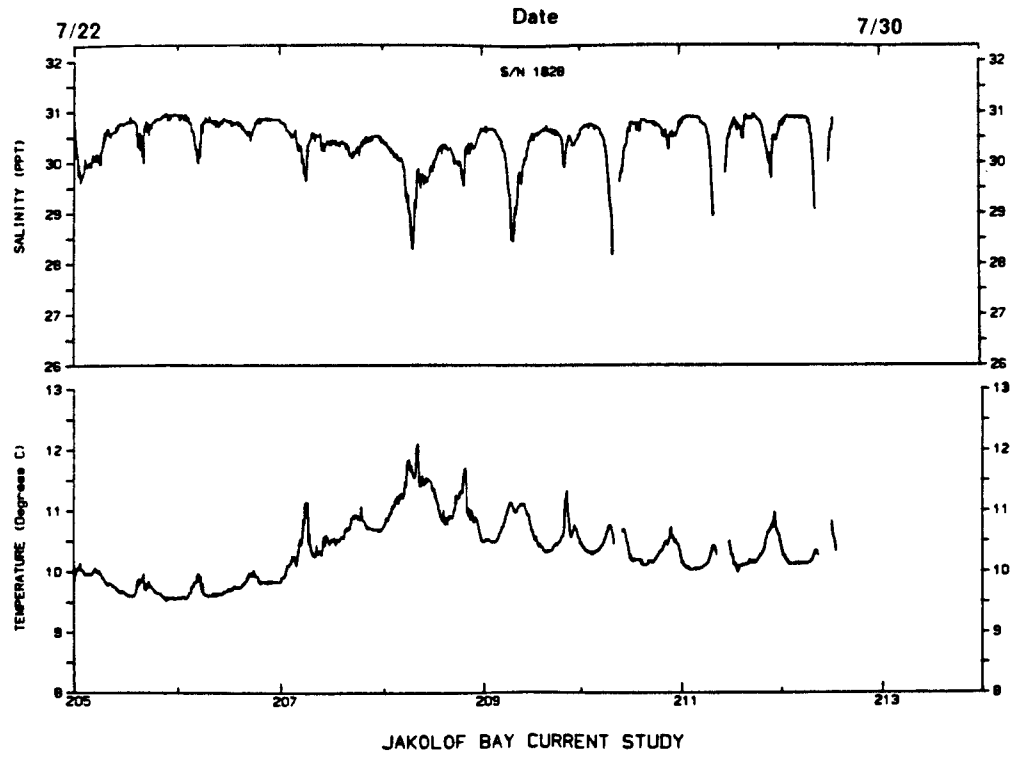


Tides At Station 2 During Fish Tracking Experiments
(PISA = 1lbs/in² in Addition to Atmospheric Pressure)
Figure 3-2

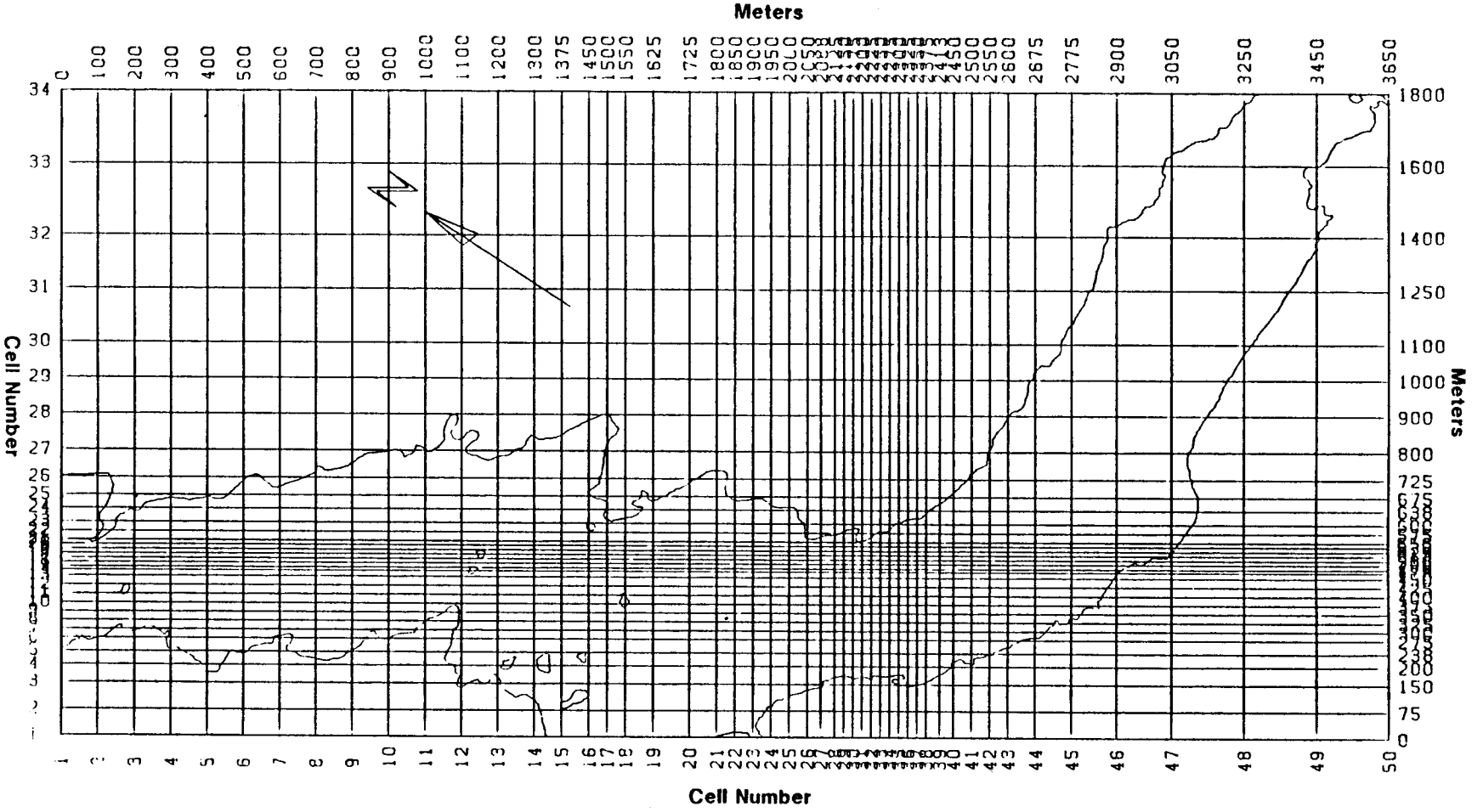


Currents at Diffuser During Experiments
Figure 3-3

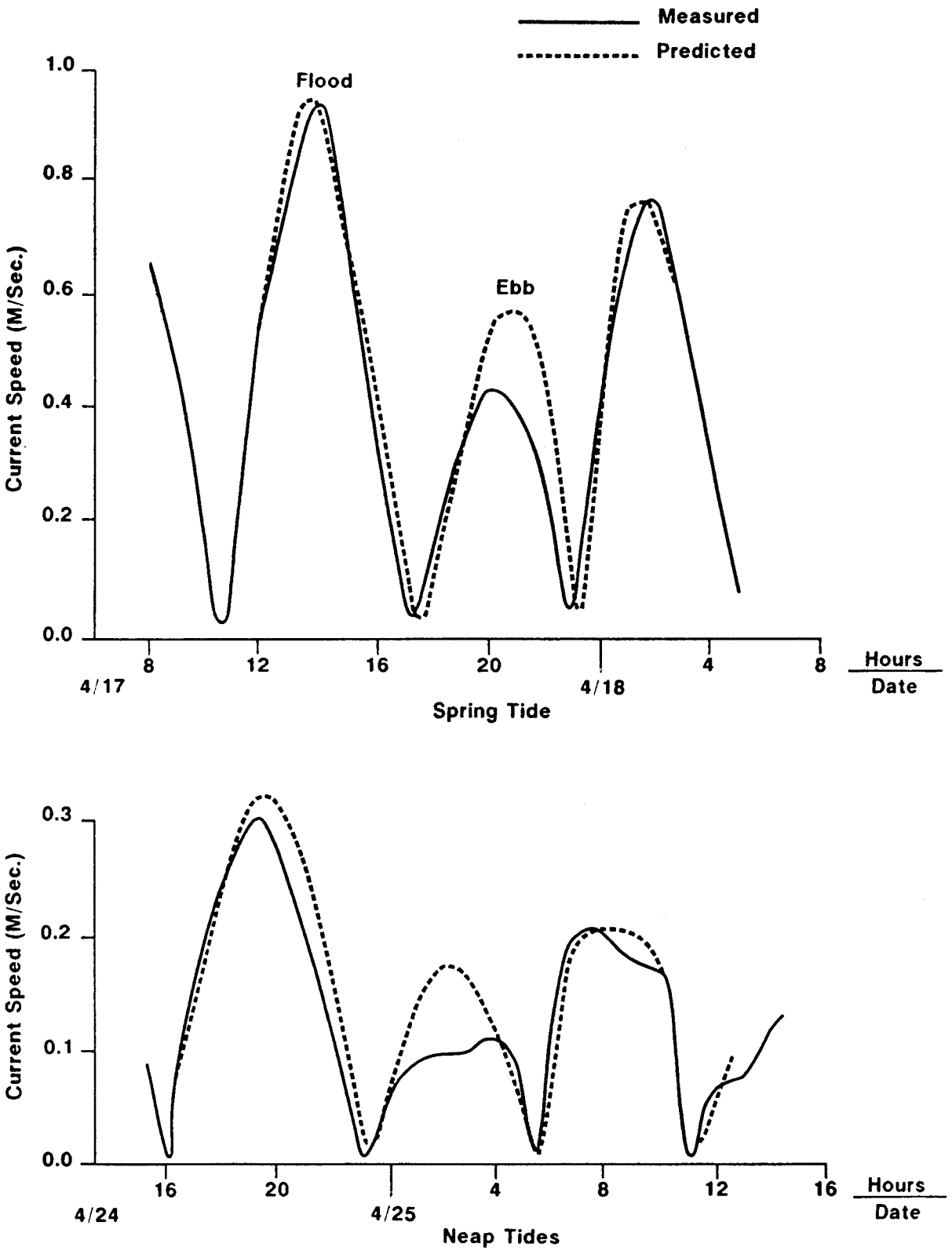




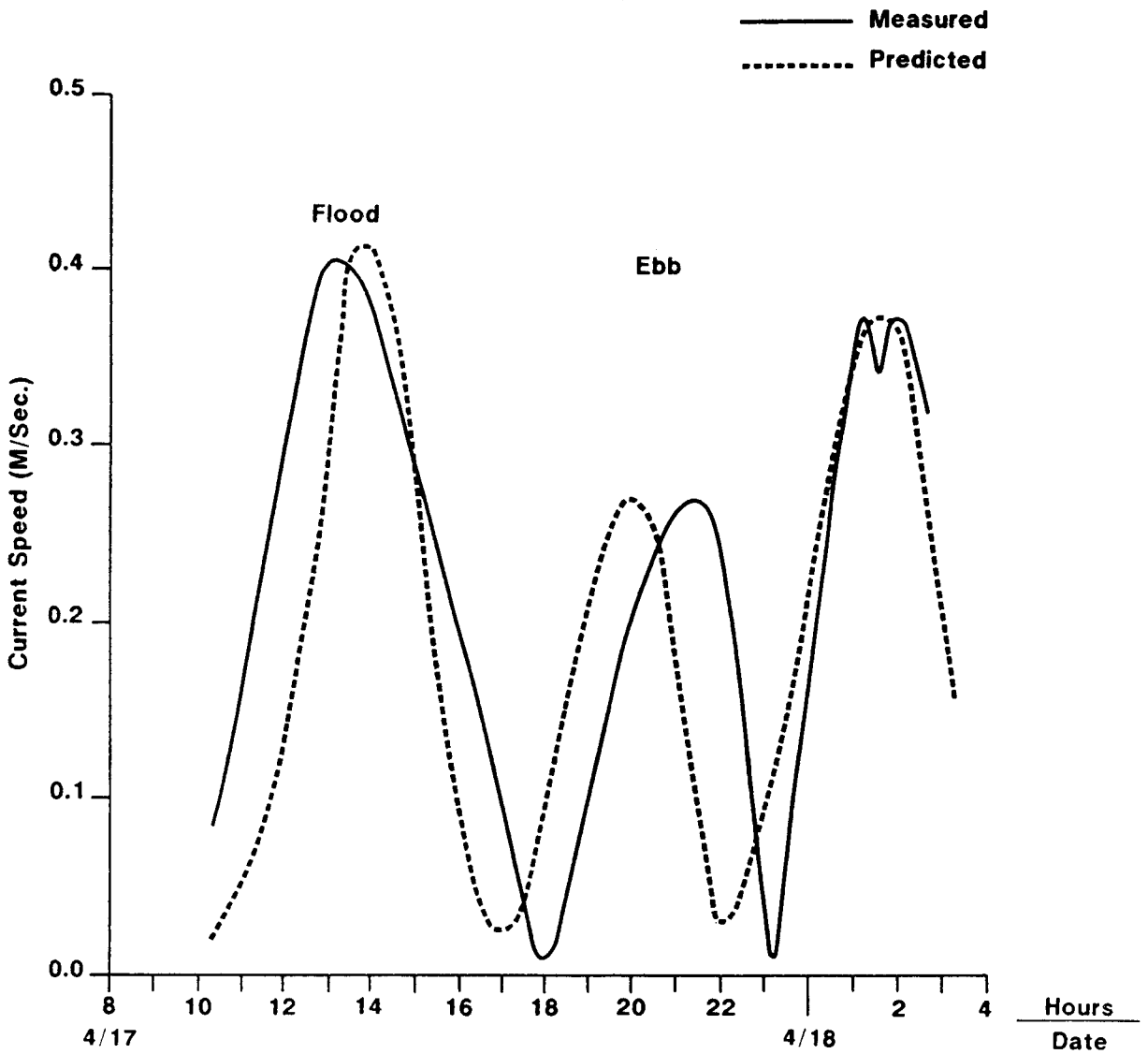
Temperature and Salinity at Diffuser During Experiments
Figure 3-4



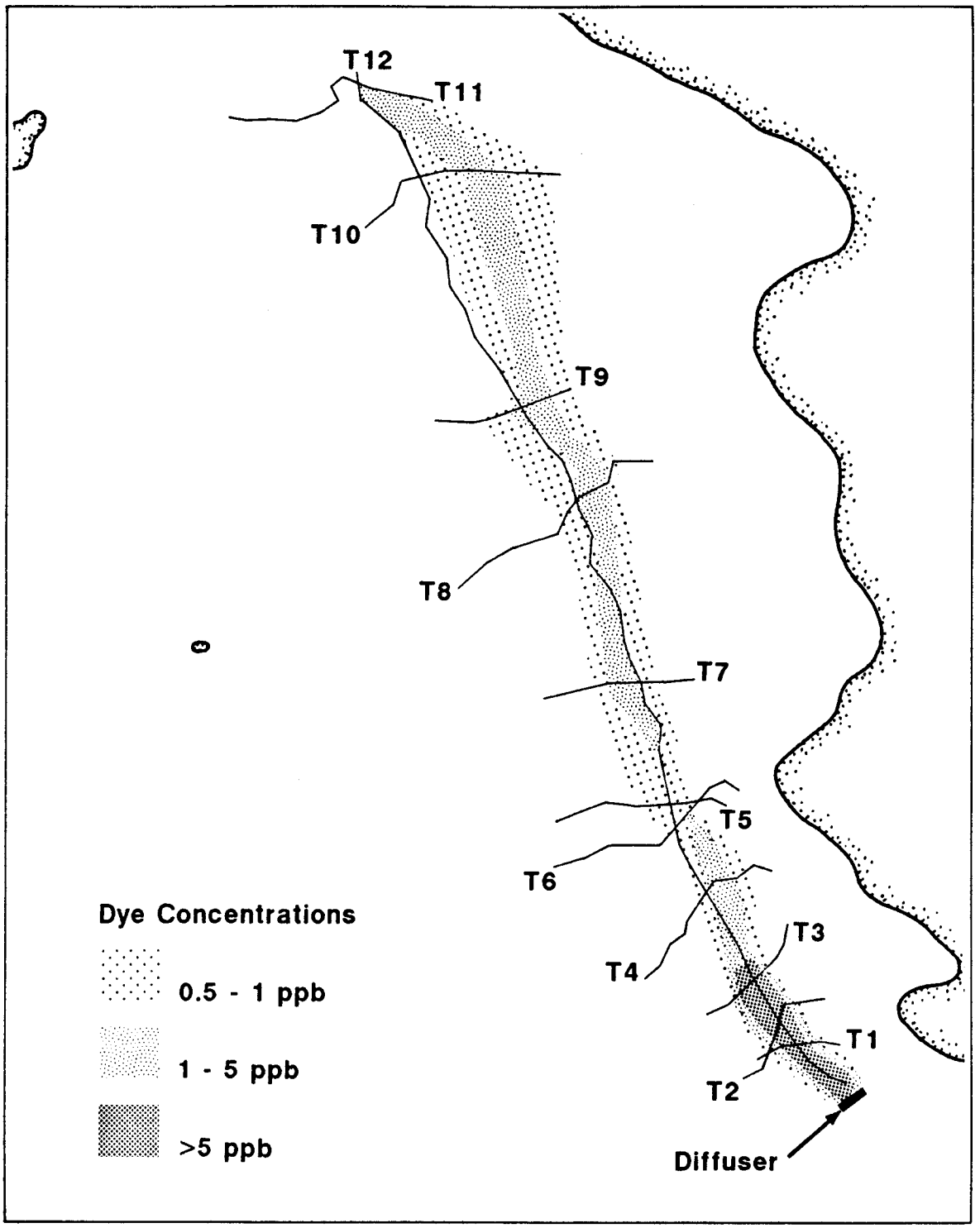
Finite - Difference Grid
Figure 3-5



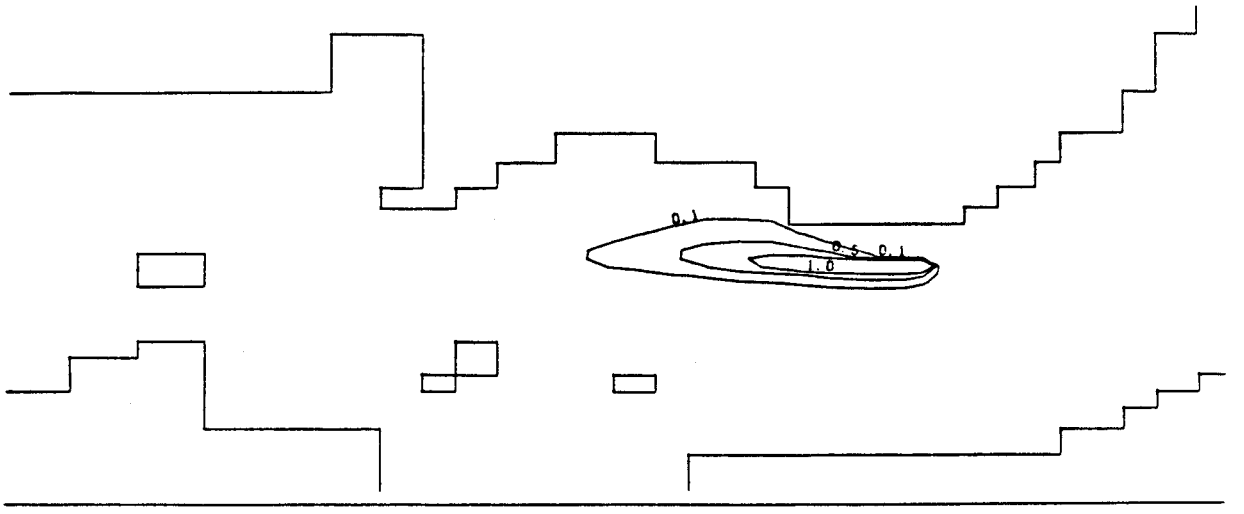
Hydrodynamic Calibration, Currents at Mouth of Jakolof Bay (Sta. 1)
Figure 3-6



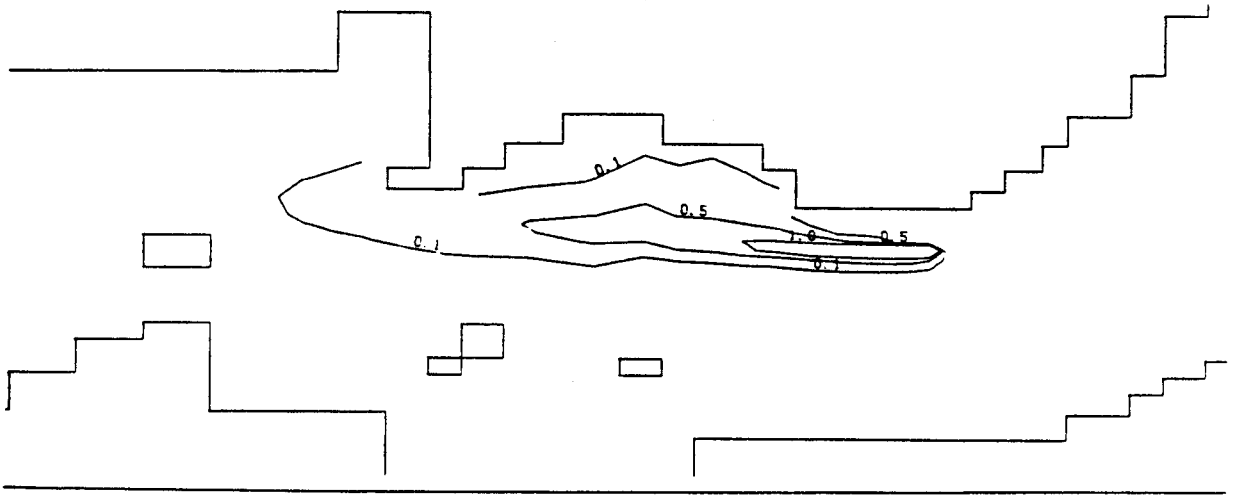
Hydrodynamic Calibration, Currents Near Center of Jakolof Bay (Sta. 2)
Figure 3-7



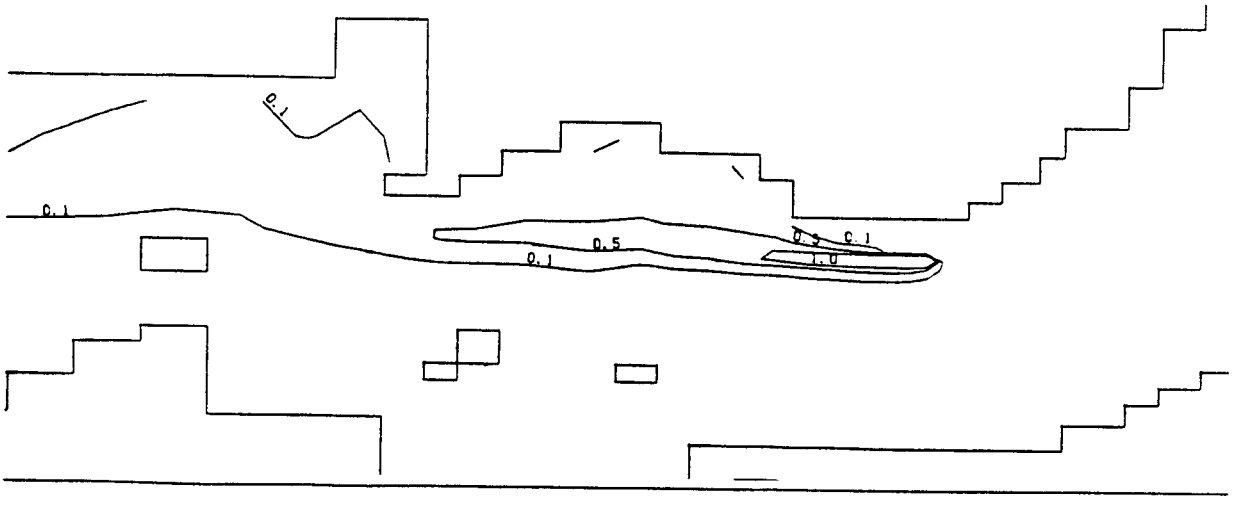
Dye Concentrations (ppb) Used for Water Quality Calibrations
Figure 3-8



NOAA: DYE PLUME AT DT= 40 MIN, JULY 30, RUN WD11

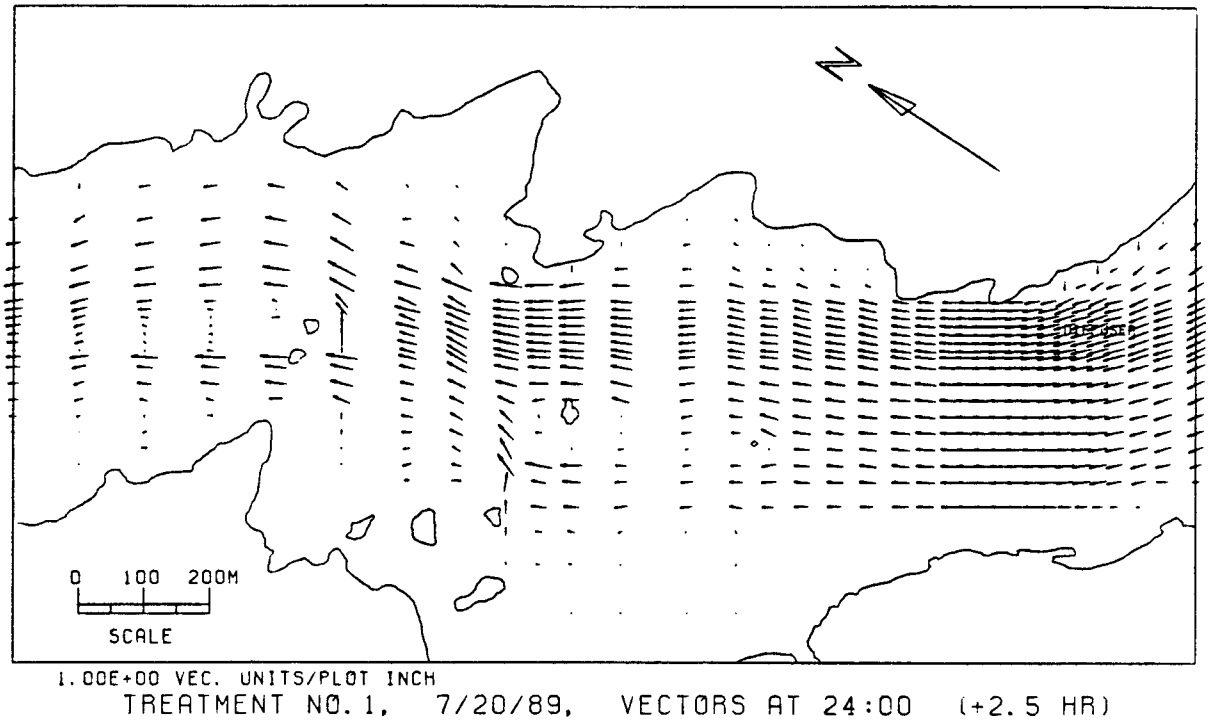


NOAA: DYE PLUME AT DT= 80 MIN, JULY 30, RUN WD11

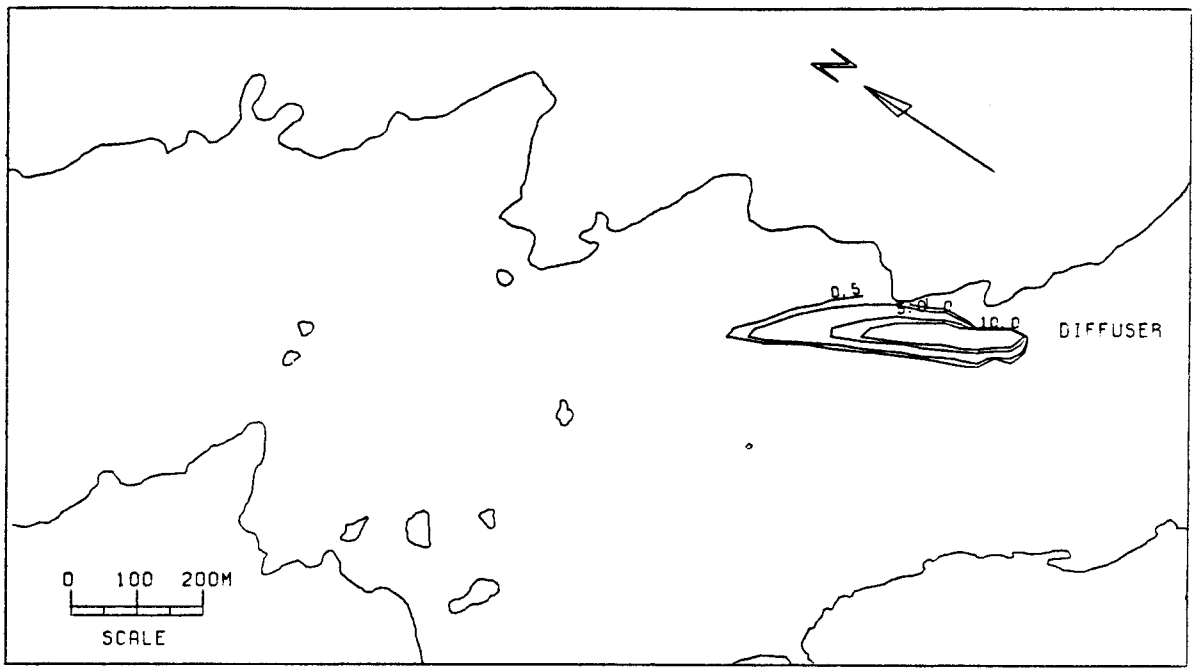


NOAA: DYE PLUME AT DT= 120 MIN, JULY 30, RUN WD11

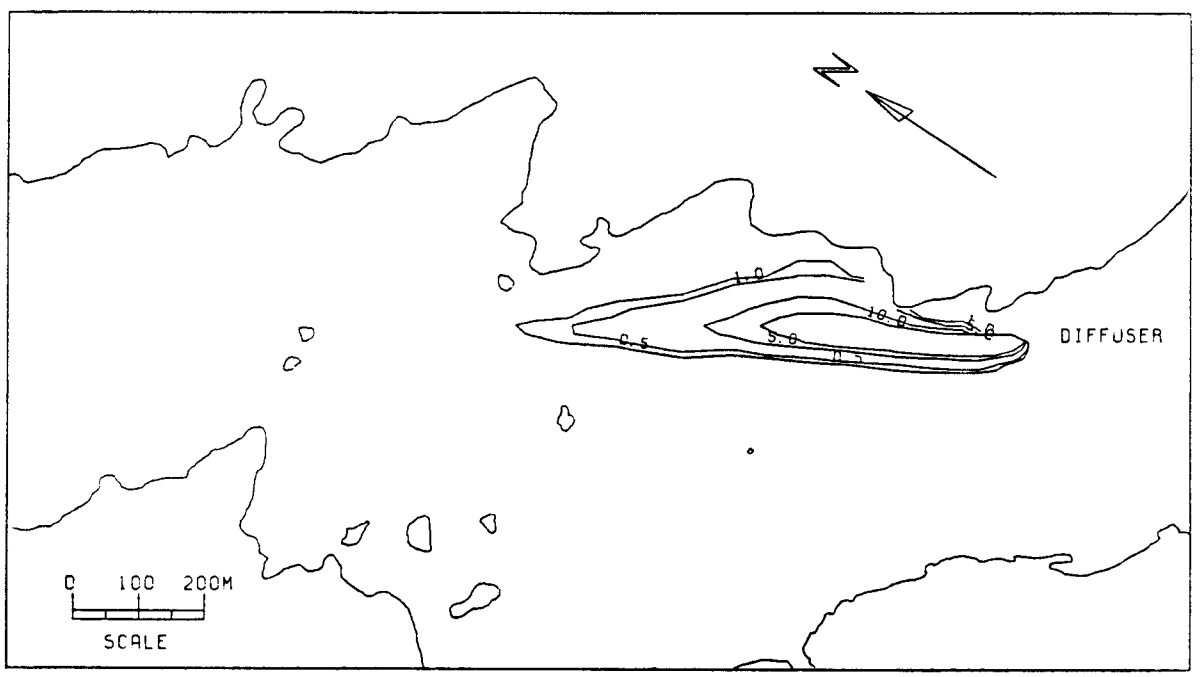
Water Quality Calibration, Predicted Concentrations (ppb)
Figure 3-9



Vector Plot of Currents on 7/20/88
Figure 3-10

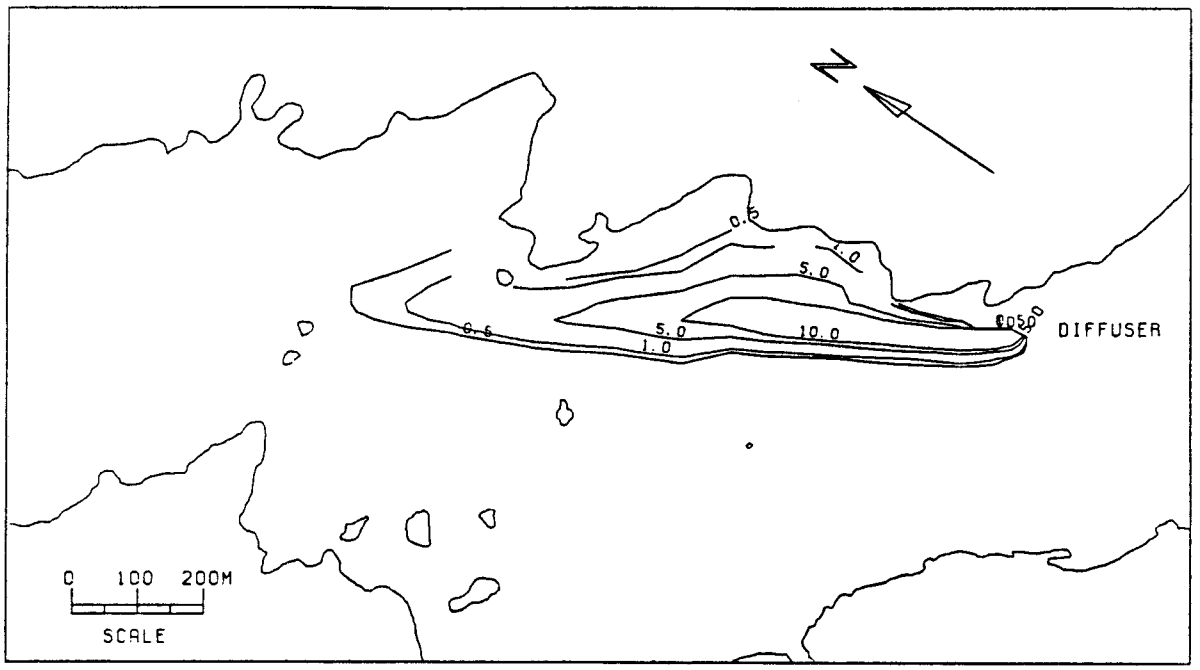


TREATMENT NO. 1, 7/20/89, PLUME AT 22:00 (+0.5 HRS)

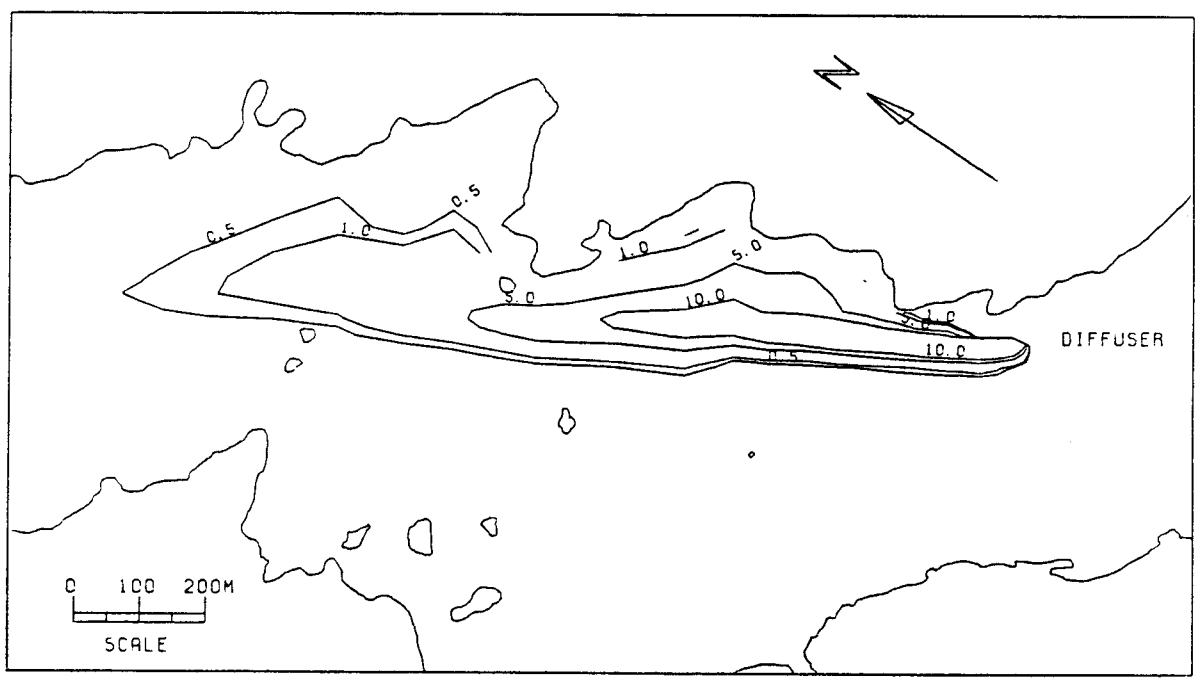


TREATMENT NO. 1, 7/20/89, PLUME AT 22:30 (+1.0 HRS)

Predicted Hydrocarbon Concentrations (ppb) During Treatment 1
Figure 3-11

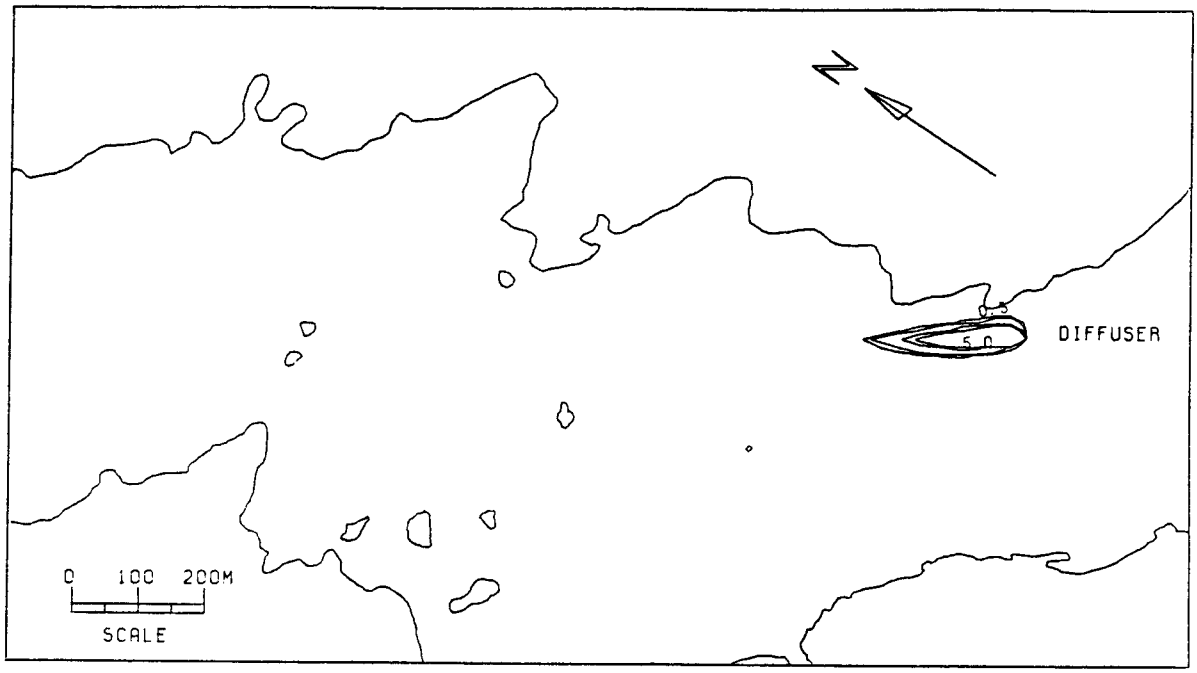


TREATMENT NO. 1, 7/20/89, PLUME AT 23:00 (+1.5 HRS)

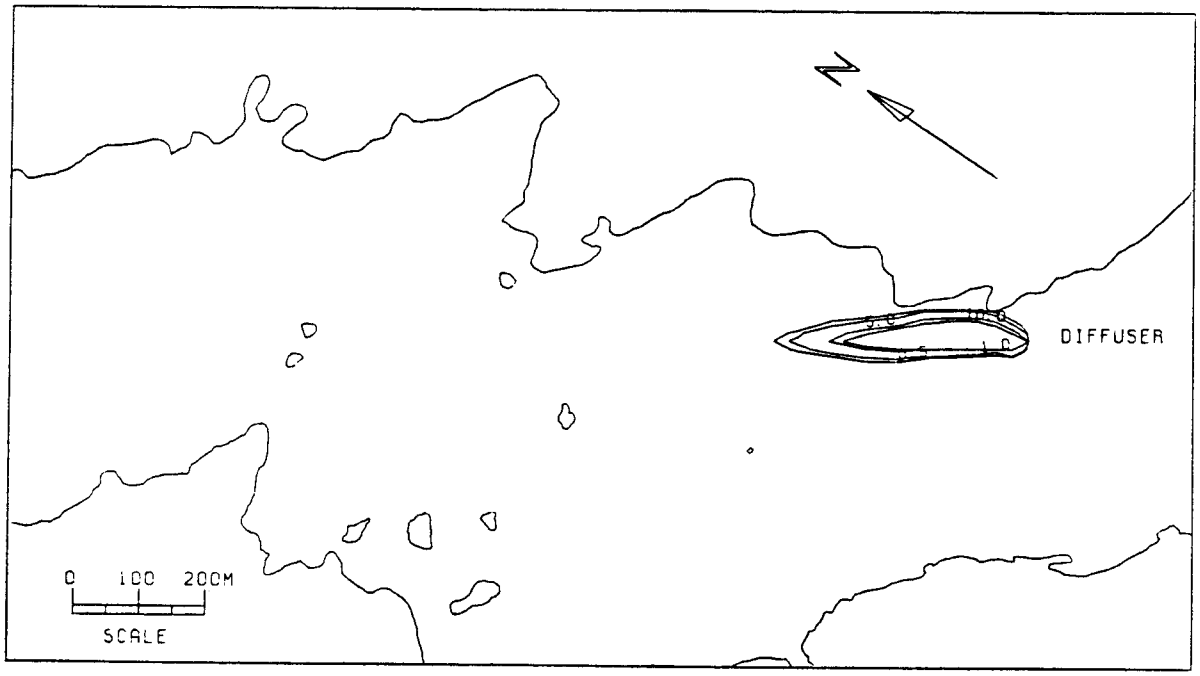


TREATMENT NO. 1, 7/20/89, PLUME AT 23:30 (+2.0 HRS)

Predicted Hydrocarbon Concentrations (ppb) During Treatment 1
Figure 3-11 (continued)

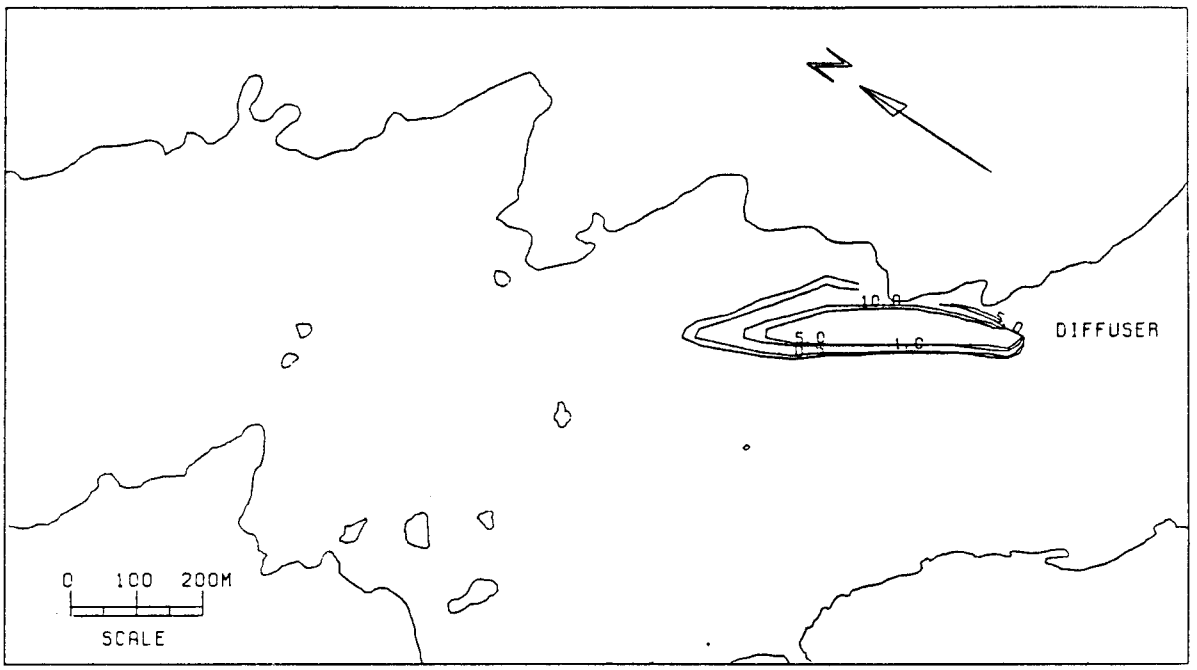


TREATMENT NO. 2, 7/25/89, PLUME AT 14:00 (+0.5 HRS)

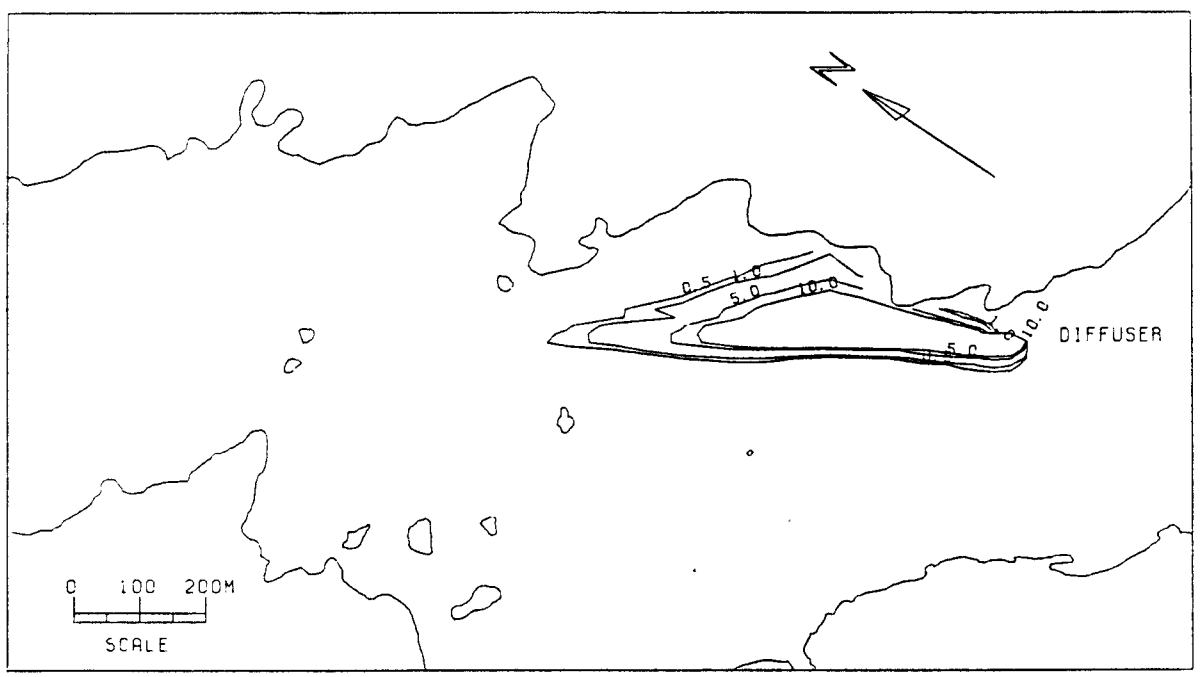


TREATMENT NO. 2, 7/25/89, PLUME AT 14:30 (+1.0 HRS)

Predicted Hydrocarbon Concentrations (ppb) During Treatment 2
Figure 3-12

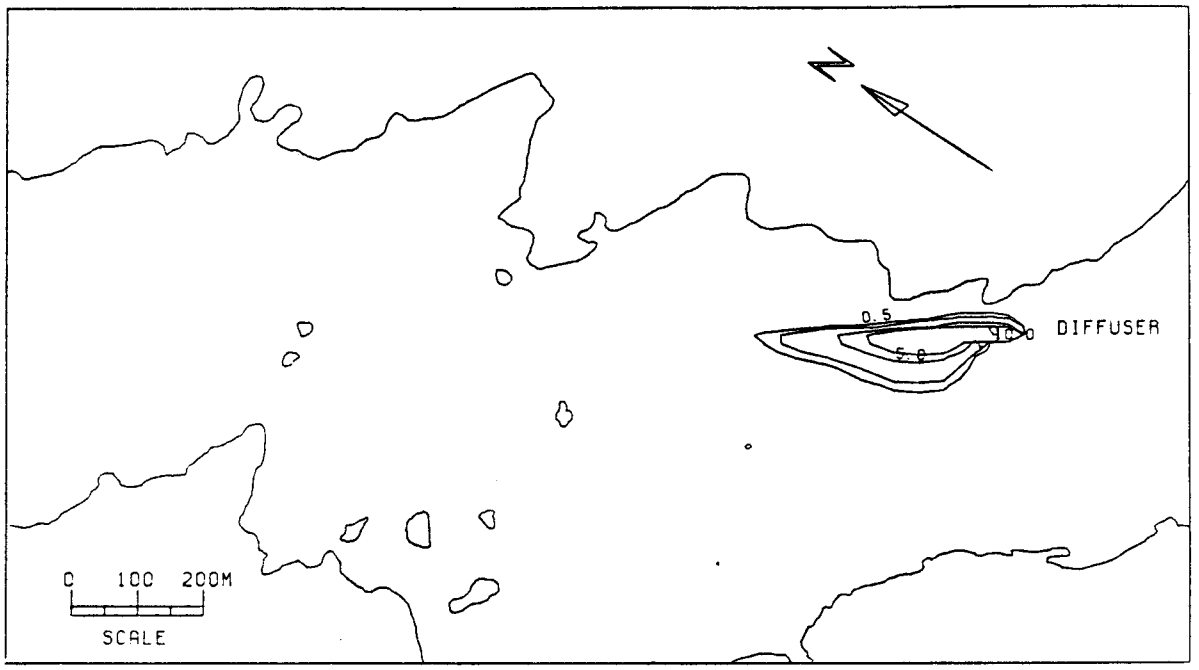


TREATMENT NO. 2, 7/25/89, PLUME AT 15:00 (+1.5 HRS)

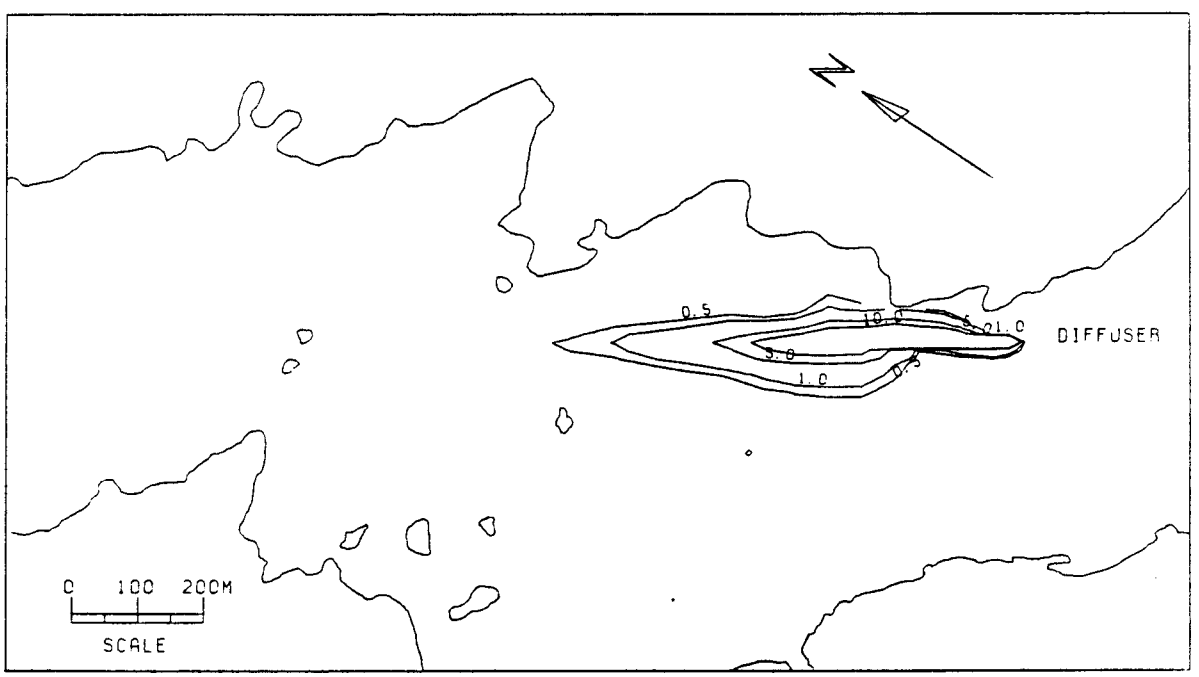


TREATMENT NO. 2, 7/25/89, PLUME AT 15:30 (+2.0 HRS)

Predicted Hydrocarbon Concentrations (ppb) During Treatment 2
Figure 3-12 (continued)

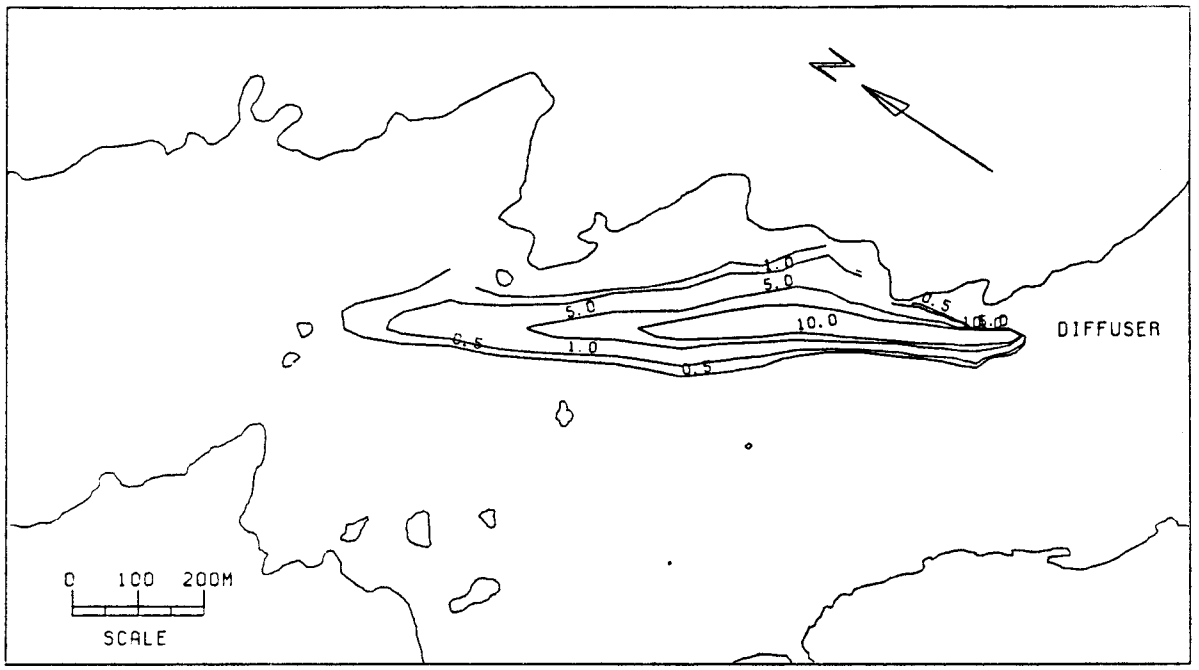


TREATMENT NO. 3, 7/29/89, PLUME AT 17:30 (+1.0 HRS)

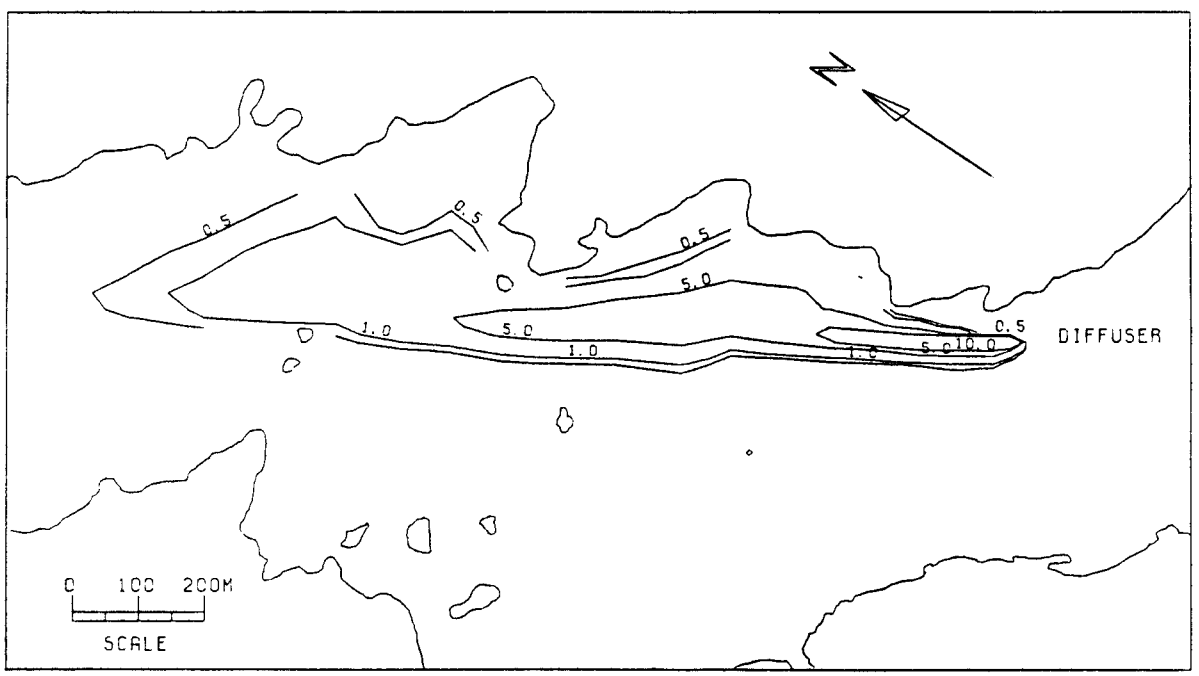


TREATMENT NO. 3, 7/29/89, PLUME AT 18:00 (+1.5 HRS)

Predicted Hydrocarbon Concentrations (ppb) During Treatment 3
Figure 3-13

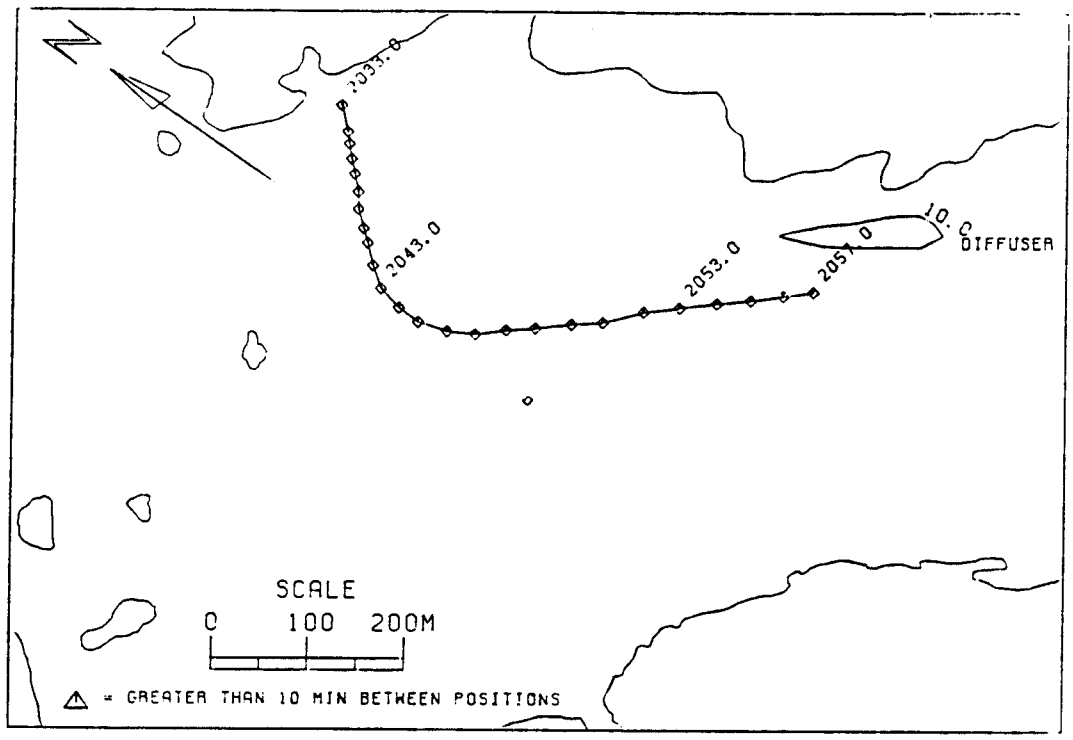


TREATMENT NO. 3, 7/29/89, PLUME AT 18:30 (+2.0 HRS)

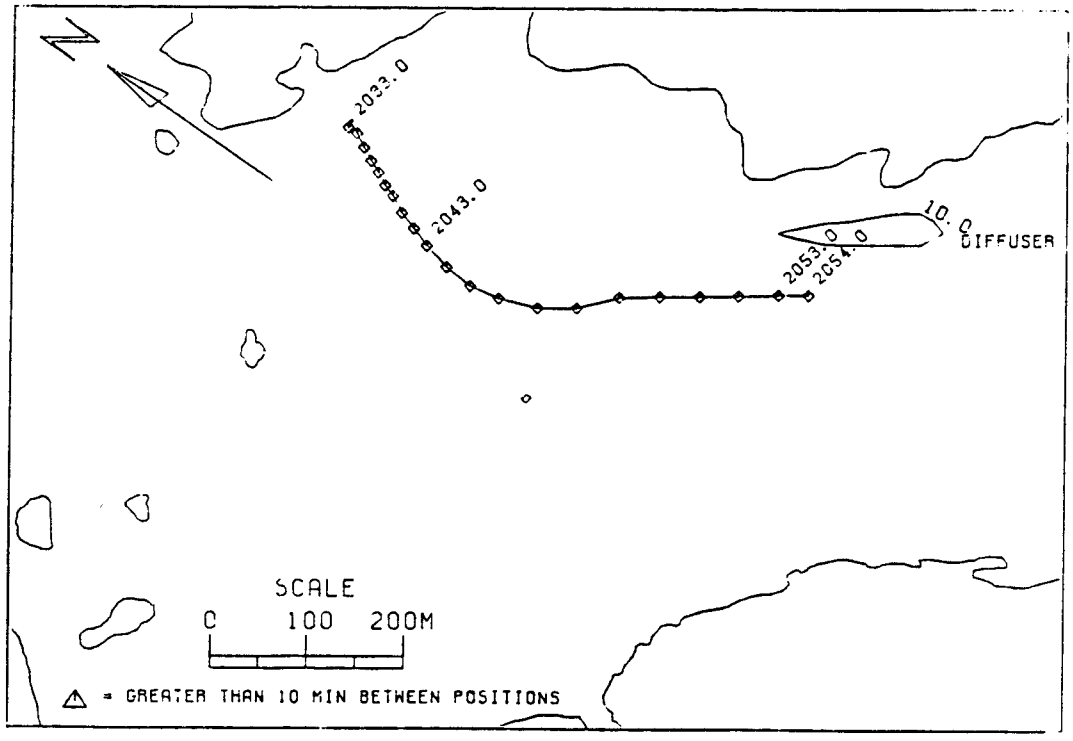


TREATMENT NO. 3, 7/29/89, PLUME AT 19:00 (+2.5 HRS)

Predicted Hydrocarbon Concentrations (ppb) During Treatment 3
Figure 3-13 (continued)

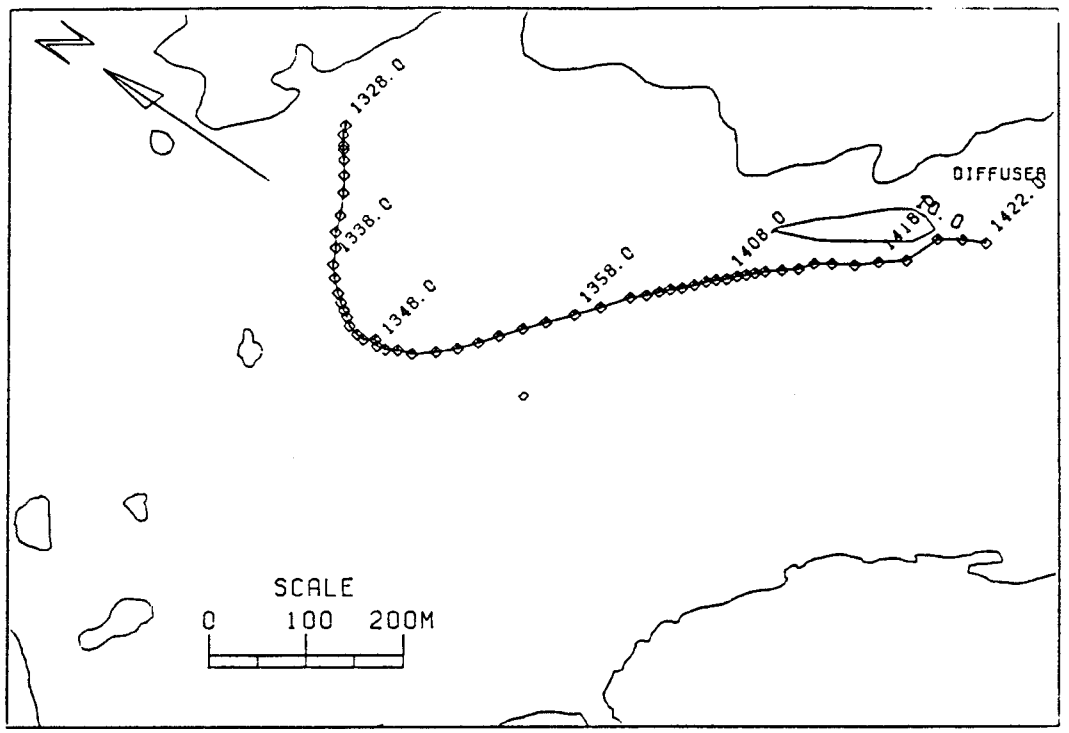


JAKOLOF BAY, FISH 09, CONTROL NO. 1, 7/19/88

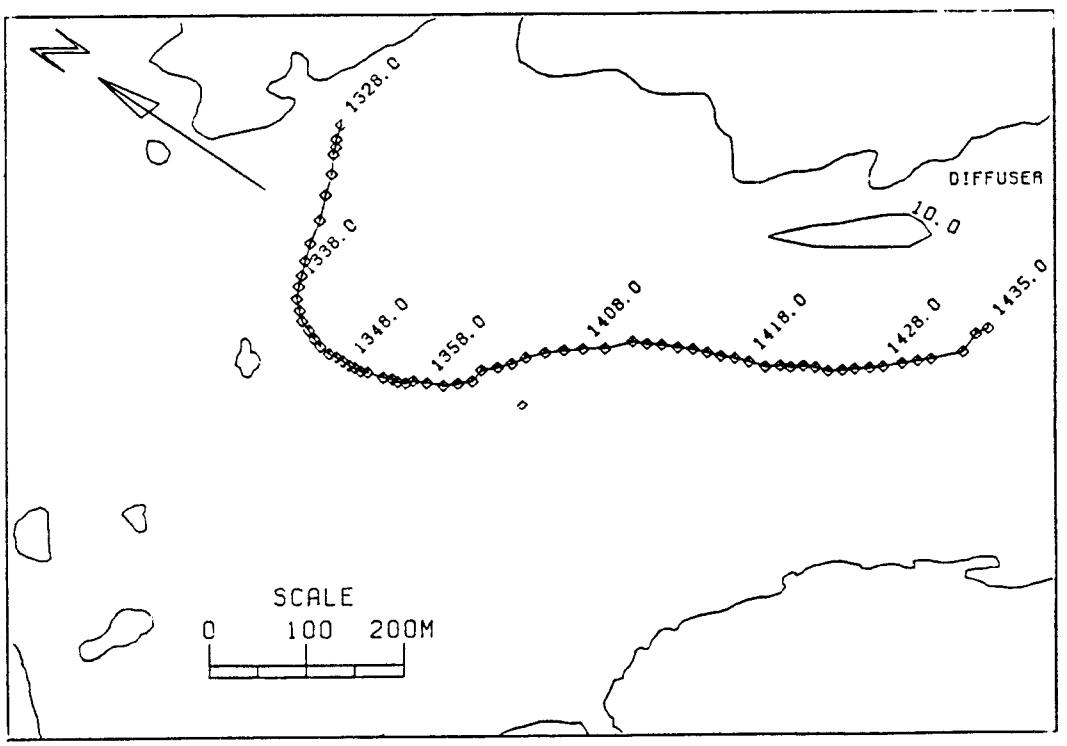


JAKOLOF BAY, FISH 10, CONTROL NO. 1, 7/19/88

Horizontal Movements of Fish Numbers 9 and 10 During Control 1
Figure 3-14



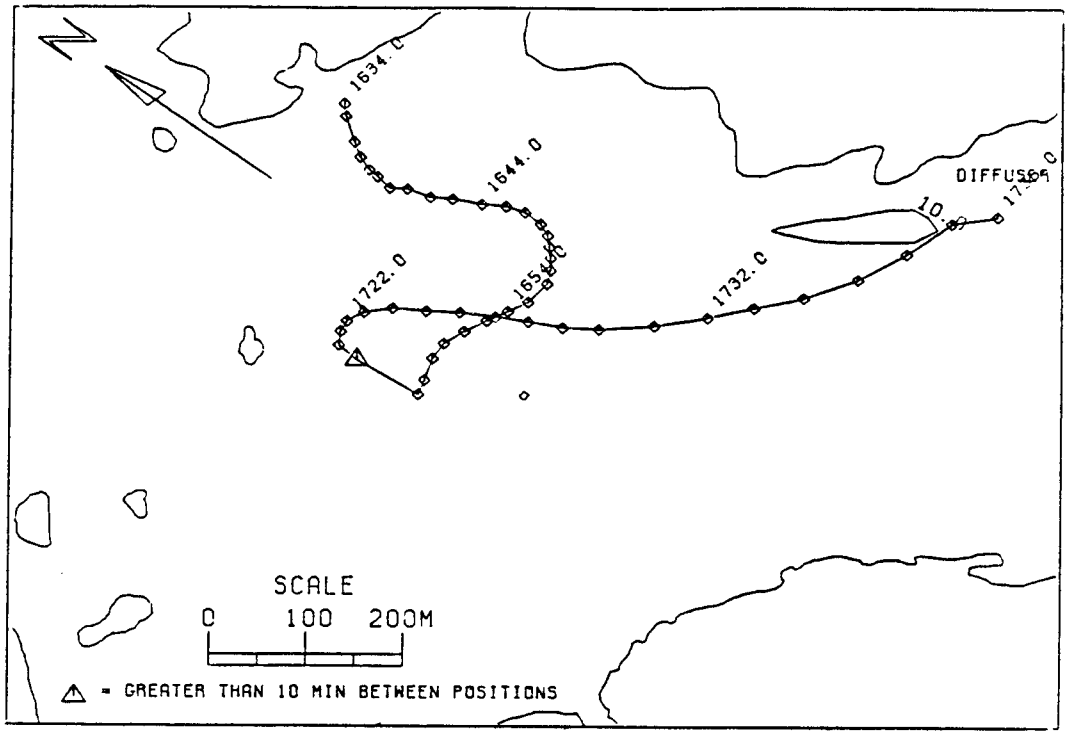
JAKOLOF BAY, FISH 34, CONTROL NO. 2, 7/24/88



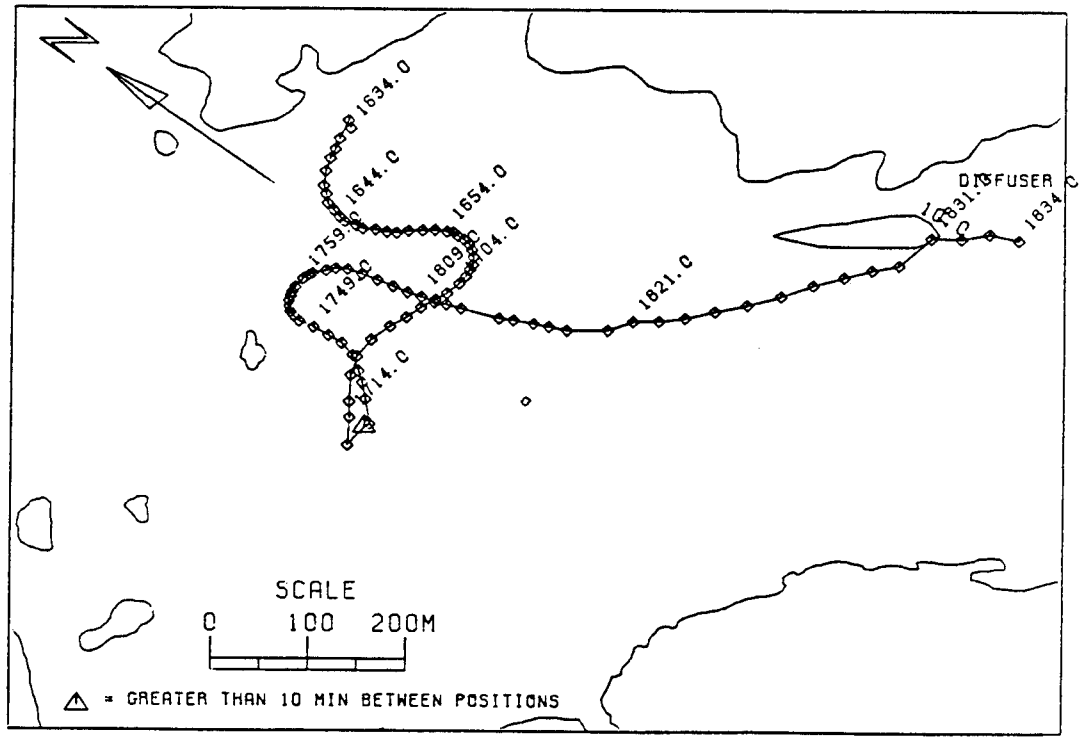
JAKOLOF BAY, FISH 39, CONTROL NO. 2, 7/24/88

Horizontal Movements of Fish Numbers 34 and 39 During Control 2

Figure 3-15

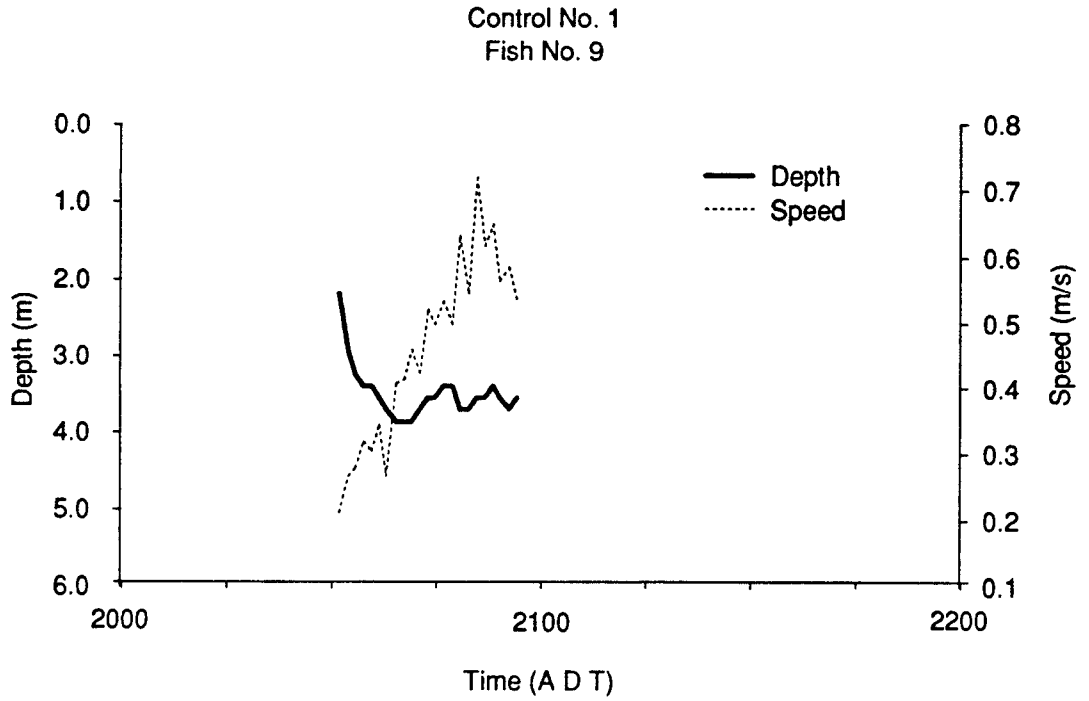


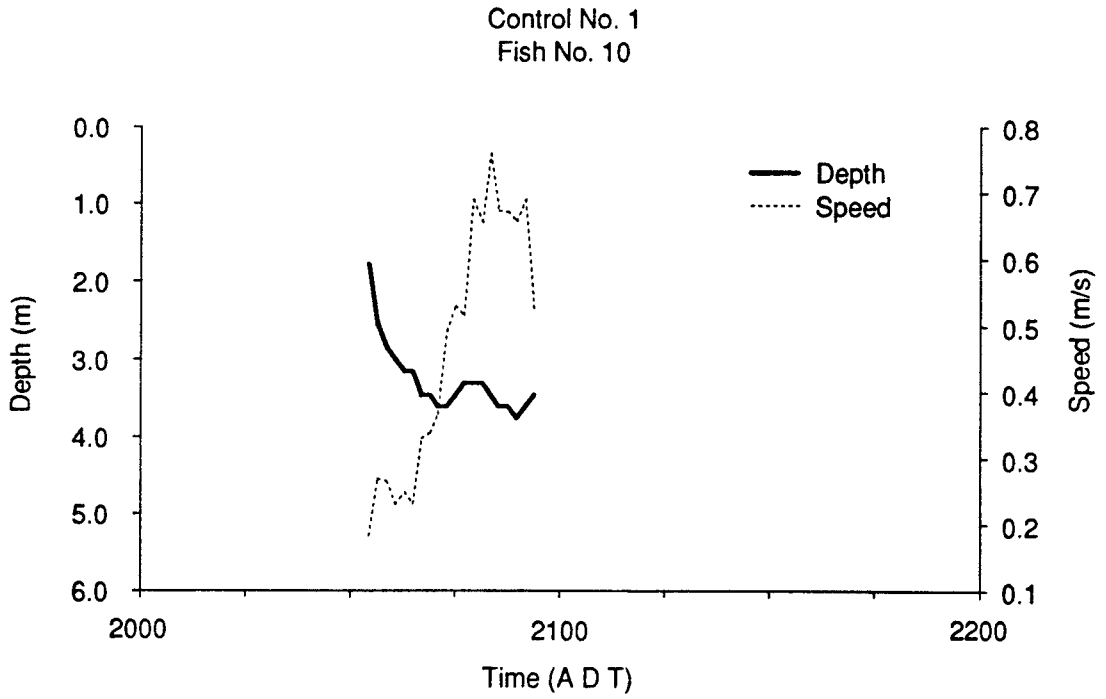
JAKOLOF BAY, FISH 58, CONTROL NO. 3, 7/28/88



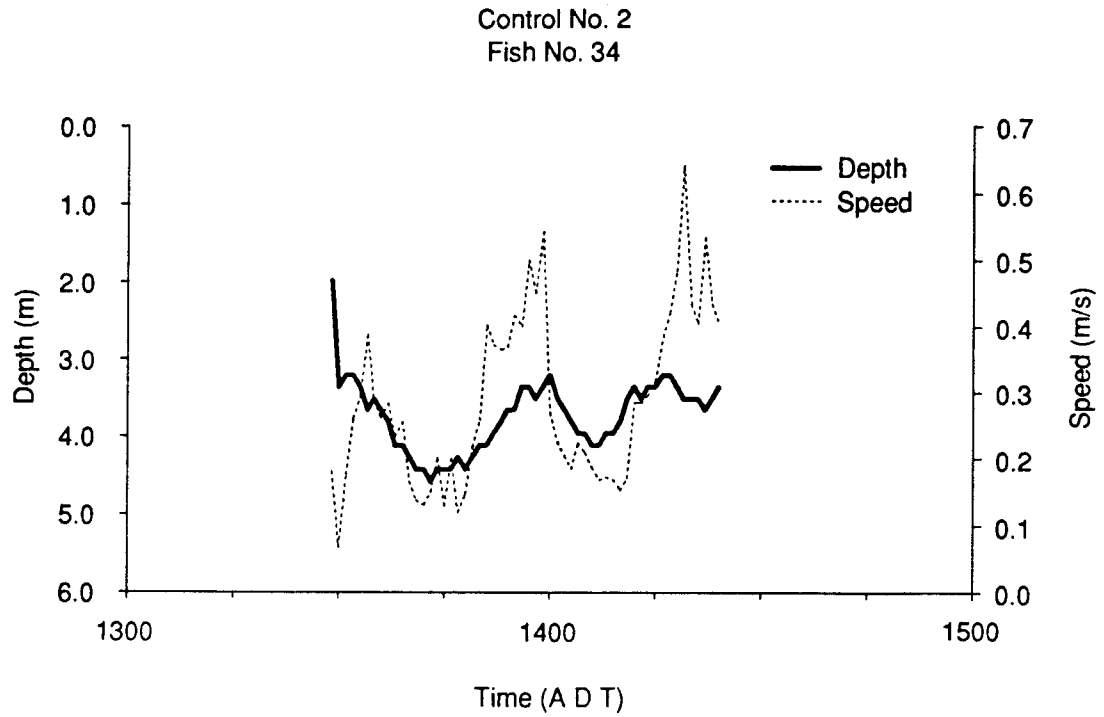
JAKOLOF BAY, FISH 72, CONTROL NO. 3, 7/28/88

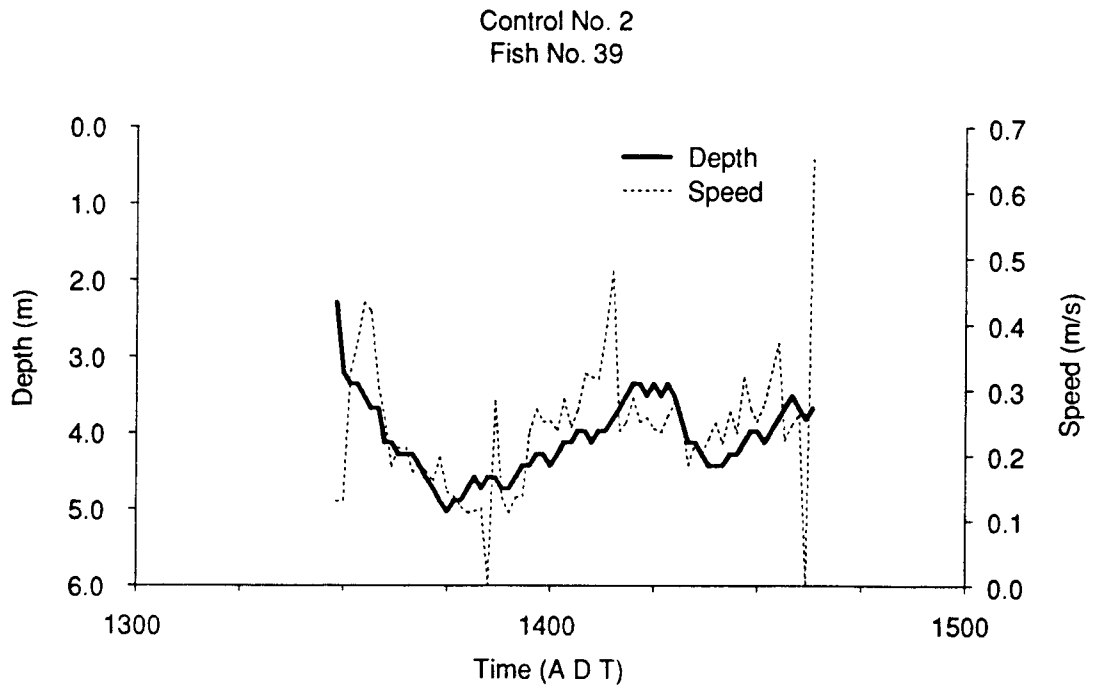
Horizontal Movements of Fish Numbers 58 and 72 During Control 3
Figure 3-16



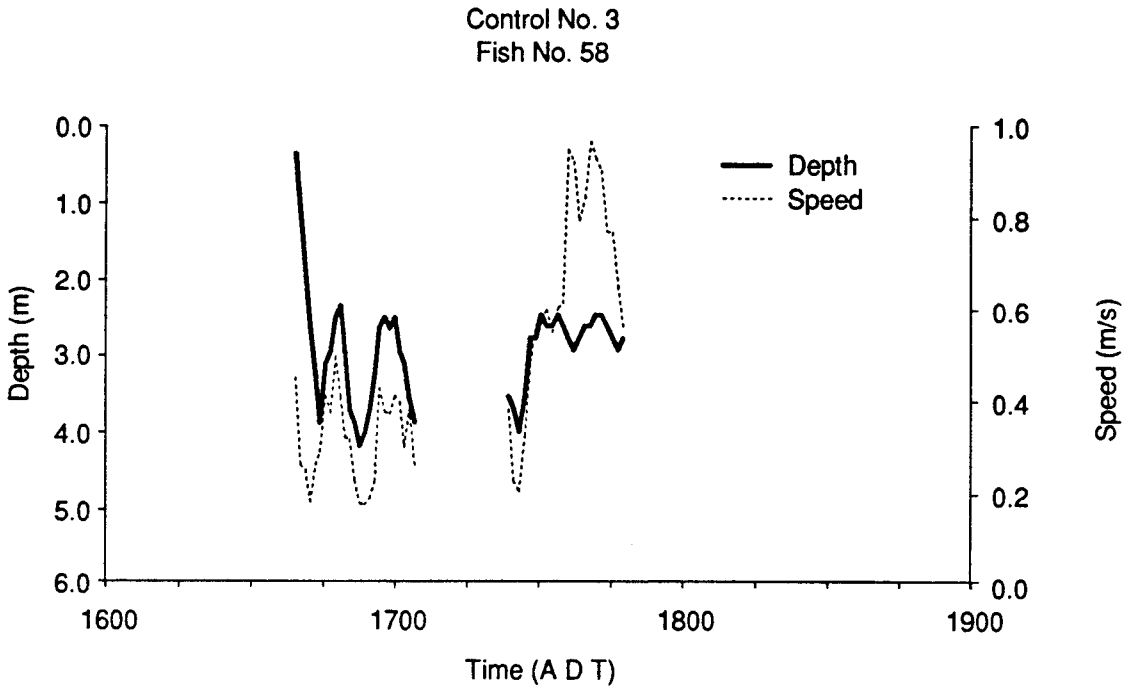


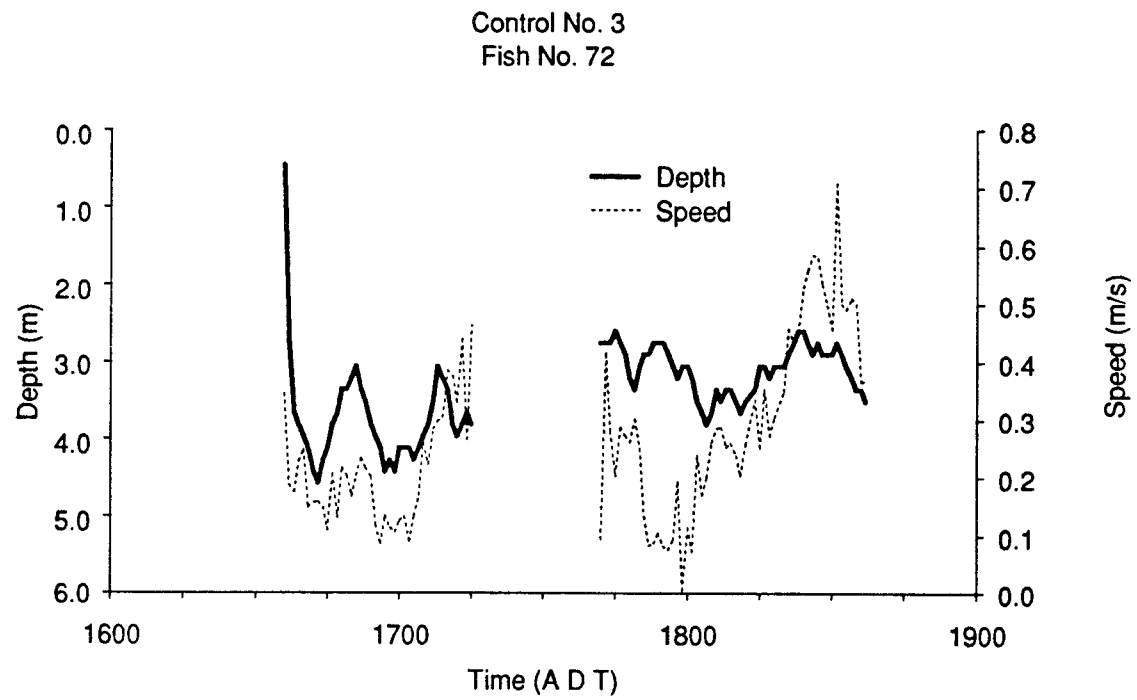
Depth and Ground Speed Versus Time for Fish Numbers 9 and 10 During Control 1
Figure 3-17



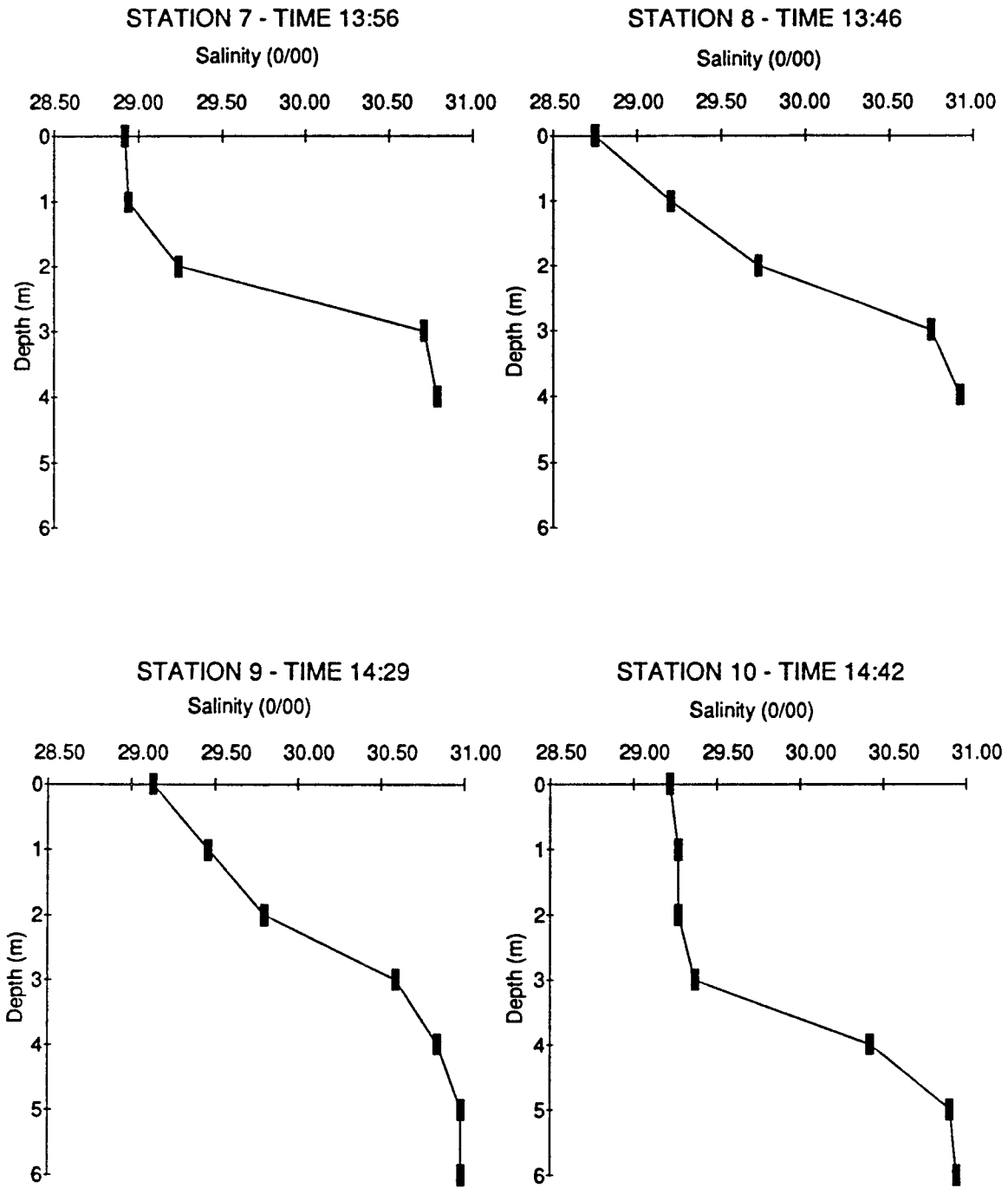


Depth and Ground Speed Versus Time for Fish Numbers 34 and 39 During Control 2
Figure 3-18

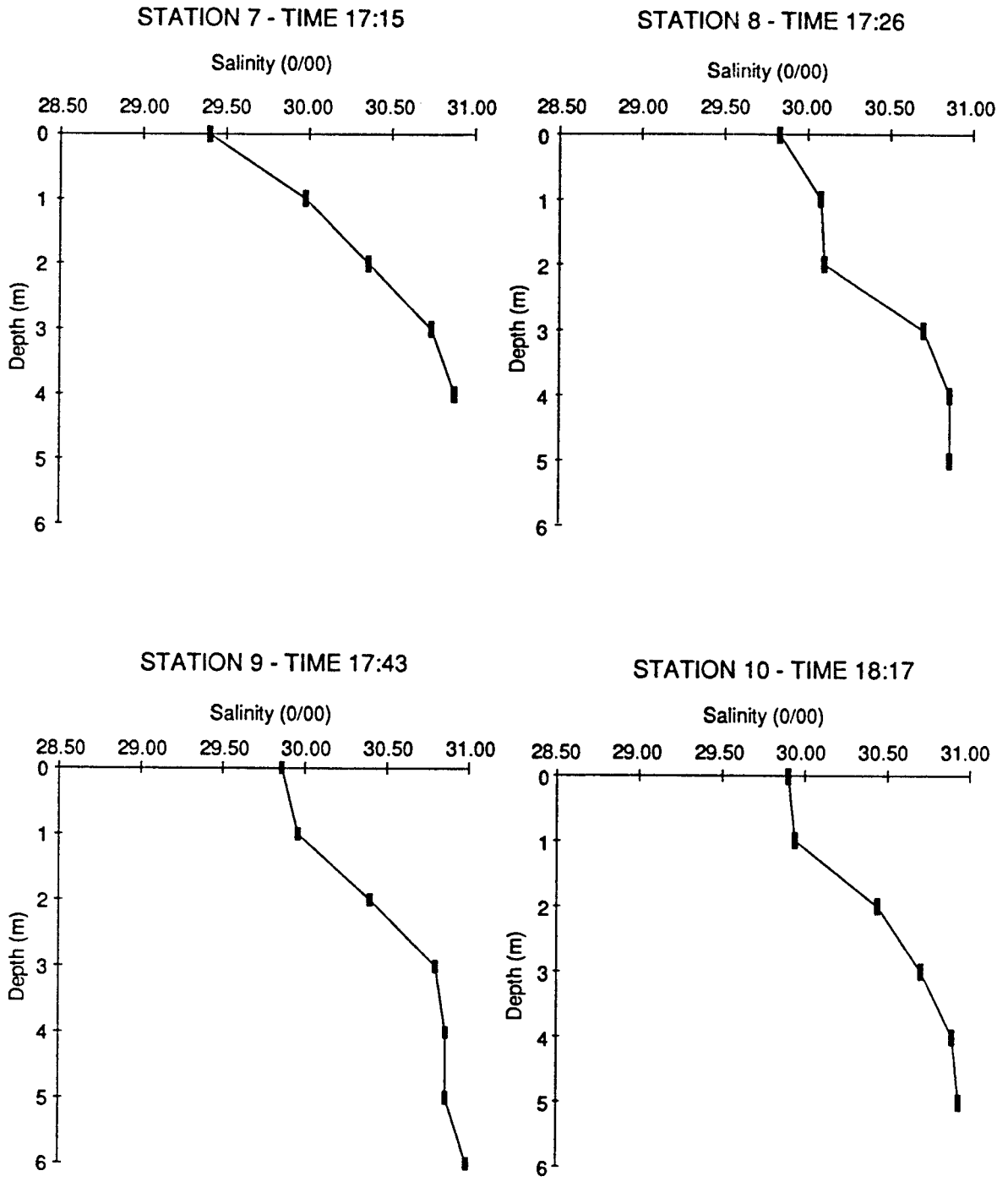




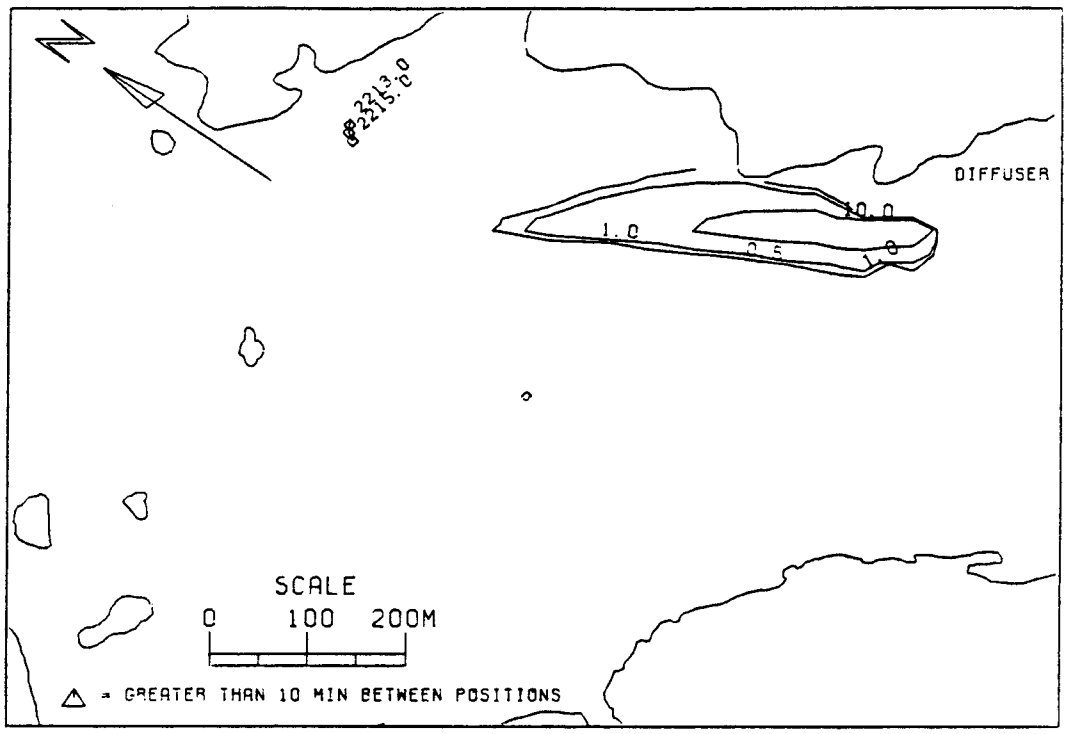
Depth and Ground Speed Versus Time for Fish Numbers 58 and 72 During Control 3
Figure 3-19



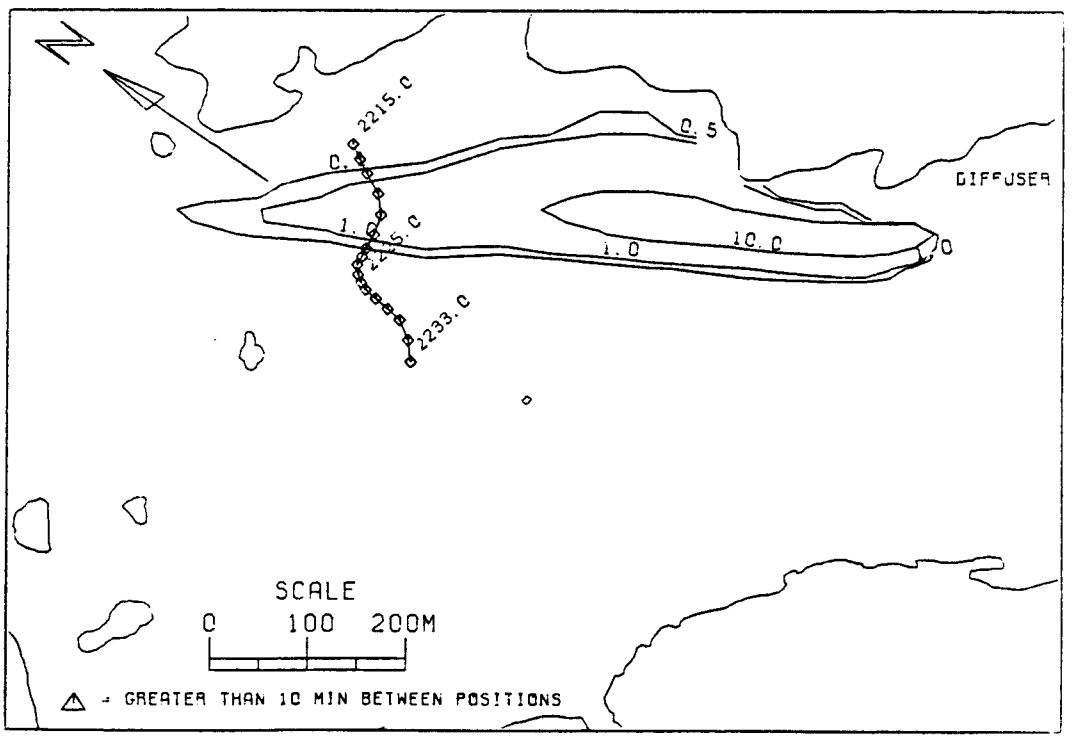
Salinity Profile with Depth for Control 2
Figure 3-20



Salinity Profile with Depth for Control 3
Figure 3-21

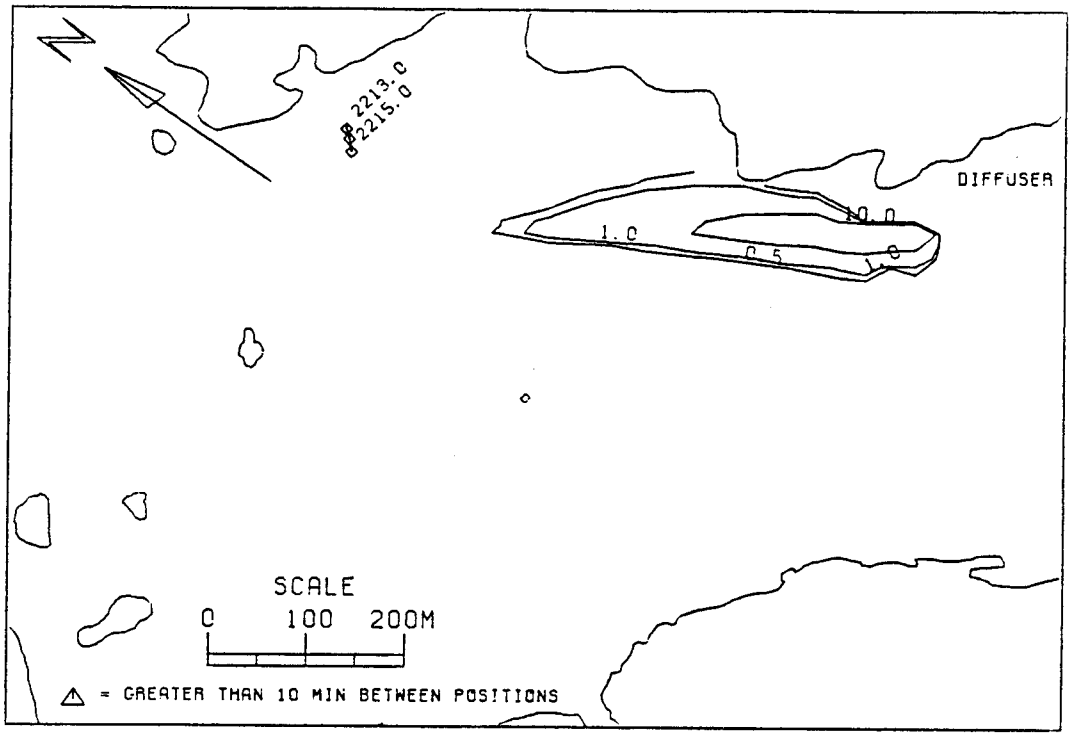


FISH 19, TREATMENT NO. 1, PLUME AT 22:00

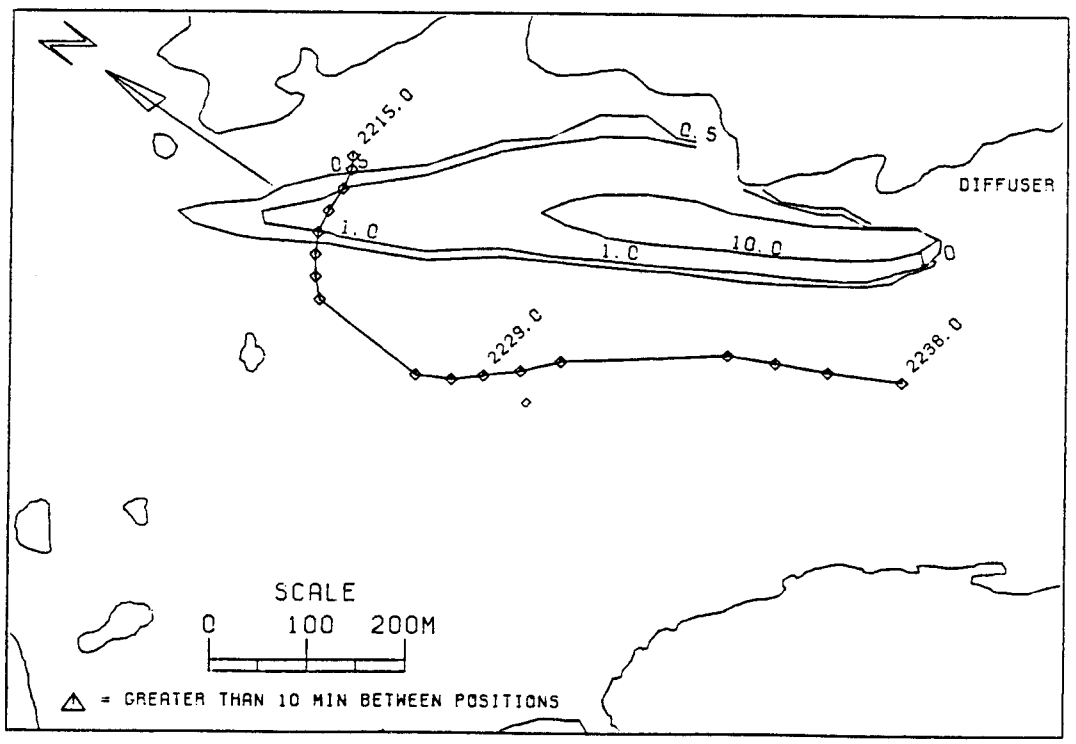


FISH 19, TREATMENT NO. 1, PLUME AT 22:30

Horizontal Movements of Fish Number 19 and Plume Trajectories at Time Intervals During Treatment 1
Figure 3-22

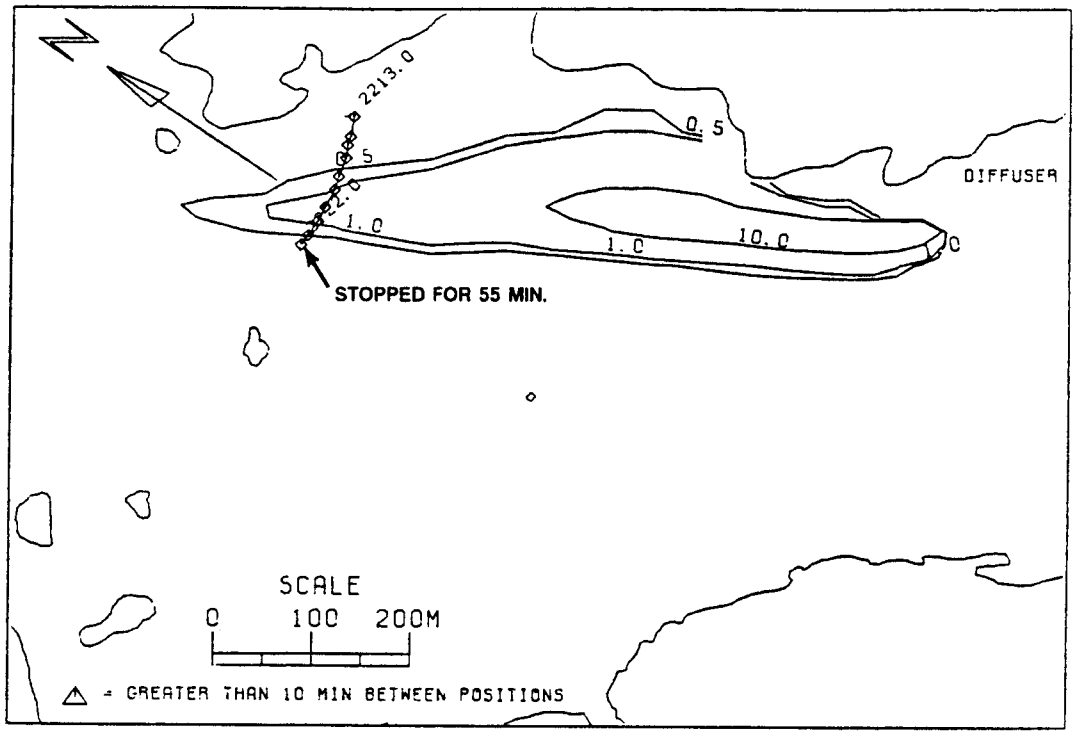


FISH 18, TREATMENT NO. 1, PLUME AT 22:00

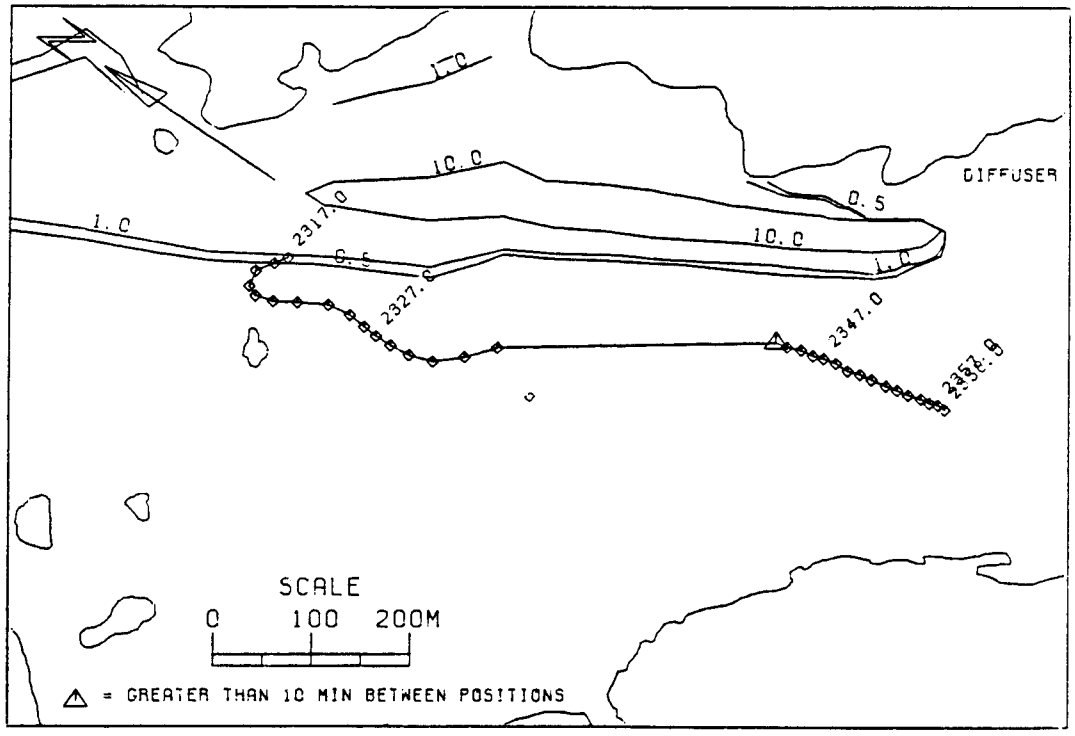


FISH 18, TREATMENT NO. 1, PLUME AT 22:30

Horizontal Movements of Fish Number 18 and Plume Trajectories at Time Intervals During Treatment 1
Figure 3-23

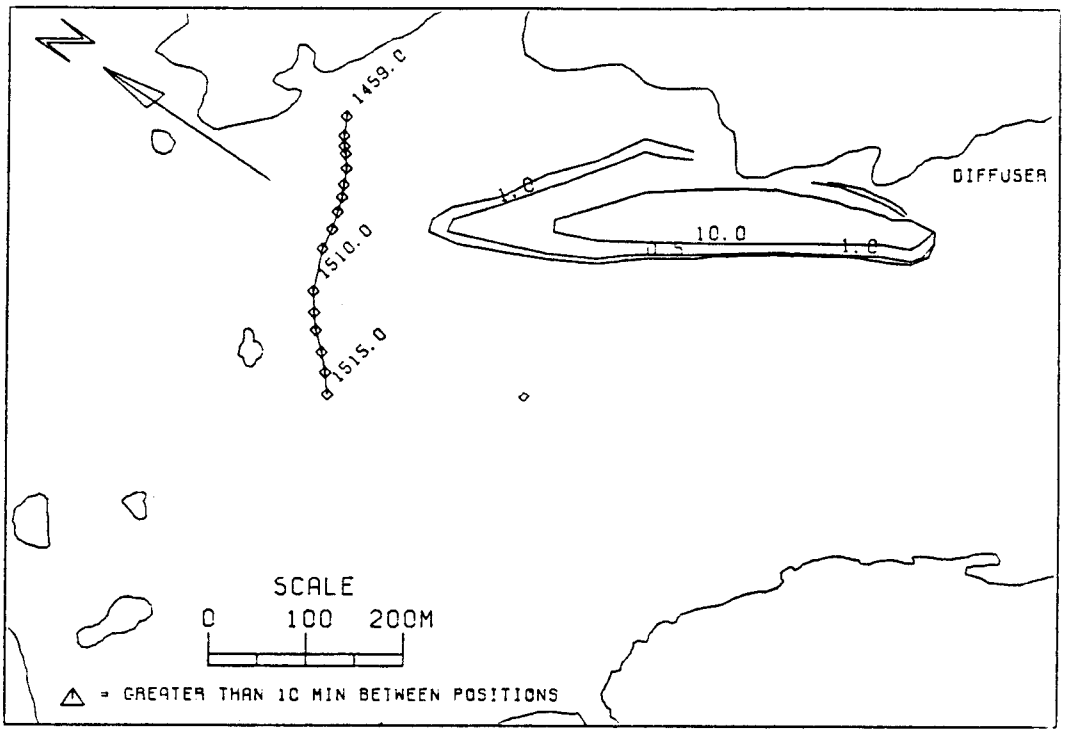


FISH 14. TREATMENT NO. 1, PLUME AT 22:30

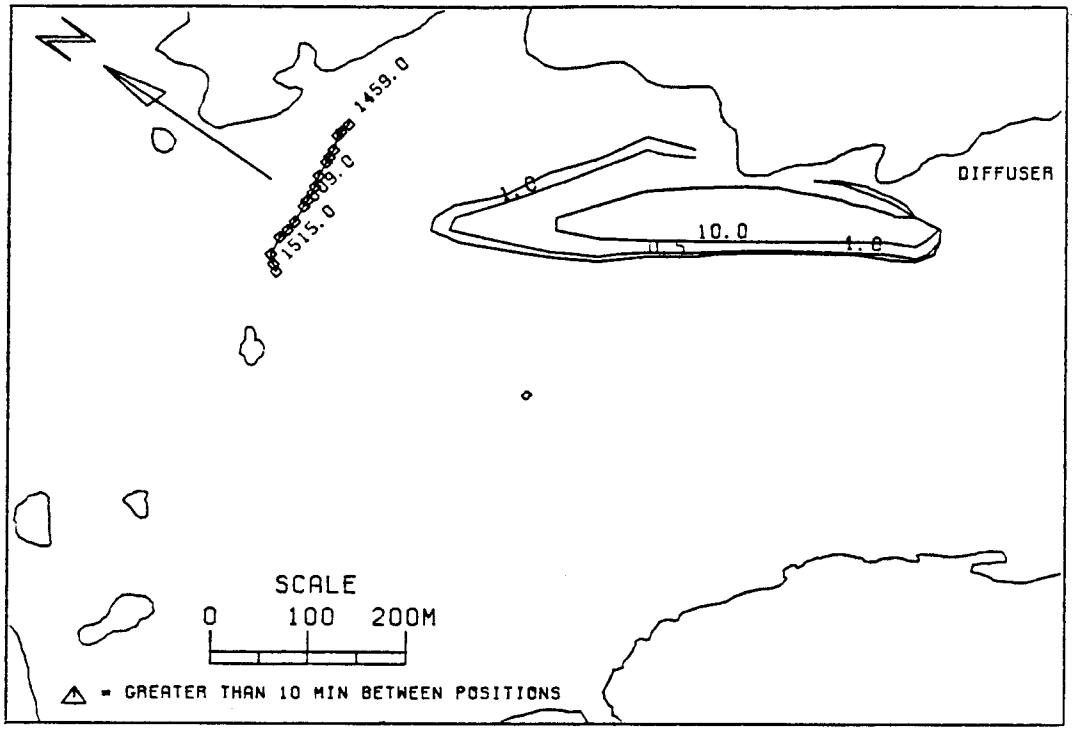


FISH 14. TREATMENT NO. 1, PLUME AT 23:30

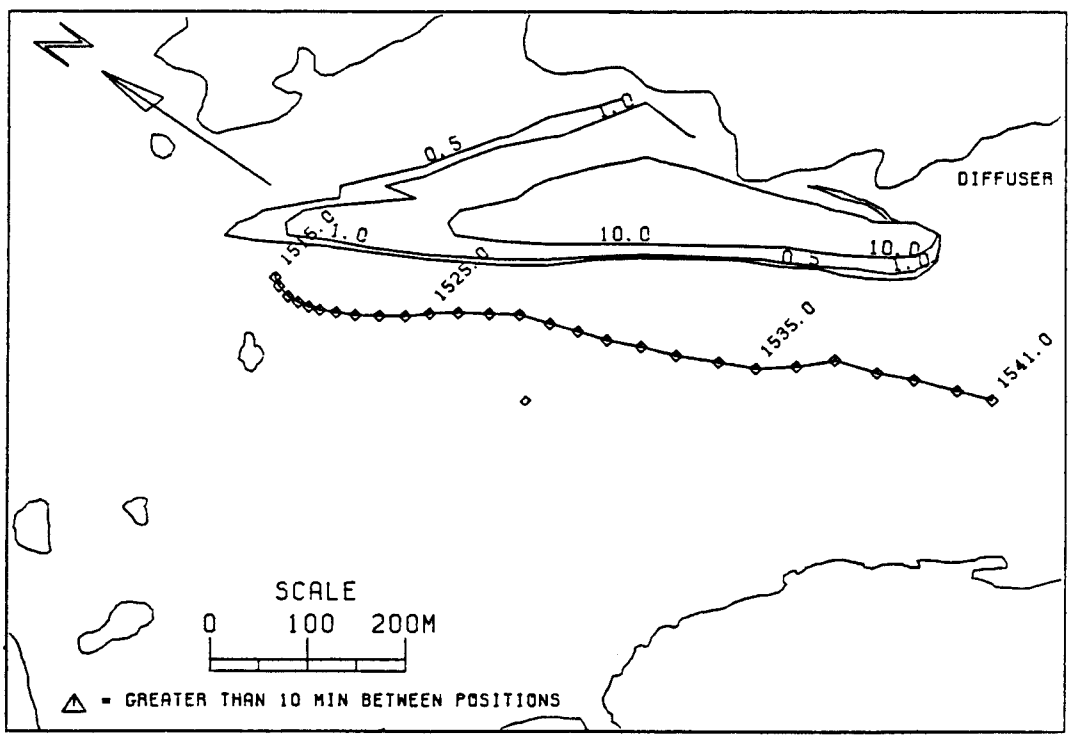
Horizontal Movements of Fish Number 14 and Plume Trajectories at Time Intervals During Treatment 1
Figure 3-24



Horizontal Movements of Fish Number 51 and Plume Trajectories at Time Intervals During Treatment 2
Figure 3-25

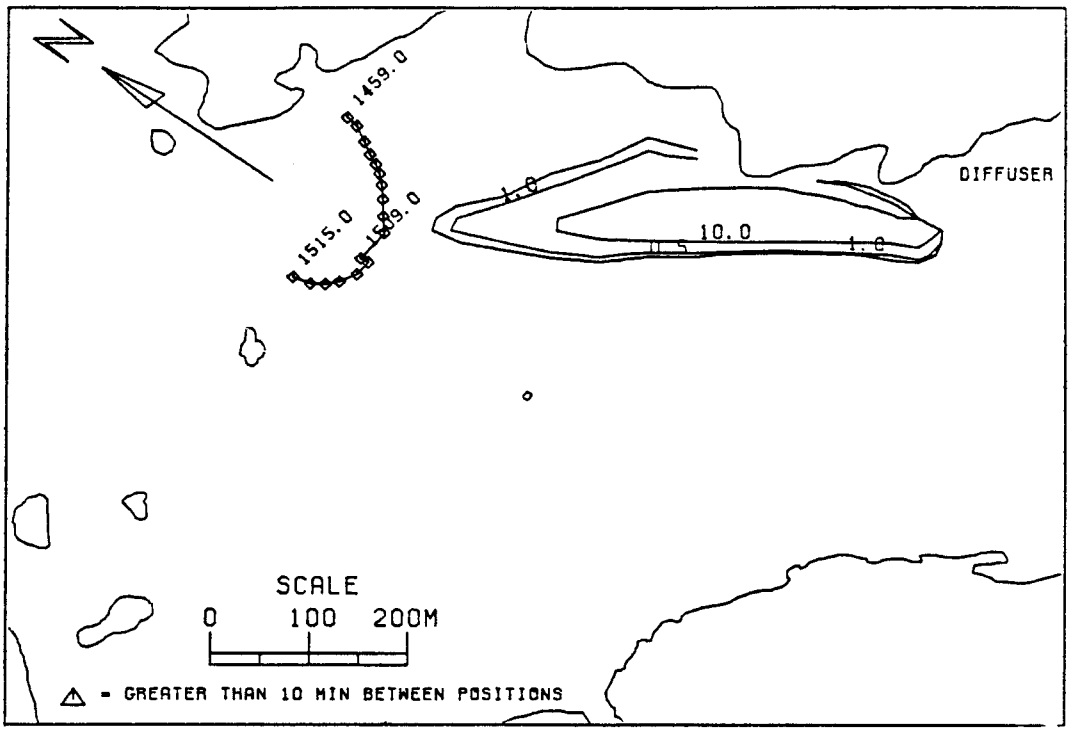


FISH 52, TREATMENT NO. 2, PLUME AT 15:00

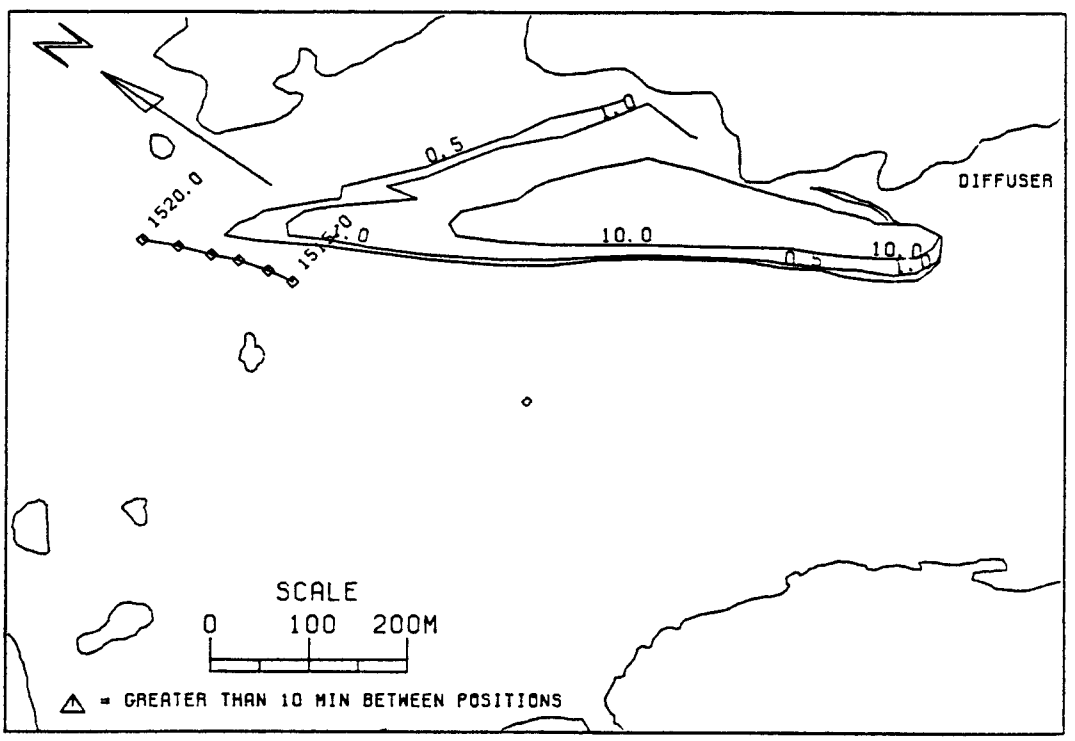


FISH 52, TREATMENT NO. 2, PLUME AT 15:30

Horizontal Movements of Fish Number 52 and Plume Trajectories at Time Intervals During Treatment 2
Figure 3-26

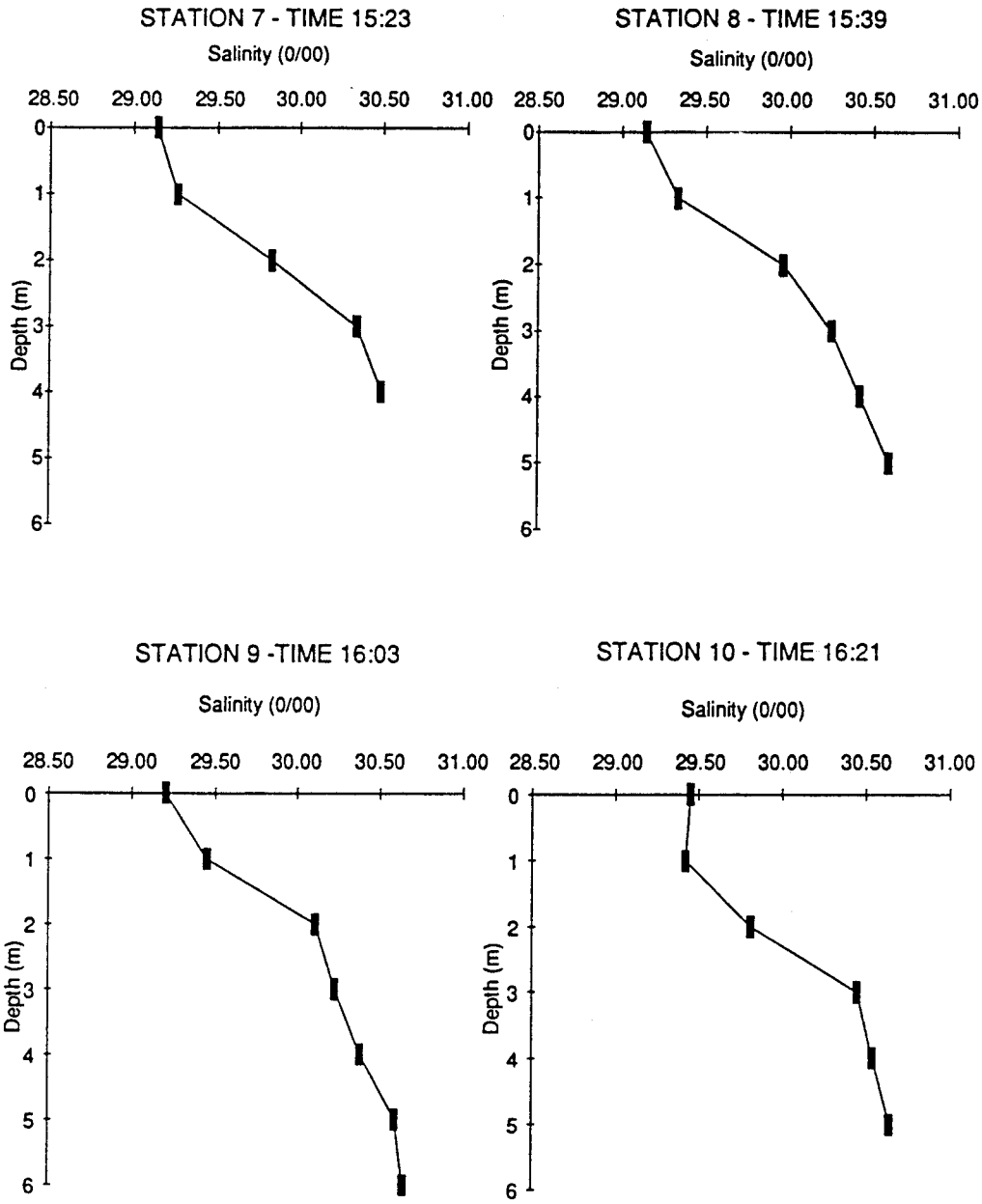


FISH 48, TREATMENT NO. 2, PLUME AT 15:00

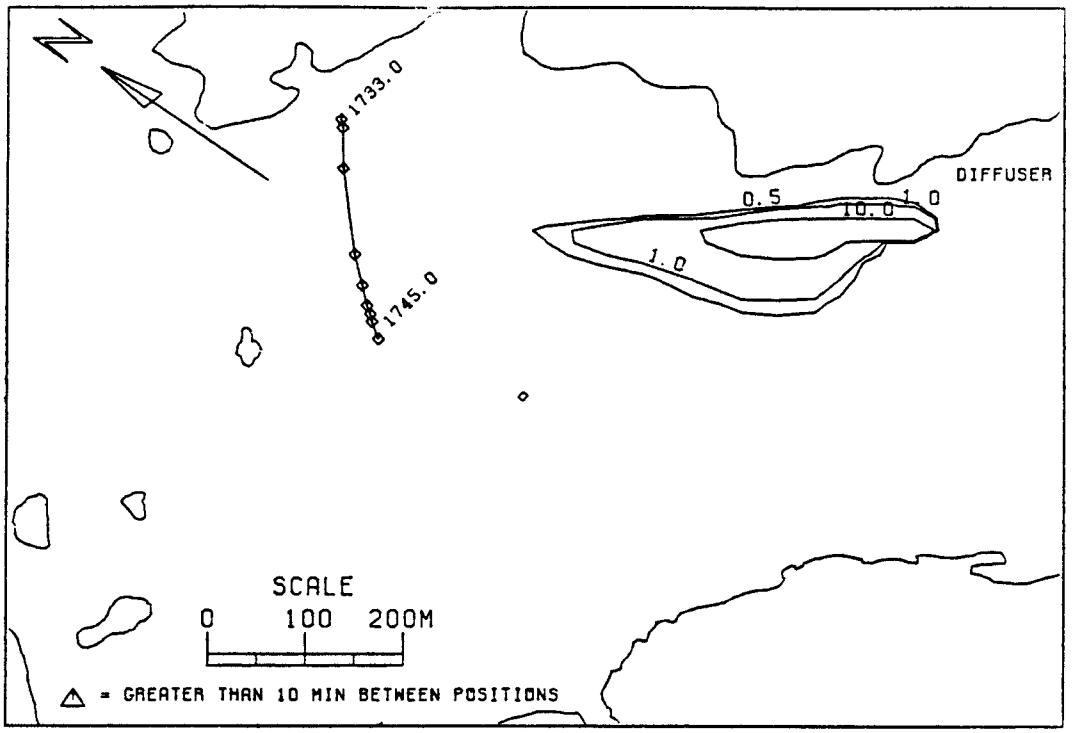


FISH 48, TREATMENT NO. 2, PLUME AT 15:30

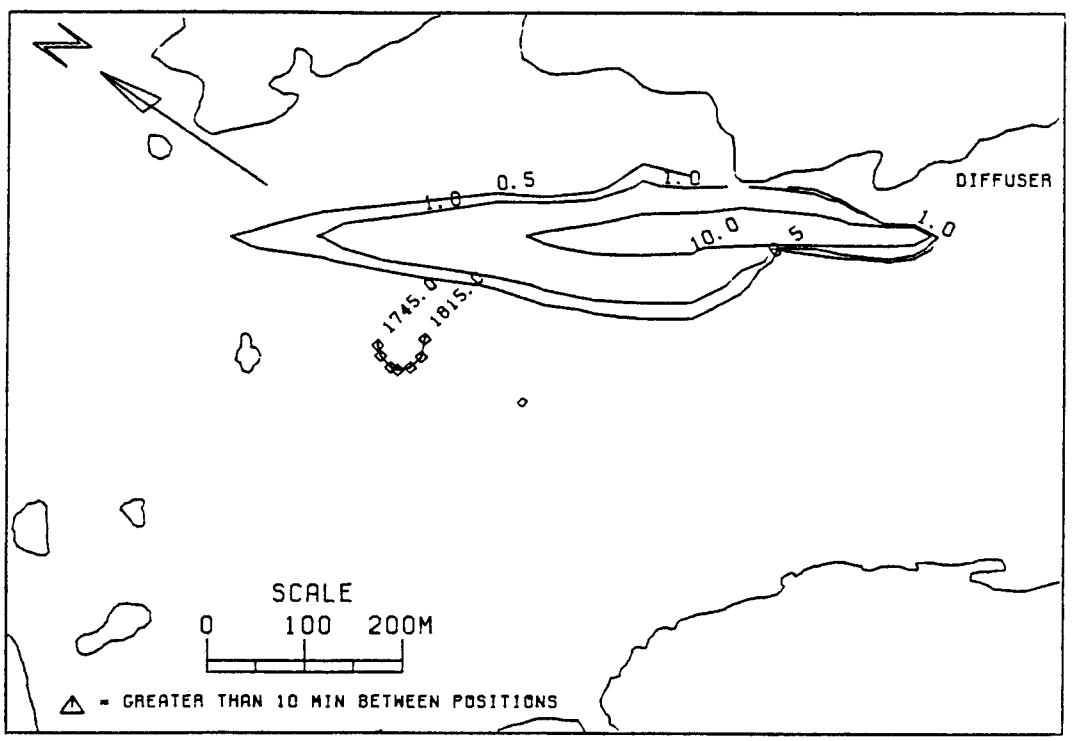
Horizontal Movements of Fish Number 48 and Plume Trajectories at Time Intervals During Treatment 2
Figure 3-27



Salinity Profile with Depth for Treatment 2
Figure 3-28

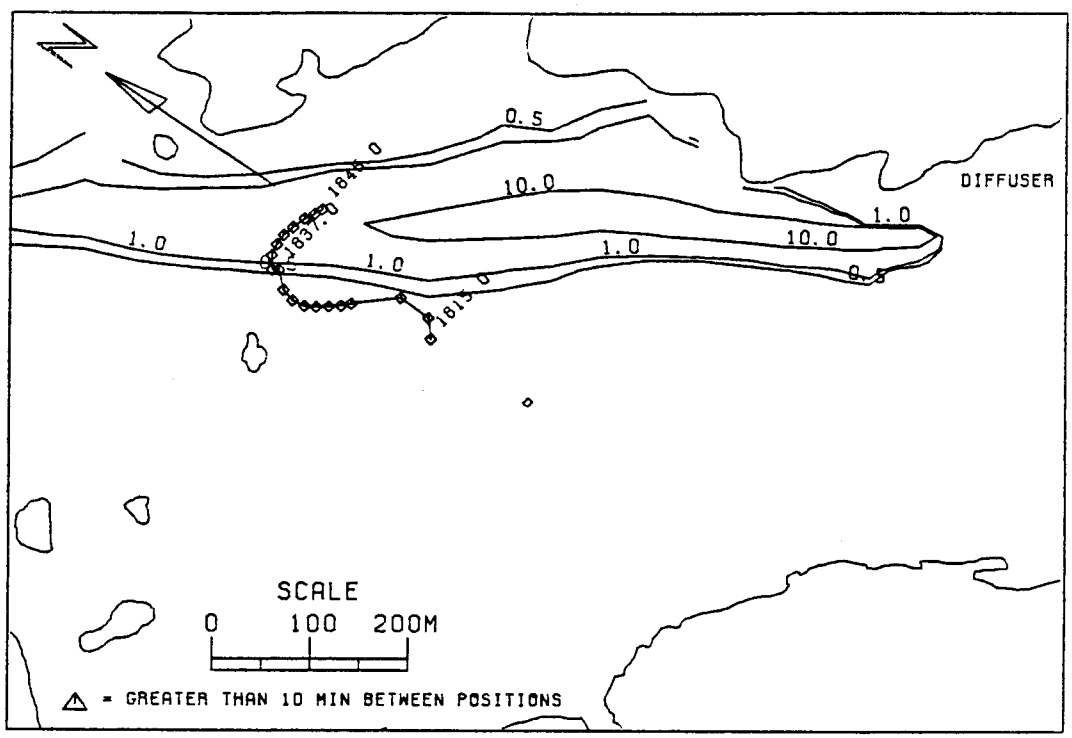


FISH 73, TREATMENT NO. 3, PLUME AT 17:30

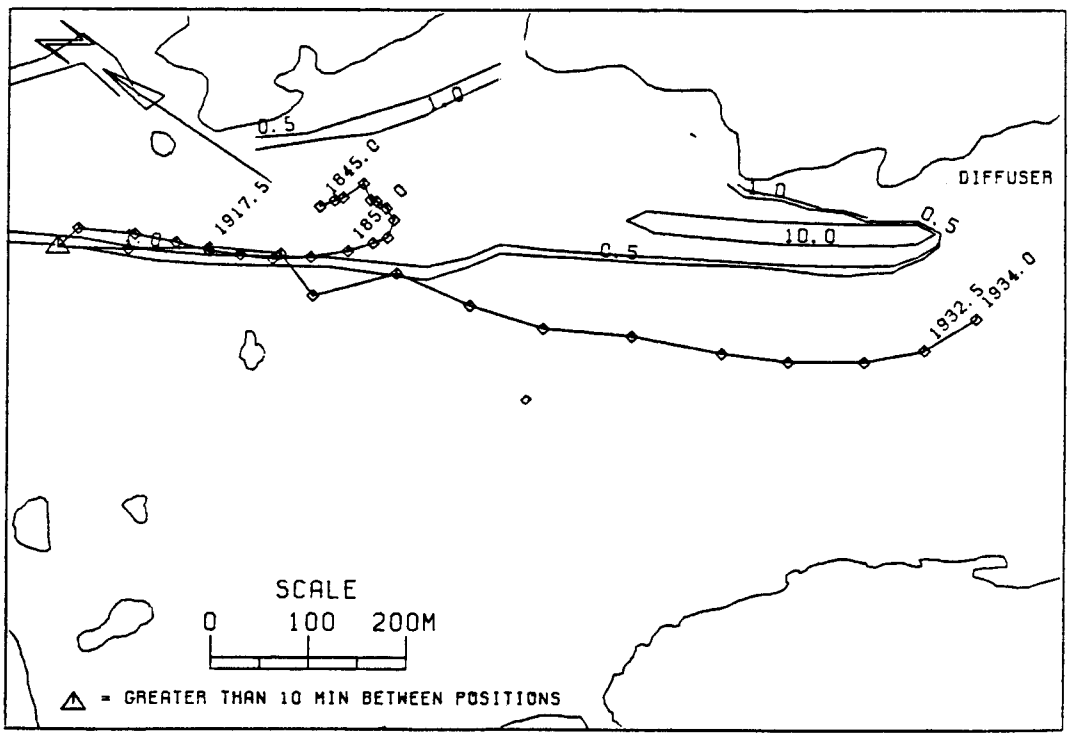


FISH 73, TREATMENT NO. 3, PLUME AT 18:00

Horizontal Movements of Fish Number 73 and Plume Trajectories at Time Intervals During Treatment 3
Figure 3-29

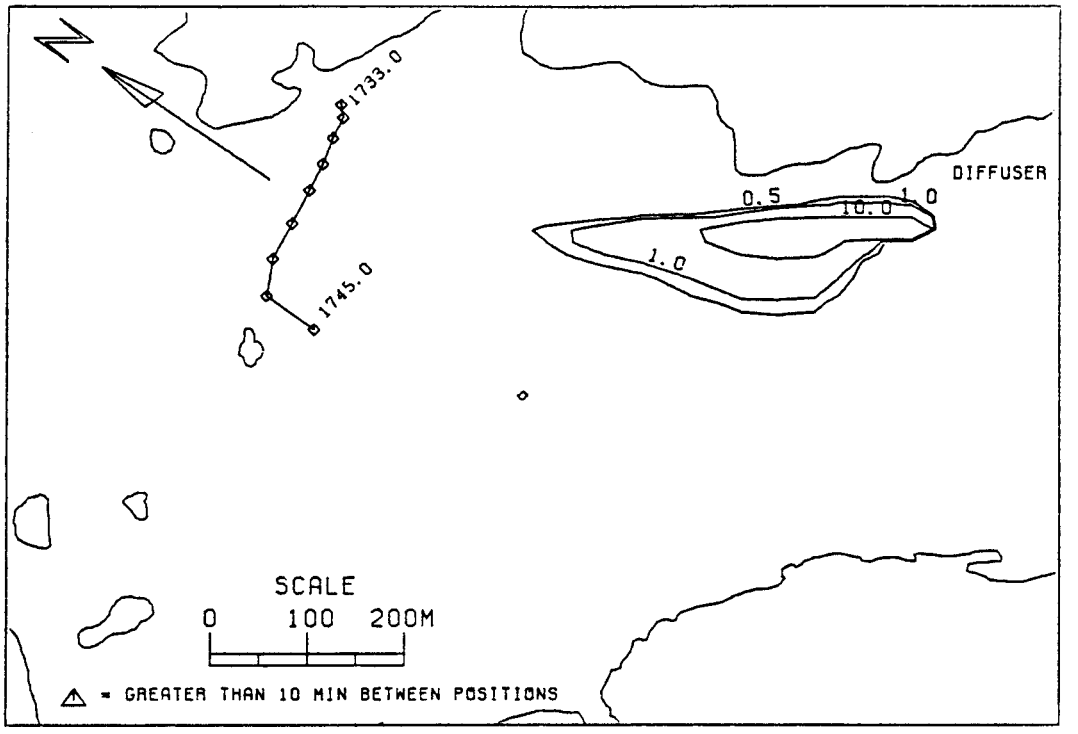


FISH 73, TREATMENT NO. 3, PLUME AT 18:30

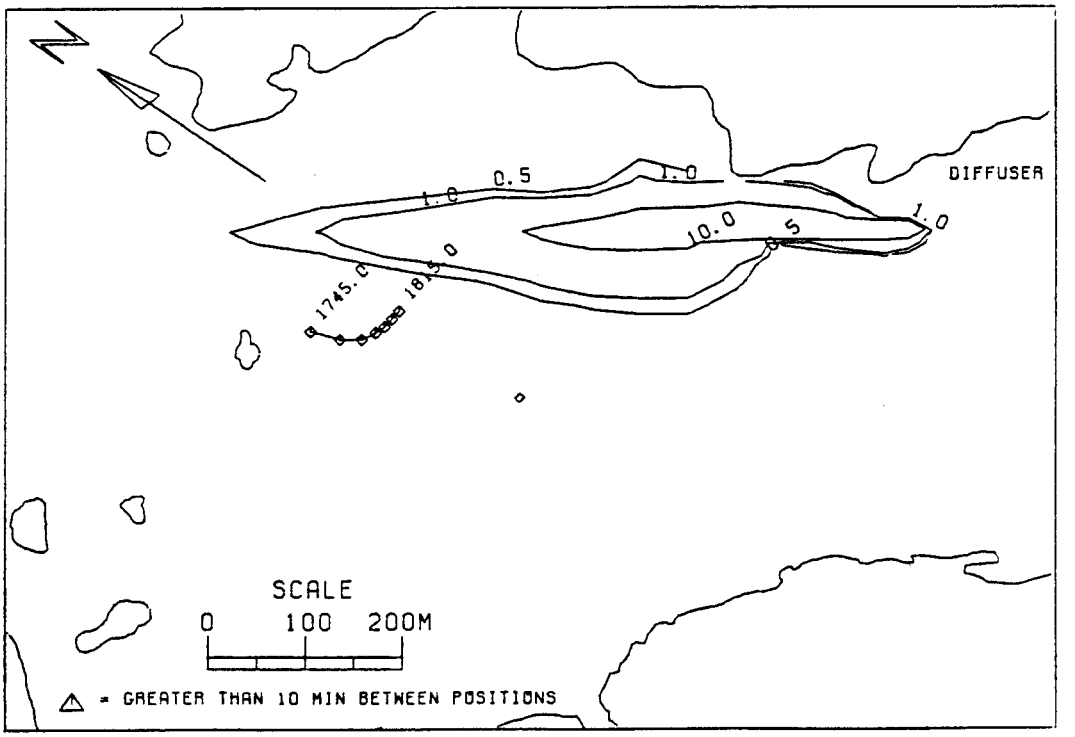


FISH 73, TREATMENT NO. 3, PLUME AT 19:00

Horizontal Movements of Fish Number 73 and Plume Trajectories at Time Intervals During Treatment 3
Figure 3-29 (continued)

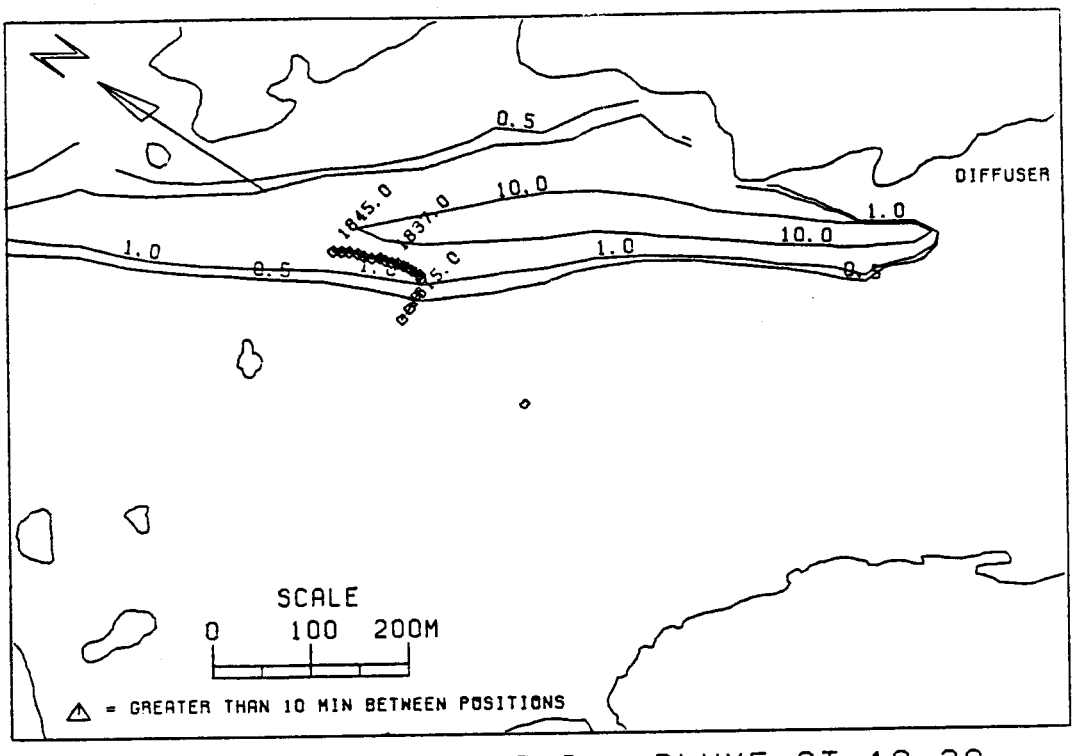


FISH 88, TREATMENT NO. 3, PLUME AT 17:30

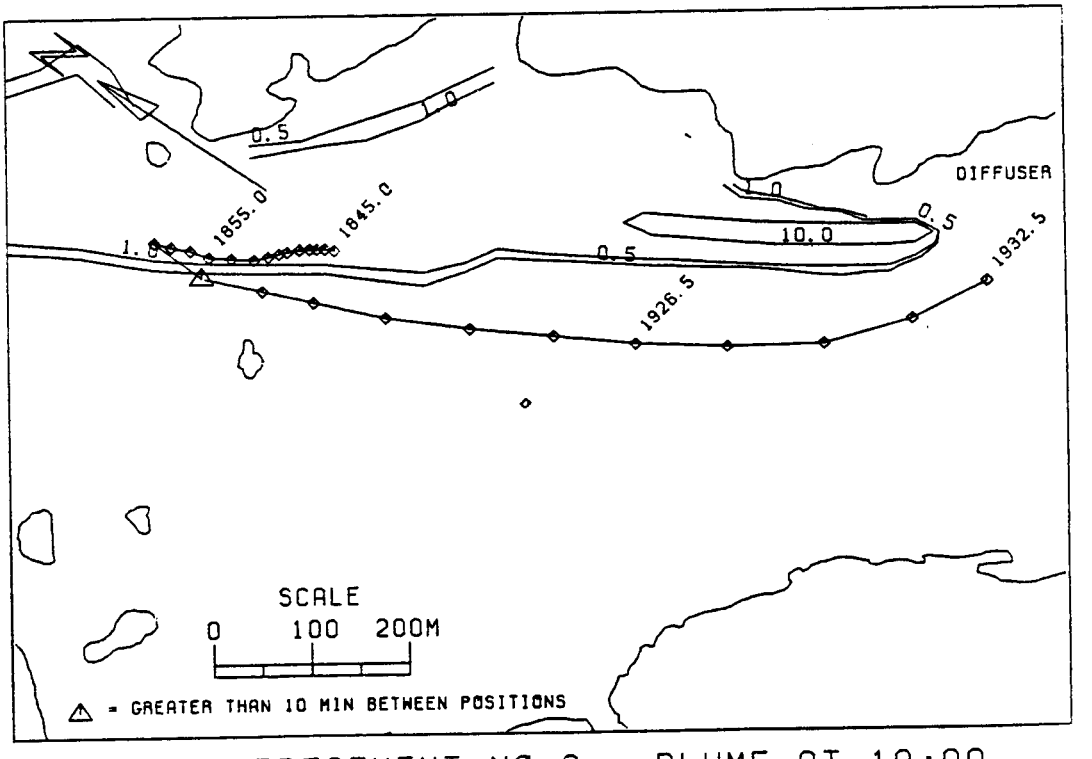


FISH 88, TREATMENT NO. 3, PLUME AT 18:00

Horizontal Movements of Fish Number 88 and Plume Trajectories at Time Intervals During Treatment 3
Figure 3-30

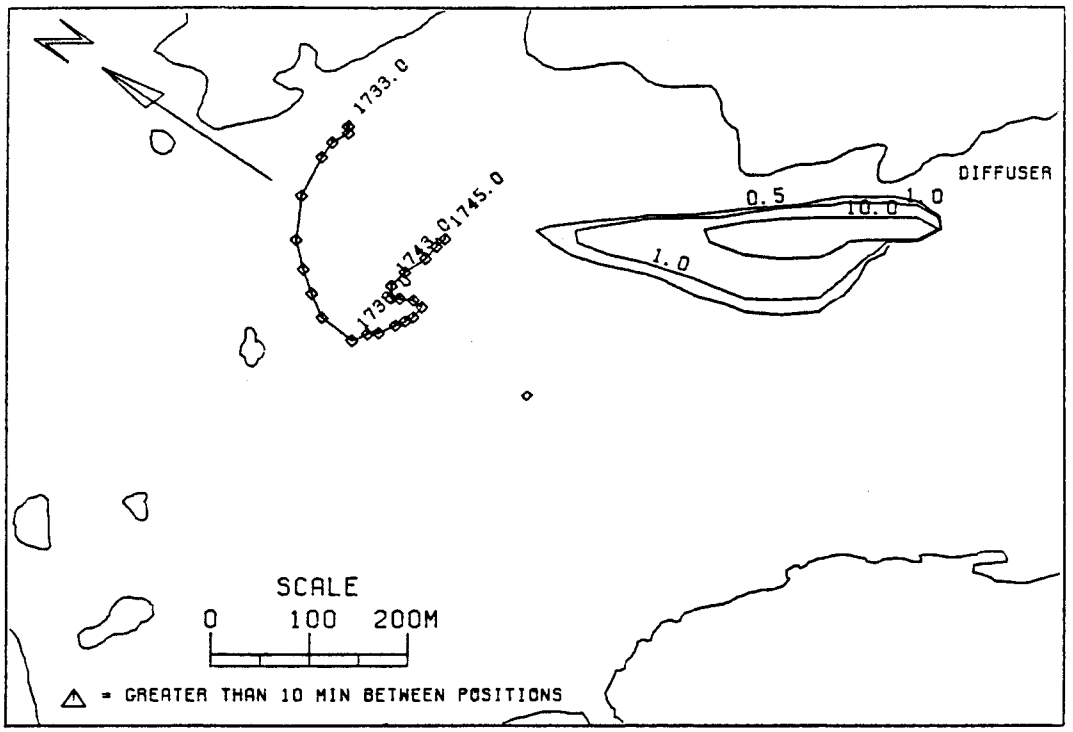


FISH 88, TREATMENT NO. 3, PLUME AT 18:30

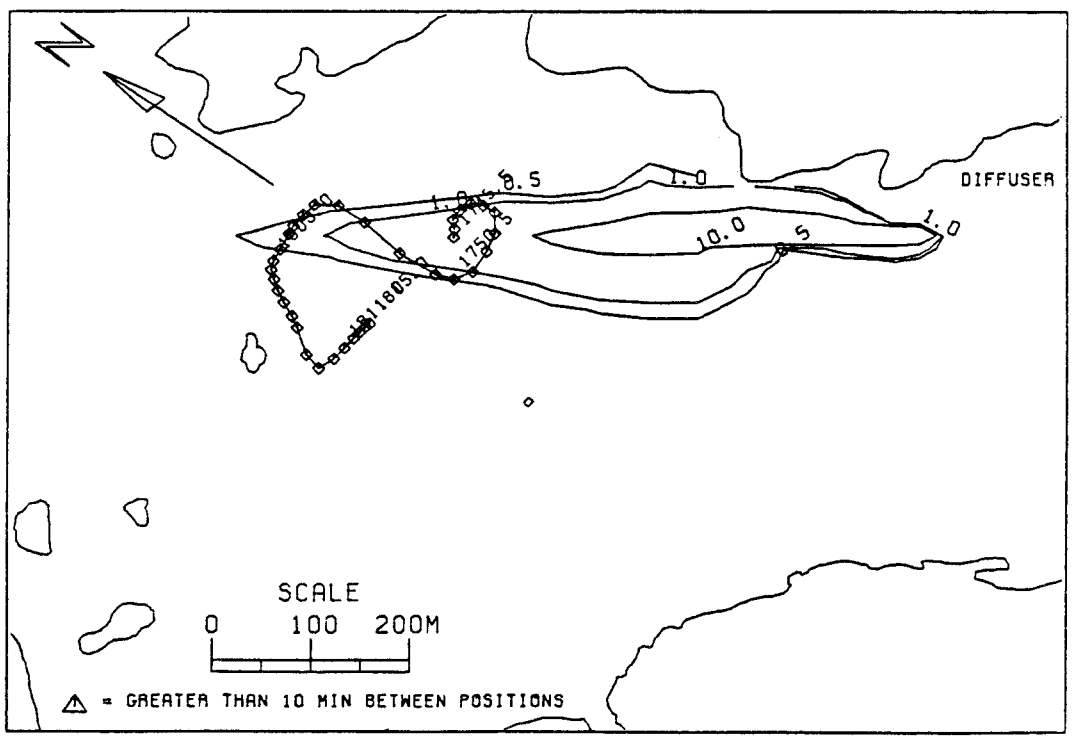


FISH 88, TREATMENT NO. 3, PLUME AT 19:00

Horizontal Movements of Fish Number 88 and Plume Trajectories at Time Intervals During Treatment 3
Figure 3-30 (continued)

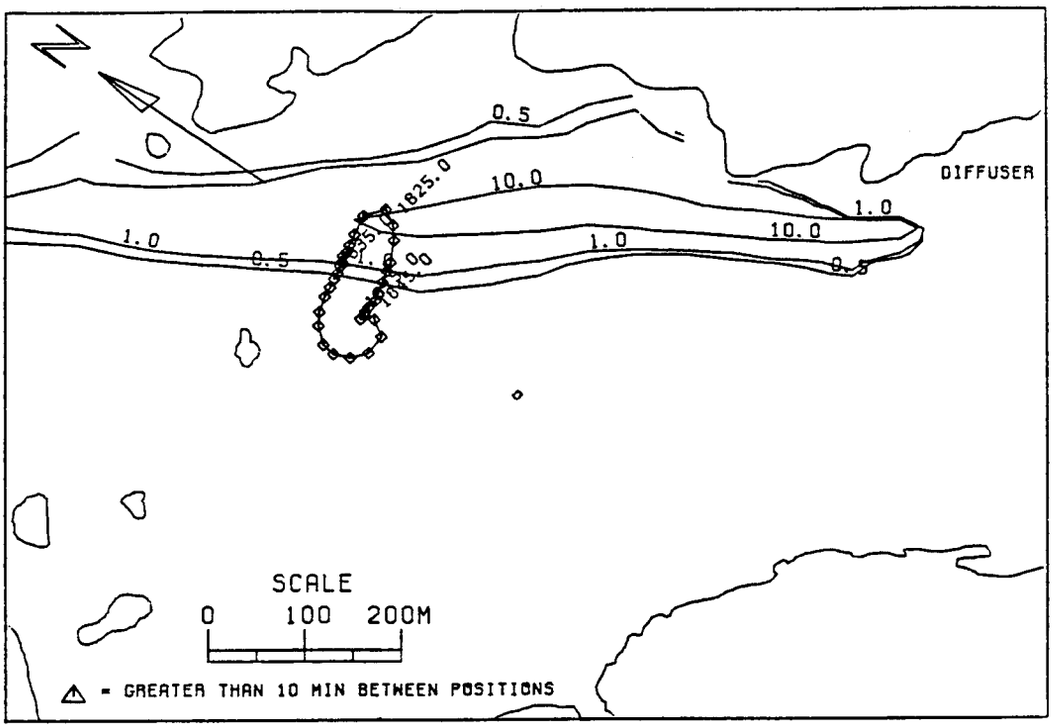


FISH 83, TREATMENT NO. 3, PLUME AT 17:30

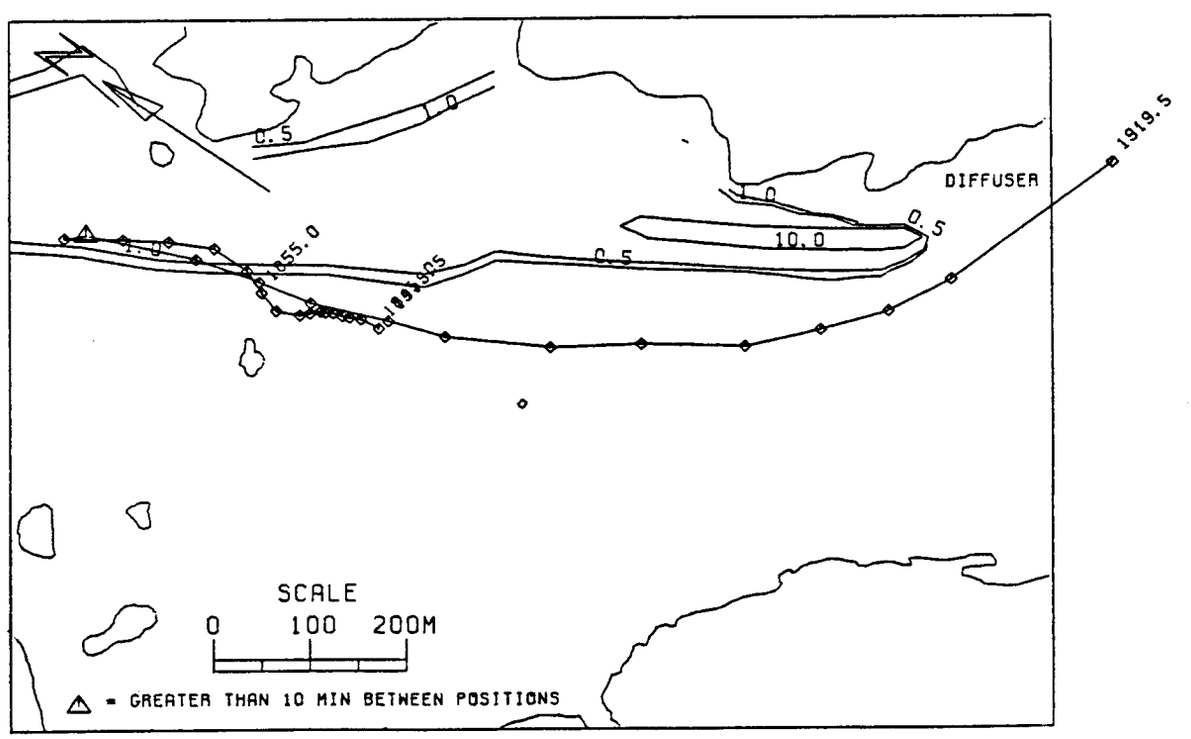


FISH 83, TREATMENT NO. 3, PLUME AT 18:00

Horizontal Movements of Fish Number 83 and Plume Trajectories at Time Intervals During Treatment 3
Figure 3-31

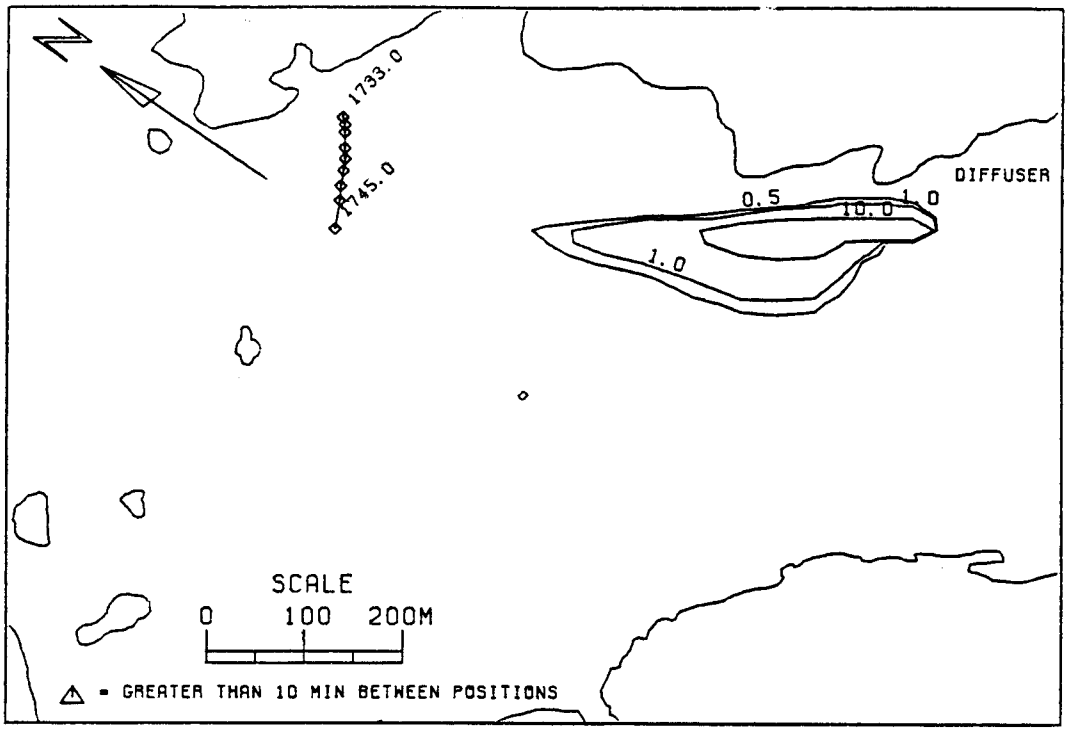


FISH 83, TREATMENT NO. 3, PLUME AT 18:30

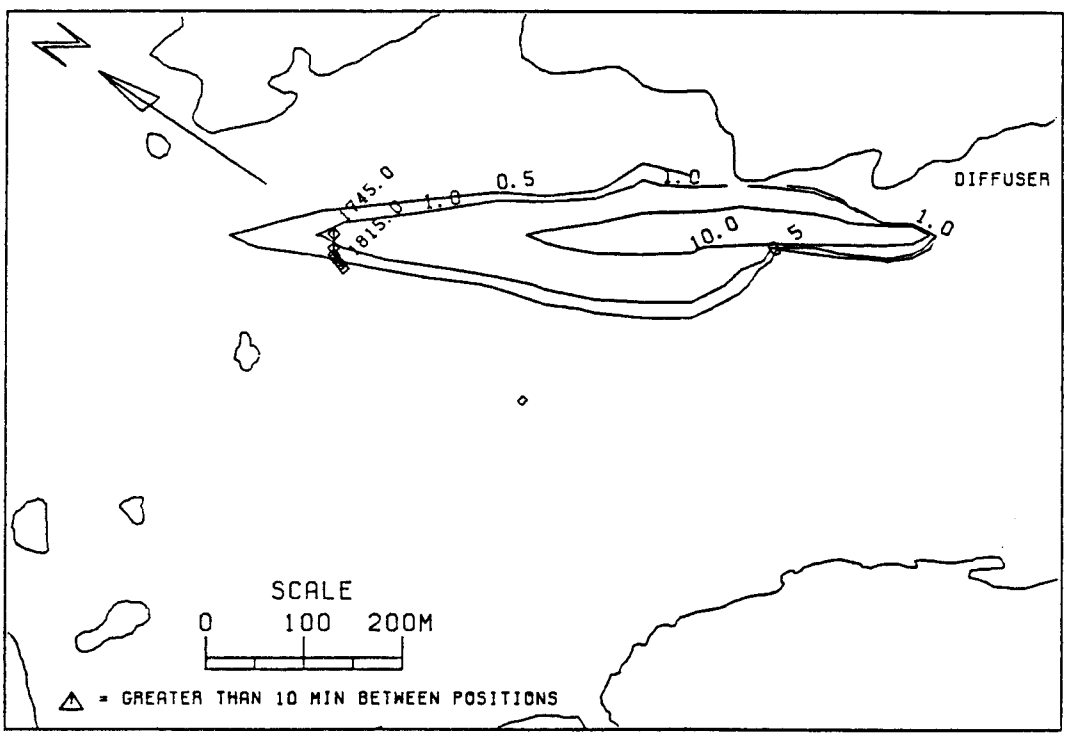


FISH 83, TREATMENT NO. 3, PLUME AT 19:00

Horizontal Movements of Fish Number 83 and Plume Trajectories at Time Intervals During Treatment 3
Figure 3-31 (continued)

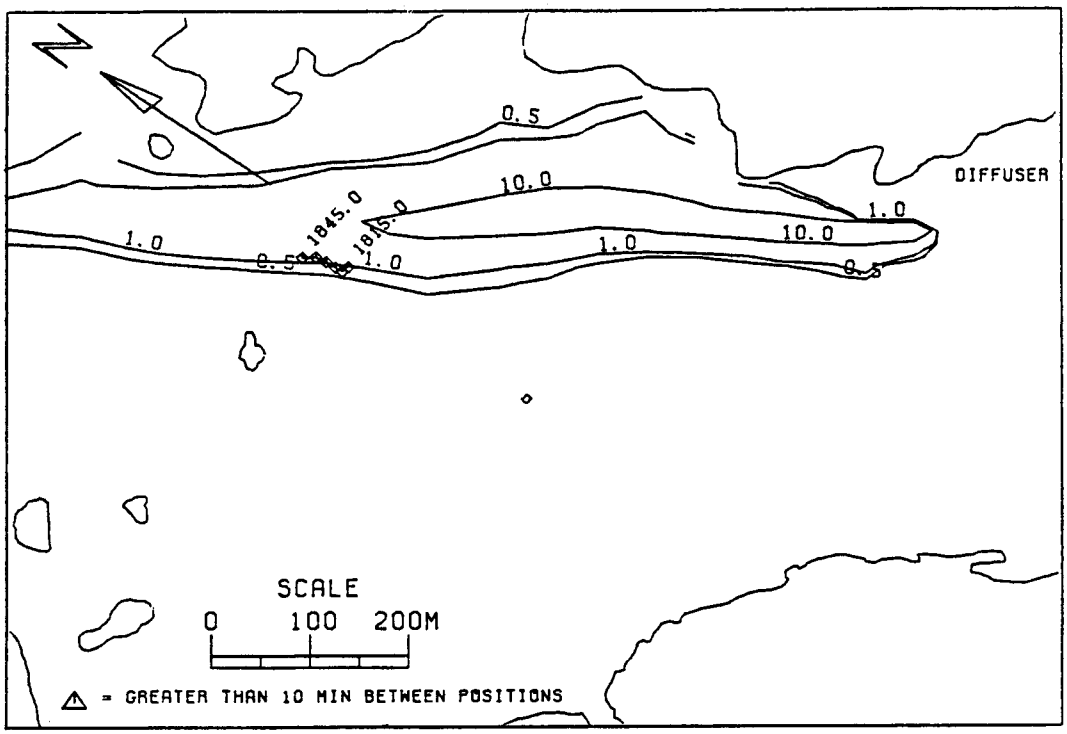


FISH 77, TREATMENT NO. 3, PLUME AT 17:30

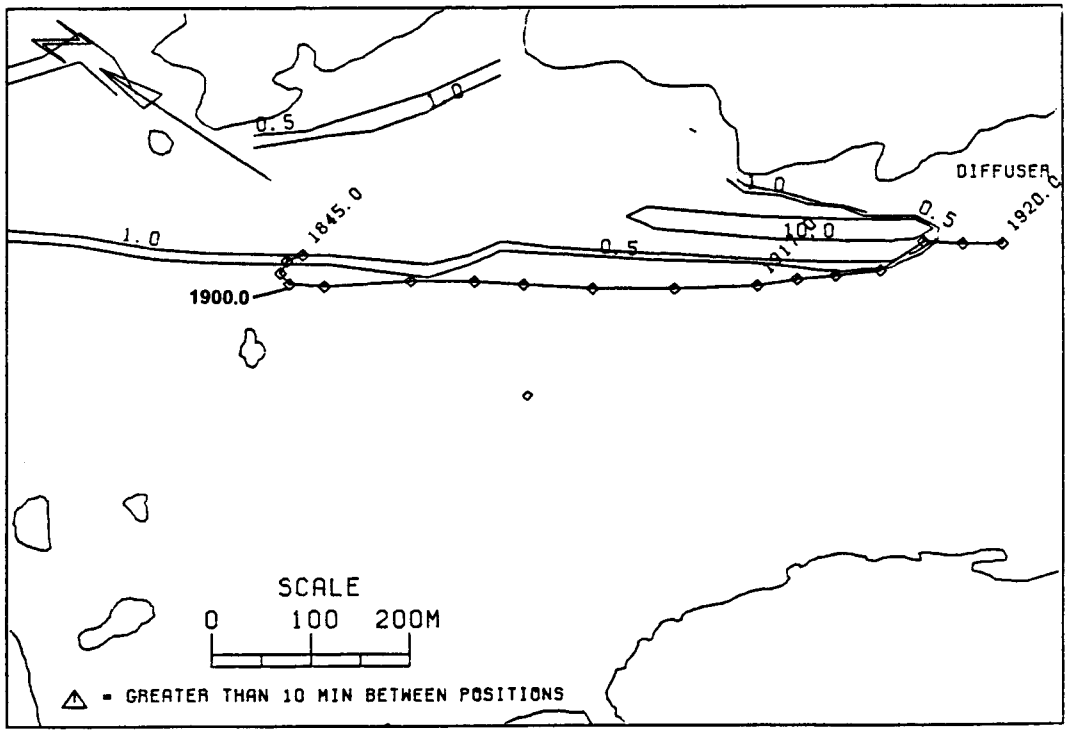


FISH 77, TREATMENT NO. 3, PLUME AT 18:00

Horizontal Movements of Fish Number 77 and Plume Trajectories at Time Intervals During Treatment 3
Figure 3-32

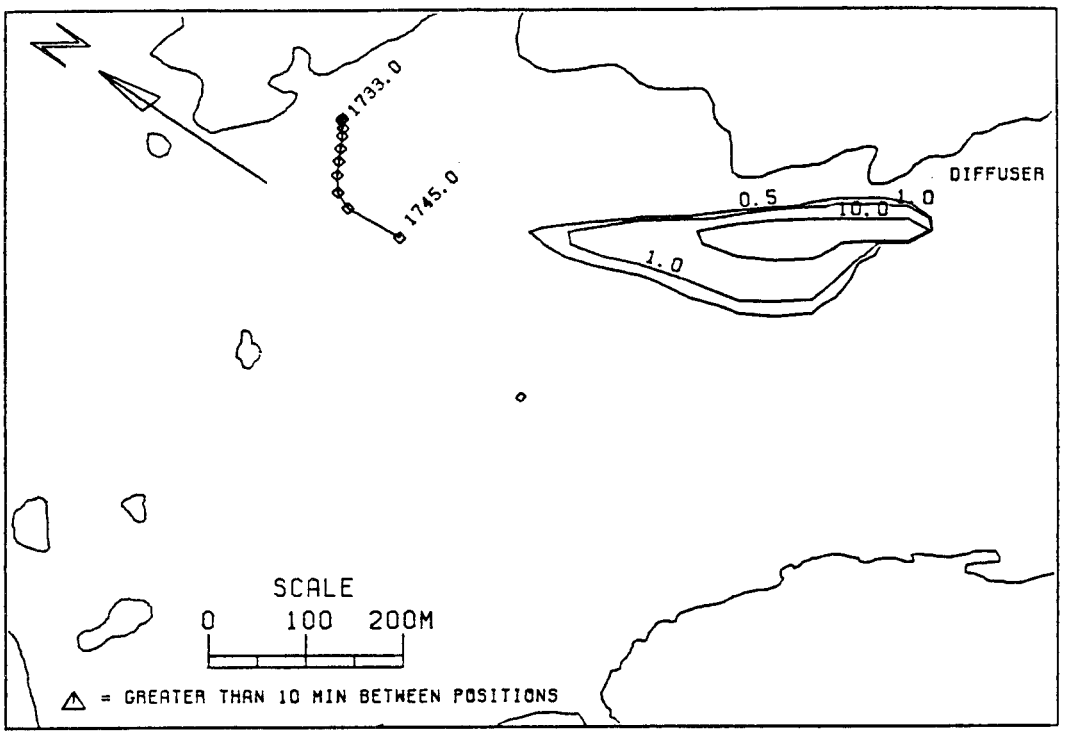


FISH 77, TREATMENT NO. 3, PLUME AT 18:30

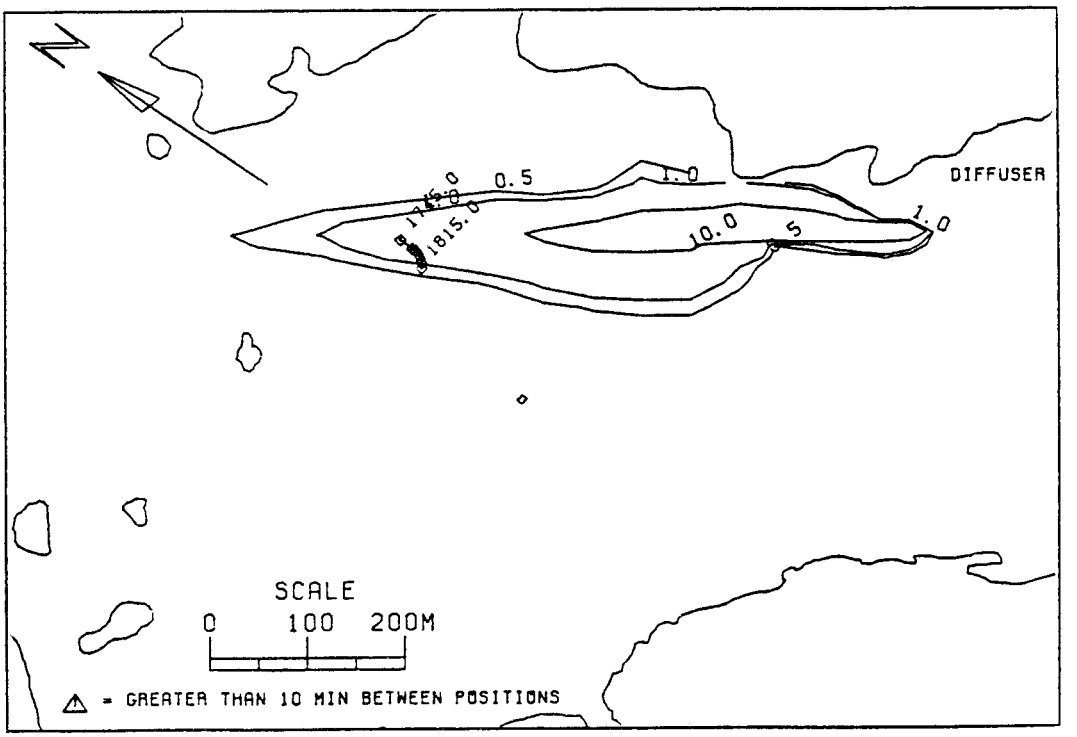


FISH 77, TREATMENT NO. 3, PLUME AT 19:00

Horizontal Movements of Fish Number 77 and Plume Trajectories at Time Intervals During Treatment 3
Figure 3-32 (continued)

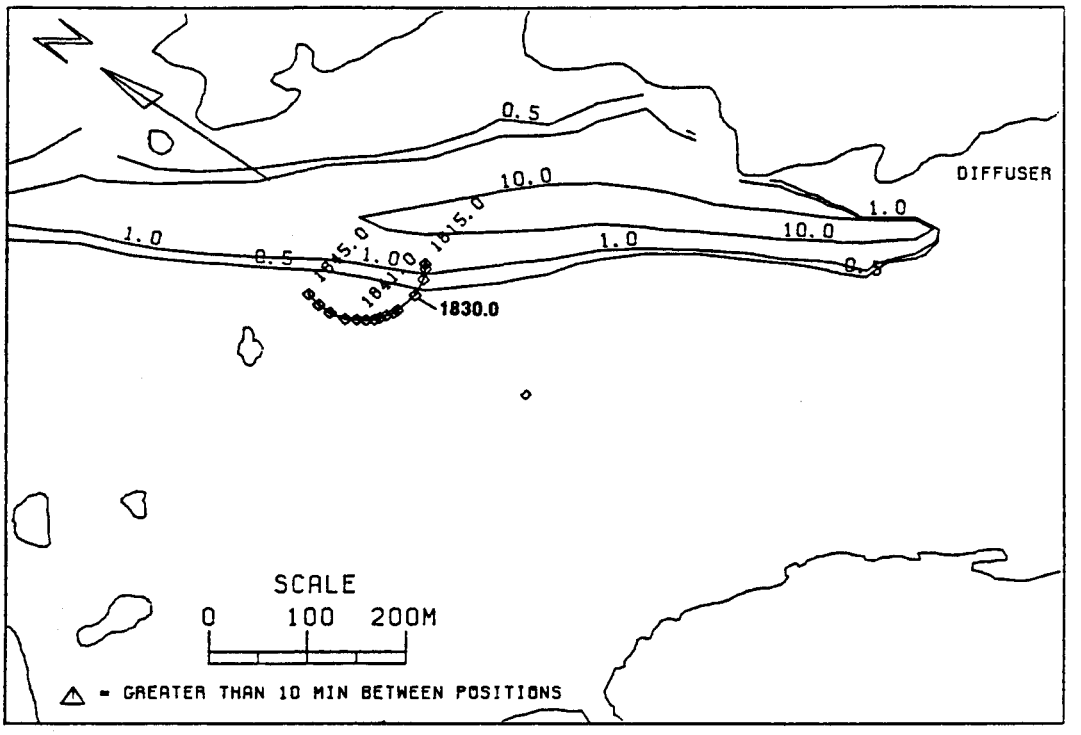


FISH 82, TREATMENT NO. 3, PLUME AT 17:30

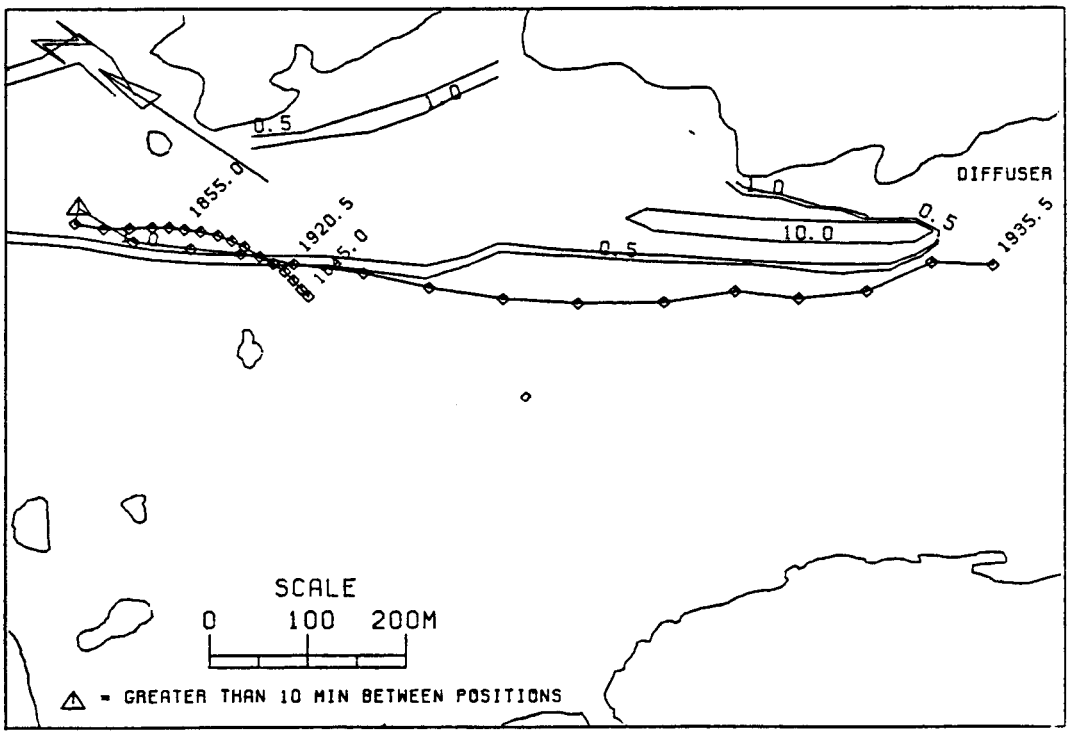


FISH 82, TREATMENT NO. 3, PLUME AT 18:00

Horizontal Movements of Fish Number 82 and Plume Trajectories at Time Intervals During Treatment 3
Figure 3-33

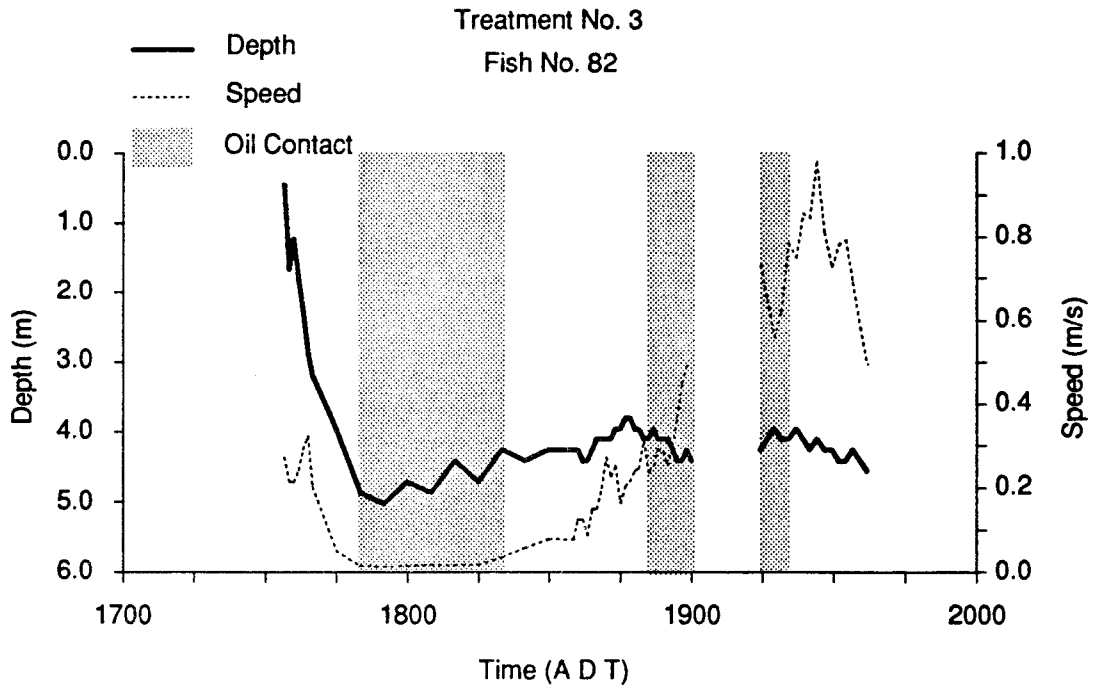


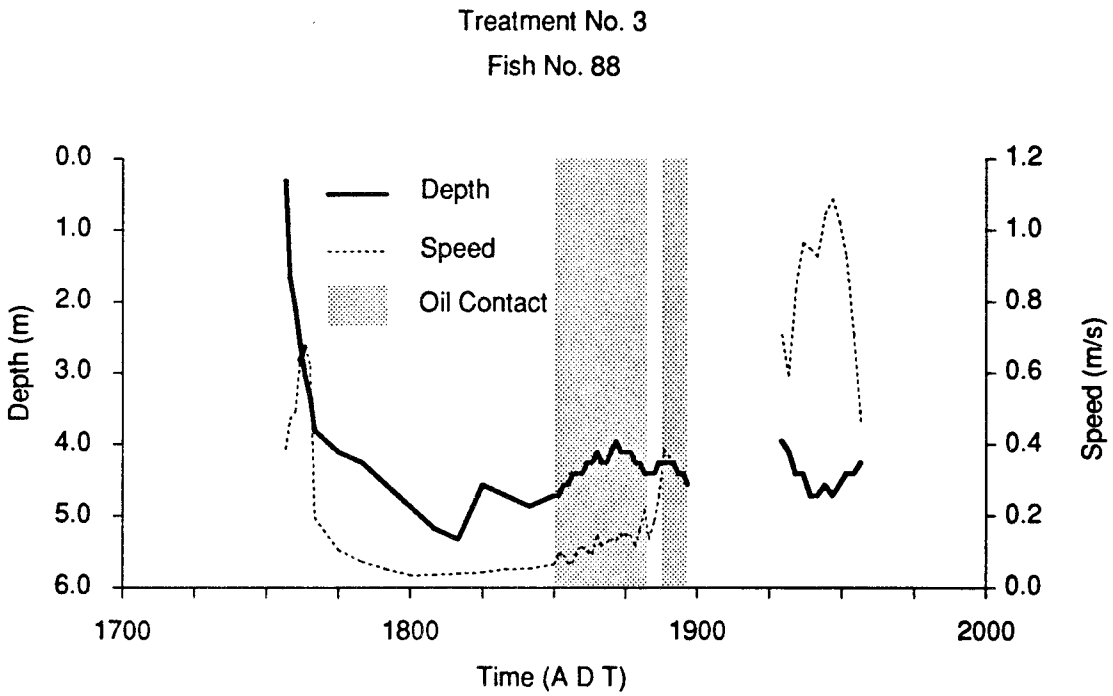
FISH 82, TREATMENT NO. 3, PLUME AT 18:30



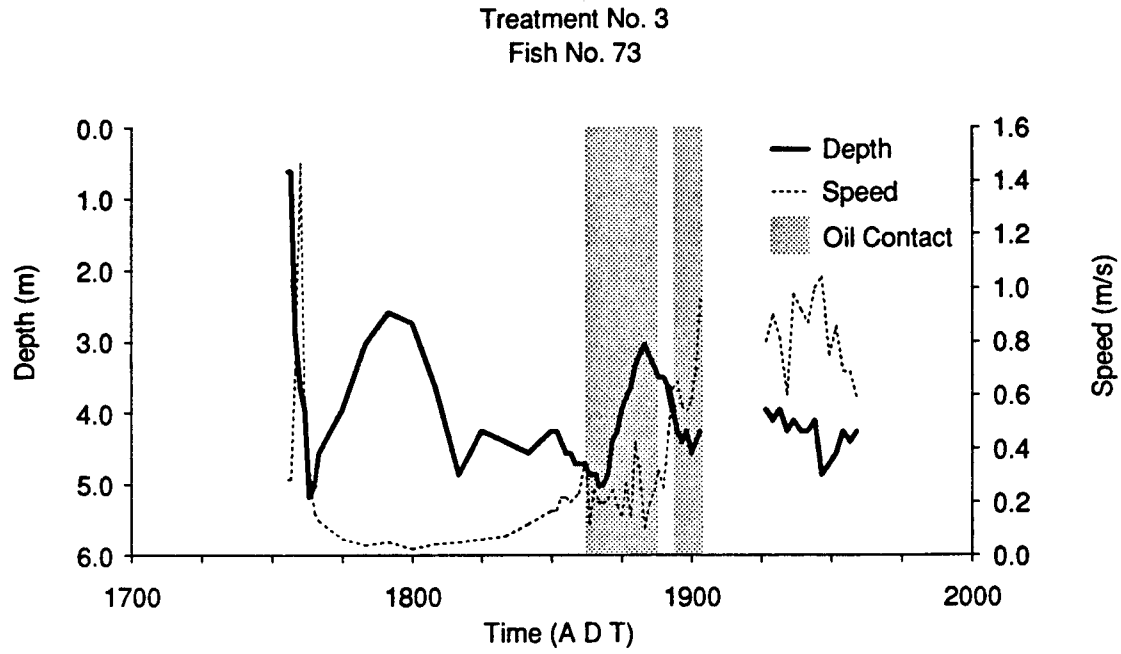
FISH 82, TREATMENT NO. 3, PLUME AT 19:00

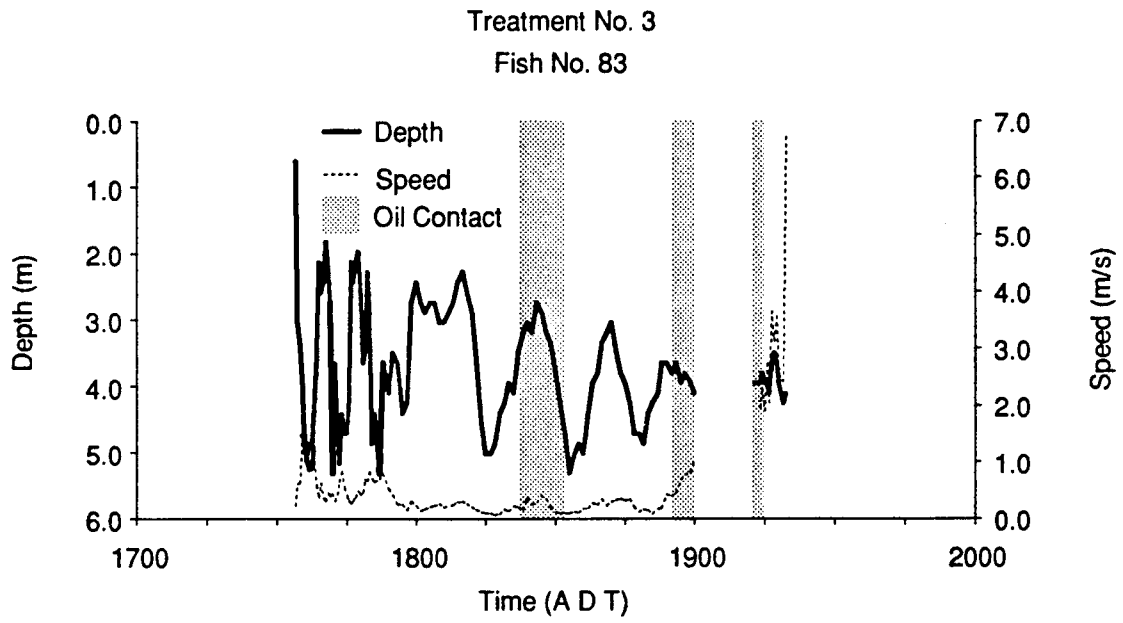
Horizontal Movements of Fish Number 82 and Plume Trajectories at Time Intervals During Treatment 3
Figure 3-33 (continuned)



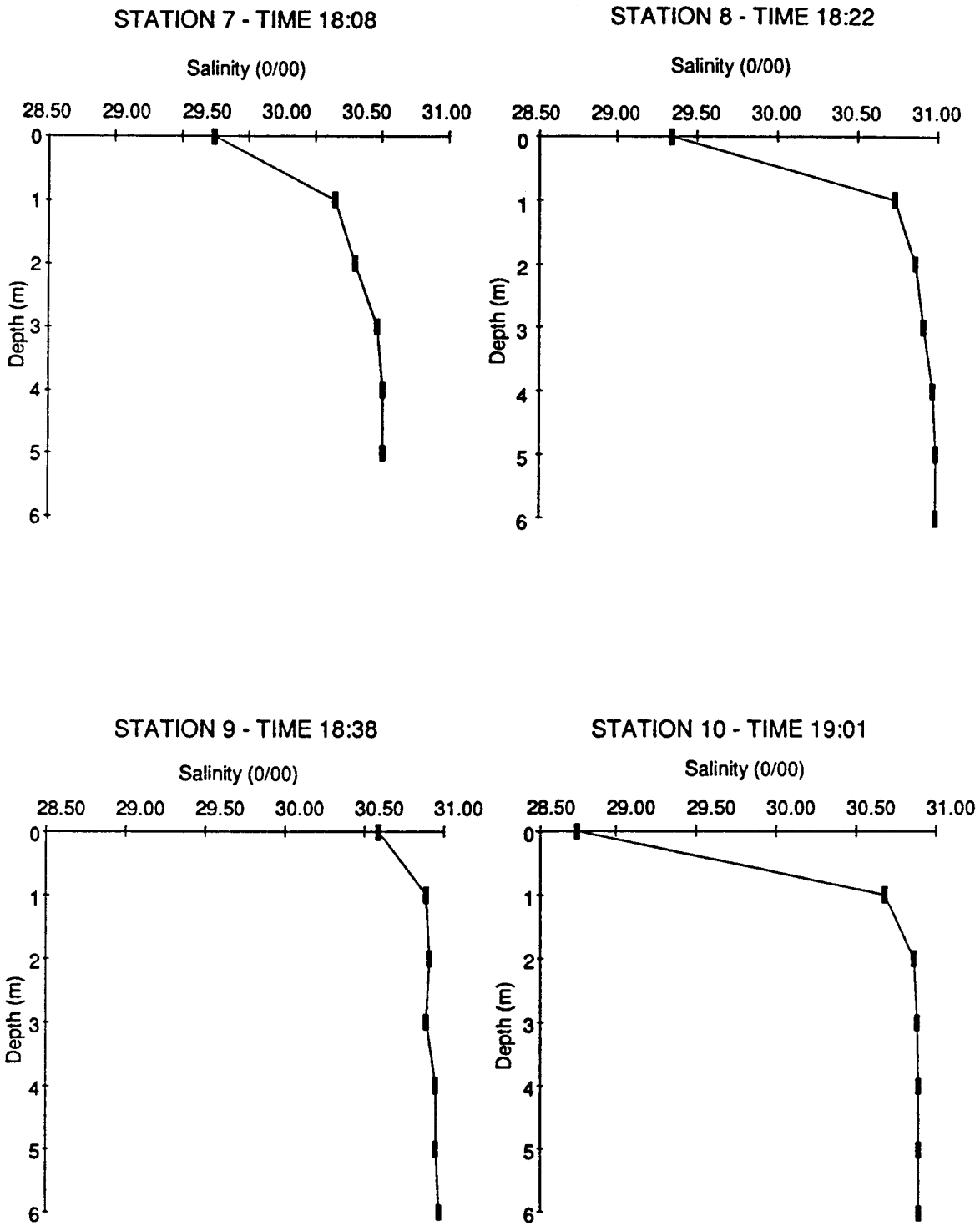


Depth and Ground Speed Versus Time and Time of Oil Contact for Fish Numbers 82 and 88 During Treatment 3
Figure 3-34





Depth and Ground Speed Versus Time and Time of Oil Contact for Fish Numbers 73 and 83 During Treatment 3
Figure 3-35



Salinity Profile with Depth for Treatment 3
Figure 3-36

4. DISCUSSION

4.1 SALMON MOVEMENT BEHAVIOR IN RESPONSE TO OIL CONTAMINATED WATERS

Differences in movement behavior of salmon during treatment 3 compared to the behavior of salmon during the control experiments indicated that hydrocarbon concentrations ranging 1.0 to 10.0 ppb caused a temporary disruption of the salmon migration to the home stream. Fish returning to the home stream through uncontaminated waters spent less time searching, showed positive rheotactic movements, and swam at the depth of the interface of the steep salinity gradient. Fish exposed to contaminated waters spent significantly more time searching, showed negative rheotactic movements, and swam at a depth well below the interface of the steep salinity gradient. Following this behavior salmon displayed an active migration behavior (positive rheotaxis) and successfully returned toward the home stream by migrating initially through low hydrocarbon concentrations (i.e., approximately 1.0 ppb) along the plume edge and finally through uncontaminated waters outside of the plume. The location of the return route was similar to the return route utilized by fish during the control experiments, indicating the home stream chemical cues, which are used for orientation, were not completely contaminated by the hydrocarbon plume.

The cause for this change in behavior and the resulting delay of the return migration after oil exposure is not clear. Salmon exposed to hydrocarbon concentrations greater than 1.0 ppb are either avoiding contaminated water by searching for an uncontaminated route or are becoming temporarily disoriented until they eventually swim clear of the plume. Understanding the mechanism for this delay is confounded by the timing when fish were exposed to the plume. Salmon encountered the plume during the searching phase of their return; therefore, the response observed may or may not be entirely due to the effects of oil. Horizontal movement patterns and the duration of the return varied during the control experiments, indicating factors other than oil contamination affect movement behavior. Variation in movement behavior during the searching phase may be related to differences in current speed and the depth of low salinity surface waters, which may affect how quickly salmon can detect the home stream cue. Had salmon encountered the plume during the active migration phase when fish were assumed to be homing, the interpretation of results would likely be more clear.

The distinction between avoidance and disorientation requires an identification of specific behavioral characteristics during migration that are indicative of either an avoidance or a disorientation response. Avoidance in this case is defined as detection of unsuitable conditions coupled with continued orientation (i.e., no loss of home stream cue) and disorientation is defined as inability to detect chemical cues necessary for orientation either by sensory impairment or by masking. Based on these definitions, a salmon avoiding the plume would likely display a searching behavior with the extent of the vertical and horizontal search more-or-less limited by the boundaries of the home stream cue. Since movement in or adjacent to the home stream cue is required for orientation, salmon could only avoid the contaminant if an uncontaminated route existed within the boundaries of the home stream cue. If the latter condition exists, then searching movements that take the fish out of the plume should be immediately followed by

active migration behavior and a return to the home stream. In contrast, a salmon that became disoriented would display a searching behavior (i.e., vertical and horizontal movements) that would not be limited by the boundaries of the home stream cue because the chemical cue would not be detectable. Based on homing behavior observed in freshwater (Johnsen 1982), a loss of the home cue (i.e., disorientation) would result in negative rheotactic movements until the fish could reestablish the cue. Homing could only be successful if a portion of the home stream cue were uncontaminated and only for those fish that by chance migrated along the uncontaminated route or if the fish fell back and sensory impairment was removed.

The movement behavior observed during treatment 3 suggests that adult pink salmon may become disoriented in the presence of hydrocarbon concentrations ranging 1.0 to 10.0 ppb. All fish showed negative rheotactic movements and headed down bay after or during exposure to the hydrocarbon plume. All but one of these fish continued down bay out of tracking range. This behavior would suggest the fish were unable to detect the home stream cue. Fish that conducted horizontal searches both within and outside of the plume (e.g., fish nos. 82 and 83) did not detect the home stream cue even though the search pattern outside of the plume crossed the eventual return route. This response suggests the chemosensory capabilities may have been impaired. Pearson et al. (1987) found the chemosensory capabilities of coho salmon were temporarily degraded (i.e., a few minutes) when fish were exposed to hydrocarbon concentrations (composed of 97% monoaromatics) of 0.1 to 1.0 ppb for 30 minutes. Exposure to WSF concentrations above 1.0 ppb and for longer periods have not been evaluated, therefore, the lasting effects of chemosensory impairment are unknown. Fish nos. 82 and 83 were exposed to concentrations >5.0 ppb for 3 to 4 minutes and to concentrations ranging 1.0 to 5.0 ppb for up to 41 minutes. The eventual return of these fish and the other fish that headed down bay indicates that the cause for the negative rheotaxis was temporary. These fish presumably headed down bay or passively fell back out of the hydrocarbon plume, became oriented in uncontaminated waters, and returned along the home stream cue. The latter assumption is supported by the behavior of fish no. 77, which successfully homed after negative rheotactic movements resulted in movement outside the plume. After a period of 10 to 15 minutes outside the plume fish no. 77 turned and actively migrated toward the home stream. All the fish that headed out of tracking range down bay returned after 12 to 19 minutes, which is similar to the orientation period exhibited by fish no. 77.

Examples of disruptions of salmon migration due to oil or other water pollution are rare. Weber et al. (1981) reported that adult coho salmon returning to two parallel fish ladders avoided usage of one ladder when contaminated with WSF concentrations reaching 3.2 ppm. Pearson et al. (1987), however, speculates that the result of this study was not an example of avoidance, but rather an indication of disorientation and most likely as a result of chemosensory impairment. Pearson et al. (1987) reanalyzed the data from Weber et al. (1981) and found that the WSF released into the test stream was at levels sufficient to cause chemosensory impairment and that fish returns to the stream were correlated with WSF concentration. Pearson et al. (1987) believe that chemosensory impairment was inhibiting salmon from locating the test stream during the experiments. Saunders and Sprague (1967) reported that Atlantic salmon avoided high levels of zinc and copper pollution in a tributary of the Miramichi River by returning prematurely downstream during their normal spawning migration. Pearson et al. (1987) were also critical of

these results because they point out that heavy metals are known to reduce olfactory response in salmonids. Therefore, the downstream movement observed by Saunders and Sprague (1967) is more likely due to the loss of ability to detect the home stream odor. Westerberg (1983a) observed negative rheotactic movements by Atlantic salmon released in a branch of the Lule estuary that was polluted with effluent from a steelworks and coke plant, whereas, salmon released in an unpolluted branch of the same estuary showed a slow but steady migration upstream. The latter may also be an example of disorientation due to chemosensory impairment. Results of these studies suggest that other pollutants, which affect chemosensory detection, may have a similar affect on migrating salmonids as was observed in this study.

4.2 IMPLICATIONS OF STUDY FINDINGS TO OIL SPILL SCENARIOS

Since all salmonids require chemosensory detection for orientation during migration, the effects of oil exposure are likely to be similar for all species. The results of this study suggest that adult salmon will become disoriented when exposed to hydrocarbon concentrations ranging 1.0 to 10.0 ppb. The concentration of hydrocarbons in the water column from accidental oil spills have ranged well above these levels (see review by Pearson et al. 1987). Therefore, it is likely that an oil spill in the path of migrating salmon could cause some disruption of the migration. The magnitude of a potential disruption would depend on the size and persistence of the spill. If the spill contaminated the entire width of the home stream corridor the migration could be blocked as a result of chemosensory impairment and loss of the ability to detect the home stream cue (Pearson et al. 1987). Disorientation and subsequent negative rheotactic behavior would probably cause salmon to hold at some location outside of the contaminated area, but within the home stream cue. Attempts to migrate through the contaminated area would most likely fail until WSF concentrations decrease below the threshold level causing chemosensory impairment. Since aromatic hydrocarbons are responsible for chemosensory degradation (Johnson 1977) and these lower molecular weight hydrocarbons are the first to dissipate from an oil spill (Clark and MacLeod 1977), the duration of the disruption may range from a few days to several weeks. Payne et al. (1984) investigated oil weathering in marine waters and found the low molecular weight aromatics were removed after 6 to 12 days by a combination of evaporation and advective processes. However, if oil is more completely dispersed into the water column by dissolution its rate of removal can take longer (Jim Payne, personal communication). For example, an assessment of several hypothetical oil spill scenarios in Bristol Bay, assuming maximum effect conditions, estimated the maximum duration that WSF concentrations >1.0 ppb would persist is 36 days (Pola et al. 1985).

A simulation of the effects of a potential oil spill scenario on migrating adult sockeye salmon in Bristol Bay was conducted by Bax (1987). Impacts on the population due to tainting and/or mortality were based on exposure thresholds derived from the literature and for two conditions: either avoidance or non-avoidance of the spill. Given these assumptions the model predicted maximum mortality and tainting impacts ranging 1% to 5% and 1% to 2% of the total returning population, respectively. This scenario, however, may not be realistic because it does not include the possibility for fish to become disoriented, which could have a different impact on the population. Disorientation and subsequent negative rheotactic movements may not result in fish exposure to levels sufficient to cause mortality or tainting, but may result in other impacts caused

by migration delays. Thus, Bax (1987) estimates of impacts due to mortality and tainting may be too high. The question of impacts to the population due to migration delays or straying was not addressed and may be a more significant consequence of an oil spill.

Adult sockeye returning to Bristol Bay may be highly vulnerable to migration disruptions due to their specific migration routes and narrow return timing. The distribution of salmon stocks offshore are mixed when the fish enter the bay and become more segregated as the fish approach their natal river (Bax 1987 and Straty 1975). Return timing is very consistent from year-to-year with 80% of the run passing the fishery over a 13 day period (Burgner 1980). This concentration of the population in a relatively small area during a short time period increases the vulnerability for impacting a significant portion of the population or an entire stock. An oil spill along the migratory route that delays a specific stock for one or two weeks could have a significant effect on time of spawning and subsequent survival of offspring. Time of spawning for sockeye stocks are synchronized with the specific temperature regime of the home stream (Miller and Brannon 1982). In Bristol Bay spawning within a particular river or stream is restricted to a period of less than two weeks (based on spawner survey data from Demory et al. 1964). This narrow window for spawning is dictated by embryo incubation requirements and the timing of fry emergence necessary to correspond with food availability of the nursery system. Late emergence may result in a size disadvantage and less time for growth to produce optimal smolt size the following spring (Miller and Brannon 1982). A delay of the migration for two weeks prior to entry in the fishery may also result in direct economic losses due to maturation and a reduction in food quality. Sockeye salmon taken during the end of the run are of lower value to the fishery than fish taken during the peak (Don Rogers, Fish. Res. Inst., Univ. of Wash., personal communication).

An oil spill in an estuary of Bristol Bay would potentially have the greatest impact on a salmon population. Salmon migration into the home stream may be reduced or completely blocked as a result of disorientation and the subsequent retrograde movement out of the contaminated area. Only those fish that by chance migrate through areas uncontaminated by the spill may successfully return to the home stream. Fish that are unsuccessful may hold until the spill dissipates or they may stray to other neighboring streams where they could eventually spawn. Saunders and Sprague (1967) reported that 62% of the Atlantic salmon, which returned downstream as a result of heavy metal pollution, were never seen again and 31% reascended the river after pollutant levels declined. Significant numbers of adult coho and chinook salmon returning to the Toutle River following the eruption of Mount St. Helens, strayed to several neighboring rivers up to 121 km away (Martin et al. 1984). Survival in non-natal streams would likely be low due to competition with natal stocks and incompatibility with local environmental conditions.

4.3 CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this study are:

- Migrating adult pink salmon do not appear to avoid aromatic hydrocarbon concentrations above the chemosensory detection threshold,

- Salmon do not appear to avoid oil contaminated waters with hydrocarbon concentrations ranging 1 to 10 ppb, but appear to become temporarily disoriented,

- Salmon behavior during disorientation was characterized by an extended period of searching and negative rheotactic movement, and

- Disorientation caused a temporary disruption of the return migration but did not prevent the eventual return to the home stream.

These findings suggest that pink salmon encountering an oil spill along their migratory route may not be exposed to levels causing tainting or mortality. Instead disorientation to low hydrocarbon concentrations would cause the fish to retreat back along the migratory route until orientation was reestablished. Continued attempts to migrate through the spill would probably fail as long as the migratory route remained contaminated. This may result in a delay in migration that could have a significant effect on the time of spawning and subsequent survival of offspring or cause straying to other streams where the probability of survival would be lower.

The conclusions of this study should be viewed with caution because they are based on a small amount of information. Further research is necessary: to verify the consistency of the avoidance/disorientation response of salmon to low hydrocarbon concentrations, to determine behavior and fate of salmon encountering a spill that contaminates either the entire width or a portion of the migratory route, and to investigate olfactory responses at exposure levels (concentration and duration) similar to those observed in this study. Repeating this field investigation, with some modification, would be required to address the first two research needs. Verification of the avoidance/disorientation response would be more clearly identified if the fish encounter the plume during the active migration phase rather than during the search phase of their return. This may be accomplished by releasing the fish from a point further downbay and by coordinating the timing of plume release to intercept salmon as they move up bay. A greater distance between the diffuser and fish release site would enable fish to become oriented and actively migrating prior to encountering the plume. Movement behavior in response to oil exposure could be separated from movements observed during the searching phase. A greater distance between the diffuser and fish release site would also enable testing of the effects of partial and complete contamination of the home cue. This could be accomplished by adding another diffuser, which when combined with the original diffuser would contaminate the entire width of the bay.

In addition to fish tracking during experiments, a continuous monitoring system should be operated after the experiments to record timing of fish returns for fish that may have been blocked by the plume and eventually return at a later date. The latter information could be used to access the fate of fish exposed to partial or complete contamination of the home cue. Research needs concerning olfactory response to hydrocarbon concentrations ranging up to 10 ppb would require a laboratory investigation similar to Pearson et al. (1987).

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APPENDIX A

DETECTION LIMITS OF KASITSNA BAY COCKTAIL SAMPLES

DILUTION FACTOR	NO DILUTION	0.20*	0.02	0.01
HYDROCARBON:				
Methane	0.15	3.60	4.34	2.08
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	4495.01	468.46	31.68	8.15
n-Pentane	1644.32	165.04	12.70	2.62
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	846.07	99.94	7.47	1.85
3-Methylpentane	60.27	4.37	2.45	N.D.
n-Hexane	33.98	2.09	0.20	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	45675.24	6841.48	516.92	229.41
Cyclohexane	1756.14	219.96	17.93	N.D.
n-Heptane	189.75	16.73	1.42	0.75
Methylcyclohexane	496.20	30.48	2.69	1.25
Toluene	15416.43	2452.63	193.50	79.00
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	2049.95	334.33	25.15	10.15
m-, p-Xylene	2684.56	456.74	34.72	13.97
o-Xylene	365.29	69.97	5.09	N.D.
Isopropylbenzene	496.70	88.59	6.79	3.08
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	76210.06	11254.41	863.05	352.31
Total w/o C1-C4	76209.91	11250.81	858.71	350.23

*$\frac{\text{Original volume}}{\text{Diluted volume}}$

KASITSNA BAY COCKTAIL SAMPLES

DILUTION FACTOR	.005	.0025	.0005	.00005
HYDROCARBON:				
Methane	2.14	2.98	3.00	4.21
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	2.61	N.D.	N.D.	N.D.
n-Pentane	0.87	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	0.65	0.10	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	86.39	41.10	3.54	0.55
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	0.73	N.D.	0.09	N.D.
Toluene	36.23	22.79	2.34	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	4.11	2.29	N.D.	N.D.
m-, p-Xylene	5.72	4.44	N.D.	N.D.
o-Xylene	0.99	N.D.	N.D.	N.D.
Isopropylbenzene	1.52	0.65	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	141.96	74.35	8.97	4.76
Total w/o C1-C4	139.82	71.37	5.97	0.55

APPENDIX B

MEASUREMENT OF HYDROCARBONS BY SOLVENT EXTRACTION AND GC ANALYSIS

Hydrocarbon Measurement by Solvent Extraction and GC Analysis

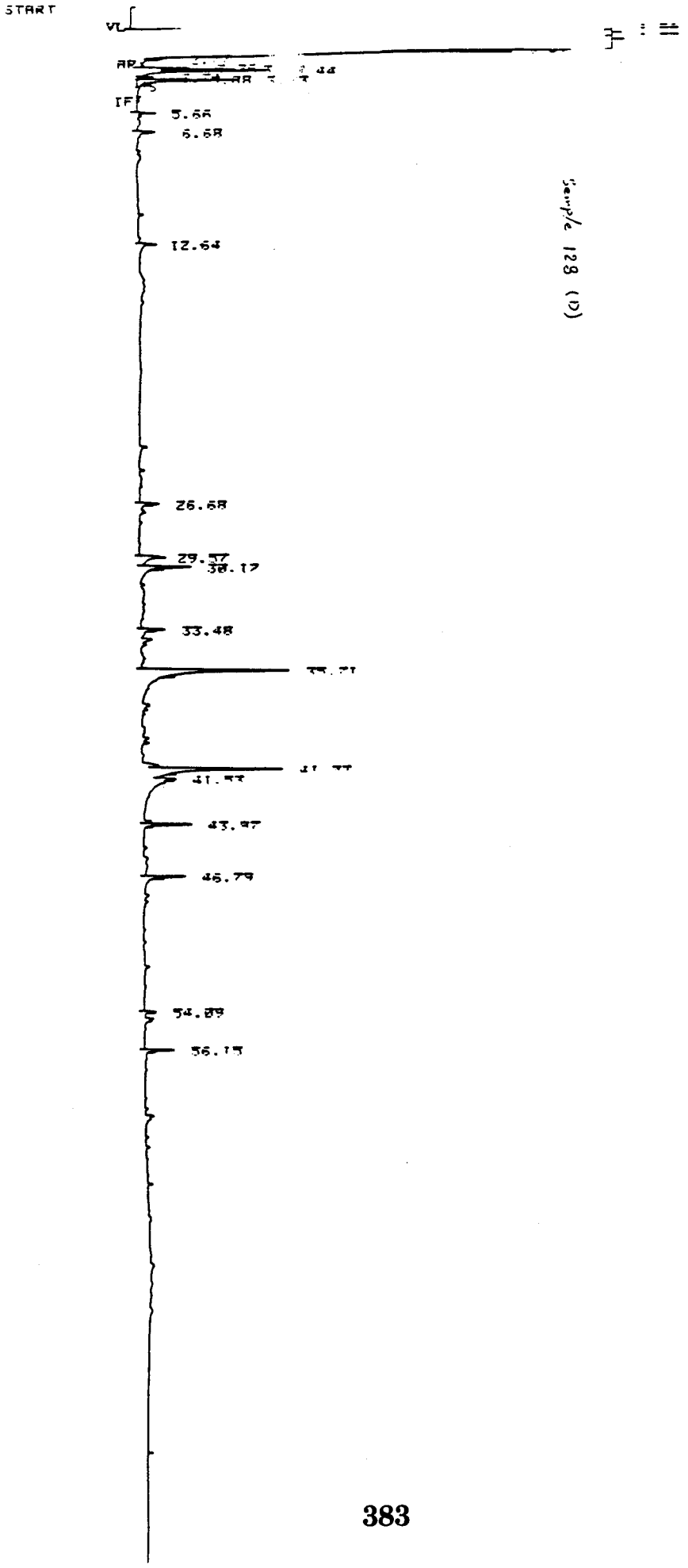
To 20 L of water sample in the carboy container, 500 ml of methylene chloride was added and the mixture was stirred for five minutes using a hand-held electric stirring motor. Then the sample was left for about 15 min to allow separation of the organic phase (bottom layer) from the aqueous phase. The organic phase was syphoned to a 2-L separatory funnel and the extraction was repeated twice, with 250 ml CH_2Cl_2 to ensure the complete recovery of hydrocarbons from water. The extracts were combined and the separatory funnel was allowed to stand for one hour to complete the separation of the residual water from the solvent. The solvent was transferred to a 1-L round-bottom distillation flask, and the flask was equipped with a Snyder column. The flask was kept in a warm-water bath under a fume hood and most of the methylene chloride was distilled away. The residue was transferred to a small glass vial and the remaining solvent was purged with nitrogen. The residue was transferred to a GC vial and the volume was adjusted to 1 ml. Two microliters were injected automatically in the GC with a capillary column and flame ionization detector.

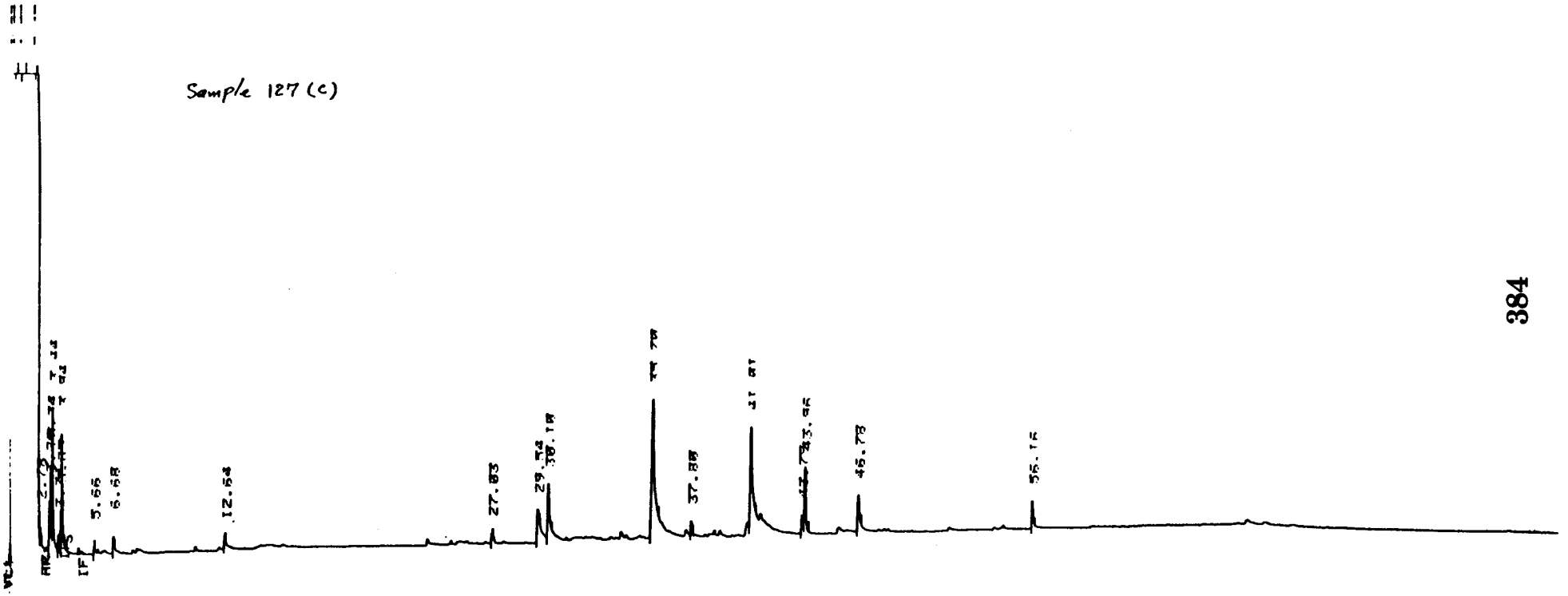
It should be noted that the solvent extraction for GC analysis was neither planned nor proposed for this study. It was undertaken only as an emergency measure to evaluate the effects of a fuel oil spill from a tug and barge operation in the study area. It should also be mentioned that the solvent extraction procedure is designed for measurement of nonvolatile hydrocarbons of WSF such as heavy paraffins and di- and tri-ring aromatic hydrocarbons. The volatile hydrocarbons of the WSF are volatilized and lost from the sample at different rates during extraction, distillation, and purging with nitrogen. Therefore, it is difficult to quantify these losses and apply the necessary correction factors. In addition, the retention time of the solvent CH_2Cl_2 is longer than the retention times of the lighter components of the cocktail; consequently, these components were masked by the CH_2Cl_2 peak. It was possible to use a somewhat lighter solvent with shorter retention time, such as CS_2, to identify qualitatively a few more components of the cocktail. However, because of the health hazards of CS_2 and the inadequacy of the laboratory facility for using hazardous solvents, CS_2 was not used.

Appendix Table B-1. List of samples taken in 20-liter glass bottles for extraction and analysis by GC.

Sample No.	Description
100	2 m deep at the diffuser site; 1:00 pm, 7/18/88
101	2 m deep at the diffuser site; 1:00 pm, 7/18/88
102	Under the surface at the barge loading site; 3:00 pm, 7/18/88
103	Under the surface at the barge loading site; 3:00 pm, 7/18/88
104	One liter CH_2Cl2 -> 1 ml for blank measurement
105	3 m deep at the diffuser site; 8:05 pm, 7/19/88
106	3 m deep at the diffusre site; 9:00 pm, 7/19/88
107	Time 0, -25 m station 4 m depth, 7/20/88. Pump started at 9:30 pm.
108	Time 0, -25 m station 1 m depth, 7/20/88.
109	Time + 25 min + 25 m station 4 m depth, 7/20/88
110	Time + 25 min + 25 m station 1 m depth, 7/20/88
111	Time + 45 min + 100 m station 4 m depth, 7/20/88
112	Time + 45 min + 100 m station 2 m depth, 7/20/88
113	Time + 65 min - 25 m station 4 m depth, 7/20/88
114	Time + 65 min - 25 m station 1 m depth, 7/20/88
115	Time + 85 min + 100 m station, 4 m depth, 7/20/88
116	Time + 85 min + 100 m station, 2 m depth, 7/20/88
117	Time + 105 min + 300 m station, 4 m depth, 7/20/88
118	Time + 105 min + 300 m station, 2 m depth, 7/20/88
119	Lateral + 100 m station, 4 m depth, 7/20/88
120	Lateral + 100 m station, 2 m depth, 7/20/88
121	Water sample at the mouth of Jakolof Creek, 12:27 pm, 7/21/88 ebb-low tide 0.3 m below surface
122	- 25 m, 25 min before start of pump, 4 m depth, 7/23/88 control[a]
123	+ 100 m, 25 min after start of pump, 4 m depth, 7/23/88 control[a]
124	Procedure efficiency
125A	20 min, - 25 station, 4 m depth, 7/24/88, control
126B	40 min, + 100 station, 4 m depth, 7/24/88, control
127C	110 min, - 25 station, 4 m depth, 7/25/88, release
128D	130 min, + 100 station, 4 m depth, 7/15/88, release

[a] Pump started 1:00 pm.

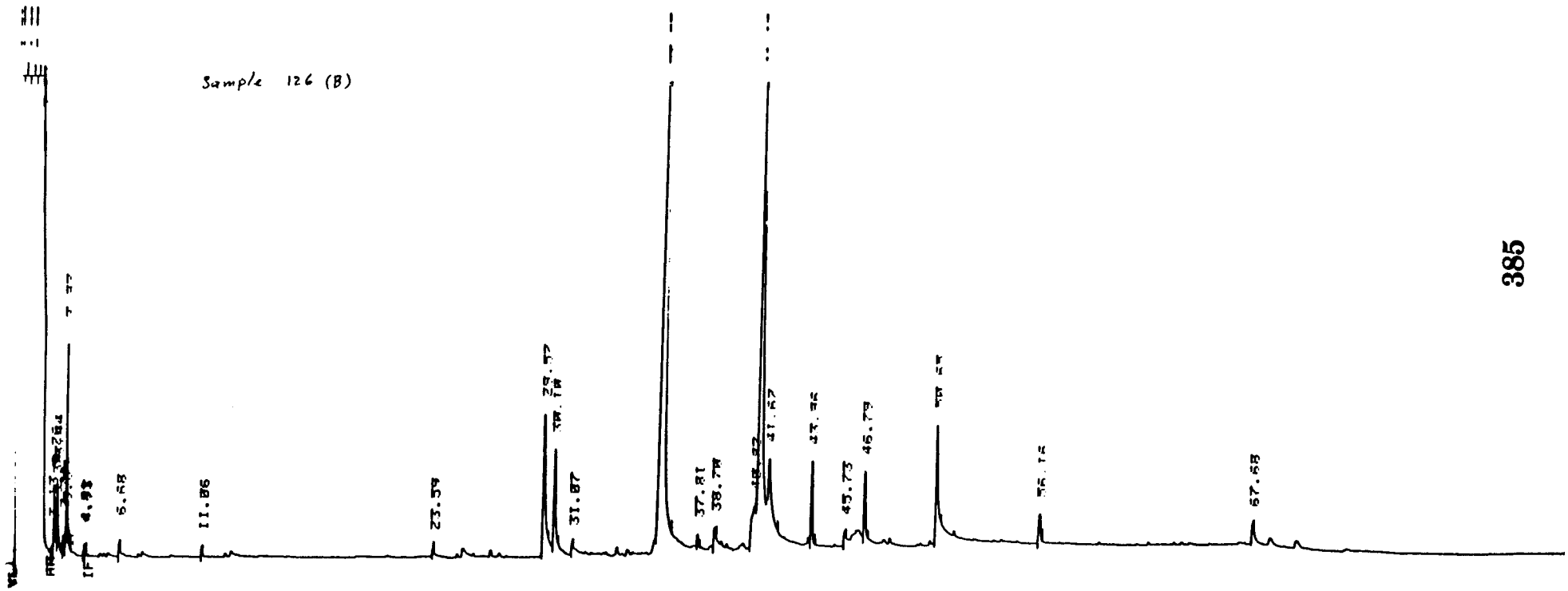

START
VL
BP
IF
5.65
6.68
12.64
26.68
29.57
38.17
33.48
41.77
43.97
45.79
54.89
56.15
Sample 128 (D)


Sample 127 (c)
5.66
6.68
12.64
27.83
29.74
30.18
34.79
37.88
41.81
43.96
46.78
55.15

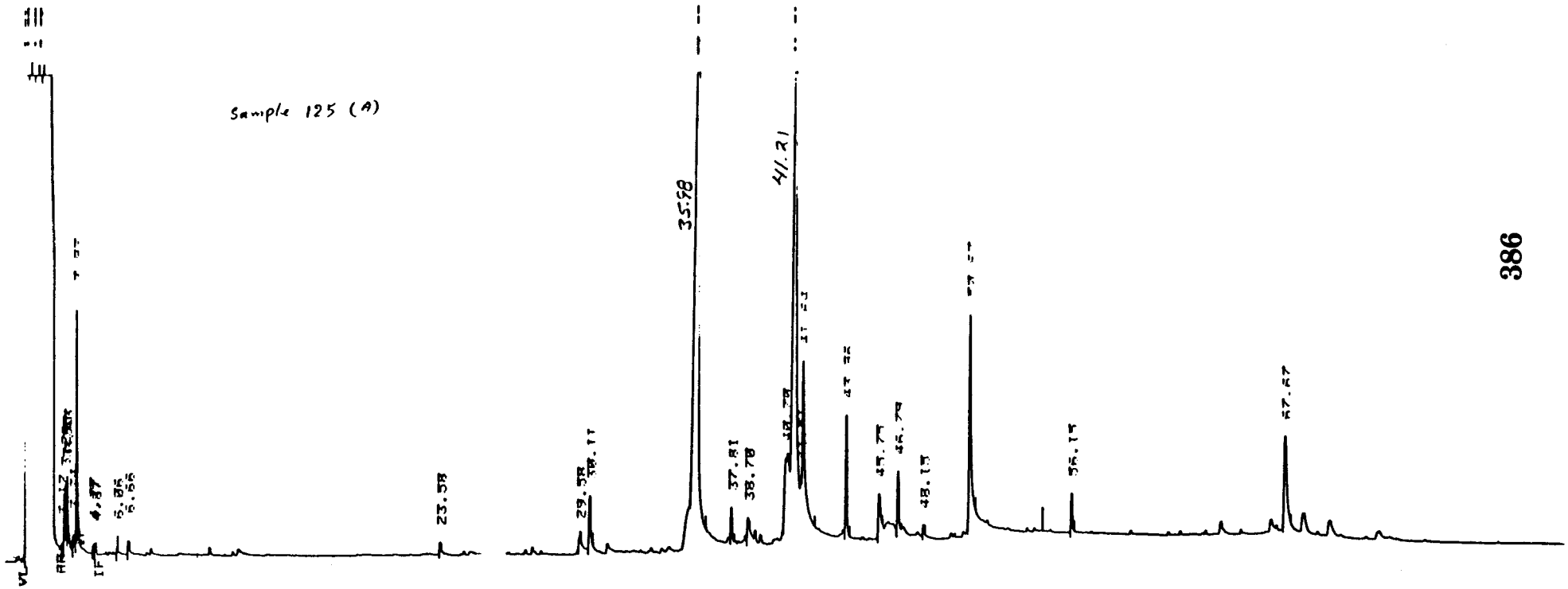
384

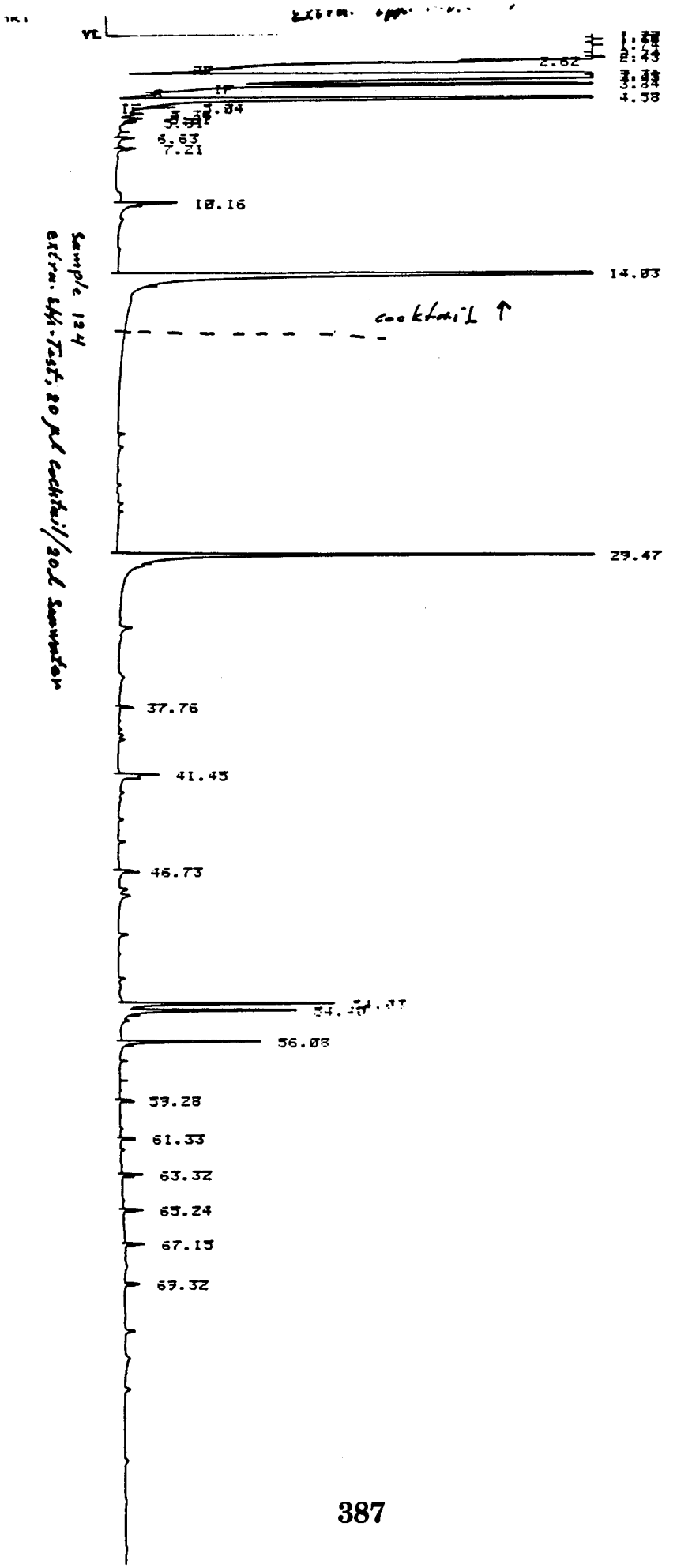
94

95

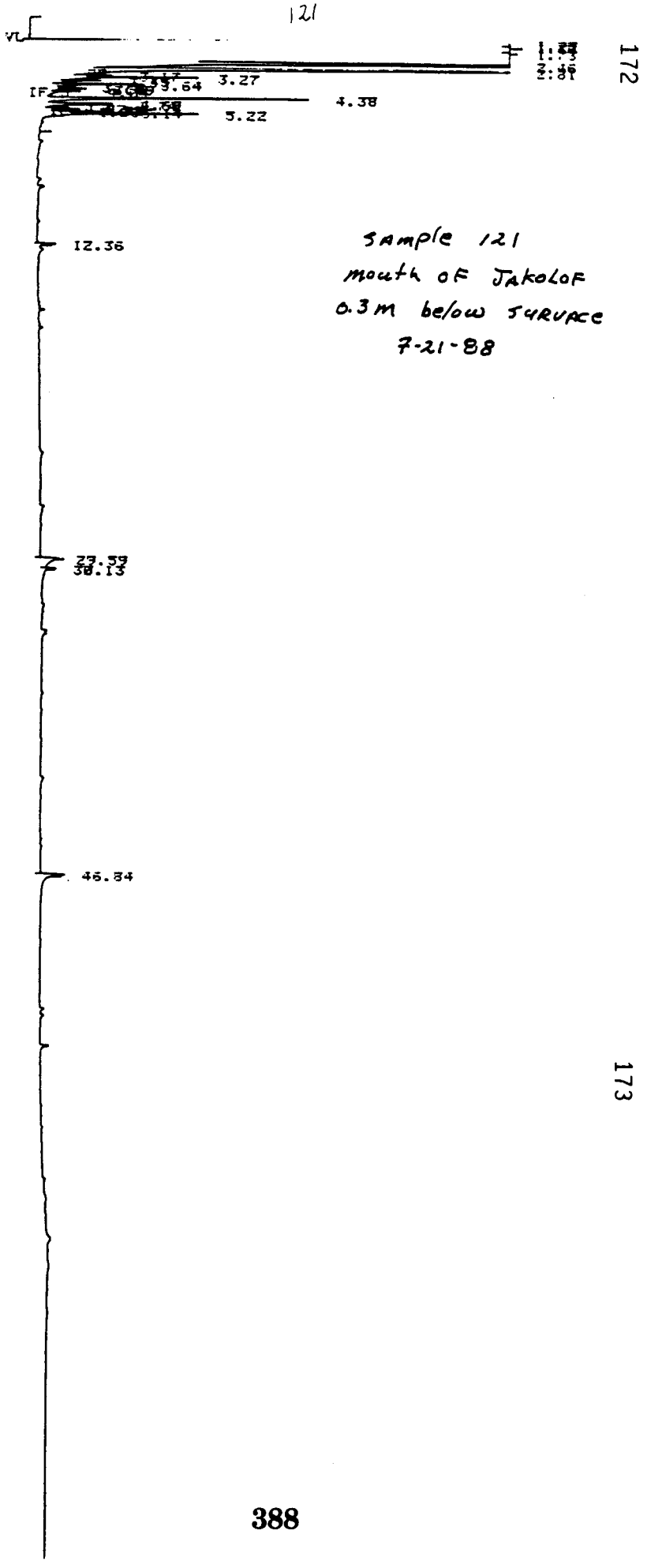

Sample 126 (B)
4.93
5.68
11.86
23.59
29.97
31.87
37.81
38.78
41.67
45.73
46.79
67.68

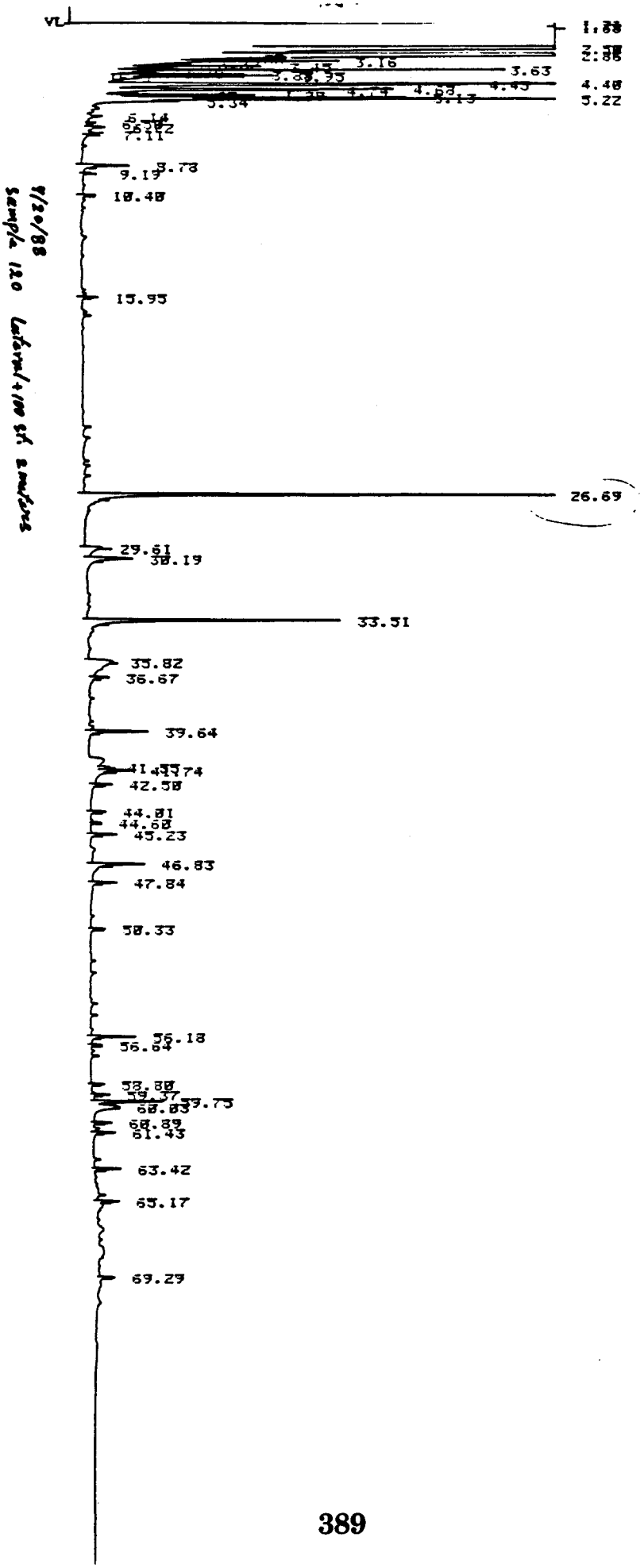
385


Sample 125 (A)
35.58
41.21
23.58
29.58
38.11
37.81
38.78
48.13
55.13
386

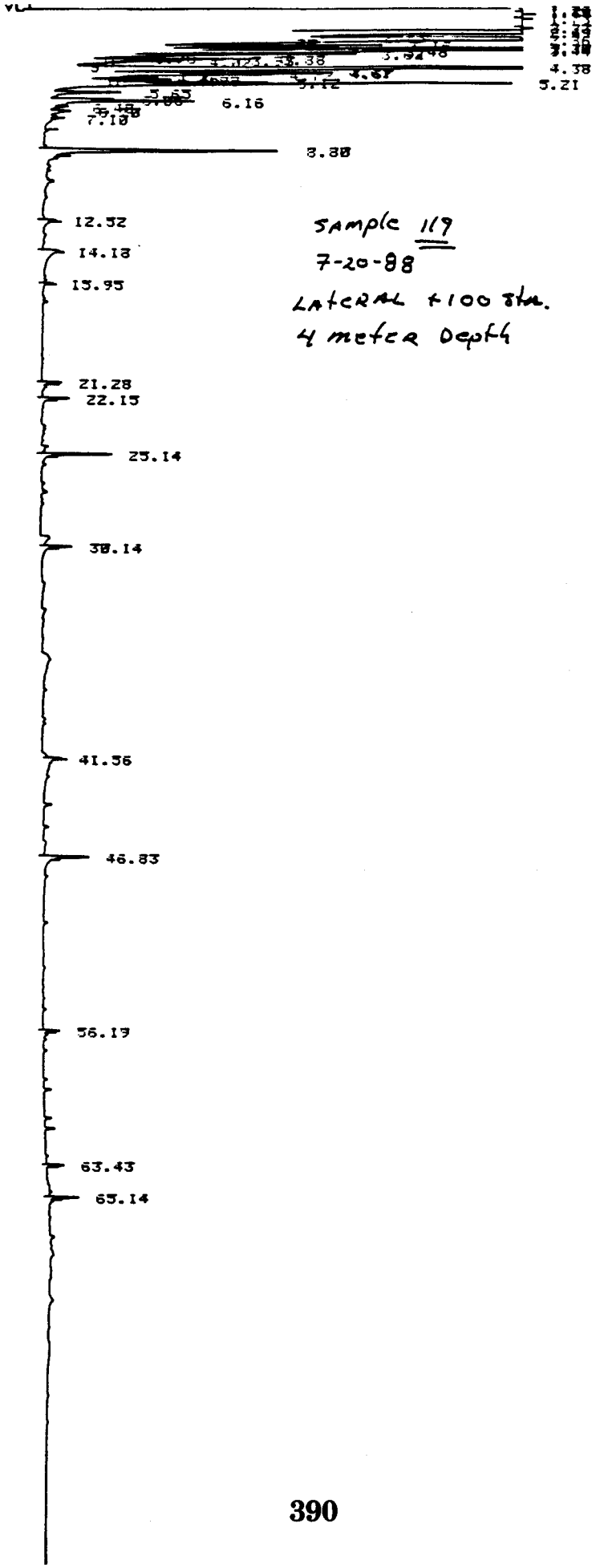

Sample 124
extra. eff. Test, 20 µL cocktail/20 µL seawater
cocktail
2.62
4.58
5.84
6.63
7.21
10.16
14.83
29.47
37.76
41.45
46.73
56.08
59.28
61.33
63.32
65.24
67.15
69.32

150

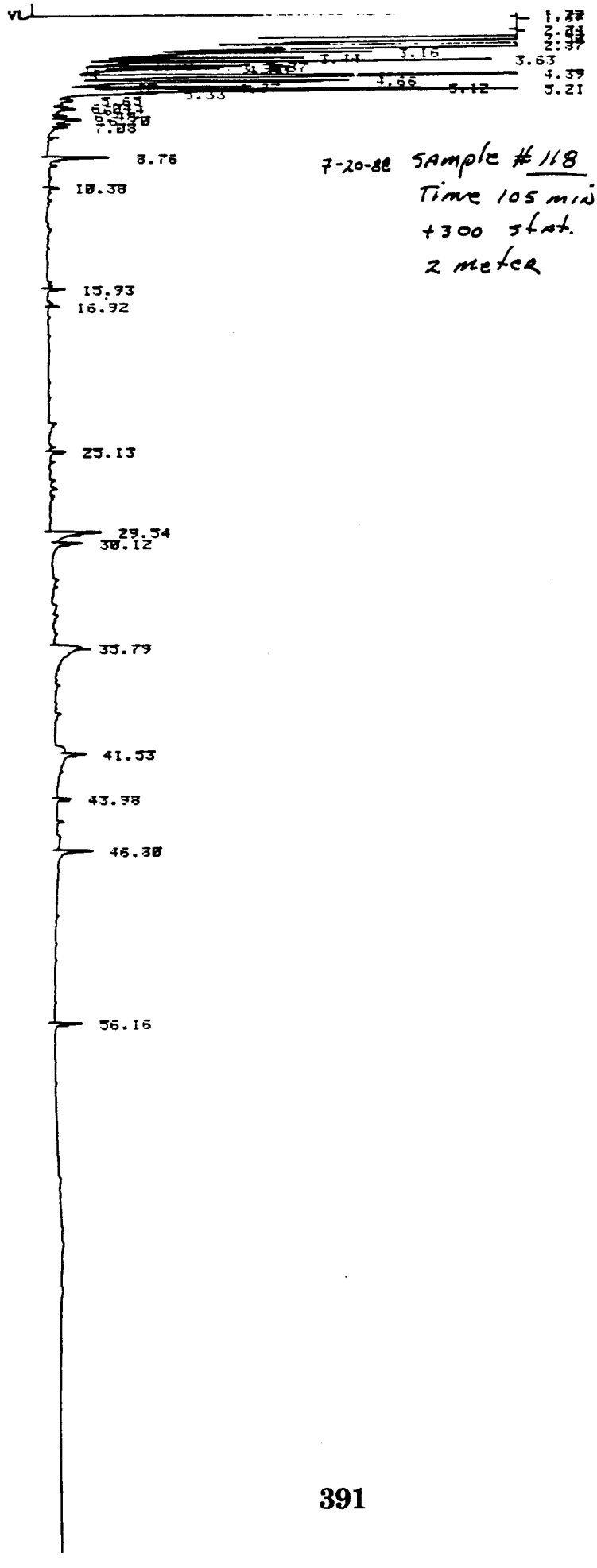

ART
121
VL
IF
3.64
3.27
4.38
5.22
12.36
23.59
38.13
46.34
172
173
Sample 121
mouth of Jakolof
0.3m below surface
7-21-88


9/20/88
Sample 120 Carbonyl+100 ppb 8 markers
VL
3.16
3.63
4.48
5.22
7.11
9.19
9.73
10.48
15.95
26.69
29.61
30.19
33.51
35.82
36.67
39.64
42.58
44.81
44.60
45.23
46.83
47.84
50.33
56.18
56.64
58.80
59.37
59.73
60.83
60.89
61.43
63.42
65.17
69.29

169

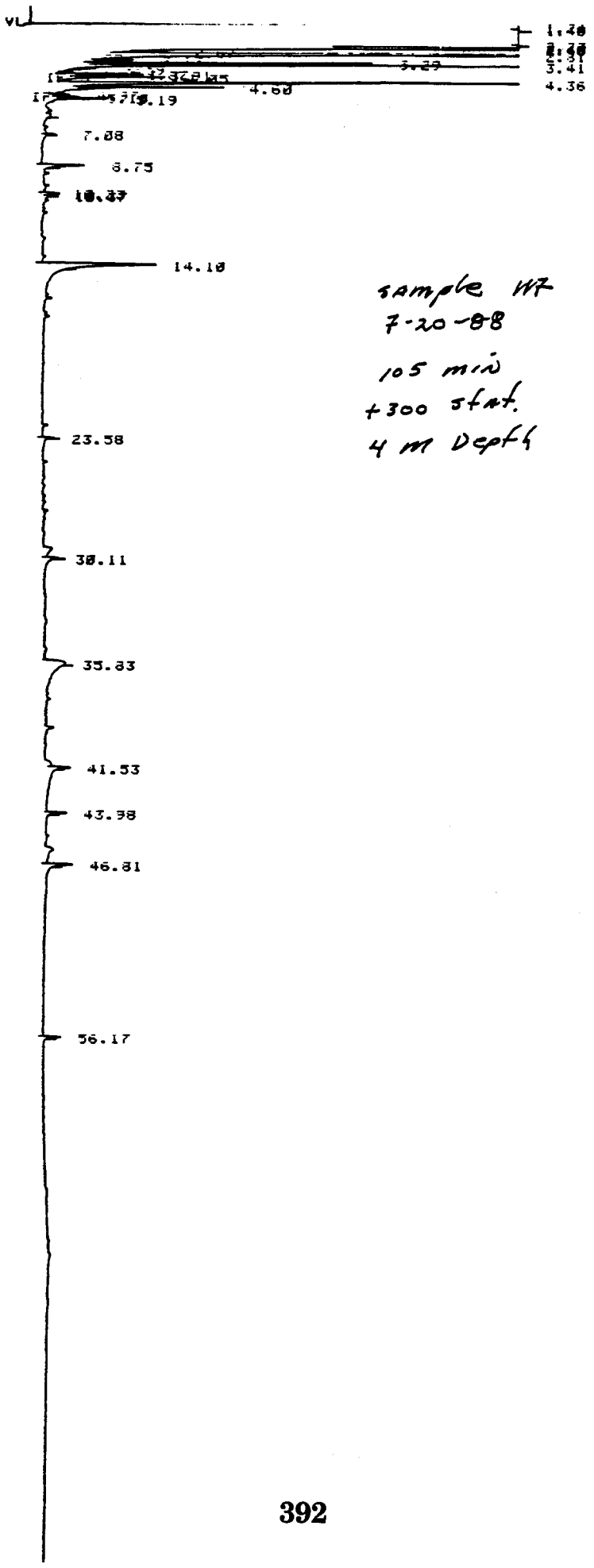

4.38
5.21
6.16
8.80
12.32
14.18
15.95
21.28
22.15
25.14
38.14
41.56
46.83
56.19
63.43
65.14
SAMPLE 119
7-20-88
LATERAL +100 ft.
4 meter Depth

166


3.15
3.63
4.39
5.21
8.76
10.38
15.93
16.92
25.13
29.54
30.12
35.79
41.53
43.98
46.30
56.16
7-20-88 Sample #118
Time 105 min
+300 stat.
2 meter

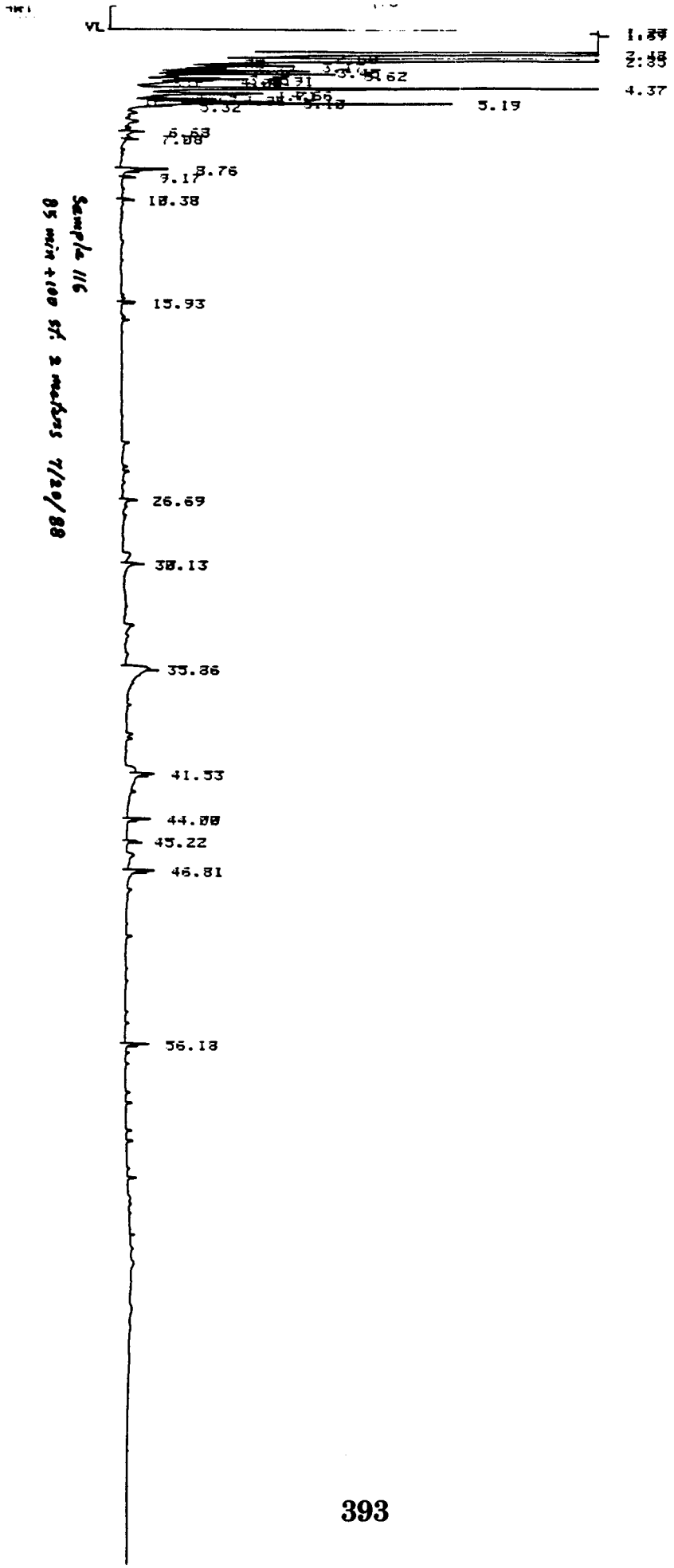
162

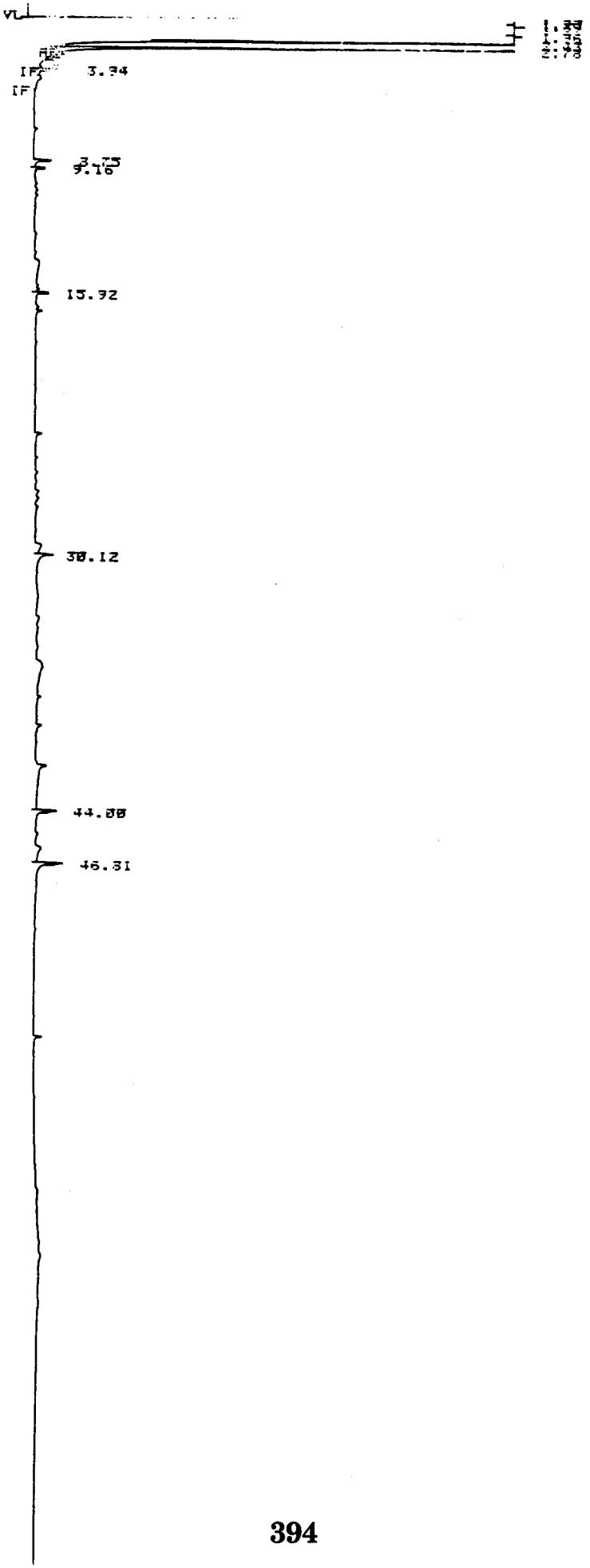
163


1.40
3.29
3.41
4.36
4.60
7.88
8.75
14.10
23.58
30.11
35.83
41.53
43.38
46.81
56.17
sample WT
7-20-88
105 min
+300 stat.
4 m Depth

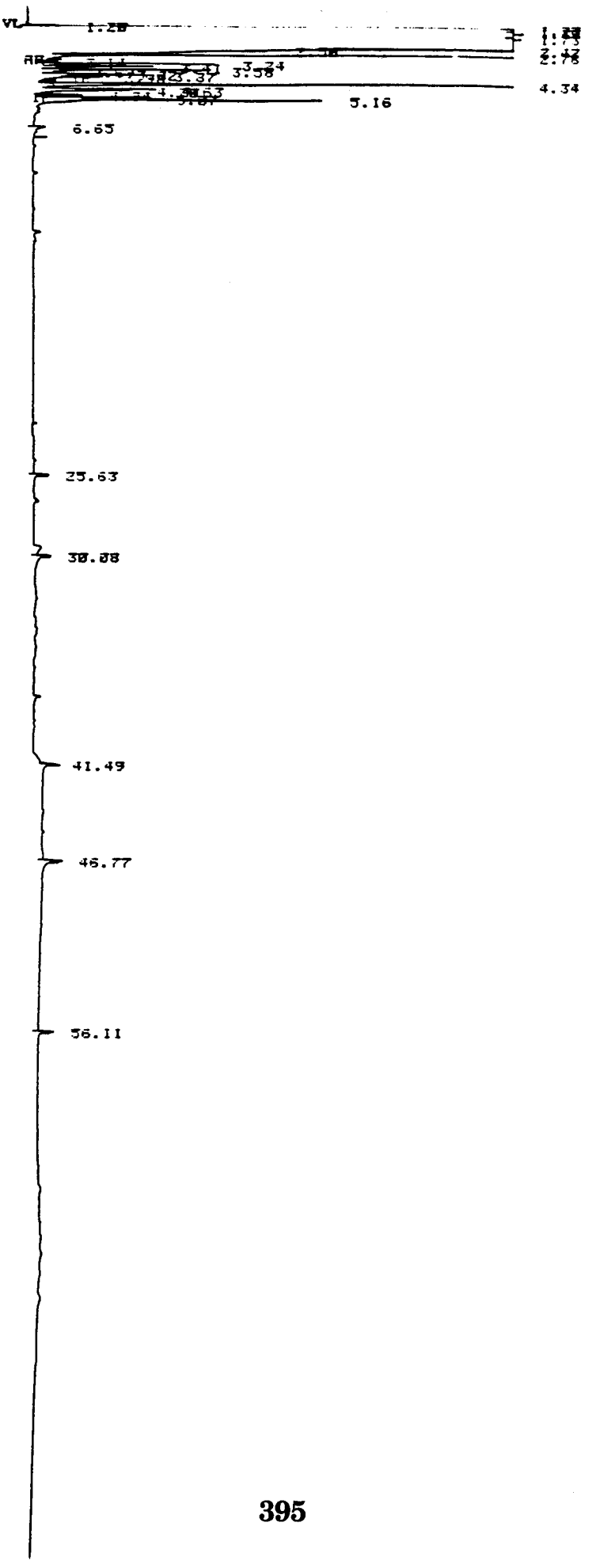
182

183


VL
4.37
5.19
9.17
10.38
15.93
26.69
30.13
35.86
41.53
44.00
45.22
46.81
56.18
Sample 116
85 min +100 sf. 2 markers 7/20/88

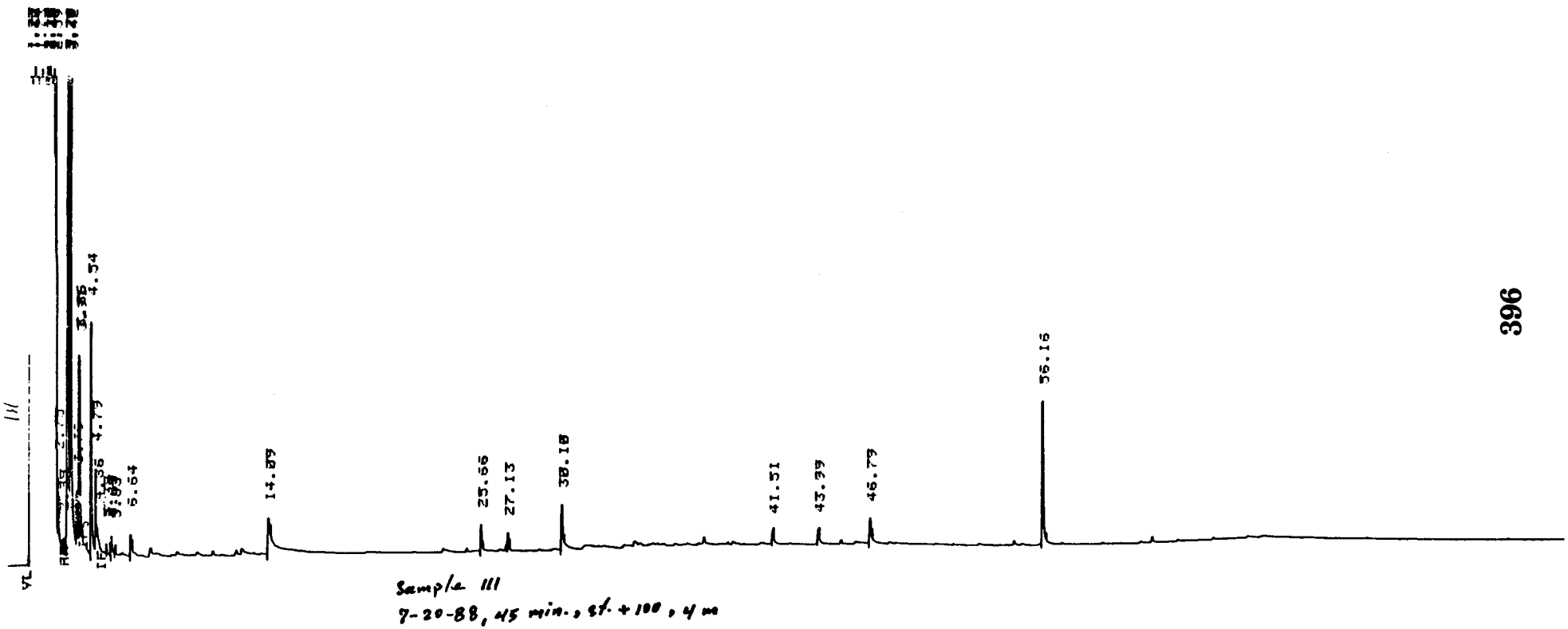

VL
IF
IF
3.34
9.16
15.92
30.12
44.00
46.31
Sample 115
85 min. + 100 sf. 4 m depth

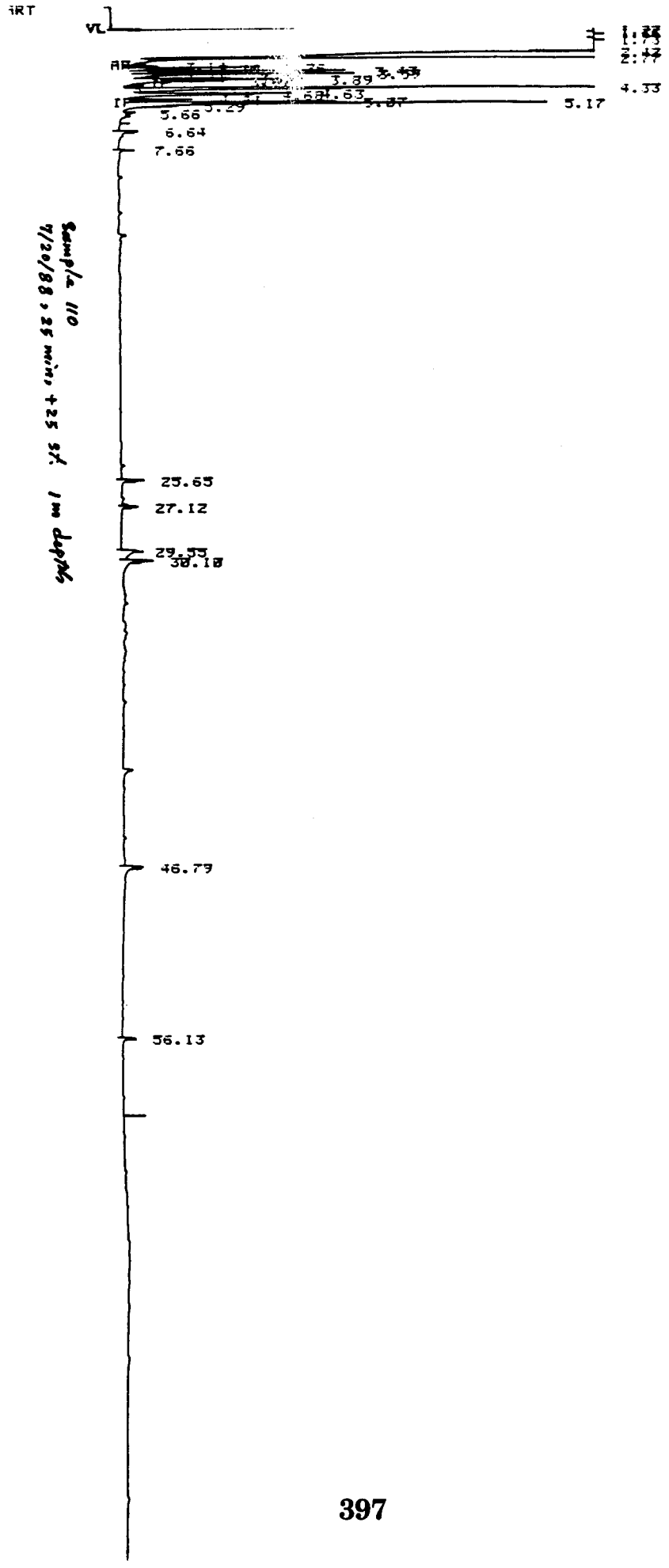
176

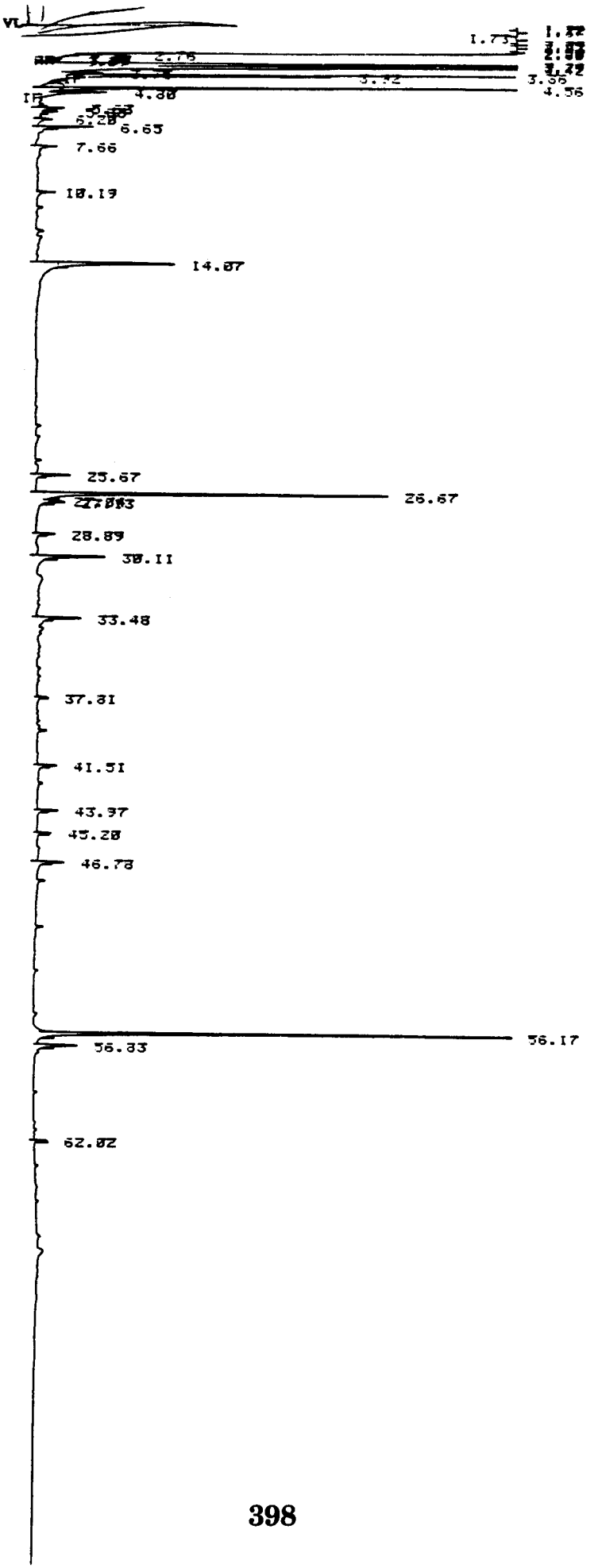

Sample 112
45 min + 100 sf. 2 m depth
1.28
3.24
3.58
4.34
5.16
6.65
25.63
30.08
41.49
46.77
56.11

159

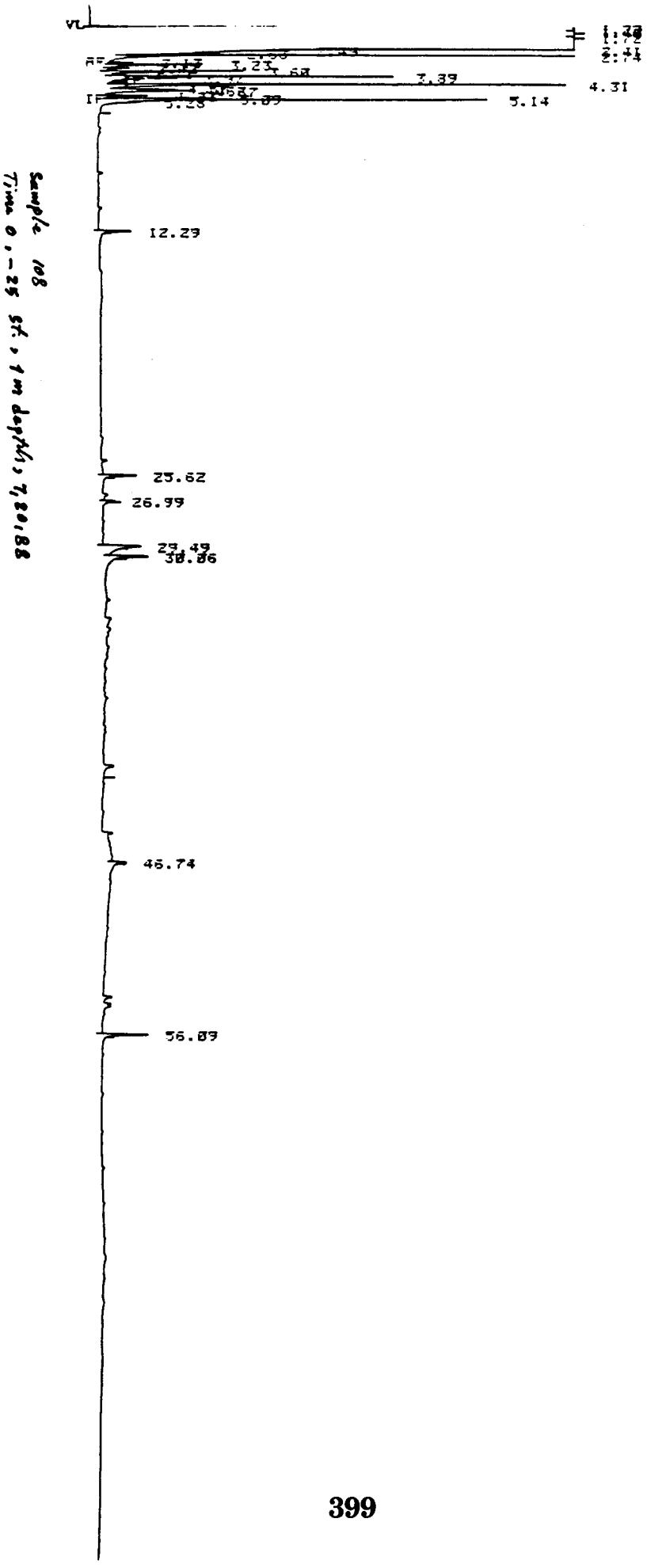
16


4.54
3.36
4.79
5.64
14.89
25.66
27.13
38.18
41.51
43.39
46.79
56.16
Sample III
7-20-88, 45 min., sf. + 100, 4 m

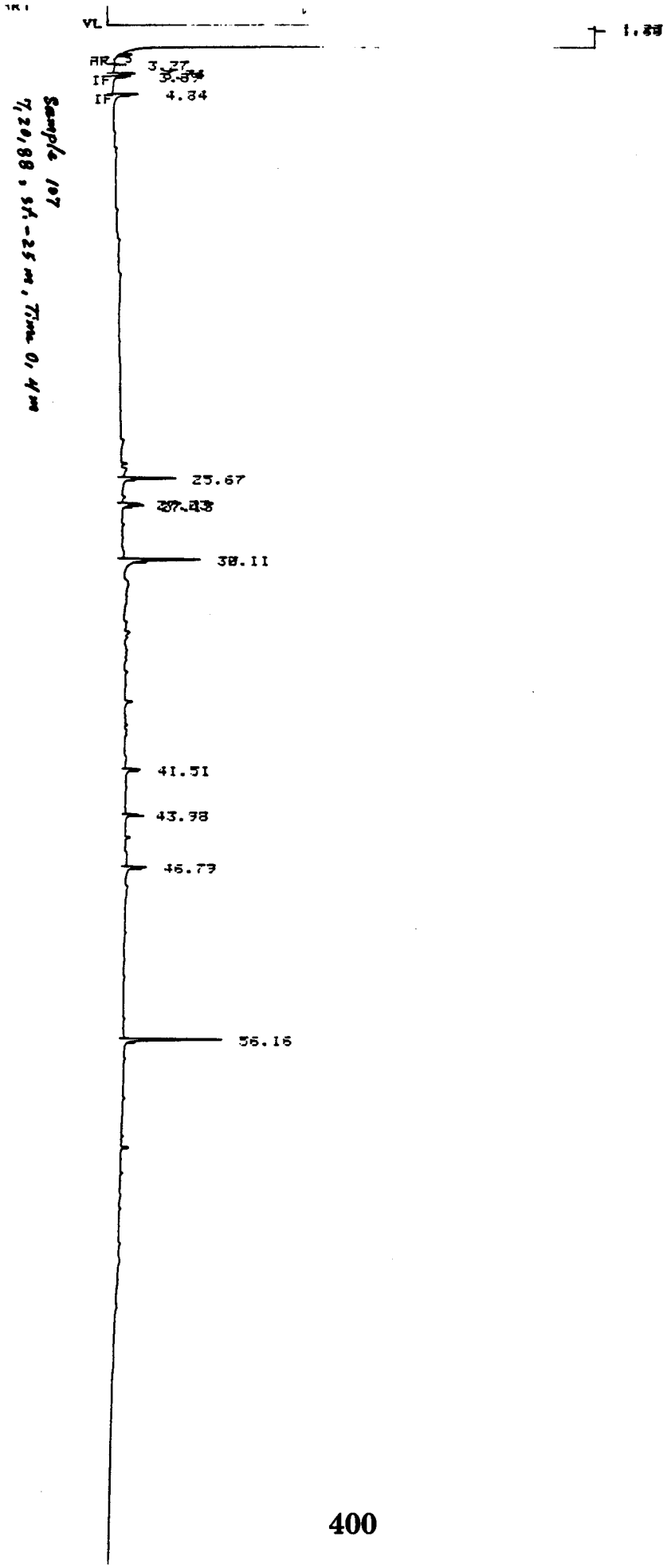

iRT
VL
AR
IP
4.33
5.17
5.66
6.64
7.66
25.65
27.12
30.10
46.79
56.13
Sample 110
7/20/88 ; 25 min. +25 s.f. 1 m depth


Sample 109
7/30/88, sf: +25, 25 min, 4m
1.73
3.92
4.38
6.65
7.66
10.19
14.87
25.67
26.67
28.89
30.11
33.48
37.81
41.51
43.37
45.28
46.78
56.17
56.83
62.02

99

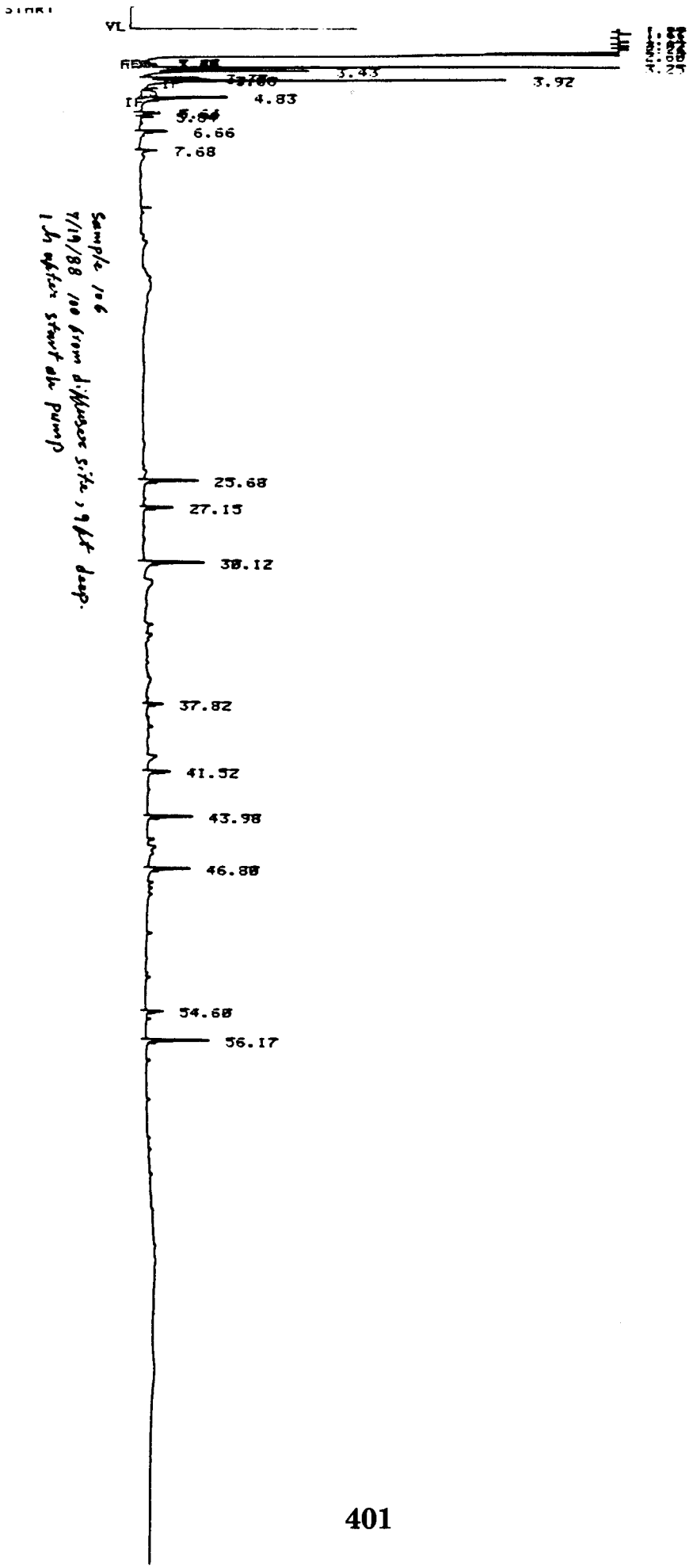


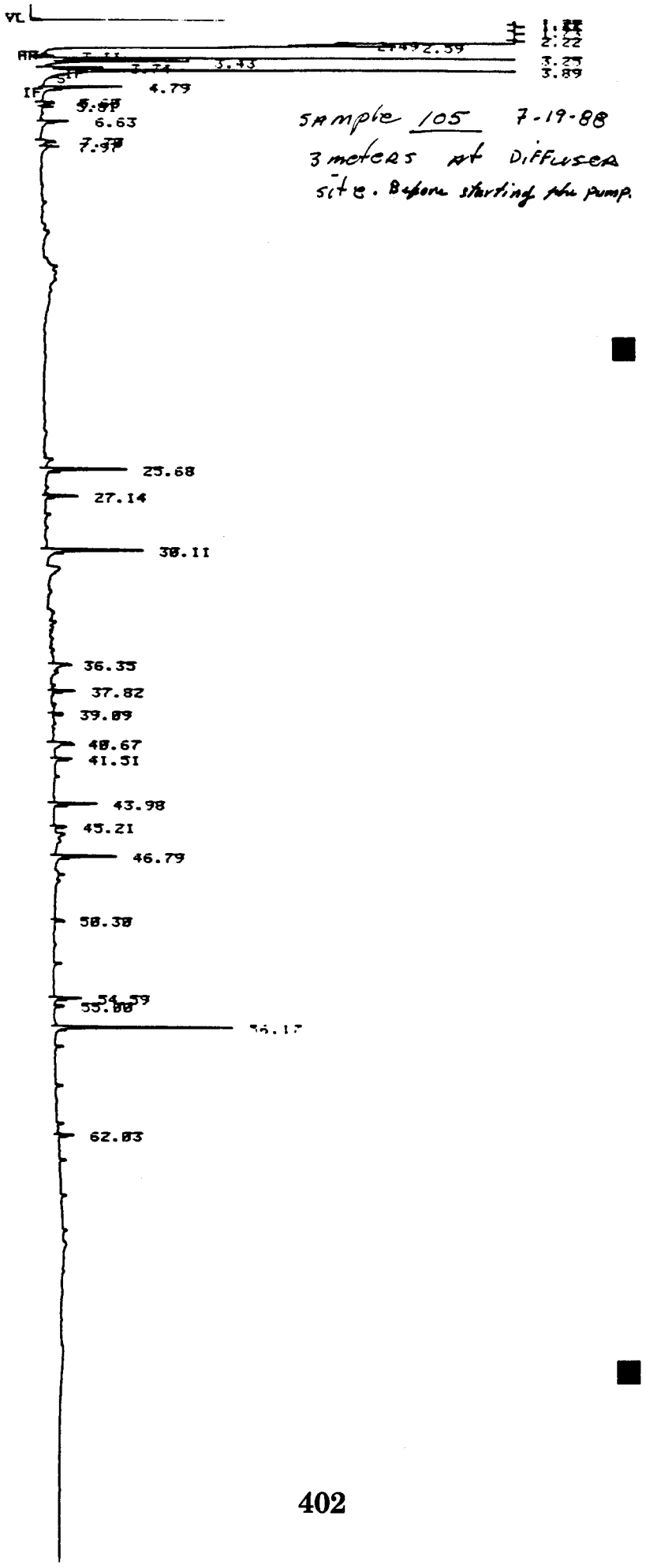
Sample 108
Time 0, -25 sec, 1 m depth, 7,80,88


Sample 107
7/20/88, sf-25 m, Trm 0.4 m
VL
AR
IF
IF
3.27
4.84
25.67
38.11
41.51
43.98
46.79
56.16

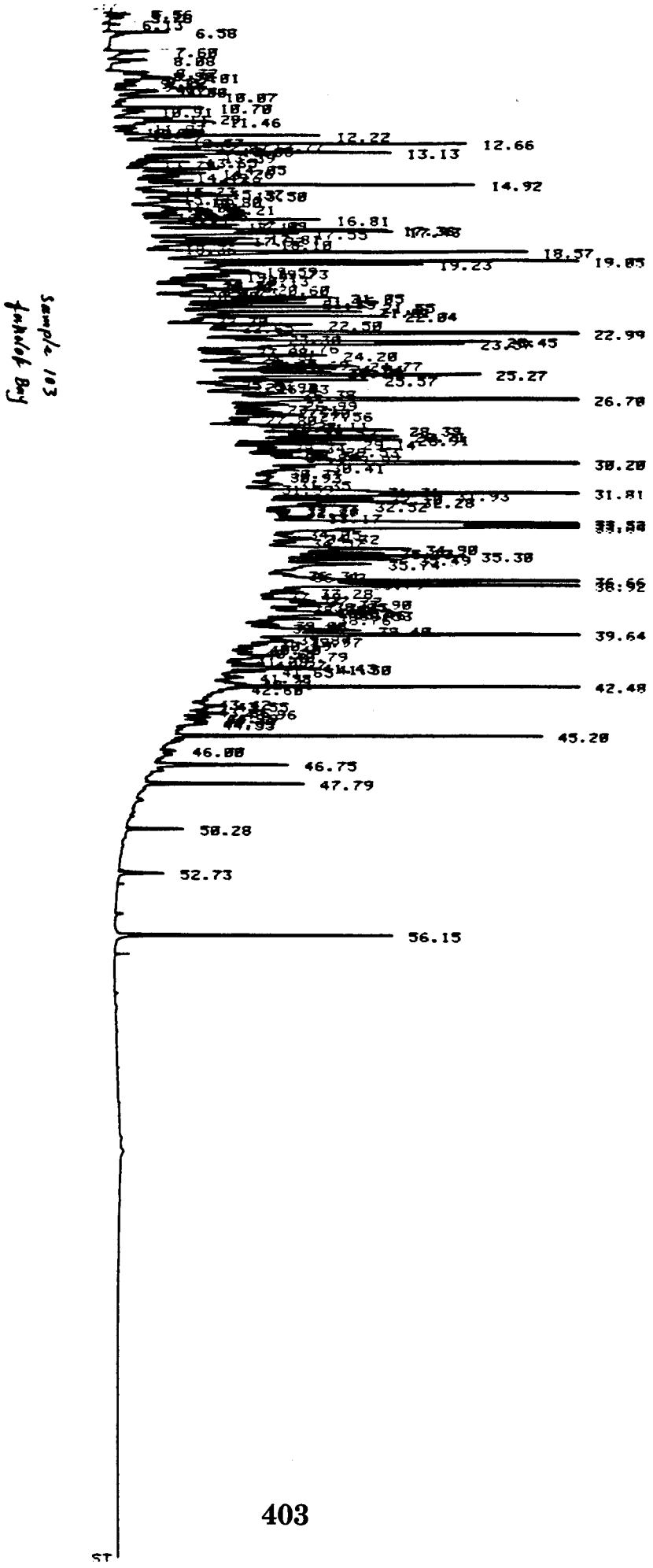
63

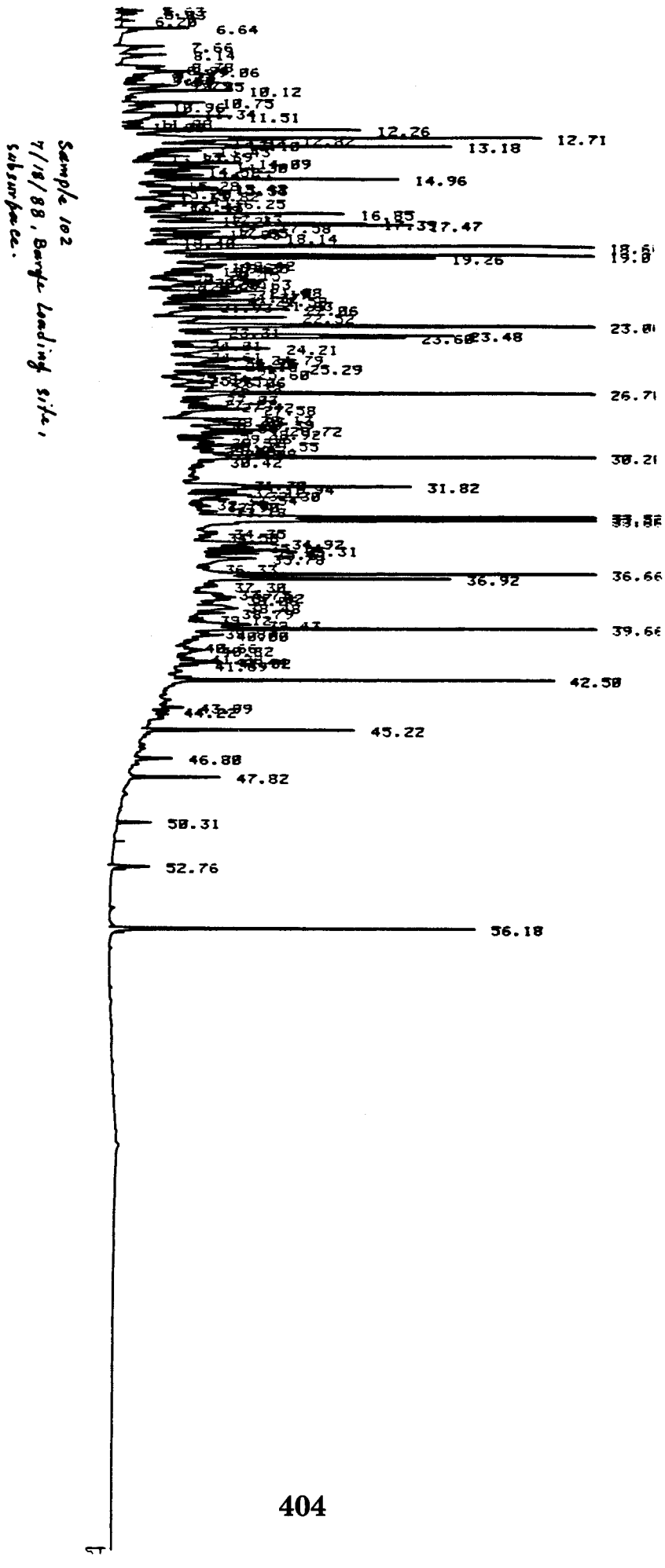
64

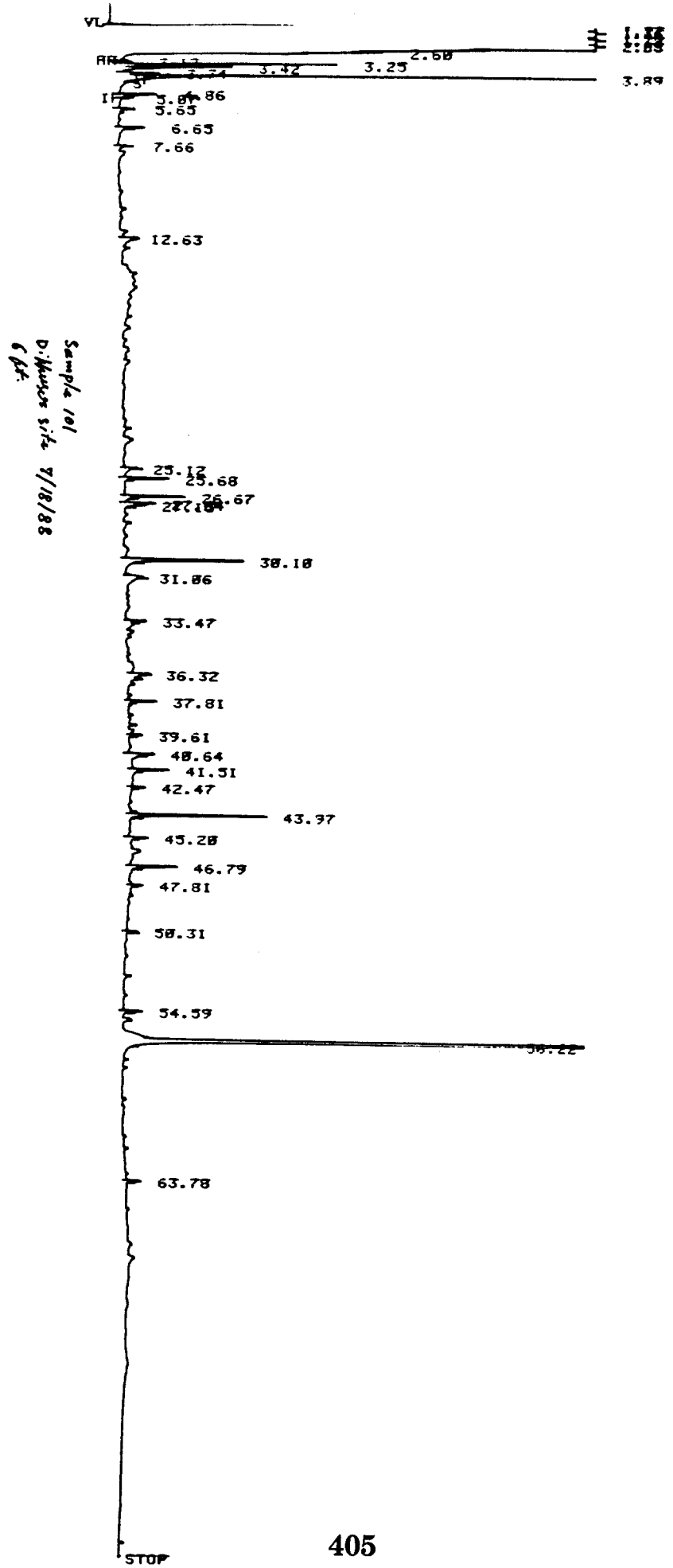

3.43
3.92
4.83
6.66
7.68
25.68
27.15
30.12
37.82
41.52
43.98
46.88
54.68
56.17
Sample 106
7/19/88 100 from diffusers site, 9 ft deep.
1 hr after start of pump

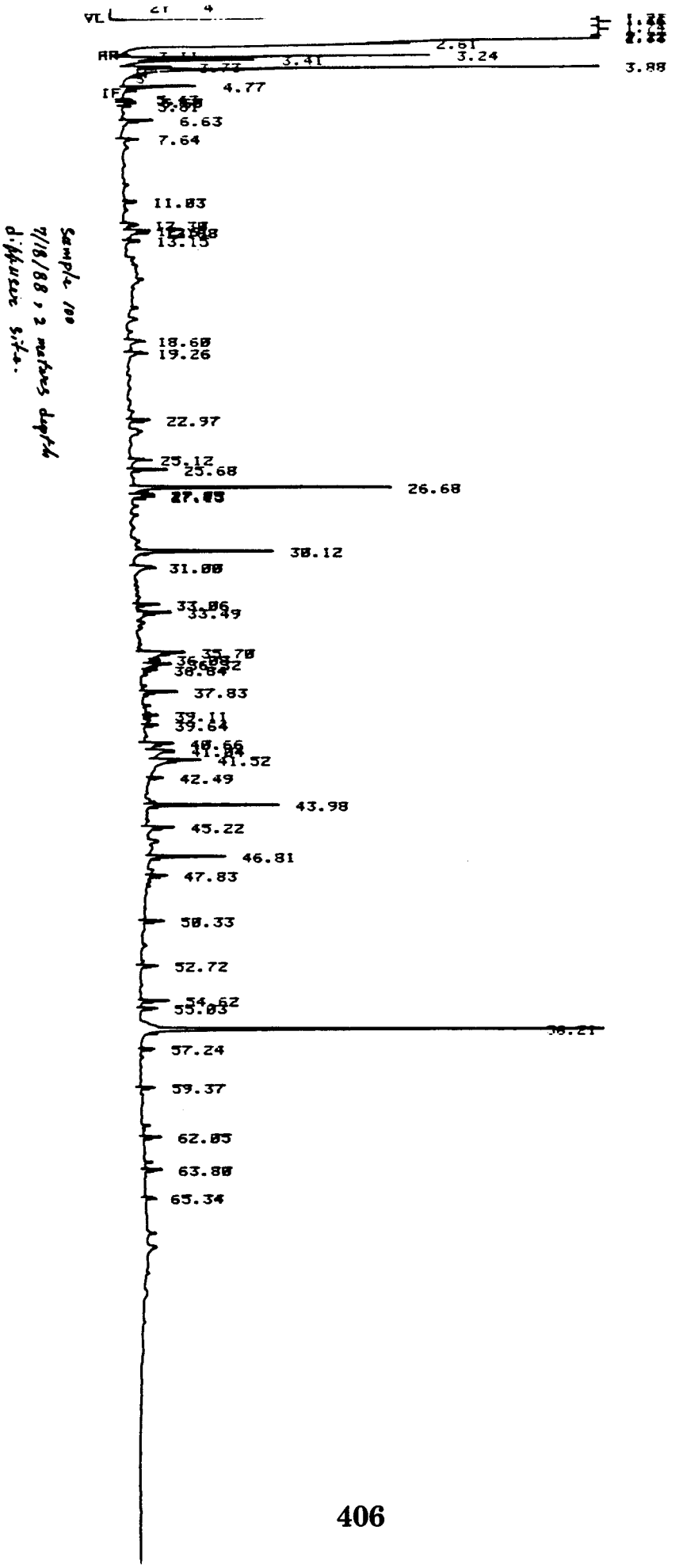


sample 105 7-19-88
3 meters at Diffuser site. Before starting the pump.


Sample 103
Tahkiok Bay
6.58
12.22
12.66
13.13
14.92
16.81
18.57
19.23
19.85
22.99
25.27
26.78
30.28
31.81
35.30
39.64
42.48
45.28
46.00
46.75
47.79
50.28
52.73
56.15


Sample 102
7/18/88, Barge loading site,
subsurface.
6.64
10.12
10.75
11.51
12.26
12.71
13.18
14.96
16.85
17.47
18.14
19.26
23.48
24.21
25.29
31.82
36.92
36.18


VL
RR
2.60
3.42
3.25
3.89
3.86
3.65
6.65
7.66
12.63
25.12
25.68
26.67
30.10
31.86
33.47
36.32
37.81
39.61
40.64
41.31
42.47
43.97
45.20
46.79
47.81
50.31
54.59
63.78
STOP
Sample 101
Diffusion site 7/18/88
6 ft.


Sample 100
7/18/88, 2 meters depth
different site.
2.51
3.24
3.41
3.88
4.77
6.63
7.64
11.83
13.13
18.60
19.26
22.97
25.12
25.68
26.68
30.12
31.00
33.06
33.49
33.70
37.83
39.64
41.52
42.49
43.98
45.22
46.81
47.83
50.33
52.72
55.03
57.24
59.37
62.05
63.80
65.34

APPENDIX C

SONIC TAG IDENTIFICATION INFORMATION AND DISPOSITION OF PINK SALMON TAKEN FROM THE MOUTH OF JAKOLOF CREEK DURING SUMMER 1988

Fish			Sonic Tag			Date				
Number	Sex (M-F)	Length (cm)	Tag No.	Frequency (Khz)	Serial No.	Fish Captured	Fish Tagged	Fish Released	Tag Recovered	Experiment No.
1	F	44	X1	76	--	7/15	7/16	7/16	7/27	Test 1
2	F	50	x2	--	--	"	"	7/17	--	Test 2
3	F	50	11	76	--	"	7/19	7/19	--	Control 1
4	M	51	0	77	--	"	"	"	--	"
5	M	60	28	72	19	"	"	"	--[b]	"
6	M	47	0	73	--	"	"	"	--	"
7	M	54	25	73	--	"	"	"	--	"
8	M	49	10	46	18	"	"	"	7/22	"
9	M	56	7	44	--	"	"	"	--	"
10	M	49	21	50	6	"	"	"	7/24	"
11	M	48	0	51	--	"	"	"	--	"
12	M	57	27	71	--	"	"	"	--	"
13	F	51	18	45	15	"	7/20	7/20	7/24	Treatment 1
14	M	48	29	75	3	"	"	"	--	"
15	F	48	30	74	1	"	"	"	--	"
16	M	47	5	46	8	"	"	"	--	"
17	F	50	0	52	11	"	"	"	--	"
18	M	46	1	71	16	"	"	"	--	"
19	M	51	9	45	12	"	"	"	--	"
20	F	52	6	71	14	"	"	"	7/27	"
21	M	49	7	47	21	"	"	"	--	"
22	F	49	0	50	9	"	"	"	--	"
23	M	47	15	46	24	7/22	7/22	7/23	--	Control 2
24	F	45	10	46	18	"	"	"	[b]	"
25	F	52	17	42	31	"	"	"	7/27	"
26	M	49	0	40	26	"	"	"	--	"
27	F	42	0	71	22	"	"	"	--	"
28	M	49	18	76	23	"	"	"	--	"
29	F	53	2	52	27	"	"	"	--	"
30	M	58	31	75	28	"	"	"	--	"
31	F	43	0	53	29	"	"	"	--	"
32	F	47	0	51	30	"	"	"	--[b]	"
33	F	47	0	53	32	"	7/23	7/24	--	Control 2R
34	M	51	23	74	33	"	"	"	--	"
35	F	54	8	45	34	"	"	"	--	"
36	F	53	28	72	35	"	"	"	--	"
37	M	49	5	44	36	"	"	"	--[b]	"
38	M	48	9	46	37	"	"	"	--	"
39	M	56	20	72	38	"	"	"	--	"
40	F	49	27	73	39	"	"	"	--	"

Appendix C, Continued

Fish			Sonic Tag			Date				
Number	Sex (M-F)	Length (cm)	Tag No.	Frequency (Khz)	Serial No.	Fish Captured	Fish Tagged	Fish Released	Tag Recovered	Experiment No.
41	F	47	0	67	40	7/22	7/23	7/24	--	Control 2R
42	M	48	0	55	41	"	"	"	--	"
43	M	46	0	52	47	7/24	7/24	7/25	--	Treatment 2
44	F	50	21	50	6	"	"	"	--	"
45	F	51	24	71	43	"	"	"	--	"
46	M	47	19	76	42	"	"	"	--	"
47	F	49	3	46	44	"	"	"	--	"
48	F	45	0	67	45	"	"	"	--	"
49	F	51	20	50	46	"	"	"	--	"
50	F	53	24	50	48	"	"	"	--	"
51	F	53	14	46	49	"	"	"	--	"
52	F	46	23	52	50	"	"	"	--	"
53	M	41	15	47	66	7/27	7/27	7/28	--	Control 3
54	M	49	2	47	65	"	"	"	--	"
55	M	57	5	48	72	"	"	"	--	"
56	M	52	4	47	60	"	"	"	--	"
57	M	50	0	54	64	"	"	"	--	"
58	F	50	13	48	63	"	"	"	--	"
59	M	48	16	44	56	"	"	"	--	"
60	F	47	8	46	58	"	"	"	--	"
61	M	53	0	75	55	"	"	"	--	"
62	M	50	6	47	60	"	"	"	--	"
63	M	52	0	47	61	"	"	"	--	"
64	F	44	1	47	54	"	"	"	--	"
65	M	55	20	72	51	"	"	"	--	"
66	M	45	1	43	57	"	"	Mortality[a]	7/29	"
67	F	53	0	72	59	"	"	7/28	--	"
68	M	48	3	47	67	"	"	"	--	"
69	M	54	7	46	62	"	"	"	--	"
70	F	55	0	48	69	"	"	"	--	"
71	F	49	14	47	71	"	"	"	--	"
72	M	53	11	47	70	"	"	"	--	"
73	F	52	22	73	23	"	7/28	7/29	--	Treatment 3
74	M	42	4	45	80	"	"	"	--	"
75	M	47	3	74	73	"	"	"	--	"
76	F	54	4	46	72	"	"	"	--	"
77	M	44	13	46	85	"	"	"	--	"
78	M	46	30	76	77	"	"	"	--	"
79	M	47	0	49	74	"	"	"	--	"
80	F	53	0	70	82	7/27	7/28	7/29	--	"
81	M	50	22	49	79	"	"	"	--	"
82	F	50	26	75	88	"	"	"	--	"
83	M	49	31	74	91	"	"	"	--	"
84	M	57	16	42	87	"	"	"	--	"
85	M	60	7	74	89	"	"	"	--	"
86	M	45	1	72	86	"	"	"	--	"

Appendix C, Concluded

Fish			Sonic Tag			Date				
Number	Sex (M-F)	Length (cm)	Tag No.	Frequency (Khz)	Serial No.	Fish Captured	Fish Tagged	Fish Released	Tag Recovered	Experiment No.
87	F	47	0	50	84	"	"	"	--[b]	Treatment 3
88	F	51	30	72	75	7/27	7/28	7/29	--	"
89	M	50	1	76	76	"	"	"	--	"
90	F	50	6	45	90	"	"	"	--	"
91	M	47	25	72	81	"	"	"	--	"
92	F	50	12	46	78	"	"	Mortality[a]	7/29	"

[a] Fish died due to entanglement in net pen.
[b] Tag recovered from Jakolof Creek after the experiment was completed.

APPENDIX D

HORIZONTAL POSITION (X Y), DEPTH, AND HYDROCARBON CONCENTRATION BY TIME FOR EACH FISH

Appendix D-1

Horizontal Position (X, Y) and Depth
by Fish and Time During Control 1

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
3	2033.0	1640	625	0.15	4	2051.0	1938	429	3.51
	2034.0	1648	601	1.98		2052.0	1972	433	3.66
	2035.0	1653	593	2.90		2053.0	2002	438	3.66
	2036.0	1659	588	3.05		2054.0	2038	443	3.66
	2037.0	1667	577	3.20		2055.0	2069	449	3.51
	2038.0	1673	541	3.20		2056.0	2098	455	3.36
	2039.0	1681	521	3.36	5	2034.0	1641	595	2.29
	2040.0	1689	499	3.36		2035.0	1644	578	2.75
	2041.0	1716	468	3.51		2036.0	1649	555	3.20
	2042.0	1730	453	3.51		2037.0	1653	534	3.20
	2043.0	1746	440	3.51		2038.0	1658	511	3.36
	2044.0	1761	430	3.66		2039.0	1663	485	3.36
	2045.0	1791	414	3.66		2040.0	1670	462	3.36
	2046.0	1778	444	3.51		2041.0	1679	436	3.51
	2047.0	1812	439	3.66		2042.0	1691	410	3.36
	2048.0	1852	442	3.81		2043.0	1708	393	3.36
	2049.0	1893	449	3.66		2044.0	1735	382	3.51
	2050.0	1923	445	3.66		2045.0	1767	381	3.66
	2051.0	1961	447	3.51		2046.0	1804	385	3.66
	2052.0	1996	449	3.36		2047.0	1836	394	3.81
	2053.0	2031	451	3.36		2048.0	1873	401	3.81
	2054.0	2059	455	3.51		2049.0	1907	409	3.51
	2055.0	2127	460	3.66		2050.0	1946	424	3.51
4	2034.0	1647	600	1.53		2051.0	1985	429	3.66
	2035.0	1651	591	2.29		2052.0	2025	432	3.66
	2036.0	1653	584	3.05		2053.0	2062	435	3.51
	2037.0	1658	572	3.20		2054.0	2099	438	3.51
	2038.0	1663	560	3.05	6	2034.0	1644	597	1.98
	2039.0	1669	541	3.36		2035.0	1646	593	2.90
	2040.0	1676	525	3.51		2036.0	1648	580	2.90
	2041.0	1683	505	3.36		2037.0	1652	563	3.05
	2042.0	1694	482	3.36		2038.0	1657	542	3.20
	2046.0	1792	418	3.51		2039.0	1664	518	3.36
	2047.0	1800	418	3.66		2040.0	1670	492	3.36
	2048.0	1830	416	3.66		2041.0	1679	472	3.51
	2049.0	1868	416	3.51		2042.0	1694	475	3.66
	2050.0	1897	419	3.51		2043.0	1708	482	3.66

Appendix D-1

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
6	2044.0	1725	466	3.81	7	2101.0	1701	532	3.97
	2045.0	1756	447	3.81		2102.0	1715	531	3.81
	2046.0	1795	422	3.81		2103.0	1729	530	3.81
	2047.0	1822	418	3.36		2104.0	1744	528	3.66
	2048.0	1856	415	3.36		2105.0	1759	525	3.66
	2049.0	1893	411	3.51		2106.0	1775	524	3.66
	2050.0	1963	435	3.66		2107.0	1792	523	3.51
	2051.0	2002	439	3.66		2108.0	1810	517	3.51
	2052.0	2043	441	3.66		2109.0	1826	516	3.66
	2053.0	2076	446	3.81		2110.0	1841	510	3.51
	2054.0	2112	453	3.66		2111.0	1858	501	3.66
7	2034.0	1643	604	3.05		2112.0	1876	489	3.81
	2035.0	1634	617	3.51		2113.0	1889	483	3.66
	2036.0	1634	603	3.81		2114.0	1915	480	3.66
	2037.0	1631	600	3.97		2115.0	1933	475	3.51
	2038.0	1629	598	4.12		2116.0	1953	469	3.36
	2039.0	1627	595	4.12		2117.0	1971	464	3.51
	2040.0	1626	586	3.97		2118.0	1991	461	3.66
	2041.0	1623	584	3.97		2119.0	2016	456	3.66
	2042.0	1621	582	4.12		2120.0	2048	453	3.81
	2043.0	1620	576	4.27		2121.0	2087	452	3.81
	2044.0	1617	566	4.42		2122.0	2124	453	3.81
	2045.0	1617	563	4.58	8	2034.0	1645	598	1.98
	2046.0	1618	559	4.73		2035.0	1649	585	2.59
	2047.0	1618	555	4.73		2036.0	1654	573	2.75
	2048.0	1621	554	4.73		2037.0	1659	556	2.90
	2049.0	1625	554	4.88		2038.0	1664	538	3.05
	2050.0	1624	549	4.73		2039.0	1670	523	3.20
	2051.0	1624	546	4.58		2040.0	1680	507	3.20
	2052.0	1628	547	4.58		2041.0	1698	489	3.36
	2053.0	1630	545	4.58		2042.0	1722	478	3.36
	2054.0	1633	544	4.42		2048.0	1931	472	3.20
	2055.0	1638	543	4.58		2049.0	1965	471	3.36
	2056.0	1641	541	4.73		2050.0	1999	470	3.51
	2057.0	1649	539	4.42		2051.0	2032	468	3.51
	2058.0	1659	537	4.27		2052.0	2073	469	3.66
	2059.0	1672	534	3.97		2053.0	2114	468	3.51
	2100.0	1685	534	4.12	9	2034.0	1641	602	2.29

Appendix D-1

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
9	2035.0	1643	590	3.05	10	2049.0	1921	434	3.66
	2036.0	1645	575	3.36		2050.0	1961	436	3.66
	2037.0	1649	559	3.51		2051.0	2001	436	3.81
	2038.0	1653	541	3.51		2052.0	2040	437	3.66
	2039.0	1653	524	3.66		2053.0	2081	438	3.51
	2040.0	1659	505	3.81		2054.0	2112	437	3.51
	2041.0	1663	490	3.97	11	2034.0	1643	604	2.44
	2042.0	1669	467	3.97		2035.0	1647	588	2.90
	2043.0	1677	445	3.97		2036.0	1651	575	3.20
	2044.0	1696	426	3.81		2037.0	1656	557	3.36
	2045.0	1716	411	3.66		2038.0	1660	543	3.36
	2046.0	1745	402	3.66		2039.0	1666	525	3.66
	2047.0	1774	399	3.51		2040.0	1670	502	3.81
	2048.0	1805	404	3.51		2041.0	1678	483	3.81
	2049.0	1834	406	3.81		2042.0	1686	460	3.66
	2050.0	1871	409	3.81		2043.0	1695	441	3.51
	2051.0	1903	411	3.66		2044.0	1709	419	3.51
	2052.0	1944	422	3.66		2045.0	1727	404	3.36
	2053.0	1980	426	3.51		2046.0	1753	397	3.36
	2054.0	2018	431	3.66		2047.0	1780	398	3.36
	2055.0	2051	434	3.81		2048.0	1813	401	3.51
	2056.0	2085	439	3.66		2049.0	1836	414	3.66
	2057.0	2116	443	3.66		2050.0	1864	418	3.66
10	2034.0	1647	607	1.83		2051.0	1891	422	3.81
	2035.0	1653	598	2.59		2052.0	1929	438	3.51
	2036.0	1660	584	2.90		2053.0	1966	448	3.51
	2037.0	1668	571	3.05		2054.0	2000	453	3.66
	2038.0	1675	559	3.20		2055.0	2033	459	3.66
	2039.0	1682	547	3.20		2056.0	2079	465	3.81
	2040.0	1690	536	3.51		2057.0	2122	469	3.66
	2041.0	1700	519	3.51	12	2034.0	1644	597	2.14
	2042.0	1712	503	3.66		2035.0	1647	580	2.90
	2043.0	1725	486	3.66		2036.0	1651	565	3.20
	2044.0	1745	464	3.51		2037.0	1655	546	3.51
	2045.0	1770	445	3.36		2038.0	1660	528	3.51
	2046.0	1798	433	3.36		2039.0	1667	509	3.66
	2047.0	1838	423	3.36		2040.0	1676	491	3.66
	2048.0	1877	424	3.51		2041.0	1698	481	3.81

Appendix D-1

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)
12	2042.0	1713	468	3.51
	2043.0	1723	450	3.36
	2044.0	1744	437	3.36
	2045.0	1766	425	3.20
	2046.0	1792	414	3.36
	2047.0	1822	409	3.51
	2048.0	1856	409	3.51
	2049.0	1894	414	3.66
	2050.0	1935	426	3.66
	2051.0	1969	433	3.66
	2052.0	2004	440	3.81
	2053.0	2041	447	3.66
	2054.0	2072	452	3.51
	2055.0	2101	453	3.36
	2056.0	2128	455	3.51

Appendix D-2

Horizontal Position (X, Y) and Depth
by Fish and Time During Control 2

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
33	1328.0	1645	606	0.31	33	1406.0	2115	435	4.58
	1329.0	1647	594	1.22		1407.0	2131	441	4.58
	1330.0	1650	586	2.59		1408.0	2149	442	4.73
	1331.0	1651	578	3.05		1409.0	2164	446	4.27
	1332.0	1654	562	3.05		1410.0	2178	451	4.27
	1333.0	1658	545	3.20		1411.0	2192	468	4.12
	1334.0	1655	521	3.51		1412.0	2211	500	3.66
	1335.0	1653	502	3.66		1413.0	2233	475	3.81
	1336.0	1649	487	3.97		1415.0	2292	478	3.51
	1337.0	1644	467	4.42		1416.0	2319	479	3.51
	1338.0	1640	446	4.58		1417.0	2365	475	3.66
	1339.0	1643	430	4.58		1418.0	2385	481	3.66
	1340.0	1651	417	4.88	34	1329.0	1643	596	1.98
	1341.0	1662	413	5.03		1330.0	1643	585	3.36
	1342.0	1672	408	5.03		1331.0	1643	581	3.20
	1343.0	1684	407	4.88		1332.0	1644	571	3.20
	1344.0	1695	405	5.03		1333.0	1644	555	3.36
	1345.0	1709	404	4.88		1334.0	1643	538	3.66
	1346.0	1721	401	4.73		1335.0	1640	515	3.51
	1347.0	1732	399	4.73		1336.0	1636	498	3.66
	1348.0	1741	400	4.88		1337.0	1636	482	3.81
	1349.0	1751	399	4.58		1338.0	1633	465	4.12
	1350.0	1762	400	4.42		1339.0	1635	452	4.12
	1352.0	1788	402	3.97		1340.0	1638	437	4.27
	1353.0	1812	407	3.66		1341.0	1641	427	4.42
	1354.0	1836	413	3.51		1342.0	1644	419	4.42
	1355.0	1858	415	3.36		1343.0	1648	413	4.58
	1356.0	1889	417	3.05		1344.0	1650	404	4.42
	1357.0	1921	425	3.20		1345.0	1658	395	4.42
	1358.0	1949	426	3.20		1346.0	1664	390	4.42
	1359.0	1977	429	3.36		1347.0	1676	390	4.27
	1400.0	2001	432	3.51		1348.0	1678	383	4.42
	1401.0	2024	433	3.81		1349.0	1686	379	4.27
	1402.0	2044	438	4.27		1350.0	1699	379	4.12
	1403.0	2061	441	4.73		1351.0	1714	375	4.12
	1404.0	2078	442	4.73		1352.0	1738	377	3.97
	1405.0	2099	435	4.58		1353.0	1760	381	3.81

Appendix D-2

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
34	1354.0	1781	387	3.66	35	1336.0	1618	497	3.97
	1355.0	1802	394	3.66		1337.0	1610	484	3.81
	1356.0	1826	401	3.36		1338.0	1604	471	3.97
	1357.0	1849	408	3.36		1339.0	1597	455	4.12
	1358.0	1878	415	3.51		1340.0	1596	441	4.42
	1359.0	1904	422	3.36		1341.0	1596	433	4.42
	1400.0	1935	432	3.20		1342.0	1598	426	4.58
	1401.0	1951	434	3.51		1343.0	1601	419	4.58
	1402.0	1964	438	3.66		1345.0	1611	408	4.88
	1403.0	1976	440	3.81		1346.0	1616	405	4.88
	1404.0	1987	441	3.97		1347.0	1622	403	4.58
	1405.0	2000	444	3.97		1348.0	1628	401	4.42
	1406.0	2012	448	4.12		1349.0	1635	401	4.42
	1407.0	2023	450	4.12		1350.0	1641	398	4.27
	1408.0	2033	451	3.97		1351.0	1651	399	4.12
	1409.0	2043	453	3.97		1352.0	1671	401	3.81
	1410.0	2053	454	3.81		1353.0	1699	406	3.66
	1411.0	2062	456	3.51		1354.0	1723	410	3.36
	1412.0	2072	458	3.36		1355.0	1754	412	3.51
	1413.0	2089	459	3.51		1357.0	1821	411	3.66
	1414.0	2106	461	3.36		1358.0	1855	405	3.81
	1415.0	2123	466	3.36		1359.0	1886	404	3.97
	1416.0	2142	465	3.20		1400.0	1908	402	4.12
	1417.0	2165	464	3.20		1401.0	1930	407	4.27
	1418.0	2190	467	3.36		1402.0	1945	405	4.42
	1419.0	2219	469	3.51		1403.0	1953	402	4.27
	1420.0	2251	490	3.51		1404.0	1966	402	4.27
	1421.0	2277	490	3.51		1405.0	1979	400	4.42
	1422.0	2301	487	3.66		1406.0	1991	400	4.58
	1423.0	2333	487	3.51		1407.0	2003	400	4.42
	1424.0	2359	488	3.36		1408.0	2018	399	4.42
	1425.0	2383	491	3.36		1409.0	2032	400	4.27
35	1329.0	1640	588	1.53		1410.0	2046	400	4.42
	1330.0	1639	582	2.59		1411.0	2063	404	4.27
	1331.0	1637	573	3.05		1412.0	2085	406	4.27
	1332.0	1635	561	3.36		1413.0	2109	413	4.12
	1333.0	1631	541	3.51		1414.0	2139	420	3.97
	1334.0	1629	528	3.66		1415.0	2170	428	3.97
	1335.0	1622	510	3.66		1416.0	2202	436	3.81

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
35	1417.0	2235	445	3.66	36	1349.0	1772	408	4.73
	1418.0	2266	470	3.51		1350.0	1782	410	4.58
	1419.0	2293	470	3.66	37	1351.0	1792	411	4.42
	1420.0	2315	469	3.81		1352.0	1806	413	4.27
	1421.0	2335	470	3.66		1353.0	1827	417	4.12
	1422.0	2355	469	3.66		1354.0	1853	421	3.97
	1423.0	2379	470	3.51		1355.0	1882	424	3.66
	1424.0	2401	472	3.66		1356.0	1901	429	3.81
36	1329.0	1637	591	1.37		1357.0	1931	437	3.66
	1330.0	1632	577	1.98		1358.0	1956	443	3.51
	1331.0	1625	563	2.59		1359.0	1982	446	3.36
	1332.0	1618	546	2.44		1400.0	2009	449	3.51
	1333.0	1609	525	2.59		1401.0	2030	450	3.81
	1334.0	1592	498	2.75		1402.0	2047	450	3.97
	1336.0	1534	486	2.90		1403.0	2065	450	4.12
	1337.0	1504	487	3.05		1404.0	2080	450	4.27
	1338.0	1470	493	2.90		1405.0	2094	450	4.27
	1339.0	1423	499	2.75		1406.0	2104	450	4.42
	1340.0	1345	506	2.90		1407.0	2116	445	4.27
37	1329.0	1644	605	1.07		1408.0	2131	445	4.27
	1330.0	1647	594	2.14		1409.0	2146	443	3.97
	1331.0	1652	587	2.90		1410.0	2165	442	3.81
	1332.0	1656	571	3.20		1411.0	2184	440	3.66
	1333.0	1660	550	3.51		1412.0	2207	441	3.66
	1334.0	1661	530	3.66		1413.0	2238	442	3.81
	1335.0	1654	504	3.97		1414.0	2266	467	3.66
	1336.0	1651	485	3.97		1415.0	2287	465	3.66
	1337.0	1649	469	3.81		1416.0	2313	463	3.51
	1338.0	1646	449	3.97		1417.0	2347	465	3.66
	1339.0	1647	429	4.12		1418.0	2385	469	3.81
	1340.0	1658	414	4.42	38	1329.0	1642	603	1.98
	1341.0	1667	409	4.42		1330.0	1640	601	2.75
	1342.0	1676	405	4.58		1331.0	1640	587	3.05
	1343.0	1688	404	4.73		1332.0	1639	565	3.36
	1344.0	1703	403	4.73		1333.0	1633	539	3.51
	1345.0	1719	402	4.88		1334.0	1634	516	3.51
	1346.0	1732	404	5.03		1335.0	1635	494	3.66
	1347.0	1745	405	4.88		1336.0	1635	474	3.51
	1348.0	1761	406	4.58		1337.0	1638	452	3.81

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
38	1339.0	1657	403	4.12	39	1331.0	1637	585	3.36
	1340.0	1677	389	4.42		1332.0	1635	565	3.36
	1341.0	1689	383	4.58		1333.0	1628	544	3.51
	1342.0	1703	382	4.73		1334.0	1622	519	3.66
	1343.0	1719	376	4.73		1335.0	1612	496	3.66
	1344.0	1734	372	4.88		1336.0	1607	478	4.12
	1345.0	1751	372	4.88		1337.0	1603	463	4.12
	1346.0	1769	372	4.88		1338.0	1600	453	4.27
	1347.0	1787	377	4.73		1339.0	1598	440	4.27
	1348.0	1803	382	4.73		1340.0	1601	428	4.27
	1349.0	1819	388	4.58		1341.0	1604	418	4.42
	1350.0	1836	393	4.58		1342.0	1610	408	4.58
	1351.0	1852	397	4.58		1343.0	1616	400	4.73
	1352.0	1871	399	4.42		1344.0	1622	392	4.88
	1353.0	1900	402	4.12		1345.0	1631	385	5.03
	1354.0	1935	411	3.97		1346.0	1639	381	4.88
	1355.0	1964	408	3.81		1347.0	1646	377	4.88
	1356.0	1987	405	3.66		1348.0	1652	373	4.73
	1357.0	2007	403	3.97		1349.0	1658	370	4.58
	1358.0	2031	399	4.12		1350.0	1664	367	4.73
	1359.0	2050	396	4.42		1351.0	1671	366	4.58
	1400.0	2069	394	4.58		1352.0	1671	366	4.58
	1401.0	2085	394	4.58		1353.0	1687	361	4.73
	1402.0	2102	391	4.42		1354.0	1695	359	4.73
	1403.0	2120	398	4.27		1355.0	1701	356	4.58
	1404.0	2142	402	4.27		1356.0	1709	355	4.42
	1405.0	2162	408	4.12		1357.0	1717	357	4.42
	1406.0	2179	411	3.97		1358.0	1731	355	4.27
	1407.0	2194	415	3.81		1359.0	1747	352	4.27
	1408.0	2212	419	3.66		1400.0	1762	354	4.42
	1409.0	2227	421	3.66		1401.0	1777	356	4.27
	1410.0	2244	425	3.51		1402.0	1786	367	4.12
	1412.0	2279	451	3.51		1403.0	1803	370	4.12
	1413.0	2301	450	3.36		1404.0	1817	374	3.97
	1414.0	2328	451	3.66		1405.0	1832	380	3.97
	1415.0	2365	452	3.81		1406.0	1851	385	4.12
	1416.0	2405	453	3.66		1407.0	1870	387	3.97
39	1329.0	1640	600	2.29		1408.0	1889	388	3.97
	1330.0	1639	593	3.20		1409.0	1912	389	3.81

Appendix D-2

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
39	1410.0	1940	396	3.66	40	1339.0	1680	471	4.27
	1411.0	1954	393	3.51		1340.0	1684	461	4.42
	1412.0	1969	392	3.36		1341.0	1685	449	4.42
	1413.0	1986	389	3.36		1342.0	1693	438	4.58
	1414.0	2001	387	3.51		1343.0	1697	426	4.73
	1415.0	2016	384	3.36		1344.0	1699	416	4.88
	1416.0	2030	380	3.51		1345.0	1706	404	4.88
	1417.0	2044	378	3.36		1346.0	1713	397	4.88
	1418.0	2059	374	3.51		1347.0	1720	392	4.73
	1419.0	2075	369	3.81		1348.0	1727	390	5.03
	1420.0	2091	371	4.12		1349.0	1734	388	4.88
	1421.0	2102	369	4.12		1350.0	1742	387	4.73
	1422.0	2115	370	4.27		1351.0	1749	385	4.58
	1423.0	2127	368	4.42		1352.0	1756	386	4.42
	1424.0	2140	365	4.42		1353.0	1765	389	4.58
	1425.0	2155	365	4.42		1354.0	1774	390	4.42
	1426.0	2168	366	4.27		1355.0	1782	395	4.42
	1427.0	2184	367	4.27		1356.0	1791	398	4.42
	1428.0	2198	369	4.12		1357.0	1801	403	4.27
	1429.0	2217	372	3.97		1358.0	1814	408	4.27
	1430.0	2233	375	3.97		1359.0	1828	415	4.27
	1431.0	2248	376	4.12		1400.0	1842	422	4.12
	1433.0	2281	383	3.81		1401.0	1855	427	3.97
	1434.0	2294	401	3.66		1402.0	1871	433	3.81
	1435.0	2306	407	3.51		1403.0	1890	438	3.66
	1436.0	2320	402	3.66		1404.0	1916	445	3.66
	1437.0	2334	409	3.81		1405.0	1942	448	3.51
	1438.0	2334	409	3.66		1406.0	1970	446	3.66
	1439.0	2357	441	3.81		1407.0	1997	445	3.97
40	1329.0	1644	605	2.44		1408.0	2025	444	4.12
	1330.0	1647	594	2.90		1409.0	2046	443	4.27
	1331.0	1650	586	2.90		1410.0	2064	442	4.42
	1332.0	1654	573	3.05		1411.0	2081	443	4.42
	1333.0	1658	561	3.20		1412.0	2103	439	4.58
	1334.0	1662	544	3.51		1413.0	2138	433	4.58
	1335.0	1667	527	3.81		1414.0	2169	424	4.42
	1336.0	1669	514	3.97		1415.0	2202	414	4.42
	1337.0	1674	502	4.12		1416.0	2224	409	4.27
	1338.0	1676	485	4.12		1417.0	2247	404	4.27

Appendix D-2

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
40	1418.0	2272	399	4.12	41	1403.0	1933	436	3.81
	1419.0	2299	409	3.97		1404.0	1960	442	3.81
	1420.0	2299	409	3.81		1405.0	1989	447	3.97
	1421.0	2342	430	3.81		1406.0	2012	449	4.12
	1422.0	2362	451	3.97		1407.0	2033	451	4.42
41	1329.0	1644	597	1.98		1408.0	2055	451	4.58
	1330.0	1643	596	2.75		1409.0	2079	451	4.58
	1331.0	1644	582	3.20		1410.0	2099	453	4.73
	1332.0	1645	568	3.20		1411.0	2116	455	4.73
	1333.0	1648	552	3.05		1412.0	2136	455	4.58
	1334.0	1649	535	3.20		1413.0	2153	455	4.42
	1335.0	1649	516	3.51		1414.0	2178	456	4.27
	1336.0	1653	502	3.81		1415.0	2207	456	3.97
	1337.0	1657	487	3.97		1416.0	2231	459	3.81
	1338.0	1659	466	3.97		1417.0	2252	482	3.81
	1339.0	1662	446	3.81		1418.0	2271	480	3.66
	1340.0	1665	427	3.97		1419.0	2289	478	3.51
	1341.0	1670	416	3.97		1420.0	2307	476	3.36
	1342.0	1674	405	4.12		1421.0	2322	475	3.36
	1343.0	1678	397	4.42		1422.0	2341	473	3.20
	1344.0	1685	388	4.42		1423.0	2360	472	3.51
	1345.0	1694	381	4.58		1424.0	2381	473	3.51
	1346.0	1701	376	4.58		1425.0	2404	475	3.36
	1347.0	1708	373	4.73	42	1329.0	1640	601	1.83
	1348.0	1714	369	4.88		1330.0	1639	593	3.05
	1349.0	1725	365	4.73		1331.0	1637	586	3.20
	1350.0	1736	364	4.73		1332.0	1634	571	3.20
	1351.0	1748	360	4.58		1333.0	1630	554	3.51
	1352.0	1757	359	4.58		1334.0	1626	534	3.51
	1353.0	1767	361	4.73		1335.0	1623	512	3.66
	1354.0	1782	360	4.58		1336.0	1623	494	3.81
	1355.0	1793	363	4.42		1337.0	1628	477	4.12
	1356.0	1804	371	4.27		1338.0	1643	462	4.27
	1357.0	1818	377	4.27		1340.0	1682	438	4.42
	1358.0	1832	386	4.27		1341.0	1703	429	4.58
	1359.0	1850	395	4.42		1342.0	1714	425	4.88
	1400.0	1872	409	4.27		1343.0	1726	420	4.88
	1401.0	1896	419	4.12		1344.0	1740	414	4.73
	1402.0	1919	435	3.97		1345.0	1751	411	4.88

Appendix D-2

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)
42	1346.0	1767	404	5.03
	1347.0	1781	400	4.73
	1349.0	1797	411	4.58
	1350.0	1814	411	4.73
	1351.0	1832	411	4.58
	1352.0	1852	413	4.42
	1353.0	1876	414	4.42
	1354.0	1903	417	4.12
	1355.0	1939	425	3.97
	1356.0	1964	427	3.97
	1357.0	1990	428	3.81
	1358.0	2019	427	3.81
	1359.0	2045	427	3.66
	1400.0	2069	426	3.66
	1401.0	2087	425	3.97
	1402.0	2109	425	4.12
	1403.0	2132	426	4.12
	1404.0	2153	426	4.27
	1405.0	2174	427	4.42
	1406.0	2189	427	4.42
	1407.0	2210	427	4.58
	1408.0	2231	428	4.42
	1409.0	2247	431	4.27
	1410.0	2272	452	3.97
	1411.0	2287	451	4.12
	1412.0	2303	450	3.66
	1413.0	2320	449	3.81
	1414.0	2343	450	3.66
	1415.0	2373	452	3.81

Appendix D-3

Horizontal Position (X, Y) and Depth
by Fish and Time During Control 3

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
53	1636	1647	600	1.98	53	1731	1791	354	3.20
	1637	1651	591	3.20		1732	1801	370	3.20
	1638	1656	582	3.81		1733	1814	383	3.05
	1639	1665	569	4.12		1734	1833	396	3.20
	1640	1675	557	4.12		1735	1852	408	3.36
	1641	1686	550	3.97		1736	1882	417	3.51
	1642	1703	540	3.81		1737	1910	418	3.66
	1643	1722	530	3.51		1738	1947	423	3.20
	1644	1741	522	3.05		1739	1979	421	3.05
	1645	1764	515	3.20		1740	2013	414	2.90
	1646	1788	509	3.20		1741	2050	416	2.90
	1647	1814	504	3.36		1743	2125	434	2.90
	1648	1839	504	3.51		1744	2159	443	3.05
	1649	1857	497	3.81		1745	2188	450	3.05
	1650	1868	481	3.97		1746	2218	455	3.20
	1651	1870	471	4.12		1747	2256	478	3.36
	1652	1870	462	4.12		1748	2284	476	3.20
	1653	1867	453	4.12		1749	2314	474	3.20
	1654	1861	447	4.27		1750	2344	472	3.36
	1655	1856	440	4.12		1751	2373	473	3.36
	1656	1849	436	4.12		1752	2395	474	3.51
	1657	1839	431	3.97	54	1636	1651	597	1.37
	1658	1828	427	3.97		1637	1658	592	1.98
	1659	1816	426	3.81		1638	1666	588	3.81
	1700	1805	424	3.66		1639	1674	581	3.97
	1701	1786	423	3.36		1640	1684	572	4.27
	1702	1772	422	3.51		1641	1694	563	4.12
	1703	1752	422	3.36		1642	1705	556	4.12
	1704	1731	421	3.05		1643	1718	546	3.66
	1705	1712	417	3.20		1644	1723	539	3.81
	1706	1692	407	3.51		1645	1732	526	3.66
	1707	1677	389	3.97		1646	1736	513	3.51
	1708	1667	366	3.81		1647	1740	501	3.05
	1709	1667	338	3.81		1648	1741	482	3.05
	1710	1671	310	3.66		1649	1740	469	2.90
	1729	1789	284	3.05		1650	1737	453	2.75
	1730	1786	331	3.05		1651	1728	435	2.90

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
54	1652	1721	418	2.90	55	1638	1673	556	3.97
	1653	1712	399	3.36		1639	1691	540	4.12
	1654	1704	383	3.81		1640	1709	530	3.66
	1655	1698	363	3.97		1641	1727	526	3.51
	1725	1625	347	3.05		1642	1748	525	3.05
	1726	1624	365	3.20		1643	1770	524	2.90
	1727	1623	383	3.51		1644	1792	520	2.90
	1728	1621	401	3.81		1645	1808	523	3.20
	1729	1621	416	3.81		1646	1830	508	3.36
	1730	1623	427	3.97		1647	1843	491	3.81
	1731	1626	434	4.12		1648	1848	480	3.97
	1732	1634	442	4.12		1649	1850	472	4.12
	1733	1645	448	3.97		1650	1853	460	4.27
	1734	1659	453	3.66		1651	1854	450	3.97
	1735	1682	452	3.81		1652	1853	439	3.81
	1736	1709	452	3.51		1653	1843	424	3.36
	1737	1733	452	3.36		1654	1826	412	3.05
	1738	1756	454	2.90		1655	1800	404	2.90
	1739	1783	452	2.90		1656	1773	405	2.75
	1740	1814	452	2.75		1657	1747	399	2.75
	1741	1845	460	2.90		1658	1723	386	2.90
	1742	1886	455	3.05		1714	1625	274	3.05
	1743	1923	447	3.20		1715	1627	348	3.51
	1744	1957	439	3.05		1716	1629	379	3.05
	1745	1994	435	2.90		1717	1643	416	3.20
	1746	2029	433	2.90		1718	1683	442	3.05
	1747	2073	431	2.75		1719	1734	453	2.90
	1748	2098	447	2.75		1720	1784	452	2.75
	1749	2141	440	2.75		1721	1840	452	2.75
	1750	2182	433	2.75		1722	1903	452	2.90
	1751	2226	428	2.75		1723	1975	464	2.75
	1752	2260	435	2.75		1724	2043	476	2.59
	1753	2289	439	2.75		1728	2271	509	2.90
	1754	2318	441	2.75		1729	2307	503	2.90
	1755	2352	456	2.90		1730	2340	495	2.75
	1756	2374	455	3.05		1731	2366	488	2.90
	1757	2399	452	2.90		1732	2393	484	3.20
55	1636	1655	585	2.14	56	1636	1650	586	1.37
	1637	1663	571	3.81		1637	1657	558	2.44

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
56	1638	1663	546	3.51	56	1729	2189	448	2.75
	1639	1670	539	3.66		1730	2221	455	2.90
	1640	1686	525	3.20		1731	2253	479	2.75
	1642	1733	509	2.90		1732	2287	475	2.90
	1643	1767	503	2.75		1733	2322	476	2.75
	1644	1798	498	2.90		1734	2354	474	2.90
	1645	1837	493	3.51		1735	2384	473	2.75
	1646	1865	488	3.66	58	1636	1652	587	1.07
	1647	1881	477	3.81		1637	1658	572	1.83
	1648	1896	465	3.66		1638	1667	559	2.59
	1649	1902	458	3.81		1639	1676	552	3.20
	1650	1912	453	3.97		1640	1688	541	3.81
	1651	1921	442	3.36		1641	1706	540	3.05
	1652	1929	428	2.90		1642	1730	532	2.90
	1653	1931	396	2.90		1643	1753	530	2.44
	1654	1901	374	2.29		1644	1783	525	2.29
	1655	1850	373	2.14		1645	1808	523	2.90
	1656	1816	368	1.83		1646	1827	517	3.66
	1657	1787	365	2.14		1647	1843	505	3.81
	1658	1767	361	2.29		1648	1851	493	4.12
	1659	1751	356	2.75		1649	1853	482	3.97
	1700	1737	345	2.90		1650	1854	471	3.66
	1701	1729	332	3.20		1651	1854	459	3.20
	1702	1725	297	3.36		1652	1850	445	2.59
	1714	1759	339	2.75		1653	1831	427	2.44
	1715	1768	371	2.75		1654	1810	417	2.59
	1716	1779	385	2.75		1655	1789	408	2.44
	1717	1795	401	2.59		1656	1766	397	2.90
	1718	1820	413	2.44		1657	1745	385	3.05
	1719	1852	423	2.44		1658	1734	370	3.51
	1720	1892	430	2.29		1659	1726	348	3.81
	1721	1940	431	2.29		1700	1719	333	3.66
	1722	1975	429	2.44		1719	1656	368	3.51
	1723	2007	430	2.44		1720	1638	383	3.66
	1724	2037	431	2.59		1721	1639	397	3.97
	1725	2061	431	2.59		1722	1646	408	3.51
	1726	2090	434	2.44		1723	1664	416	2.75
	1727	2121	441	2.59		1724	1693	421	2.75
	1728	2158	443	2.59		1725	1727	417	2.44

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
58	1726	1762	416	2.59	59	1659	1764	431	3.97
	1727	1798	412	2.59		1700	1751	422	3.81
	1728	1831	407	2.44		1701	1736	412	3.51
	1729	1867	401	2.59		1702	1722	404	3.36
	1730	1904	399	2.75		1703	1706	390	3.51
	1731	1961	403	2.90		1704	1698	373	3.66
	1732	2016	411	2.75		1705	1674	353	3.81
	1733	2063	421	2.59		1725	1622	313	2.90
	1734	2113	431	2.59		1726	1621	329	2.90
	1735	2168	450	2.44		1727	1621	345	3.05
	1736	2218	476	2.44		1728	1621	358	3.05
	1737	2263	507	2.59		1729	1624	376	3.05
	1738	2309	514	2.75		1730	1628	392	3.20
	1739	2355	520	2.90		1731	1637	409	3.05
	1740	2394	524	2.75		1732	1650	425	3.20
	1741	2428	525	2.90		1733	1669	437	3.05
59	1636	1649	602	1.68		1734	1694	446	2.90
	1637	1654	588	3.36		1735	1716	448	2.75
	1638	1658	583	3.81		1736	1734	450	3.05
	1639	1663	575	3.81		1737	1748	447	3.20
	1640	1670	566	4.12		1738	1766	444	3.51
	1641	1680	558	3.66		1739	1782	438	3.66
	1642	1690	551	3.51		1740	1804	432	3.66
	1643	1703	545	3.51		1741	1828	426	3.81
	1644	1715	539	3.36		1742	1861	419	3.66
	1645	1727	535	3.20		1743	1891	415	3.66
	1646	1738	531	3.36		1744	1931	417	3.51
	1647	1750	525	3.51		1745	1961	415	3.36
	1648	1759	521	3.81		1746	1987	417	3.36
	1649	1767	513	3.97		1747	2015	419	3.51
	1650	1774	506	4.12		1748	2045	422	3.36
	1651	1778	501	4.42		1749	2071	422	3.20
	1652	1781	495	4.42		1750	2112	428	3.05
	1653	1783	487	4.12		1751	2145	434	3.05
	1654	1786	478	4.12		1752	2178	442	3.20
	1655	1787	468	4.27		1753	2212	448	3.51
	1656	1785	457	4.42		1754	2249	471	3.66
	1657	1782	447	4.12		1755	2276	471	3.66
	1658	1773	438	3.97		1756	2304	468	3.66

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
59	1757	2331	465	3.51	60	1731	1938	412	2.90
	1758	2357	462	3.51		1732	1977	429	2.90
	1759	2380	459	3.66		1733	2017	450	2.75
	1800	2395	460	3.66		1734	2059	462	2.90
60	1636	1647	593	1.83		1735	2103	465	2.90
	1637	1650	578	2.90		1736	2142	465	3.05
	1638	1655	554	3.51		1737	2169	459	3.36
	1639	1663	540	3.81		1738	2211	459	3.20
	1640	1676	526	3.97		1739	2263	466	2.90
	1641	1702	515	3.66		1740	2299	481	3.05
	1642	1727	512	3.05		1741	2336	476	2.90
	1643	1753	513	2.75		1742	2372	475	2.75
	1644	1778	511	2.90		1743	2399	466	2.90
	1645	1804	504	3.36	61	1636	1644	586	1.07
	1646	1815	494	4.12		1637	1650	548	2.29
	1647	1822	481	3.97		1638	1668	522	3.20
	1648	1822	467	3.81		1639	1673	499	3.36
	1649	1811	449	3.36		1640	1697	482	2.90
	1650	1783	429	3.20		1641	1724	470	2.44
	1651	1744	423	2.90		1642	1764	457	2.59
	1652	1706	418	2.75		1643	1804	447	2.44
	1653	1681	412	2.90		1644	1841	443	2.59
	1654	1658	400	2.90		1645	1882	443	2.59
	1655	1640	374	3.36		1646	1927	443	2.44
	1656	1637	350	3.66		1647	1990	447	2.59
	1657	1638	319	3.81		1648	2050	449	2.59
	1718	1655	323	3.05		1649	2115	451	2.75
	1719	1656	340	3.05		1650	2181	454	2.75
	1720	1657	358	3.20		1651	2260	465	2.59
	1721	1663	380	3.51	62	1636	1629	611	1.37
	1722	1683	401	3.20		1637	1627	582	1.68
	1723	1702	408	3.05		1638	1619	564	2.90
	1724	1726	410	2.75		1639	1619	557	3.20
	1725	1743	408	2.75		1640	1618	548	4.12
	1726	1781	403	2.90		1641	1618	539	4.12
	1727	1810	397	2.75		1642	1621	534	3.97
	1728	1833	395	2.59		1643	1625	528	3.81
	1729	1863	395	2.44		1644	1630	524	3.66
	1730	1898	398	2.59		1645	1638	520	3.66

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
62	1646	1651	516	3.51	62	1737	1626	470	3.97
	1647	1663	513	3.05		1738	1628	474	4.12
	1648	1678	508	2.90		1739	1633	478	3.97
	1649	1691	505	2.75		1740	1636	479	3.81
	1650	1704	500	2.90		1741	1644	481	3.81
	1651	1716	497	2.90		1742	1652	482	3.66
	1652	1730	493	3.05		1743	1665	480	3.51
	1653	1744	488	3.51		1744	1681	474	3.05
	1654	1755	485	3.66		1745	1699	470	2.90
	1655	1758	482	3.81		1746	1719	469	2.75
	1656	1764	480	3.97		1747	1738	470	2.75
	1657	1768	475	3.97		1748	1756	469	2.90
	1658	1771	469	3.81		1749	1778	470	2.75
	1659	1772	462	3.97		1750	1797	468	2.59
	1700	1768	456	3.81		1751	1813	471	2.44
	1701	1765	452	3.81		1752	1834	470	2.59
	1702	1756	447	3.51		1753	1859	470	2.59
	1703	1743	445	3.05		1754	1893	469	2.44
	1704	1727	444	2.90		1755	1925	471	2.44
	1705	1717	441	2.90		1757	1983	465	2.44
	1706	1707	436	2.59		1758	2016	458	2.59
	1707	1693	429	2.44		1759	2047	451	2.75
	1708	1677	421	2.75		1800	2075	447	2.90
	1709	1665	411	3.20		1801	2110	444	2.90
	1710	1656	399	3.51		1802	2148	448	2.75
	1711	1651	386	3.66		1803	2189	456	2.75
	1712	1648	369	3.81		1804	2225	467	2.90
	1713	1649	357	3.66		1805	2266	490	2.75
	1714	1652	357	3.51		1806	2299	489	2.90
	1726	1634	346	2.90		1807	2337	486	2.90
	1727	1635	361	2.75		1808	2376	486	2.75
	1728	1635	373	2.75		1809	2408	484	2.75
	1729	1636	384	2.59	63	1636	1643	585	2.14
	1730	1639	400	2.59		1637	1644	571	3.20
	1731	1637	413	2.44		1638	1645	551	3.51
	1732	1635	426	2.90		1639	1645	525	3.66
	1733	1629	441	3.20		1640	1653	514	3.97
	1735	1623	458	3.51		1641	1666	504	4.12
	1736	1623	465	3.81		1642	1668	496	4.27

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
63	1643	1677	490	4.27	63	1734	2028	449	3.20
	1644	1687	487	4.12		1735	2058	459	3.36
	1645	1701	482	3.97		1738	2143	465	3.20
	1646	1716	479	3.51		1740	2333	497	3.36
	1647	1732	478	3.05		1746	2418	543	3.51
	1648	1751	476	2.90		1747	2427	525	3.05
	1649	1774	478	3.36	64	1636	1643	596	2.29
	1650	1803	477	3.66		1637	1645	582	2.59
	1651	1817	478	4.12		1638	1650	574	3.51
	1652	1827	477	4.42		1639	1657	563	3.81
	1653	1835	474	4.27		1640	1670	555	3.81
	1654	1841	471	4.27		1641	1687	551	3.36
	1655	1847	465	4.12		1642	1706	548	3.20
	1656	1850	458	3.97		1643	1724	548	2.75
	1657	1852	452	3.66		1644	1741	546	2.75
	1658	1853	444	3.81		1645	1763	546	2.59
	1659	1852	435	3.66		1646	1776	543	2.59
	1700	1848	426	3.81		1647	1789	540	2.75
	1701	1835	414	3.66		1648	1798	535	3.05
	1702	1817	406	3.81		1649	1804	529	3.51
	1703	1795	398	3.81		1650	1809	523	3.66
	1704	1774	390	3.66		1651	1813	518	3.81
	1705	1755	366	3.66		1652	1815	511	3.97
	1706	1743	348	3.51		1653	1815	504	3.66
	1708	1729	328	3.36		1654	1812	496	3.51
	1718	1691	346	2.90		1655	1809	486	3.20
	1720	1704	359	2.75		1656	1799	474	2.75
	1721	1709	371	2.75		1657	1788	467	2.59
	1722	1717	377	2.90		1658	1776	459	2.59
	1723	1724	386	3.05		1659	1764	448	2.44
	1724	1738	393	3.05		1700	1756	436	2.75
	1725	1757	398	3.20		1701	1750	425	3.20
	1727	1808	402	3.51		1702	1743	408	3.20
	1728	1839	402	3.36		1703	1741	387	3.36
	1729	1877	403	3.36		1704	1737	367	3.05
	1730	1913	407	3.20		1705	1735	350	3.05
	1731	1946	420	3.20		1718	1698	354	2.75
	1732	1975	429	3.05		1719	1689	383	2.75
	1733	2002	441	3.05		1720	1666	396	2.90

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
64	1721	1644	400	3.20	67	1652	1763	472	3.36
	1722	1632	407	3.36		1653	1755	457	3.20
	1723	1625	413	3.51		1654	1744	438	2.75
	1724	1623	423	3.66		1655	1735	418	2.75
	1725	1624	430	3.66		1656	1727	394	2.59
	1726	1626	435	3.51		1657	1721	378	3.20
	1727	1628	440	3.36		1658	1718	357	3.05
	1728	1634	446	3.51		1714	1705	353	2.75
	1729	1640	450	3.20		1715	1703	382	2.59
	1730	1649	452	3.05		1716	1709	413	2.59
	1731	1663	458	2.90		1717	1737	432	2.44
	1732	1680	460	2.75		1718	1773	434	2.59
	1733	1702	460	2.90		1719	1810	434	2.75
	1734	1734	460	2.75		1720	1850	431	2.90
	1740	2026	455	2.44		1721	1883	430	2.90
	1741	2049	476	2.59		1722	1927	432	2.90
	1742	2094	472	2.59		1723	1966	432	2.75
	1744	2175	519	2.90		1724	2014	432	2.75
	1745	2248	482	2.90		1725	2060	432	2.90
	1746	2296	472	3.05		1726	2106	437	2.75
	1747	2340	462	3.20		1727	2154	447	2.59
	1748	2375	459	3.05		1728	2195	459	2.59
	1749	2405	459	2.90		1729	2239	487	2.75
67	1636	1645	616	1.22		1730	2279	486	2.90
	1637	1654	594	1.98		1731	2317	484	3.05
	1638	1661	589	3.20		1732	2356	482	3.20
	1639	1670	579	4.12		1733	2389	483	3.05
	1640	1681	574	3.97		1734	2416	485	2.90
	1641	1692	567	3.66	68	1636	1641	594	1.83
	1642	1707	561	3.51		1637	1641	575	2.90
	1643	1723	556	3.05		1638	1640	558	3.81
	1644	1736	552	2.90		1639	1644	536	4.27
	1645	1750	544	2.44		1640	1652	517	4.12
	1646	1758	539	3.20		1641	1660	505	3.97
	1647	1761	530	3.81		1642	1659	497	3.51
	1648	1765	521	3.97		1643	1699	489	3.05
	1649	1767	513	3.97		1644	1723	487	2.75
	1650	1767	504	3.66		1645	1743	488	2.90
	1651	1766	490	3.36		1646	1761	488	3.51

Appendix D-3

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
68	1647	1773	485	4.12	68	1740	1646	480	3.05
	1648	1780	488	4.27		1741	1669	474	2.75
	1649	1788	486	4.42		1742	1699	469	2.90
	1650	1796	485	3.97		1743	1732	468	2.90
	1651	1803	480	4.12		1745	1787	469	2.75
	1652	1807	470	3.97		1746	1819	469	2.59
	1653	1801	463	3.81		1747	1843	470	2.44
	1654	1786	459	3.51		1748	1872	466	2.59
	1655	1762	465	3.05		1749	1906	461	2.59
	1656	1736	448	3.20		1750	1946	467	2.75
	1657	1723	436	2.90		1751	1978	472	2.75
	1658	1710	413	3.05		1752	2010	479	2.90
	1659	1704	390	3.36		1753	2047	488	2.75
	1700	1700	365	3.51		1759	2257	527	3.36
	1702	1690	352	3.81		1800	2286	517	3.20
	1716	1614	316	2.44		1801	2316	500	3.20
	1717	1617	330	2.44		1802	2338	487	3.51
	1718	1607	303	2.90		1803	2357	474	3.36
	1719	1619	365	3.05		1804	2383	460	3.51
	1720	1622	391	3.05		1805	2405	449	3.20
	1721	1620	414	3.51	69	1636	1639	600	2.29
	1722	1613	439	3.81		1637	1637	586	3.20
	1723	1608	449	4.12		1638	1637	576	3.66
	1724	1605	456	4.27		1639	1635	566	3.97
	1725	1601	464	4.42		1640	1640	552	4.12
	1726	1597	469	4.27		1641	1644	543	3.97
	1727	1594	474	4.27		1642	1649	539	3.81
	1728	1592	481	4.12		1643	1655	534	3.51
	1729	1588	486	4.27		1644	1663	534	3.05
	1730	1585	492	4.12		1645	1669	529	3.05
	1731	1582	499	3.97		1646	1676	529	3.20
	1732	1580	508	3.66		1647	1684	527	3.05
	1733	1582	516	3.51		1648	1690	525	2.90
	1734	1588	522	3.20		1649	1700	523	2.90
	1735	1593	524	3.20		1650	1712	519	2.90
	1736	1603	524	3.36		1651	1717	517	2.75
	1737	1615	516	3.51		1652	1723	512	2.75
	1738	1625	501	3.51		1653	1729	508	2.90
	1739	1634	490	3.20		1654	1737	501	3.05

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
69	1655	1742	493	3.05	69	1757	2152	494	3.51
	1656	1746	488	3.20		1758	2190	503	3.51
	1657	1750	479	3.05		1759	2226	528	3.66
	1658	1754	468	3.20		1800	2257	522	3.81
	1659	1755	455	3.05		1801	2286	515	3.81
	1700	1754	441	3.36		1802	2313	511	3.66
	1701	1750	430	3.51		1803	2341	506	3.51
	1702	1744	418	3.66		1804	2365	506	3.51
	1704	1732	393	4.12		1805	2391	504	3.36
	1705	1726	382	4.12	70	1636	1631	592	2.29
	1706	1722	362	3.81		1637	1626	576	2.59
	1707	1717	350	3.66		1638	1623	562	3.51
	1708	1717	350	3.51		1639	1621	545	3.66
	1730	1689	353	2.90		1640	1615	519	3.66
	1731	1689	353	2.90		1641	1610	504	3.81
	1732	1702	341	3.05		1642	1606	494	3.97
	1733	1700	365	3.05		1643	1602	485	4.12
	1734	1701	379	3.20		1644	1600	477	4.12
	1735	1703	396	3.05		1645	1599	467	4.27
	1736	1706	411	3.05		1646	1602	460	4.42
	1737	1707	427	2.90		1647	1607	455	4.42
	1738	1710	444	2.90		1648	1613	451	4.27
	1739	1721	461	2.75		1649	1620	449	4.12
	1740	1731	471	2.75		1650	1631	447	3.97
	1741	1747	475	2.90		1651	1646	447	3.66
	1742	1764	478	2.90		1652	1662	448	3.66
	1743	1781	479	3.05		1653	1678	446	3.81
	1744	1804	473	3.05		1654	1701	450	3.66
	1745	1825	468	3.20		1655	1728	452	3.51
	1746	1848	462	3.20		1656	1751	458	3.36
	1747	1876	457	3.36		1657	1770	464	3.51
	1748	1902	453	3.36		1658	1779	465	3.66
	1749	1932	452	3.51		1659	1787	464	3.81
	1750	1965	452	3.36		1700	1793	462	3.97
	1751	1997	456	3.51		1701	1799	457	3.97
	1752	2023	460	3.36		1702	1802	450	4.12
	1753	2050	468	3.36		1703	1800	443	4.27
	1755	2097	481	3.66		1704	1794	437	4.27
	1756	2122	489	3.66		1705	1781	424	4.12

Appendix D-3

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
70	1706	1766	412	3.97	71	1641	1647	548	3.81
	1707	1748	400	3.66		1642	1651	537	3.36
	1708	1730	391	3.51		1643	1655	527	3.36
	1709	1718	370	3.66		1644	1658	518	3.20
	1710	1714	346	3.81		1645	1668	513	2.90
	1727	1647	315	3.05		1646	1678	507	2.75
	1728	1647	339	3.05		1647	1687	504	2.75
	1729	1648	361	3.20		1648	1701	498	2.59
	1730	1652	384	3.05		1649	1713	496	2.90
	1731	1662	404	3.20		1650	1723	488	3.36
	1732	1673	414	3.36		1651	1728	483	3.81
	1733	1672	411	3.36		1652	1730	479	3.97
	1734	1700	429	3.20		1653	1731	472	4.12
	1735	1720	435	3.36		1654	1729	466	3.97
	1736	1739	443	3.36		1655	1726	462	3.81
	1737	1760	443	3.36		1656	1721	456	3.51
	1738	1784	446	3.36		1657	1715	452	3.05
	1739	1817	448	3.20		1658	1703	445	3.05
	1740	1848	451	3.05		1659	1688	440	2.90
	1741	1879	452	3.05		1700	1667	431	2.75
	1742	1908	458	3.20		1701	1652	415	2.90
	1743	1936	465	3.20		1702	1651	396	3.20
	1744	1969	475	3.05		1703	1649	374	3.20
	1745	2001	485	2.90		1704	1648	358	3.36
	1746	2036	491	2.90		1705	1649	341	3.51
	1748	2098	499	2.90		1717	1631	337	2.75
	1749	2139	497	3.05		1718	1634	359	2.44
	1750	2178	501	3.36		1719	1632	375	2.59
	1751	2207	519	3.51		1720	1634	393	2.44
	1752	2245	516	3.36		1721	1636	412	2.59
	1753	2284	512	3.20		1722	1639	432	2.90
	1754	2321	509	3.20		1723	1646	450	3.05
	1755	2348	510	3.05		1724	1656	472	3.51
	1756	2383	510	3.20		1725	1679	491	3.66
71	1636	1640	600	1.98		1726	1706	509	3.81
	1637	1640	588	3.05		1729	1794	483	2.90
	1638	1640	579	3.81		1730	1823	467	2.90
	1639	1641	569	3.97		1731	1852	452	2.75
	1640	1643	557	4.12		1732	1894	444	2.90

Appendix D-3

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Fish No.	Time	X (m)	Y (m)	Depth (m)
71	1733	1949	443	2.90	72	1707	1719	425	3.05
	1734	2014	445	2.90		1708	1704	416	3.20
	1735	2078	446	2.75		1709	1688	407	3.36
	1736	2140	452	2.59		1710	1669	393	3.81
	1737	2210	454	2.59		1711	1654	376	3.97
	1738	2279	464	2.44		1712	1648	358	3.81
	1740	2380	446	2.90		1713	1647	331	3.66
	1741	2413	444	2.90		1714	1647	315	3.81
72	1636	1634	595	2.75		1715	1645	288	3.66
	1637	1630	585	3.66		1741	1663	307	2.75
	1638	1625	575	3.81		1742	1668	309	2.75
	1639	1620	562	3.97		1743	1664	334	2.75
	1640	1618	548	4.12		1744	1660	351	2.59
	1641	1621	539	4.42		1745	1656	362	2.75
	1642	1623	530	4.58		1746	1650	378	2.90
	1643	1629	523	4.27		1747	1639	390	3.20
	1644	1635	516	4.12		1748	1625	397	3.36
	1645	1640	512	3.81		1749	1609	406	3.05
	1646	1652	508	3.66		1750	1595	411	2.90
	1647	1659	505	3.36		1751	1589	417	2.90
	1648	1672	504	3.36		1752	1586	421	2.75
	1649	1684	502	3.20		1753	1585	426	2.75
	1650	1694	501	3.05		1754	1584	432	2.75
	1651	1706	503	3.36		1755	1586	437	2.90
	1652	1720	504	3.51		1756	1587	441	3.05
	1653	1733	504	3.81		1757	1590	446	3.20
	1654	1745	502	3.97		1758	1598	454	3.05
	1655	1752	501	4.12		1759	1598	454	3.05
	1656	1756	498	4.42		1800	1604	458	3.20
	1657	1763	494	4.27		1801	1608	459	3.51
	1658	1768	489	4.42		1802	1622	463	3.66
	1659	1771	484	4.12		1803	1632	465	3.81
	1700	1773	476	4.12		1804	1644	464	3.66
	1701	1772	468	4.12		1805	1659	459	3.36
	1702	1769	464	4.27		1806	1675	453	3.51
	1703	1765	457	4.12		1807	1691	447	3.36
	1704	1758	450	3.97		1808	1705	441	3.36
	1705	1746	440	3.81		1809	1720	436	3.51
	1706	1734	434	3.51		1810	1733	430	3.66

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)
72	1811	1745	428	3.51
	1812	1760	425	3.36
	1814	1799	415	3.05
	1815	1814	413	3.05
	1816	1835	410	3.20
	1817	1851	406	3.05
	1818	1869	403	3.05
	1820	1911	403	2.90
	1821	1937	412	2.75
	1822	1963	413	2.59
	1823	1990	416	2.59
	1824	2021	423	2.75
	1825	2054	429	2.90
	1826	2088	438	2.75
	1827	2121	449	2.90
	1828	2152	457	2.90
	1829	2181	465	2.90
	1830	2208	469	2.75
	1831	2240	497	2.90
	1832	2270	496	3.05
	1833	2299	501	3.20
	1834	2329	495	3.36
	1835	2359	494	3.36
	1836	2381	495	3.51
	1837	2403	494	3.36

Appendix D-4

Horizontal Position (X, Y) and Depth
by Fish and Time During Treatment 1

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
13	2213.0	1645	606	0.46	< 1.00E-01	14	2326.0	1658	402	3.97	< 1.00E-01
	2214.0	1648	595	1.83	< 1.00E-01		2327.0	1670	393	3.81	< 1.00E-01
	2215.0	1651	583	2.75	< 1.00E-01		2328.0	1685	383	3.81	< 1.00E-01
	2216.0	1653	567	3.20	1.38E-01		2329.0	1704	374	3.66	< 1.00E-01
	2217.0	1655	548	3.20	4.53E-01		2330.0	1728	367	3.66	< 1.00E-01
	2218.0	1655	531	3.51	4.48E-01		2331.0	1761	372	3.51	< 1.00E-01
	2219.0	1655	511	3.36	8.76E-01		2332.0	1794	382	3.51	< 1.00E-01
	2220.0	1659	500	3.51	4.01E-01		2343.0	2077	387	3.36	< 1.00E-01
	2221.0	1660	489	3.66	1.68E-01		2344.0	2089	383	3.51	< 1.00E-01
	2222.0	1660	481	3.81	< 1.00E-01		2345.0	2103	379	3.51	< 1.00E-01
	2223.0	1658	472	3.97	< 1.00E-01		2346.0	2115	374	3.51	< 1.00E-01
	2224.0	1649	458	4.42	< 1.00E-01		2347.0	2125	371	3.66	< 1.00E-01
	2225.0	1641	444	4.73	< 1.00E-01		2348.0	2138	366	3.66	< 1.00E-01
	2226.0	1636	434	4.42	< 1.00E-01		2349.0	2150	358	3.51	< 1.00E-01
	2227.0	1635	422	4.27	< 1.00E-01		2350.0	2163	355	3.36	< 1.00E-01
	2228.0	1638	410	4.42	< 1.00E-01		2351.0	2174	350	3.36	< 1.00E-01
	2229.0	1645	394	4.42	< 1.00E-01		2352.0	2189	343	3.51	< 1.00E-01
	2230.0	1651	374	4.42	< 1.00E-01		2353.0	2201	339	3.66	< 1.00E-01
14	2214.0	1641	595	1.37	< 1.00E-01		2354.0	2212	334	3.81	< 1.00E-01
	2215.0	1638	586	1.98	< 1.00E-01		2355.0	2225	330	3.97	< 1.00E-01
	2216.0	1637	573	2.90	1.36E-01		2356.0	2234	326	3.97	< 1.00E-01
	2217.0	1630	554	3.97	1.96E-01		2357.0	2242	324	3.81	< 1.00E-01
	2218.0	1626	540	4.12	5.22E-01	15	2214.0	1639	582	2.14	< 1.00E-01
	2219.0	1616	523	4.42	5.01E-01		2215.0	1628	555	3.20	1.45E-01
	2220.0	1609	508	4.58	2.65E-01		2216.0	1591	539	3.81	1.69E-01
	2221.0	1599	494	4.73	< 1.00E-01		2217.0	1538	529	4.12	1.09E-01
	2222.0	1592	485	4.73	4.64E-01		2218.0	1509	520	4.27	< 1.00E-01
	2317.0	1580	472	5.03	4.73E-01		2220.0	1533	472	4.58	< 1.00E-01
	2318.0	1566	466	4.73	3.24E-01		2221.0	1610	456	4.27	< 1.00E-01
	2319.0	1547	459	4.58	1.05E-01		2222.0	1677	402	4.42	< 1.00E-01
	2320.0	1541	443	4.58	1.28E-01		2223.0	1779	368	3.97	< 1.00E-01
	2321.0	1547	434	4.42	< 1.00E-01		2225.0	1993	403	3.51	< 1.00E-01
	2322.0	1565	428	4.42	1.17E-01		2226.0	2095	386	3.51	< 1.00E-01
	2323.0	1590	427	4.27	< 1.00E-01	16	2214.0	1645	598	1.83	< 1.00E-01
	2324.0	1621	424	3.97	< 1.00E-01		2215.0	1648	584	2.59	< 1.00E-01
	2325.0	1643	414	4.12	< 1.00E-01		2216.0	1648	564	3.20	1.48E-01

Appendix D-4

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
16	2217.0	1648	546	3.36	4.45E-01	18	2235.0	2034	381	3.66	< 1.00E-01
	2218.0	1643	529	3.36	3.54E-01		2236.0	2083	374	3.51	< 1.00E-01
	2219.0	1638	507	3.51	< 1.00E-01		2237.0	2136	364	3.36	< 1.00E-01
	2220.0	1632	479	3.81	< 1.00E-01	19	2214.0	1646	599	2.14	< 1.00E-01
	2222.0	1623	432	4.27	< 1.00E-01		2215.0	1650	590	2.90	< 1.00E-01
	2223.0	1622	405	4.42	< 1.00E-01		2216.0	1657	575	3.36	1.40E-01
	2224.0	1626	382	3.97	< 1.00E-01		2217.0	1664	561	3.51	3.63E-01
	2225.0	1634	359	3.66	< 1.00E-01		2218.0	1675	540	3.51	9.48E-01
17	2214.0	1644	591	2.29	< 1.00E-01		2219.0	1679	519	3.81	5.84E-01
	2215.0	1645	582	3.36	< 1.00E-01		2220.0	1672	499	3.97	1.85E-01
	2216.0	1645	568	3.20	1.53E-01		2221.0	1664	485	4.12	1.41E-01
	2217.0	1643	555	3.51	2.12E-01		2222.0	1660	477	4.42	< 1.00E-01
	2218.0	1640	542	3.36	4.04E-01		2223.0	1655	469	4.42	< 1.00E-01
	2219.0	1638	530	3.51	4.98E-01		2224.0	1656	459	4.58	< 1.00E-01
	2220.0	1636	517	3.66	4.05E-01		2225.0	1659	451	4.73	< 1.00E-01
	2221.0	1630	502	3.81	1.24E-01		2226.0	1664	443	4.27	< 1.00E-01
	2222.0	1624	485	4.12	< 1.00E-01		2227.0	1674	435	4.12	< 1.00E-01
	2223.0	1617	464	4.42	< 1.00E-01		2228.0	1686	424	3.97	< 1.00E-01
	2224.0	1613	440	4.42	< 1.00E-01		2229.0	1698	413	3.66	< 1.00E-01
	2225.0	1613	419	4.27	< 1.00E-01		2230.0	1707	393	3.66	< 1.00E-01
	2226.0	1613	398	3.97	< 1.00E-01		2231.0	1709	371	3.81	< 1.00E-01
	2227.0	1617	379	4.12	< 1.00E-01		2232.0	1709	371	3.66	< 1.00E-01
	2228.0	1622	364	3.66	< 1.00E-01	20	2214.0	1638	591	2.59	< 1.00E-01
18	2214.0	1647	593	1.68	< 1.00E-01		2215.0	1625	568	3.05	< 1.00E-01
	2215.0	1648	580	2.59	< 1.00E-01		2216.0	1582	545	3.51	< 1.00E-01
	2216.0	1648	567	2.90	< 1.00E-01		2217.0	1541	536	3.97	1.83E-01
	2217.0	1639	547	3.36	4.82E-01		2219.0	1495	508	4.42	< 1.00E-01
	2218.0	1624	525	3.51	5.65E-01		2220.0	1527	487	4.58	< 1.00E-01
	2219.0	1613	503	3.81	< 1.00E-01		2221.0	1603	470	4.27	< 1.00E-01
	2220.0	1611	481	3.97	< 1.00E-01		2225.0	1982	415	3.66	< 1.00E-01
	2221.0	1612	458	4.27	< 1.00E-01		2226.0	2094	401	3.66	< 1.00E-01
	2222.0	1616	435	4.42	< 1.00E-01	21	2214.0	1644	597	1.53	< 1.00E-01
	2227.0	1714	360	4.27	< 1.00E-01		2215.0	1645	578	2.59	1.59E-01
	2228.0	1750	356	4.12	< 1.00E-01		2216.0	1646	551	3.20	4.02E-01
	2229.0	1783	360	3.97	< 1.00E-01		2217.0	1643	529	3.51	2.89E-01
	2230.0	1821	364	3.97	< 1.00E-01		2218.0	1636	507	3.81	1.08E-01
	2231.0	1863	374	3.81	< 1.00E-01		2219.0	1628	489	3.97	< 1.00E-01

Appendix D-4

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
21	2220.0	1626	478	4.42	< 1.00E-01
	2221.0	1625	467	4.27	< 1.00E-01
	2222.0	1626	458	4.27	< 1.00E-01
	2223.0	1627	447	4.12	< 1.00E-01
	2224.0	1633	437	3.97	< 1.00E-01
	2225.0	1638	424	3.66	< 1.00E-01
	2226.0	1644	409	3.66	< 1.00E-01
	2227.0	1653	392	3.81	< 1.00E-01
	2228.0	1656	372	3.66	< 1.00E-01
22	2214.0	1640	610	1.83	< 1.00E-01
	2215.0	1642	589	2.59	< 1.00E-01
	2216.0	1642	573	3.20	1.38E-01
	2217.0	1642	556	3.36	2.79E-01
	2218.0	1637	538	3.66	2.99E-01
	2219.0	1628	519	4.12	5.72E-01
	2220.0	1614	506	4.27	2.79E-01
	2221.0	1602	496	4.42	< 1.00E-01
	2222.0	1593	486	4.27	< 1.00E-01
	2223.0	1586	472	4.42	< 1.00E-01
	2224.0	1585	464	4.27	< 1.00E-01
	2225.0	1586	453	4.12	< 1.00E-01
	2226.0	1591	442	3.97	< 1.00E-01
	2227.0	1601	434	3.66	< 1.00E-01
	2228.0	1615	425	3.66	< 1.00E-01
	2229.0	1625	415	3.81	< 1.00E-01
	2230.0	1638	388	3.66	< 1.00E-01
	2231.0	1645	362	3.51	< 1.00E-01

Appendix D-5

Horizontal Position (X, Y) and Depth
by Fish and Time During Treatment 2

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
43	1459.0	1642	613	0.46	< 1.00E-01	45	1505.0	1617	463	1.83	< 1.00E-01
	1500.0	1653	598	1.37	< 1.00E-01		1506.0	1633	428	1.98	< 1.00E-01
	1501.0	1658	592	1.83	< 1.00E-01		1507.0	1616	369	2.29	< 1.00E-01
	1502.0	1661	577	2.14	< 1.00E-01		1508.0	1653	356	2.75	< 1.00E-01
	1503.0	1662	560	2.29	< 1.00E-01	46	1500.0	1643	590	1.68	< 1.00E-01
	1504.0	1656	538	2.29	1.93E-01		1501.0	1639	578	1.68	< 1.00E-01
	1505.0	1639	516	2.44	1.60E-01		1502.0	1632	562	1.83	< 1.00E-01
	1506.0	1621	493	2.75	< 1.00E-01		1503.0	1616	542	1.83	< 1.00E-01
	1507.0	1607	471	2.59	< 1.00E-01		1504.0	1598	518	1.68	< 1.00E-01
	1508.0	1596	439	2.59	< 1.00E-01		1505.0	1591	490	1.83	< 1.00E-01
	1509.0	1597	414	2.75	< 1.00E-01		1506.0	1601	465	2.14	< 1.00E-01
	1510.0	1598	384	2.75	< 1.00E-01		1507.0	1617	438	2.29	< 1.00E-01
44	1500.0	1652	583	1.53	< 1.00E-01		1508.0	1630	408	2.29	< 1.00E-01
	1501.0	1652	569	1.68	< 1.00E-01		1509.0	1632	380	2.44	< 1.00E-01
	1502.0	1648	554	1.68	< 1.00E-01	47	1500.0	1634	582	1.37	< 1.00E-01
	1503.0	1641	531	1.83	< 1.00E-01		1501.0	1623	562	1.68	< 1.00E-01
	1504.0	1634	510	2.14	< 1.00E-01		1502.0	1604	536	1.98	< 1.00E-01
	1505.0	1626	487	2.29	< 1.00E-01		1503.0	1577	510	2.14	< 1.00E-01
	1506.0	1619	482	2.29	< 1.00E-01		1504.0	1562	486	2.14	< 1.00E-01
	1507.0	1630	444	2.14	< 1.00E-01		1505.0	1560	470	1.98	< 1.00E-01
	1508.0	1646	420	2.14	< 1.00E-01		1506.0	1562	452	2.14	< 1.00E-01
	1509.0	1676	398	2.44	< 1.00E-01		1507.0	1576	439	2.29	< 1.00E-01
	1510.0	1719	382	2.29	< 1.00E-01		1508.0	1611	431	2.14	< 1.00E-01
	1511.0	1778	378	2.29	< 1.00E-01		1509.0	1675	423	2.29	< 1.00E-01
	1512.0	1833	387	2.44	< 1.00E-01		1510.0	1746	397	2.44	< 1.00E-01
	1513.0	1891	387	2.59	< 1.00E-01		1511.0	1838	395	2.44	< 1.00E-01
	1514.0	1964	383	2.75	< 1.00E-01		1512.0	1935	396	2.59	< 1.00E-01
	1515.0	2031	363	2.90	< 1.00E-01		1514.0	2132	315	2.75	< 1.00E-01
	1516.0	2100	347	2.90	< 1.00E-01	48	1500.0	1652	605	1.98	< 1.00E-01
	1517.0	2180	330	2.75	< 1.00E-01		1501.0	1660	588	1.98	< 1.00E-01
	1518.0	2248	323	2.90	< 1.00E-01		1502.0	1666	576	2.44	< 1.00E-01
45	1500.0	1646	588	1.22	< 1.00E-01		1503.0	1672	566	2.29	< 1.00E-01
	1501.0	1646	575	1.37	< 1.00E-01		1504.0	1676	557	2.14	< 1.00E-01
	1502.0	1637	550	1.53	< 1.00E-01		1505.0	1678	545	2.29	2.02E-01
	1503.0	1625	526	1.68	1.31E-01		1506.0	1679	531	2.14	5.90E-01
	1504.0	1617	498	1.53	< 1.00E-01		1507.0	1679	514	1.98	5.86E-01

Appendix D-5

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
48	1508.0	1681	497	2.14	< 1.00E-01	50	1506.0	1616	494	2.14	< 1.00E-01
	1509.0	1657	471	2.14	< 1.00E-01		1507.0	1600	478	2.44	< 1.00E-01
	1510.0	1665	467	2.29	< 1.00E-01		1508.0	1587	460	2.59	< 1.00E-01
	1511.0	1653	455	2.44	< 1.00E-01		1509.0	1578	438	2.59	< 1.00E-01
	1512.0	1636	448	2.44	< 1.00E-01		1510.0	1585	413	2.75	< 1.00E-01
	1513.0	1621	445	2.59	< 1.00E-01		1511.0	1608	396	2.59	< 1.00E-01
	1514.0	1606	446	2.75	< 1.00E-01		1512.0	1634	392	2.44	< 1.00E-01
	1515.0	1588	453	2.90	< 1.00E-01		1513.0	1666	391	2.59	< 1.00E-01
	1516.0	1564	464	2.90	< 1.00E-01		1514.0	1701	387	2.75	< 1.00E-01
	1517.0	1534	474	3.05	< 1.00E-01		1515.0	1743	389	2.59	< 1.00E-01
	1518.0	1506	480	3.20	< 1.00E-01		1516.0	1790	398	2.90	< 1.00E-01
	1519.0	1473	488	3.05	< 1.00E-01		1517.0	1850	397	3.05	< 1.00E-01
49	1500.0	1651	597	1.83	< 1.00E-01		1518.0	1929	389	3.20	< 1.00E-01
	1501.0	1656	586	1.68	< 1.00E-01		1519.0	1989	362	3.05	< 1.00E-01
	1502.0	1660	573	1.68	< 1.00E-01		1520.0	1989	362	3.20	< 1.00E-01
	1503.0	1662	562	1.53	< 1.00E-01		1521.0	2129	329	3.05	< 1.00E-01
	1504.0	1662	544	1.68	1.51E-01		1522.0	2202	323	2.75	< 1.00E-01
	1505.0	1661	530	1.83	2.54E-01		1523.0	2268	329	2.75	< 1.00E-01
	1506.0	1653	511	1.98	2.22E-01		1524.0	2325	396	2.59	< 1.00E-01
	1507.0	1646	497	2.14	< 1.00E-01	51	1500.0	1642	595	1.83	< 1.00E-01
	1508.0	1634	476	1.98	< 1.00E-01		1501.0	1642	585	1.68	< 1.00E-01
	1509.0	1622	455	2.14	< 1.00E-01		1502.0	1644	577	1.68	< 1.00E-01
	1510.0	1615	438	2.29	< 1.00E-01		1503.0	1645	562	1.83	< 1.00E-01
	1511.0	1604	416	2.44	< 1.00E-01		1504.0	1642	546	1.98	< 1.00E-01
	1512.0	1599	395	2.75	< 1.00E-01		1505.0	1640	534	2.14	1.50E-01
	1513.0	1598	373	2.75	< 1.00E-01		1506.0	1636	519	2.14	2.41E-01
	1514.0	1599	352	2.90	< 1.00E-01		1507.0	1631	501	2.14	< 1.00E-01
	1524.0	1767	389	3.05	< 1.00E-01		1508.0	1620	482	1.98	< 1.00E-01
	1525.0	1787	417	2.59	< 1.00E-01		1510.0	1611	439	2.29	< 1.00E-01
	1526.0	1821	430	2.59	< 1.00E-01		1511.0	1612	418	2.44	< 1.00E-01
	1527.0	1852	427	2.44	< 1.00E-01		1512.0	1614	399	2.59	< 1.00E-01
50	1500.0	1645	598	1.53	< 1.00E-01		1513.0	1620	377	2.75	< 1.00E-01
	1501.0	1649	585	1.68	< 1.00E-01		1514.0	1624	357	2.90	< 1.00E-01
	1502.0	1652	569	1.83	< 1.00E-01	52	1500.0	1637	598	1.98	< 1.00E-01
	1503.0	1656	550	1.83	1.07E-01		1501.0	1634	594	1.68	< 1.00E-01
	1504.0	1653	531	2.14	1.46E-01		1502.0	1630	579	1.83	< 1.00E-01
	1505.0	1638	509	1.98	1.51E-01		1503.0	1626	572	1.98	< 1.00E-01

Appendix D-5

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
52	1504.0	1623	567	1.98	< 1.00E-01
	1505.0	1615	553	2.14	< 1.00E-01
	1506.0	1611	543	2.14	< 1.00E-01
	1507.0	1604	529	2.29	< 1.00E-01
	1508.0	1600	523	2.44	1.49E-01
	1509.0	1591	507	2.59	1.23E-01
	1510.0	1584	499	2.75	1.20E-01
	1511.0	1576	492	2.90	< 1.00E-01
	1513.0	1566	474	3.05	< 1.00E-01
	1514.0	1569	464	3.20	< 1.00E-01
	1515.0	1572	457	3.20	< 1.00E-01
	1516.0	1576	448	3.05	< 1.00E-01
	1517.0	1585	437	3.20	< 1.00E-01
	1518.0	1596	432	2.90	< 1.00E-01
	1519.0	1606	427	2.59	< 1.00E-01
	1520.0	1617	424	2.44	< 1.00E-01
	1521.0	1634	421	2.59	< 1.00E-01
	1522.0	1654	419	2.44	< 1.00E-01
	1523.0	1678	418	2.59	< 1.00E-01
	1524.0	1704	418	2.44	< 1.00E-01
	1525.0	1729	421	2.59	< 1.00E-01
	1526.0	1759	421	2.44	< 1.00E-01
	1527.0	1790	420	2.44	< 1.00E-01
	1528.0	1822	419	2.44	< 1.00E-01

Appendix D-6

Horizontal Position (X, Y) and Depth
by Fish and Time During Treatment 3

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
73	1733.5	1641	612	0.61	< 1.00E-01	73	1849.0	1668	533	3.20	8.50E+00
	1734.0	1643	603	0.61	< 1.00E-01		1850.0	1674	531	3.05	1.01E+01
	1735.0	1644	562	2.90	< 1.00E-01		1851.0	1683	524	3.20	7.06E+00
	1736.0	1656	475	3.66	< 1.00E-01		1852.0	1691	512	3.36	6.76E+00
	1737.0	1664	443	3.97	< 1.00E-01		1853.0	1684	495	3.51	5.25E+00
	1738.0	1668	424	5.19	< 1.00E-01		1854.0	1670	489	3.51	5.19E+00
	1739.0	1672	415	5.03	< 1.00E-01		1855.0	1644	481	3.66	1.31E+00
	1740.0	1673	407	4.58	< 1.00E-01		1856.0	1607	475	3.97	8.47E-01
	1745.0	1680	390	3.97	< 1.00E-01		1857.0	1568	473	4.27	3.44E-01
	1750.0	1683	379	3.05	< 1.00E-01		1858.0	1535	478	4.42	2.01E+00
	1755.0	1693	367	2.59	< 1.00E-01		1859.0	1503	481	4.27	5.07E-01
	1800.0	1700	365	2.75	< 1.00E-01		1900.0	1469	490	4.58	2.43E+00
	1805.0	1713	367	3.66	< 1.00E-01		1901.0	1428	498	4.42	2.04E+00
	1810.0	1724	378	4.88	< 1.00E-01		1902.0	1371	504	4.27	2.74E+00
	1815.0	1728	396	4.27	< 1.00E-01		1914.5	1350	484	3.81	3.02E-01
	1820.0	1725	417	4.42	< 1.00E-01		1916.0	1422	483	3.97	5.91E-01
	1825.0	1696	437	4.58	4.39E-01		1917.5	1503	485	4.12	2.28E-01
	1830.0	1646	432	4.27	1.76E-01		1919.0	1576	479	3.97	1.03E+00
	1831.0	1636	430	4.27	1.29E-01		1920.5	1609	436	4.27	1.49E-01
	1832.0	1623	428	4.42	3.26E-01		1922.0	1694	459	4.12	5.09E-01
	1833.0	1610	428	4.58	2.83E-01		1923.5	1770	426	4.27	2.06E-01
	1834.0	1598	429	4.58	2.40E-01		1925.0	1845	404	4.27	< 1.00E-01
	1835.0	1586	435	4.73	1.84E-01		1926.5	1935	396	4.12	< 1.00E-01
	1836.0	1577	445	4.73	1.20E-01		1928.0	2027	378	4.88	< 1.00E-01
	1837.0	1572	466	4.73	9.09E-01		1929.5	2094	371	4.73	< 1.00E-01
	1838.0	1565	465	4.88	1.40E-01		1931.0	2171	370	4.58	< 1.00E-01
	1839.0	1565	480	4.88	1.27E+00		1932.5	2232	382	4.27	< 1.00E-01
	1840.0	1570	491	5.03	3.55E+00		1934.0	2285	414	4.42	< 1.00E-01
	1841.0	1576	501	5.03	8.62E+00		1935.5	2338	415	4.27	< 1.00E-01
	1842.0	1586	509	4.88	6.18E+00	74	1734.0	1643	613	0.61	< 1.00E-01
	1843.0	1598	517	4.42	1.15E+01		1735.0	1642	585	1.53	< 1.00E-01
	1844.0	1608	522	4.27	9.95E+00		1736.0	1640	566	1.98	< 1.00E-01
	1845.0	1616	526	3.97	1.48E+01		1737.0	1639	542	2.29	< 1.00E-01
	1846.0	1631	532	3.81	4.90E+00		1738.0	1637	516	3.05	< 1.00E-01
	1847.0	1639	535	3.66	3.43E+00		1739.0	1631	487	3.36	< 1.00E-01
	1848.0	1660	549	3.36	3.11E+00		1745.0	1632	407	4.12	< 1.00E-01

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
74	1750.0	1648	386	4.27	< 1.00E-01	74	1918.0	1647	457	4.58	2.30E-01
	1755.0	1657	382	4.42	< 1.00E-01		1919.0	1720	445	4.73	2.87E-01
	1800.0	1670	384	4.73	< 1.00E-01		1920.0	1806	433	4.73	< 1.00E-01
	1805.0	1679	386	4.88	< 1.00E-01		1921.0	1880	424	4.73	< 1.00E-01
	1810.0	1684	387	4.88	< 1.00E-01		1922.0	1961	421	4.58	< 1.00E-01
	1815.0	1690	390	5.03	< 1.00E-01		1923.0	2036	422	4.73	< 1.00E-01
	1820.0	1701	394	5.19	< 1.00E-01		1924.0	2103	428	4.58	< 1.00E-01
	1825.0	1710	400	4.58	1.32E-01		1925.0	2156	431	4.42	< 1.00E-01
	1830.0	1717	412	4.42	1.94E-01		1926.0	2209	435	4.27	< 1.00E-01
	1835.0	1724	439	4.58	6.24E-01		1926.5	2239	440	4.27	< 1.00E-01
	1836.0	1723	449	4.58	6.73E-01		1927.0	2267	458	4.27	< 1.00E-01
	1837.0	1721	457	4.42	1.41E+00		1927.5	2295	463	4.42	< 1.00E-01
	1838.0	1717	465	4.42	1.45E+00		1928.0	2318	455	4.42	< 1.00E-01
	1839.0	1707	470	4.42	2.63E+00		1928.5	2346	453	4.58	< 1.00E-01
	1840.0	1693	470	4.42	2.20E+00		1929.0	2370	457	4.73	< 1.00E-01
	1841.0	1685	466	4.42	2.00E+00		1929.5	2393	459	4.73	< 1.00E-01
	1842.0	1677	463	4.27	7.79E-01		1930.0	2411	464	4.58	< 1.00E-01
	1843.0	1668	457	4.42	6.73E-01	75	1734.0	1640	625	0.61	< 1.00E-01
	1844.0	1659	447	4.27	2.08E-01		1735.0	1637	585	1.83	< 1.00E-01
	1845.0	1646	440	4.27	1.49E-01		1736.0	1632	561	2.29	< 1.00E-01
	1846.0	1635	435	4.27	1.08E-01		1737.0	1622	534	2.29	< 1.00E-01
	1847.0	1622	436	4.27	3.08E-01		1738.0	1612	507	2.59	< 1.00E-01
	1848.0	1608	442	4.42	2.43E-01		1739.0	1599	467	3.05	< 1.00E-01
	1849.0	1594	452	4.42	5.55E-01		1740.0	1602	434	3.66	< 1.00E-01
	1850.0	1582	462	4.27	3.25E-01		1745.0	1635	412	4.12	< 1.00E-01
	1852.0	1560	503	4.42	5.08E+00		1750.0	1662	410	4.73	< 1.00E-01
	1853.0	1572	498	4.42	1.94E+00		1755.0	1678	411	4.88	< 1.00E-01
	1854.0	1562	506	4.58	3.87E+00		1800.0	1687	412	5.19	< 1.00E-01
	1855.0	1544	519	4.58	1.20E+01		1805.0	1696	415	5.34	< 1.00E-01
	1856.0	1531	534	4.73	7.26E+00		1810.0	1706	419	4.73	< 1.00E-01
	1857.0	1505	550	4.58	4.76E+00		1815.0	1712	422	4.27	1.43E-01
	1859.0	1533	544	4.42	7.25E+00		1820.0	1717	426	4.73	4.20E-01
	1900.0	1556	528	4.42	7.57E+00		1825.0	1723	431	4.27	5.40E-01
	1901.0	1580	517	4.58	8.26E+00		1830.0	1729	437	4.42	1.64E-01
	1914.0	1575	516	4.42	6.36E+00		1835.0	1737	447	4.27	< 1.00E-01
	1916.0	1572	518	4.27	5.04E+00		1840.0	1741	468	4.12	1.58E+00
	1917.0	1578	492	4.42	2.35E+00		1841.0	1728	484	4.12	8.78E-01

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
75	1842.0	1728	481	3.97	1.59E+00	76	1739.0	1628	449	3.51	< 1.00E-01
	1843.0	1721	483	3.97	5.46E+00		1742.0	1637	401	3.81	< 1.00E-01
	1844.0	1712	486	4.12	4.76E+00		1743.0	1649	398	3.97	< 1.00E-01
	1845.0	1703	486	4.12	4.20E+00		1744.0	1658	397	4.12	< 1.00E-01
	1846.0	1695	483	4.12	3.84E+00		1745.0	1674	402	4.12	< 1.00E-01
	1847.0	1689	473	4.12	1.75E+00		1750.0	1694	408	4.27	< 1.00E-01
	1848.0	1685	457	4.27	7.96E-01		1755.0	1703	412	4.42	< 1.00E-01
	1849.0	1676	441	4.42	2.75E-01		1800.0	1713	417	4.73	< 1.00E-01
	1850.0	1660	433	4.27	2.11E-01		1805.0	1720	420	5.03	< 1.00E-01
	1851.0	1643	431	4.27	1.45E-01		1810.0	1727	423	4.88	< 1.00E-01
	1852.0	1628	437	4.12	< 1.00E-01		1815.0	1732	427	5.03	2.26E-01
	1853.0	1612	449	4.12	2.18E-01		1820.0	1736	430	4.88	2.80E-01
	1854.0	1602	458	4.12	4.77E-01		1825.0	1742	434	4.88	3.09E-01
	1855.0	1591	470	4.12	8.54E-01		1830.0	1749	441	4.73	2.76E-01
	1856.0	1568	483	3.97	9.36E-01		1831.0	1751	445	4.73	2.36E-01
	1857.0	1416	521	3.81	5.07E+00		1832.0	1752	449	4.58	1.86E-01
	1858.0	1407	523	4.12	3.69E+00		1833.0	1753	451	4.58	1.12E+00
	1859.0	1386	524	4.27	1.47E+00		1834.0	1752	453	4.73	9.89E-01
	1900.0	1370	525	4.27	3.82E+00		1835.0	1750	456	4.73	7.66E-01
	1901.0	1344	525	4.73	2.41E+00		1836.0	1747	459	4.73	5.50E-01
	1915.0	1362	514	4.58	3.42E+00		1837.0	1744	462	4.58	3.55E-01
	1916.5	1457	474	4.42	1.13E-01		1838.0	1738	465	4.58	1.37E-01
	1918.0	1553	430	4.27	< 1.00E-01		1839.0	1733	467	4.58	1.62E+00
	1919.5	1632	413	4.27	< 1.00E-01		1841.0	1721	470	4.73	2.89E+00
	1921.0	1726	396	4.42	< 1.00E-01		1842.0	1711	472	4.58	2.58E+00
	1924.0	1897	381	4.27	< 1.00E-01		1843.0	1700	469	4.42	2.26E+00
	1925.5	1992	376	4.12	< 1.00E-01		1844.0	1690	468	4.42	2.00E+00
	1927.0	2099	384	4.12	< 1.00E-01		1845.0	1683	467	4.42	1.82E+00
	1928.5	2202	412	4.27	< 1.00E-01		1846.0	1674	466	4.42	1.64E+00
	1930.0	2289	451	4.42	< 1.00E-01		1847.0	1660	462	4.42	4.84E-01
	1931.5	2350	454	4.42	< 1.00E-01		1848.0	1647	461	4.42	3.44E-01
	1933.0	2403	462	4.58	< 1.00E-01		1849.0	1633	461	4.42	1.63E-01
76	1734.0	1641	627	0.46	< 1.00E-01		1850.0	1617	462	4.42	6.05E-01
	1735.0	1644	582	1.83	< 1.00E-01		1851.0	1607	464	4.42	4.95E-01
	1736.0	1643	557	2.29	< 1.00E-01		1852.0	1595	466	4.27	1.18E+00
	1737.0	1627	518	2.44	< 1.00E-01		1853.0	1581	470	4.27	7.15E-01
	1738.0	1632	486	3.20	< 1.00E-01		1854.0	1569	474	4.27	3.30E-01

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
76	1855.0	1556	478	4.27	9.32E-01	77	1845.0	1599	476	4.12	2.90E+00
	1856.0	1530	490	4.42	4.19E+00		1850.0	1582	469	4.27	8.46E-01
	1857.0	1508	493	4.42	1.82E+00		1855.0	1576	457	3.97	2.98E-01
	1858.0	1482	496	4.58	2.92E+00		1900.0	1585	446	3.81	1.12E-01
	1859.0	1452	496	4.58	5.43E-01		1905.0	1620	444	4.12	2.02E-01
	1900.0	1417	494	4.58	1.71E+00		1910.0	1708	449	4.42	2.75E-01
	1916.0	1484	437	4.27	1.17E-01		1913.0	1773	448	4.58	< 1.00E-01
	1917.0	1540	440	4.27	1.42E-01		1914.0	1824	445	4.73	< 1.00E-01
	1918.0	1596	438	4.58	1.24E-01		1915.0	1894	441	4.58	< 1.00E-01
	1919.0	1649	437	4.73	< 1.00E-01		1916.0	1978	440	4.27	< 1.00E-01
	1920.0	1710	434	4.58	2.42E-01		1917.0	2063	443	4.42	< 1.00E-01
	1921.0	1776	432	4.58	1.83E-01		1917.5	2104	450	4.42	< 1.00E-01
	1922.0	1839	429	4.73	< 1.00E-01		1918.0	2143	453	4.42	5.75E-01
	1923.0	1902	427	4.58	< 1.00E-01		1918.5	2189	458	4.58	6.74E-01
	1924.0	1970	428	4.42	< 1.00E-01		1919.0	2233	487	4.58	1.62E-01
	1925.0	2029	431	4.42	< 1.00E-01		1919.5	2273	484	4.42	< 1.00E-01
	1926.0	2090	434	4.27	< 1.00E-01		1920.0	2313	485	4.42	< 1.00E-01
	1929.0	2279	447	4.58	< 1.00E-01		1920.5	2345	485	4.58	< 1.00E-01
	1932.0	2400	452	4.27	< 1.00E-01		1921.0	2370	485	4.73	< 1.00E-01
77	1734.0	1643	614	0.61	< 1.00E-01		1921.5	2401	486	4.58	< 1.00E-01
	1735.0	1645	598	1.37	< 1.00E-01		1922.0	2428	487	4.58	< 1.00E-01
	1736.0	1645	582	2.44	< 1.00E-01	78	1734.0	1645	598	0.61	< 1.00E-01
	1737.0	1645	572	3.51	< 1.00E-01		1735.0	1635	589	1.83	< 1.00E-01
	1738.0	1644	560	3.97	< 1.00E-01		1736.0	1625	568	1.98	< 1.00E-01
	1739.0	1641	544	4.27	< 1.00E-01		1737.0	1614	543	2.44	< 1.00E-01
	1740.0	1640	529	4.58	< 1.00E-01		1738.0	1604	520	2.59	< 1.00E-01
	1745.0	1635	500	4.58	1.85E-01		1739.0	1588	485	3.05	< 1.00E-01
	1750.0	1635	486	4.88	< 1.00E-01		1740.0	1582	463	3.51	< 1.00E-01
	1755.0	1636	479	5.34	3.33E-01		1745.0	1597	425	4.42	< 1.00E-01
	1800.0	1636	476	5.64	6.23E-01		1750.0	1612	414	4.58	< 1.00E-01
	1805.0	1639	473	5.19	3.43E-01		1755.0	1620	407	5.03	< 1.00E-01
	1810.0	1643	470	5.03	5.79E-01		1800.0	1631	400	5.19	< 1.00E-01
	1815.0	1645	466	4.88	8.58E-01		1805.0	1639	394	5.34	< 1.00E-01
	1825.0	1639	461	4.73	2.82E-01		1810.0	1649	390	4.88	< 1.00E-01
	1830.0	1632	466	4.58	8.39E-01		1815.0	1661	381	4.58	< 1.00E-01
	1835.0	1623	471	4.42	1.53E+00		1820.0	1685	374	4.73	< 1.00E-01
	1840.0	1612	476	3.97	3.50E+00		1825.0	1714	373	4.12	< 1.00E-01

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
78	1830.0	1732	395	3.66	< 1.00E-01	79	1739.0	1578	438	3.97	< 1.00E-01
	1835.0	1720	405	4.27	1.85E-01		1740.0	1594	416	4.27	< 1.00E-01
	1840.0	1704	414	4.73	1.75E-01		1745.0	1644	395	4.42	< 1.00E-01
	1845.0	1683	430	4.88	3.36E-01		1750.0	1673	395	4.58	< 1.00E-01
	1846.0	1675	434	4.88	2.93E-01		1755.0	1687	398	4.73	< 1.00E-01
	1847.0	1672	439	4.73	2.73E-01		1800.0	1696	402	4.73	< 1.00E-01
	1848.0	1669	450	4.73	2.37E-01		1805.0	1701	409	4.88	< 1.00E-01
	1849.0	1673	459	4.58	6.37E-01		1810.0	1702	417	4.73	< 1.00E-01
	1850.0	1684	463	4.58	7.27E-01		1815.0	1683	432	4.73	2.67E-01
	1851.0	1703	469	4.58	2.00E+00		1820.0	1643	437	4.42	1.26E-01
	1852.0	1720	485	4.58	4.26E+00		1825.0	1648	453	4.58	4.87E-01
	1853.0	1709	497	4.42	6.50E+00		1830.0	1670	455	5.03	7.84E-01
	1854.0	1678	454	4.42	6.49E-01		1835.0	1681	456	5.19	9.00E-01
	1859.0	1515	493	4.58	2.25E+00		1840.0	1689	459	4.88	9.72E-01
	1900.0	1466	495	4.42	1.67E+00		1841.0	1692	461	5.03	9.97E-01
	1901.0	1402	497	4.27	1.10E+00		1842.0	1694	464	4.88	1.02E+00
	1914.0	1404	450	4.27	< 1.00E-01		1843.0	1694	470	4.88	2.11E+00
	1915.5	1455	441	4.42	< 1.00E-01		1844.0	1692	474	4.73	1.95E+00
	1917.0	1501	443	4.12	< 1.00E-01		1845.0	1689	476	4.73	4.08E+00
	1918.5	1558	443	3.97	< 1.00E-01		1846.0	1682	481	4.73	3.40E+00
	1920.0	1603	430	4.12	1.49E-01		1847.0	1672	484	4.58	2.64E+00
	1921.5	1679	450	3.97	1.61E-01		1848.0	1663	485	4.73	2.00E+00
	1923.0	1752	456	3.81	3.03E-01		1849.0	1653	487	4.73	1.31E+00
	1924.5	1826	457	3.97	< 1.00E-01		1850.0	1645	489	4.73	3.85E+00
	1926.0	1891	446	4.27	< 1.00E-01		1851.0	1631	488	4.73	3.00E+00
	1927.5	1959	433	4.42	< 1.00E-01		1852.0	1620	488	4.58	7.34E+00
	1929.0	2028	413	4.58	< 1.00E-01		1853.0	1606	487	4.58	1.98E+00
	1930.5	2118	401	4.42	< 1.00E-01		1854.0	1593	486	4.58	1.58E+00
	1932.0	2198	408	4.27	< 1.00E-01		1855.0	1579	486	4.58	1.07E+00
	1933.5	2272	443	4.58	< 1.00E-01		1856.0	1550	490	4.42	1.78E+00
	1935.0	2334	447	4.42	< 1.00E-01		1857.0	1525	490	4.58	3.73E+00
	1936.5	2388	458	4.73	< 1.00E-01		1858.0	1488	489	4.58	3.99E+00
79	1734.0	1645	606	0.61	< 1.00E-01		1859.0	1451	491	4.73	1.10E+00
	1735.0	1626	572	1.68	< 1.00E-01		1900.0	1414	494	4.58	1.60E+00
	1736.0	1614	543	2.29	< 1.00E-01		1901.0	1399	495	4.42	1.04E+00
	1737.0	1597	511	3.05	< 1.00E-01		1914.0	1363	479	4.73	3.96E-01
	1738.0	1580	470	3.81	< 1.00E-01		1915.0	1394	476	4.42	3.58E-01

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
79	1916.0	1434	472	4.42	3.37E-01	81	1740.0	1647	451	4.42	< 1.00E-01
	1917.0	1463	468	4.27	2.94E-01		1745.0	1671	442	4.73	< 1.00E-01
	1918.0	1489	463	4.42	2.40E-01		1750.0	1679	436	4.58	< 1.00E-01
	1919.0	1516	461	4.27	1.45E-01		1755.0	1687	432	4.73	< 1.00E-01
	1920.0	1552	454	4.42	1.18E-01		1800.0	1689	429	4.88	1.21E-01
	1921.0	1586	448	4.58	< 1.00E-01		1805.0	1693	425	5.19	< 1.00E-01
	1922.0	1620	444	4.58	1.58E-01		1810.0	1700	421	5.03	< 1.00E-01
	1923.0	1668	438	4.58	1.33E-01		1815.0	1697	417	5.34	1.09E-01
	1924.0	1709	430	4.73	2.28E-01		1820.0	1699	414	5.19	1.27E-01
	1925.0	1754	428	4.58	1.51E-01		1825.0	1702	405	4.88	1.34E-01
	1926.0	1794	424	4.58	< 1.00E-01		1830.0	1700	401	4.58	1.39E-01
	1927.0	1833	424	4.42	< 1.00E-01		1831.0	1698	400	4.58	1.34E-01
	1928.0	1880	422	4.73	< 1.00E-01		1832.0	1697	399	4.73	< 1.00E-01
	1929.0	1926	424	4.73	< 1.00E-01		1833.0	1695	397	4.58	< 1.00E-01
	1930.0	1971	423	4.58	< 1.00E-01		1834.0	1693	396	4.42	< 1.00E-01
	1931.0	2011	419	4.42	< 1.00E-01		1835.0	1694	396	4.42	< 1.00E-01
	1932.0	2052	416	4.42	< 1.00E-01		1836.0	1688	394	4.42	< 1.00E-01
	1933.0	2099	411	4.58	< 1.00E-01		1837.0	1686	394	4.42	< 1.00E-01
	1937.0	2301	431	4.58	< 1.00E-01		1838.0	1681	394	4.27	< 1.00E-01
	1938.0	2342	426	4.42	< 1.00E-01		1839.0	1678	394	4.42	< 1.00E-01
	1939.0	2342	426	4.73	< 1.00E-01		1840.0	1676	395	4.42	< 1.00E-01
80	1734.0	1644	605	0.92	< 1.00E-01		1841.0	1669	396	4.42	< 1.00E-01
	1734.5	1639	593	2.29	< 1.00E-01		1842.0	1663	398	4.58	< 1.00E-01
	1735.0	1624	579	2.59	< 1.00E-01		1843.0	1657	398	4.42	< 1.00E-01
	1735.5	1617	573	3.05	< 1.00E-01		1844.0	1652	400	4.42	< 1.00E-01
	1736.0	1596	545	3.20	< 1.00E-01		1845.0	1647	402	4.27	< 1.00E-01
	1736.5	1571	527	2.75	< 1.00E-01		1846.0	1639	404	4.27	< 1.00E-01
	1737.0	1536	512	3.81	< 1.00E-01		1847.0	1631	407	4.27	< 1.00E-01
	1737.5	1498	503	4.12	< 1.00E-01		1848.0	1624	412	4.42	1.13E-01
	1738.0	1456	501	4.27	< 1.00E-01		1849.0	1616	416	4.42	< 1.00E-01
	1738.5	1405	503	4.42	< 1.00E-01		1850.0	1609	423	4.42	< 1.00E-01
81	1734.0	1643	613	0.76	< 1.00E-01		1851.0	1601	428	4.42	2.46E-01
	1735.0	1640	587	2.14	< 1.00E-01		1852.0	1591	433	4.58	1.91E-01
	1736.0	1635	566	2.59	< 1.00E-01		1853.0	1579	444	4.58	1.17E-01
	1737.0	1631	534	2.90	< 1.00E-01		1854.0	1568	457	4.42	2.49E-01
	1738.0	1628	492	3.51	< 1.00E-01		1855.0	1555	468	4.58	4.34E-01
	1739.0	1635	460	3.97	< 1.00E-01		1856.0	1532	488	4.73	4.71E+00

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
81	1857.0	1509	497	4.58	1.32E+00	82	1738.0	1639	558	2.29	< 1.00E-01
	1858.0	1479	503	4.73	6.32E+00		1739.0	1640	540	2.90	< 1.00E-01
	1859.0	1441	503	4.58	5.17E+00		1740.0	1650	524	3.20	< 1.00E-01
	1900.0	1402	501	4.42	2.79E+00		1745.0	1703	494	3.97	4.16E-01
	1901.0	1347	501	4.58	2.23E+00		1750.0	1715	485	4.88	6.64E-01
	1914.0	1355	503	4.42	1.75E+00		1755.0	1719	483	5.03	1.40E+00
	1915.0	1388	489	4.58	6.44E-01		1800.0	1721	479	4.73	2.20E+00
	1916.0	1418	477	4.58	5.57E-01		1805.0	1723	475	4.88	3.14E+00
	1917.0	1452	464	4.73	< 1.00E-01		1810.0	1725	470	4.42	2.24E+00
	1918.0	1488	452	4.58	2.82E-01		1815.0	1725	465	4.73	1.40E+00
	1919.0	1532	443	4.73	1.06E-01		1820.0	1725	460	4.27	1.46E+00
	1920.0	1567	433	4.58	< 1.00E-01		1825.0	1723	449	4.42	6.78E-01
	1921.0	1600	427	4.42	1.49E-01		1830.0	1715	433	4.27	5.49E-01
	1922.0	1641	420	4.27	< 1.00E-01		1835.0	1697	418	4.27	1.68E-01
	1924.0	1713	402	4.42	< 1.00E-01		1836.0	1693	416	4.27	1.56E-01
	1924.5	1730	397	4.27	< 1.00E-01		1837.0	1686	413	4.42	1.38E-01
	1925.0	1747	392	4.27	< 1.00E-01		1838.0	1679	410	4.42	1.23E-01
	1925.5	1771	386	4.42	< 1.00E-01		1839.0	1674	409	4.27	1.13E-01
	1926.0	1790	384	4.58	< 1.00E-01		1840.0	1665	408	4.12	< 1.00E-01
	1926.5	1826	369	4.58	< 1.00E-01		1841.0	1656	409	4.12	< 1.00E-01
	1927.0	1837	382	4.73	< 1.00E-01		1842.0	1644	409	4.12	< 1.00E-01
	1927.5	1860	383	4.73	< 1.00E-01		1843.0	1629	416	4.12	< 1.00E-01
	1928.0	1886	387	4.73	< 1.00E-01		1844.0	1618	424	3.97	< 1.00E-01
	1928.5	1903	385	4.73	< 1.00E-01		1845.0	1607	434	3.97	2.61E-01
	1929.0	1926	384	4.58	< 1.00E-01		1846.0	1600	442	3.81	2.17E-01
	1930.0	1973	387	4.42	< 1.00E-01		1847.0	1592	451	3.81	5.54E-01
	1931.0	2018	386	4.27	< 1.00E-01		1848.0	1583	460	3.97	3.57E-01
	1932.0	2074	388	4.42	< 1.00E-01		1849.0	1571	468	3.97	7.38E-01
	1933.0	2132	392	4.42	< 1.00E-01		1850.0	1558	475	4.12	1.44E-01
	1934.0	2188	400	4.58	< 1.00E-01		1851.0	1542	485	4.12	2.22E+00
	1935.0	2251	405	4.58	< 1.00E-01		1852.0	1529	491	3.97	4.38E+00
	1936.0	2304	420	4.73	< 1.00E-01		1853.0	1515	496	4.12	2.05E+00
	1938.0	2304	420	4.58	< 1.00E-01		1854.0	1498	500	4.12	9.90E+00
82	1734.0	1643	614	0.46	< 1.00E-01		1855.0	1481	502	4.12	6.97E+00
	1735.0	1644	597	1.68	< 1.00E-01		1856.0	1466	504	4.27	4.28E+00
	1736.0	1642	585	1.22	< 1.00E-01		1857.0	1448	504	4.42	5.72E+00
	1737.0	1641	572	1.83	< 1.00E-01		1858.0	1426	503	4.42	4.23E+00

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
82	1859.0	1399	503	4.27	2.55E+00	83	1743.0	1688	444	4.73	< 1.00E-01
	1900.0	1370	509	4.42	2.62E+00		1743.5	1702	458	5.19	< 1.00E-01
	1914.5	1374	524	4.27	3.42E+00		1744.0	1723	472	4.42	2.19E-01
	1916.0	1430	490	4.12	1.50E+00		1744.5	1734	484	4.73	2.14E-01
	1917.5	1488	483	3.97	1.10E+00		1745.0	1743	491	4.73	6.06E-01
	1919.0	1538	478	4.12	1.54E+00		1745.5	1750	498	4.27	5.72E-01
	1920.5	1593	467	4.12	6.75E-01		1746.0	1751	506	2.14	6.82E-01
	1922.0	1663	458	3.97	3.16E-01		1746.5	1749	516	2.44	4.92E-01
	1923.5	1729	443	4.12	< 1.00E-01		1747.0	1756	524	2.14	2.12E-01
	1925.0	1805	432	4.27	< 1.00E-01		1747.5	1768	532	1.98	2.60E-01
	1926.5	1881	427	4.12	< 1.00E-01		1748.0	1780	530	2.59	3.90E-01
	1928.0	1969	428	4.27	< 1.00E-01		1748.5	1792	523	3.66	5.98E-01
	1929.5	2041	439	4.27	< 1.00E-01		1749.0	1792	502	3.51	2.11E+00
	1931.0	2106	432	4.42	< 1.00E-01		1749.5	1784	483	2.29	1.47E+00
	1932.5	2176	439	4.42	< 1.00E-01		1750.0	1770	463	2.75	3.89E-01
	1934.0	2241	469	4.27	7.44E-01		1750.5	1750	456	4.88	2.49E-01
	1935.5	2303	466	4.42	< 1.00E-01		1751.0	1731	460	4.42	< 1.00E-01
	1937.0	2355	471	4.58	< 1.00E-01		1752.0	1695	482	5.34	7.49E-01
	1938.5	2399	478	4.58	< 1.00E-01		1753.0	1659	513	3.66	6.70E-01
83	1734.0	1644	597	0.61	< 1.00E-01		1754.0	1633	530	4.12	2.04E-01
	1734.5	1628	588	3.05	< 1.00E-01		1755.0	1608	530	3.51	2.19E-01
	1735.0	1617	573	3.36	< 1.00E-01		1756.0	1597	520	3.66	3.46E-01
	1735.5	1596	534	3.97	< 1.00E-01		1757.0	1587	509	4.42	4.72E-01
	1736.0	1591	490	4.88	< 1.00E-01		1758.0	1583	501	4.27	8.15E-01
	1736.5	1598	460	5.03	< 1.00E-01		1759.0	1574	485	2.75	2.83E-01
	1737.0	1607	436	4.88	< 1.00E-01		1800.0	1567	474	2.44	1.29E-01
	1737.5	1618	412	4.88	< 1.00E-01		1801.0	1565	465	2.75	< 1.00E-01
	1738.0	1648	388	4.42	< 1.00E-01		1802.0	1568	455	2.90	1.05E-01
	1738.5	1664	395	3.66	< 1.00E-01		1803.0	1572	444	2.75	< 1.00E-01
	1739.0	1675	396	2.14	< 1.00E-01		1804.0	1578	432	2.75	< 1.00E-01
	1739.5	1692	404	2.59	< 1.00E-01		1805.0	1586	418	3.05	< 1.00E-01
	1740.0	1702	408	2.44	< 1.00E-01		1806.0	1591	407	3.05	< 1.00E-01
	1740.5	1710	413	1.83	< 1.00E-01		1808.0	1601	379	2.75	< 1.00E-01
	1741.0	1719	422	2.29	< 1.00E-01		1809.0	1613	366	2.44	< 1.00E-01
	1741.5	1710	430	2.75	< 1.00E-01		1810.0	1629	376	2.29	< 1.00E-01
	1742.0	1697	431	5.34	< 1.00E-01		1811.0	1640	386	2.59	< 1.00E-01
	1742.5	1688	432	3.66	< 1.00E-01		1812.0	1648	396	2.90	< 1.00E-01

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
83	1813.0	1655	402	3.66	< 1.00E-01	83	1850.0	1624	427	4.42	3.29E-01
	1814.0	1660	407	4.58	< 1.00E-01		1851.0	1619	428	4.27	3.04E-01
	1815.0	1665	411	5.03	< 1.00E-01		1852.0	1609	426	4.12	2.69E-01
	1816.0	1669	415	5.03	< 1.00E-01		1853.0	1598	424	3.66	< 1.00E-01
	1817.0	1670	418	4.88	< 1.00E-01		1854.0	1573	429	3.66	1.43E-01
	1818.0	1673	423	4.42	< 1.00E-01		1855.0	1558	447	3.81	< 1.00E-01
	1819.0	1680	429	4.27	2.82E-01		1856.0	1543	470	3.66	1.03E+00
	1820.0	1683	436	3.97	3.29E-01		1857.0	1509	492	3.97	1.95E+00
	1821.0	1688	448	4.12	4.14E-01		1858.0	1463	499	3.81	1.16E+00
	1822.0	1692	460	3.51	1.02E+00		1859.0	1415	501	3.97	3.65E+00
	1823.0	1696	469	3.20	2.23E+00		1900.0	1355	503	4.12	2.42E+00
	1824.0	1699	491	3.05	9.07E+00		1913.0	1377	505	3.97	6.94E-01
	1825.0	1698	507	3.20	1.16E+01		1914.0	1491	481	3.97	1.26E+00
	1826.0	1691	523	2.75	7.49E+00		1914.5	1556	458	3.81	1.06E-01
	1827.0	1668	516	2.90	1.02E+01		1915.0	1609	436	3.97	1.61E-01
	1828.0	1659	497	3.20	4.60E+00		1915.5	1689	418	3.97	< 1.00E-01
	1829.0	1653	486	3.36	2.01E+00		1916.0	1748	402	4.12	< 1.00E-01
	1830.0	1651	479	3.81	2.37E+00		1916.5	1857	390	3.66	< 1.00E-01
	1831.0	1647	474	4.27	7.84E-01		1917.0	1951	393	3.51	< 1.00E-01
	1832.0	1646	469	4.73	1.01E+00		1917.5	2058	390	3.66	< 1.00E-01
	1833.0	1644	464	5.34	3.28E-01		1918.0	2137	408	3.97	< 1.00E-01
	1834.0	1641	457	5.03	3.76E-01		1918.5	2208	426	4.12	1.46E-01
	1835.0	1638	451	4.88	4.16E-01		1919.0	2273	458	4.27	< 1.00E-01
	1836.0	1633	443	5.03	< 1.00E-01		1919.5	2437	575	4.12	< 1.00E-01
	1837.0	1628	433	4.42	< 1.00E-01	84	1734.0	1646	599	0.61	< 1.00E-01
	1838.0	1622	418	3.97	1.02E-01		1735.0	1640	579	1.37	< 1.00E-01
	1839.0	1621	404	3.81	1.13E-01		1736.0	1636	554	2.29	< 1.00E-01
	1840.0	1627	384	3.36	< 1.00E-01		1737.0	1629	523	3.20	< 1.00E-01
	1841.0	1637	375	3.20	< 1.00E-01		1738.0	1621	488	3.97	< 1.00E-01
	1842.0	1654	371	3.05	< 1.00E-01		1739.0	1615	451	4.27	< 1.00E-01
	1843.0	1673	376	3.51	< 1.00E-01		1740.0	1615	412	4.42	< 1.00E-01
	1844.0	1686	393	3.81	< 1.00E-01		1745.0	1674	397	4.27	< 1.00E-01
	1845.0	1679	410	3.97	1.13E-01		1750.0	1690	405	4.42	< 1.00E-01
	1846.0	1661	420	4.27	< 1.00E-01		1755.0	1698	412	4.73	< 1.00E-01
	1847.0	1649	422	4.73	< 1.00E-01		1800.0	1705	416	4.58	< 1.00E-01
	1848.0	1642	423	4.73	< 1.00E-01		1805.0	1711	418	4.88	< 1.00E-01
	1849.0	1633	426	4.88	1.26E-01		1810.0	1715	423	4.88	1.19E-01

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
84	1815.0	1720	428	5.03	3.77E-01	84	1928.0	2013	461	4.27	1.29E-01
	1820.0	1727	433	5.03	1.65E-01		1929.0	2064	402	4.27	< 1.00E-01
	1825.0	1735	440	4.88	1.81E-01		1933.0	2337	442	4.58	< 1.00E-01
	1830.0	1743	447	4.73	1.64E-01		1934.0	2383	446	4.73	< 1.00E-01
	1835.0	1746	456	4.73	7.46E-01		1935.0	2416	450	4.58	< 1.00E-01
	1836.0	1741	458	4.73	5.47E-01	85	1734.0	1647	600	0.61	< 1.00E-01
	1837.0	1736	458	4.73	4.90E-01		1735.0	1641	576	1.98	< 1.00E-01
	1838.0	1731	457	4.58	4.33E-01		1736.0	1644	536	2.59	< 1.00E-01
	1839.0	1726	458	4.58	3.40E-01		1737.0	1637	511	3.05	< 1.00E-01
	1840.0	1721	460	4.58	1.41E+00		1738.0	1615	496	3.51	< 1.00E-01
	1841.0	1716	458	4.42	1.30E+00		1739.0	1590	479	3.66	< 1.00E-01
	1842.0	1708	457	4.42	1.16E+00		1740.0	1588	452	3.97	< 1.00E-01
	1843.0	1699	456	4.27	1.03E+00		1745.0	1622	425	4.12	< 1.00E-01
	1850.0	1615	436	4.58	2.78E-01		1750.0	1644	425	4.27	< 1.00E-01
	1851.0	1614	446	4.73	2.41E-01		1755.0	1658	426	4.73	< 1.00E-01
	1852.0	1606	456	4.73	5.58E-01		1800.0	1668	426	4.73	< 1.00E-01
	1853.0	1592	462	4.58	3.73E-01		1805.0	1676	425	4.88	1.32E-01
	1854.0	1581	469	4.58	7.76E-01		1810.0	1686	424	5.03	< 1.00E-01
	1855.0	1568	476	4.58	1.49E+00		1815.0	1689	422	4.88	1.06E-01
	1856.0	1552	483	4.58	4.41E-01		1820.0	1696	421	5.19	1.36E-01
	1857.0	1530	495	4.42	3.51E+00		1825.0	1699	419	5.03	1.58E-01
	1858.0	1506	498	4.27	7.67E-01		1830.0	1705	419	4.73	1.86E-01
	1859.0	1473	499	4.42	1.91E+00		1835.0	1710	423	4.58	2.07E-01
	1900.0	1437	500	4.27	4.85E+00		1836.0	1710	426	4.58	4.86E-01
	1901.0	1390	500	4.42	5.96E-01		1837.0	1712	427	4.42	5.01E-01
	1902.0	1342	504	4.58	1.87E+00		1838.0	1711	431	4.42	5.13E-01
	1915.0	1354	510	4.58	1.49E+00		1839.0	1712	433	4.58	5.20E-01
	1916.0	1408	504	4.58	2.16E+00		1840.0	1712	436	4.58	5.23E-01
	1917.0	1449	497	4.27	1.96E+00		1841.0	1709	439	4.58	5.10E-01
	1918.0	1491	489	4.42	2.84E+00		1842.0	1707	443	4.42	4.97E-01
	1919.0	1538	481	4.27	1.39E+00		1843.0	1703	446	4.27	4.73E-01
	1920.0	1587	472	4.58	4.66E-01		1844.0	1697	448	4.42	4.30E-01
	1921.0	1642	463	4.58	1.45E-01		1845.0	1692	451	4.42	9.23E-01
	1922.0	1696	451	4.73	5.18E-01		1846.0	1684	453	4.42	8.35E-01
	1923.0	1750	445	4.73	< 1.00E-01		1848.0	1665	457	4.27	5.86E-01
	1926.0	1926	434	4.58	< 1.00E-01		1849.0	1652	458	4.27	4.19E-01
	1927.0	1985	430	4.42	< 1.00E-01		1850.0	1637	462	4.27	2.01E-01

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Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
85	1851.0	1625	465	4.27	< 1.00E-01	86	1745.0	1665	404	4.27	< 1.00E-01
	1852.0	1611	467	4.27	1.37E+00		1750.0	1679	401	4.42	< 1.00E-01
	1853.0	1597	467	4.27	1.11E+00		1755.0	1694	403	4.42	< 1.00E-01
	1854.0	1579	469	4.27	7.46E-01		1800.0	1702	407	4.73	< 1.00E-01
	1855.0	1560	472	4.27	3.07E-01		1805.0	1711	412	5.03	< 1.00E-01
	1856.0	1522	479	4.42	1.52E+00		1810.0	1721	421	4.42	1.22E-01
	1857.0	1491	482	4.27	1.74E+00		1815.0	1729	428	4.88	1.93E-01
	1858.0	1449	497	4.42	2.95E+00		1820.0	1742	439	4.58	2.60E-01
	1859.0	1410	506	4.42	3.07E+00		1825.0	1757	456	4.27	1.08E+00
	1900.0	1352	511	4.58	1.91E+00		1830.0	1765	479	4.12	4.82E+00
	1914.0	1321	526	4.58	3.31E+00		1831.0	1765	484	3.97	3.03E+00
	1915.0	1369	511	4.73	1.85E+00		1832.0	1764	489	3.97	1.04E+01
	1916.0	1404	508	4.58	1.76E+00		1833.0	1760	497	4.12	6.01E+00
	1917.0	1433	501	4.73	3.26E+00		1834.0	1756	501	4.12	1.58E+01
	1918.0	1469	494	4.73	1.47E+00		1835.0	1750	503	4.12	1.26E+01
	1919.0	1503	487	4.58	1.27E-01		1836.0	1744	507	3.97	8.40E+00
	1920.0	1546	477	4.42	1.78E+00		1837.0	1736	508	3.97	5.90E+00
	1921.0	1590	467	4.42	6.50E-01		1838.0	1727	506	3.81	6.15E+00
	1922.0	1643	457	4.27	2.00E-01		1839.0	1720	504	3.81	1.79E+01
	1923.0	1695	450	4.42	2.03E-01		1840.0	1712	500	3.81	1.82E+01
	1924.0	1752	443	4.58	< 1.00E-01		1841.0	1708	496	3.81	9.27E+00
	1927.0	1935	432	4.58	< 1.00E-01		1842.0	1700	490	3.81	9.22E+00
	1928.0	1995	431	4.73	< 1.00E-01		1843.0	1688	491	3.81	7.85E+00
	1929.0	2055	432	4.42	< 1.00E-01		1844.0	1671	492	3.97	5.87E+00
	1930.0	2115	430	4.27	1.32E-01		1845.0	1654	493	3.97	4.25E+00
	1931.0	2167	433	4.42	1.66E-01		1846.0	1636	492	3.97	2.69E+00
	1932.0	2219	438	4.27	1.65E-01		1847.0	1609	489	4.12	6.78E+00
	1933.0	2272	458	4.42	< 1.00E-01		1848.0	1571	482	4.12	1.30E+00
	1935.0	2369	452	4.58	< 1.00E-01		1849.0	1580	482	4.12	1.61E+00
	1936.0	2398	461	4.73	< 1.00E-01		1850.0	1597	472	4.12	9.81E-01
86	1734.0	1644	597	0.76	< 1.00E-01		1851.0	1609	459	4.12	5.58E-01
	1735.0	1637	581	2.44	< 1.00E-01		1852.0	1603	444	4.27	2.05E-01
	1736.0	1632	537	2.59	< 1.00E-01		1853.0	1587	458	4.42	3.81E-01
	1737.0	1626	493	3.05	< 1.00E-01		1854.0	1579	471	4.27	6.61E-01
	1738.0	1617	446	2.90	< 1.00E-01		1855.0	1573	481	4.27	1.29E+00
	1739.0	1626	433	3.36	< 1.00E-01		1856.0	1545	486	4.58	2.04E+00
	1740.0	1636	420	3.81	< 1.00E-01		1857.0	1508	491	4.42	2.12E+00

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
86	1858.0	1477	484	4.12	1.14E+00	87	1833.0	1696	438	4.58	4.65E-01
	1859.0	1442	505	4.27	5.23E+00		1834.0	1691	437	4.58	4.25E-01
	1900.0	1400	511	4.42	1.97E+00		1835.0	1683	436	4.58	3.79E-01
	1901.0	1324	519	4.58	2.05E+00		1836.0	1675	436	4.58	3.34E-01
	1913.5	1357	485	4.12	3.47E-01		1837.0	1666	435	4.73	2.81E-01
	1916.5	1483	474	4.27	4.11E-01		1838.0	1658	435	4.73	2.40E-01
	1918.0	1532	472	4.27	5.10E-01		1839.0	1646	435	4.73	1.75E-01
	1919.5	1606	457	4.42	3.40E-01		1840.0	1634	436	4.73	1.03E-01
	1921.0	1664	443	4.42	1.21E-01		1841.0	1628	438	4.73	< 1.00E-01
	1922.5	1739	431	4.27	1.06E-01		1842.0	1618	440	4.58	2.91E-01
	1924.0	1819	418	4.12	< 1.00E-01		1843.0	1610	446	4.58	2.47E-01
	1925.5	1897	410	4.42	< 1.00E-01		1844.0	1604	452	4.42	6.38E-01
	1930.0	2117	417	4.58	< 1.00E-01		1845.0	1599	457	4.58	5.33E-01
	1931.5	2154	427	4.73	< 1.00E-01		1846.0	1597	464	4.58	4.29E-01
	1933.0	2200	435	4.42	2.22E-01		1847.0	1595	473	4.42	9.00E-01
	1936.0	2287	465	4.27	< 1.00E-01		1848.0	1591	480	4.42	2.20E+00
	1937.5	2327	467	4.12	< 1.00E-01		1849.0	1590	488	4.27	5.47E+00
	1939.0	2362	470	4.27	< 1.00E-01		1850.0	1587	494	4.27	4.03E+00
87	1734.0	1644	605	0.46	< 1.00E-01		1851.0	1584	501	4.27	8.92E+00
	1735.0	1635	572	1.37	< 1.00E-01		1852.0	1577	509	4.12	4.58E+00
	1736.0	1636	533	2.44	< 1.00E-01		1853.0	1563	516	4.27	7.70E+00
	1737.0	1630	497	3.51	< 1.00E-01		1854.0	1554	519	4.27	4.59E+00
	1738.0	1627	472	3.81	< 1.00E-01		1855.0	1541	520	4.42	1.09E+01
	1739.0	1624	444	3.97	< 1.00E-01		1856.0	1520	519	4.27	7.63E+00
	1740.0	1623	421	4.42	< 1.00E-01		1857.0	1496	516	4.27	1.26E+01
	1745.0	1646	390	4.58	< 1.00E-01		1858.0	1465	512	4.12	2.14E+00
	1750.0	1664	392	4.73	< 1.00E-01		1859.0	1423	511	4.12	3.76E+00
	1755.0	1674	394	4.58	< 1.00E-01		1900.0	1381	512	4.27	5.09E-01
	1800.0	1683	396	4.88	< 1.00E-01		1901.0	1357	510	4.27	2.07E+00
	1805.0	1688	397	5.03	< 1.00E-01		1915.0	1334	475	4.42	2.79E-01
	1810.0	1695	397	5.03	< 1.00E-01		1916.0	1370	472	4.58	1.97E-01
	1815.0	1704	398	4.88	< 1.00E-01		1917.0	1401	465	4.58	< 1.00E-01
	1820.0	1713	403	4.73	1.21E-01		1918.0	1434	463	4.42	1.67E-01
	1825.0	1725	412	4.73	< 1.00E-01		1919.0	1468	459	4.42	1.42E-01
	1830.0	1719	433	4.58	5.69E-01		1920.0	1504	452	4.27	1.43E-01
	1831.0	1712	436	4.58	5.45E-01		1921.0	1543	448	4.12	1.25E-01
	1832.0	1705	437	4.42	5.12E-01		1922.0	1585	442	4.27	< 1.00E-01

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
87	1923.0	1627	436	4.42	< 1.00E-01	88	1840.0	1673	482	4.27	3.29E+00
	1929.0	1935	426	4.58	< 1.00E-01		1841.0	1666	483	4.27	2.70E+00
	1930.0	1987	428	4.58	< 1.00E-01		1842.0	1659	486	4.12	2.05E+00
	1931.0	2046	431	4.42	< 1.00E-01		1843.0	1651	488	3.97	5.10E+00
	1932.0	2098	435	4.27	< 1.00E-01		1844.0	1643	488	4.12	4.31E+00
	1933.0	2149	441	4.27	1.90E-01		1845.0	1634	489	4.12	3.38E+00
	1934.0	2200	450	4.27	< 1.00E-01		1846.0	1625	490	4.12	7.89E+00
	1935.0	2251	472	4.42	< 1.00E-01		1847.0	1616	490	4.27	7.15E+00
	1936.0	2300	468	4.58	< 1.00E-01		1848.0	1609	490	4.27	6.55E+00
	1937.0	2345	466	4.58	< 1.00E-01		1849.0	1599	490	4.42	5.78E+00
	1938.0	2381	470	4.42	< 1.00E-01		1850.0	1586	487	4.42	1.36E+00
88	1734.0	1642	613	0.31	< 1.00E-01		1851.0	1578	486	4.42	1.18E+00
	1735.0	1631	592	1.68	< 1.00E-01		1852.0	1567	483	4.27	9.41E-01
	1736.0	1621	566	2.14	< 1.00E-01		1853.0	1552	480	4.27	6.99E-01
	1737.0	1607	539	2.59	< 1.00E-01		1854.0	1529	482	4.27	1.68E+00
	1738.0	1589	506	3.05	< 1.00E-01		1855.0	1507	483	4.27	5.87E-01
	1739.0	1570	470	3.36	< 1.00E-01		1856.0	1487	490	4.42	3.94E+00
	1740.0	1564	433	3.81	< 1.00E-01		1857.0	1468	494	4.42	2.05E+00
	1745.0	1612	399	4.12	< 1.00E-01		1858.0	1450	498	4.58	2.54E-01
	1750.0	1643	391	4.27	< 1.00E-01		1917.5	1499	462	3.97	3.00E-01
	1755.0	1665	391	4.58	< 1.00E-01		1919.0	1561	448	4.12	< 1.00E-01
	1800.0	1679	398	4.88	< 1.00E-01		1920.5	1613	436	4.42	1.57E-01
	1805.0	1688	404	5.19	< 1.00E-01		1922.0	1686	420	4.42	< 1.00E-01
	1810.0	1696	412	5.34	< 1.00E-01		1923.5	1772	408	4.73	< 1.00E-01
	1815.0	1704	420	4.58	1.25E-01		1925.0	1857	400	4.73	< 1.00E-01
	1820.0	1711	431	4.73	4.34E-01		1926.5	1940	391	4.58	< 1.00E-01
	1825.0	1719	444	4.88	6.13E-01		1928.0	2034	387	4.73	< 1.00E-01
	1830.0	1723	460	4.73	1.55E+00		1929.5	2132	389	4.58	< 1.00E-01
	1831.0	1723	464	4.73	1.59E+00		1931.0	2221	413	4.42	< 1.00E-01
	1832.0	1718	467	4.58	2.92E+00		1932.5	2296	450	4.42	< 1.00E-01
	1833.0	1713	469	4.58	2.86E+00		1934.0	2359	458	4.27	< 1.00E-01
	1834.0	1710	472	4.42	2.82E+00		1935.5	2399	471	4.42	< 1.00E-01
	1835.0	1706	474	4.42	2.70E+00	89	1734.0	1643	603	0.61	< 1.00E-01
	1836.0	1700	476	4.42	5.10E+00		1735.0	1637	576	1.98	< 1.00E-01
	1837.0	1693	477	4.27	4.70E+00		1736.0	1635	544	2.59	< 1.00E-01
	1838.0	1687	479	4.27	4.27E+00		1737.0	1629	507	3.05	< 1.00E-01
	1839.0	1682	482	4.12	3.81E+00		1738.0	1620	465	3.51	< 1.00E-01

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
89	1739.0	1617	420	3.66	< 1.00E-01	89	1900.0	1373	520	4.58	4.61E+00
	1740.0	1627	377	3.81	< 1.00E-01		1901.0	1347	524	4.42	2.69E+00
	1741.0	1633	360	3.81	< 1.00E-01		1915.0	1376	521	4.73	7.00E-01
	1742.0	1644	343	3.66	< 1.00E-01		1916.5	1445	502	4.73	3.75E+00
	1743.0	1660	343	3.81	< 1.00E-01		1917.0	1469	494	4.58	1.49E+00
	1747.0	1722	323	4.12	< 1.00E-01		1917.5	1494	485	4.58	1.21E+00
	1748.0	1737	297	4.27	< 1.00E-01		1918.0	1514	479	4.42	8.05E-01
	1749.0	1750	276	4.42	< 1.00E-01		1919.5	1597	454	4.27	3.23E-01
	1750.0	1764	253	4.42	< 1.00E-01		1921.0	1688	438	4.27	1.88E-01
	1755.0	1734	377	4.58	< 1.00E-01		1922.5	1770	417	4.12	< 1.00E-01
	1800.0	1729	393	4.73	< 1.00E-01		1924.0	1874	400	4.27	< 1.00E-01
	1805.0	1723	408	4.73	< 1.00E-01		1925.5	1991	396	4.27	< 1.00E-01
	1810.0	1718	417	4.88	1.11E-01		1927.0	2104	409	4.42	< 1.00E-01
	1815.0	1708	429	5.03	3.48E-01		1928.5	2207	427	4.58	< 1.00E-01
	1820.0	1699	435	4.88	4.07E-01		1930.0	2292	455	4.58	< 1.00E-01
	1825.0	1686	441	4.73	3.95E-01		1931.5	2354	462	4.42	< 1.00E-01
	1830.0	1666	444	4.42	2.89E-01		1933.0	2407	474	4.42	< 1.00E-01
	1835.0	1644	450	4.27	1.30E-01	90	1734.0	1640	625	0.61	< 1.00E-01
	1840.0	1620	462	4.27	6.71E-01		1735.0	1642	595	2.44	< 1.00E-01
	1842.0	1606	476	4.42	3.18E+00		1736.0	1641	576	2.90	< 1.00E-01
	1843.0	1598	483	4.27	2.31E+00		1737.0	1639	553	3.05	< 1.00E-01
	1844.0	1591	489	4.27	5.52E+00		1738.0	1637	524	3.20	< 1.00E-01
	1845.0	1583	495	4.12	3.55E+00		1739.0	1640	489	3.81	< 1.00E-01
	1846.0	1573	503	4.12	7.15E+00		1740.0	1655	453	3.97	< 1.00E-01
	1847.0	1560	513	4.12	9.47E+00		1741.0	1658	441	3.97	< 1.00E-01
	1848.0	1543	527	4.27	1.36E+01		1742.0	1663	432	4.12	< 1.00E-01
	1849.0	1355	515	4.27	4.33E+00		1743.0	1666	421	4.12	< 1.00E-01
	1850.0	1361	507	4.27	2.53E+00		1744.0	1666	412	4.27	< 1.00E-01
	1851.0	1369	504	4.42	3.00E+00		1745.0	1668	404	4.27	< 1.00E-01
	1852.0	1389	504	4.42	1.91E+00		1746.0	1667	402	4.27	< 1.00E-01
	1853.0	1404	504	4.42	2.91E+00		1747.0	1665	399	4.42	< 1.00E-01
	1854.0	1420	504	4.27	3.97E+00		1748.0	1665	397	4.42	< 1.00E-01
	1855.0	1436	503	4.42	5.00E+00		1749.0	1662	394	4.42	< 1.00E-01
	1856.0	1446	504	4.27	5.59E+00		1750.0	1663	393	4.42	< 1.00E-01
	1857.0	1427	507	4.12	4.22E+00		1751.0	1659	391	4.27	< 1.00E-01
	1858.0	1408	512	4.27	2.63E+00		1752.0	1657	390	4.42	< 1.00E-01
	1859.0	1393	516	4.42	3.61E+00		1753.0	1656	391	4.58	< 1.00E-01

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)	Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
90	1754.0	1653	390	4.58	< 1.00E-01	90	1832.0	1597	487	4.27	1.90E+00
	1755.0	1650	390	4.58	< 1.00E-01		1833.0	1593	491	4.27	5.27E+00
	1756.0	1647	389	4.42	< 1.00E-01		1834.0	1589	494	4.27	4.44E+00
	1757.0	1647	390	4.58	< 1.00E-01		1835.0	1583	496	4.27	3.54E+00
	1758.0	1645	390	4.58	< 1.00E-01		1836.0	1578	497	4.27	2.94E+00
	1759.0	1643	391	4.73	< 1.00E-01		1837.0	1571	500	4.12	1.87E+00
	1800.0	1642	392	4.73	< 1.00E-01		1838.0	1567	501	4.12	7.26E+00
	1801.0	1639	390	4.73	< 1.00E-01		1839.0	1556	505	3.97	4.28E+00
	1802.0	1637	391	4.73	< 1.00E-01		1840.0	1552	506	3.97	3.33E+00
	1803.0	1636	393	4.88	< 1.00E-01		1841.0	1546	508	3.97	9.64E+00
	1804.0	1635	394	4.88	< 1.00E-01		1842.0	1541	509	4.12	8.35E+00
	1805.0	1634	395	4.88	< 1.00E-01		1843.0	1536	510	4.12	7.14E+00
	1806.0	1632	397	4.73	< 1.00E-01		1844.0	1529	511	4.27	5.65E+00
	1807.0	1627	397	4.73	< 1.00E-01		1845.0	1524	512	4.12	4.55E+00
	1808.0	1624	398	4.58	< 1.00E-01		1846.0	1519	512	4.12	3.35E+00
	1809.0	1624	403	4.58	< 1.00E-01		1847.0	1512	513	4.27	9.52E+00
	1810.0	1624	405	4.73	< 1.00E-01		1848.0	1507	515	4.42	7.72E+00
	1811.0	1622	408	4.73	< 1.00E-01		1849.0	1501	516	4.27	6.14E+00
	1812.0	1619	410	4.73	< 1.00E-01		1850.0	1493	517	4.27	1.19E+01
	1813.0	1618	414	4.88	< 1.00E-01		1851.0	1484	517	4.27	9.96E+00
	1814.0	1617	417	5.03	< 1.00E-01		1852.0	1476	519	4.12	7.71E+00
	1815.0	1617	421	4.88	< 1.00E-01		1854.0	1458	520	4.12	3.79E+00
	1816.0	1616	424	4.88	< 1.00E-01		1855.0	1446	521	4.12	8.05E+00
	1818.0	1614	432	4.73	1.99E-01		1856.0	1431	521	4.12	6.70E+00
	1819.0	1612	437	4.58	1.98E-01		1857.0	1416	521	4.27	5.06E+00
	1820.0	1611	441	4.58	2.01E-01		1858.0	1407	523	4.42	3.69E+00
	1821.0	1611	444	4.58	2.03E-01		1859.0	1386	524	4.58	1.47E+00
	1822.0	1610	447	4.42	2.05E-01		1900.0	1370	525	4.58	3.82E+00
	1823.0	1610	451	4.42	6.12E-01		1901.0	1344	525	4.42	2.41E+00
	1824.0	1610	454	4.58	5.95E-01		1915.5	1360	492	4.73	8.31E-01
	1825.0	1609	457	4.58	5.75E-01		1917.0	1411	481	4.88	4.73E-01
	1826.0	1608	462	4.58	5.33E-01		1918.5	1455	476	4.73	4.70E-01
	1827.0	1608	467	4.58	1.38E+00		1920.0	1493	473	4.42	5.31E-01
	1828.0	1607	472	4.42	1.18E+00		1921.5	1544	466	4.58	8.13E-01
	1829.0	1605	476	4.42	3.09E+00		1923.0	1594	466	4.42	7.24E-01
	1830.0	1592	476	4.42	2.65E+00		1924.5	1644	444	4.27	< 1.00E-01
	1831.0	1601	483	4.42	2.38E+00		1926.0	1703	435	4.27	2.10E-01

Appendix D-6

Continued

Fish No.	Time	X (m)	Y (m)	Depth (m)	Conc (ppb)
90	1927.5	1785	431	4.42	1.88E-01
	1929.0	1892	438	4.73	< 1.00E-01
	1930.5	1970	443	4.58	< 1.00E-01
	1932.0	2034	449	4.42	< 1.00E-01
	1933.5	2102	454	4.88	3.76E-01
	1936.5	2256	471	4.73	< 1.00E-01

APPENDIX E

CONCENTRATIONS (μg/L) OF INDIVIDUAL HYDROCARBON COMPONENTS DETECTED IN 94 SAMPLES COLLECTED IN JAKOLOF BAY

KASITSNA BAY BACKGROUND WATER SAMPLES

WATER SAMPLE #	1	2	3	4
HYDROCARBON:				
Methane	0.16	0.14	0.07	0.13
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	0.05	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	N.D.
n-Pentane	N.D.	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	1.10	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	0.16	1.12	N.D.
Octanes or cycloheptanes	N.D.	N.D.	0.15	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	1.32	0.30	1.33	0.13
Total w/o C1-C4	1.10	0.16	1.27	0.00

KASITSNA BAY BACKGROUND WATER SAMPLES

WATER SAMPLE #	5
HYDROCARBON:	
Methane	0.07
Ethane	N.D.
Propane	N.D.
Isobutane	N.D.
n-Butane	N.D.
Isopentane	N.D.
n-Pentane	N.D.
2,2-Dimethylbutane	N.D.
Cyclopentane + 2-Methylpentane	N.D.
3-Methylpentane	N.D.
n-Hexane	N.D.
Methylcyclopentane	N.D.
Benzene	N.D.
Cyclohexane	N.D.
n-Heptane	N.D.
Methylcyclohexane	N.D.
Toluene	N.D.
Octanes or cycloheptanes	N.D.
Octanes or cycloheptanes	N.D.
Octanes or cycloheptanes	N.D.
Octanes or cycloheptanes	N.D.
Octanes or cycloheptanes	N.D.
Ethylbenzene	N.D.
m-, p-Xylene	N.D.
o-Xylene	N.D.
Isopropylbenzene	N.D.
C3 Benzenes	N.D.
o-Methylethylbenzene	N.D.
1,2,4-Trimethylbenzene	N.D.
1,2,3-Trimethylbenzene	N.D.
Total Hydrocarbons	0.07
Total w/o C1-C4	0.00

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	6	7	8	9
HYDROCARBON:				
Methane	0.30	0.32	0.33	0.33
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	N.D.
n-Pentane	N.D.	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	0.15	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	0.77	1.51	0.52	0.73
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	1.06	1.99	0.85	1.07
Total w/o C1-C4	0.77	1.66	0.52	0.73

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	10	11	12	13
HYDROCARBON:				
Methane	0.25	0.33	0.34	0.23
Ethane	N.D.	0.12	N.D.	N.D.
Propane	N.D.	0.19	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	N.D.
n-Pentane	N.D.	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	0.43	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	0.67	1.78	1.02	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	0.92	2.85	1.36	0.23
Total w/o C1-C4	0.67	2.20	1.02	0.00

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	14	15	16	17
HYDROCARBON:				
Methane	0.21	0.29	0.27	0.27
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	8.23	0.30	0.46
n-Pentane	N.D.	9.98	0.14	0.56
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	0.61	N.D.	0.08
3-Methylpentane	N.D.	0.09	N.D.	N.D.
n-Hexane	N.D.	0.20	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	17.24	N.D.	0.98
Cyclohexane	N.D.	1.44	N.D.	N.D.
n-Heptane	N.D.	0.57	N.D.	N.D.
Methylcyclohexane	N.D.	0.79	N.D.	N.D.
Toluene	1.32	13.19	1.15	1.08
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	4.67	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	1.53	57.31	1.86	3.43
Total w/o C1-C4	1.32	57.02	1.59	3.16

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	18	19	20	21
HYDROCARBON:				
Methane	0.28	0.30	*	0.28
Ethane	N.D.	N.D.		N.D.
Propane	N.D.	N.D.		N.D.
Isobutane	N.D.	N.D.		N.D.
n-Butane	N.D.	N.D.		N.D.
Isopentane	N.D.	N.D.		1.58
n-Pentane	0.07	N.D.		1.93
2,2-Dimethylbutane	N.D.	N.D.		N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.		0.21
3-Methylpentane	N.D.	N.D.		N.D.
n-Hexane	N.D.	N.D.		N.D.
Methylcyclopentane	0.16	N.D.		N.D.
Benzene	N.D.	N.D.		3.58
Cyclohexane	N.D.	N.D.		0.30
n-Heptane	N.D.	N.D.		N.D.
Methylcyclohexane	N.D.	N.D.		0.39
Toluene	2.61	0.75		5.37
Octanes or cycloheptanes	N.D.	N.D.		N.D.
Octanes or cycloheptanes	N.D.	N.D.		N.D.
Octanes or cycloheptanes	N.D.	N.D.		N.D.
Octanes or cycloheptanes	N.D.	N.D.		N.D.
Octanes or cycloheptanes	N.D.	N.D.		N.D.
Ethylbenzene	N.D.	N.D.		N.D.
m-, p-Xylene	N.D.	N.D.		1.58
o-Xylene	N.D.	N.D.		N.D.
Isopropylbenzene	N.D.	N.D.		N.D.
C3 Benzenes	N.D.	N.D.		N.D.
o-Methylethylbenzene	N.D.	N.D.		N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.		N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.		N.D.
Total Hydrocarbons	3.12	1.05	0.00	15.20
Total w/o C1-C4	2.84	0.75	0.00	14.93

* SAMPLE BOTTLE BROKEN

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	22	23	24	25
HYDROCARBON:				
Methane	0.38	0.28	0.29	*
Ethane	N.D.	N.D.	N.D.	
Propane	N.D.	N.D.	N.D.	
Isobutane	N.D.	N.D.	N.D.	
n-Butane	N.D.	N.D.	N.D.	
Isopentane	1.06	6.18	N.D.	
n-Pentane	0.14	7.27	0.09	
2,2-Dimethylbutane	N.D.	N.D.	N.D.	
Cyclopentane + 2-Methylpentane	N.D.	0.78	N.D.	
3-Methylpentane	N.D.	0.09	N.D.	
n-Hexane	N.D.	0.19	N.D.	
Methylcyclopentane	N.D.	N.D.	N.D.	
Benzene	N.D.	11.39	N.D.	
Cyclohexane	N.D.	1.05	N.D.	
n-Heptane	N.D.	0.60	N.D.	
Methylcyclohexane	N.D.	0.71	N.D.	
Toluene	N.D.	12.56	1.44	
Octanes or cycloheptanes	N.D.	N.D.	N.D.	
Octanes or cycloheptanes	N.D.	N.D.	N.D.	
Octanes or cycloheptanes	N.D.	N.D.	N.D.	
Octanes or cycloheptanes	N.D.	N.D.	N.D.	
Octanes or cycloheptanes	N.D.	N.D.	N.D.	
Ethylbenzene	N.D.	N.D.	N.D.	
m-, p-Xylene	N.D.	2.95	N.D.	
o-Xylene	N.D.	N.D.	N.D.	
Isopropylbenzene	N.D.	N.D.	N.D.	
C3 Benzenes	N.D.	N.D.	N.D.	
o-Methylethylbenzene	N.D.	N.D.	N.D.	
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	
Total Hydrocarbons	1.58	44.06	1.82	0.00
Total w/o C1-C4	1.20	43.78	1.53	0.00

* SAMPLE BOTTLE BROKEN

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	26	27(1)	27(2)
HYDROCARBON:			
Methane	0.32	0.30	0.31
Ethane	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.
Isopentane	0.17	N.D.	N.D.
n-Pentane	0.18	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.
n-Hexane	.D.	N.D.	N.D.
Methylcyclopentane	D.	N.D.	N.D.
Benzene	D.	N.D.	N.D.
Cyclohexane	.D.	N.D.	N.D.
n-Heptane	0.18	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.
Toluene	0.61	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.
m-, p-Xylene	0.65	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.
C3 Benzenes	6.79	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.
Total Hydrocarbons	8.90	0.30	0.31
Total w/o C1-C4	8.58	0.00	0.00

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	28	29	30	31
HYDROCARBON:				
Methane	*	*	*	0.17
Ethane				N.D.
Propane				N.D.
Isobutane				N.D.
n-Butane				N.D.
Isopentane				N.D.
n-Pentane				N.D.
2,2-Dimethylbutane				N.D.
Cyclopentane + 2-Methylpentane				N.D.
3-Methylpentane				N.D.
n-Hexane				N.D.
Methylcyclopentane				N.D.
Benzene				N.D.
Cyclohexane				N.D.
n-Heptane				N.D.
Methylcyclohexane				N.D.
Toluene				N.D.
Octanes or cycloheptanes				N.D.
Octanes or cycloheptanes				N.D.
Octanes or cycloheptanes				N.D.
Octanes or cycloheptanes				N.D.
Octanes or cycloheptanes				N.D.
Ethylbenzene				N.D.
m-, p-Xylene				N.D.
o-Xylene				N.D.
Isopropylbenzene				N.D.
C3 Benzenes				N.D.
o-Methylethylbenzene				N.D.
1,2,4-Trimethylbenzene				N.D.
1,2,3-Trimethylbenzene				N.D.
Total Hydrocarbons	0.00	0.00	0.00	0.17
Total w/o C1-C4	0.00	0.00	0.00	0.00

* SAMPLES MISSING

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	32	33	34	35
HYDROCARBON:				
Methane	*	0.08	*	*
Ethane		N.D.		
Propane		N.D.		
Isobutane		N.D.		
n-Butane		N.D.		
Isopentane		N.D.		
n-Pentane		N.D.		
2,2-Dimethylbutane		N.D.		
Cyclopentane + 2-Methylpentane		N.D.		
3-Methylpentane		N.D.		
n-Hexane		N.D.		
Methylcyclopentane		N.D.		
Benzene		N.D.		
Cyclohexane		N.D.		
n-Heptane		N.D.		
Methylcyclohexane		N.D.		
Toluene		N.D.		
Octanes or cycloheptanes		N.D.		
Octanes or cycloheptanes		N.D.		
Octanes or cycloheptanes		N.D.		
Octanes or cycloheptanes		N.D.		
Octanes or cycloheptanes		N.D.		
Ethylbenzene		N.D.		
m-, p-Xylene		N.D.		
o-Xylene		N.D.		
Isopropylbenzene		N.D.		
C3 Benzenes		N.D.		
o-Methylethylbenzene		N.D.		
1,2,4-Trimethylbenzene		N.D.		
1,2,3-Trimethylbenzene		N.D.		
Total Hydrocarbons	0.00	0.08	0.00	0.00
Total w/o C1-C4	0.00	0.00	0.00	0.00

* SAMPLES MISSING

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	36	37	38	39
HYDROCARBON:				
Methane	0.38	0.26	0.29	0.32
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	N.D.
n-Pentane	N.D.	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	0.96	1.15	N.D.	1.43
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	1.34	1.42	0.29	1.75
Total w/o C1-C4	0.96	1.15	0.00	1.43

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	40	41	42	43
HYDROCARBON:				
Methane	0.26	0.36	0.35	0.33
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	N.D.
n-Pentane	N.D.	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	0.26	0.36	0.35	0.33
Total w/o C1-C4	0.00	0.00	0.00	0.00

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	44	45	46	47
HYDROCARBON:				
Methane	0.26	0.40	0.28	0.31
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	10.72
n-Pentane	N.D.	N.D.	N.D.	13.75
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	1.23
3-Methylpentane	N.D.	N.D.	N.D.	0.12
n-Hexane	N.D.	N.D.	N.D.	0.28
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	17.94
Cyclohexane	N.D.	N.D.	N.D.	1.89
n-Heptane	N.D.	N.D.	N.D.	0.83
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	N.D.	1.01	N.D.	16.11
Octanes or cycloheptanes	N.D.	N.D.	N.D.	0.93
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	1.10
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	0.26	1.41	0.28	65.22
Total w/o C1-C4	0.00	1.01	0.00	64.91

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	48	49	50	51
HYDROCARBON:				
Methane	0.30	0.40	0.30	0.39
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	N.D.
n-Pentane	N.D.	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	2.52	0.97	2.35	0.67
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	2.82	1.37	2.65	1.06
Total w/o C1-C4	2.52	0.97	2.35	0.67

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	52	53	54	55
HYDROCARBON:				
Methane	0.32	0.30	0.31	0.36
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	N.D.
n-Pentane	N.D.	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	2.01	0.48	0.81	0.92
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	2.34	0.78	1.12	1.27
Total w/o C1-C4	2.01	0.48	0.81	0.92

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	56	57	58	59
HYDROCARBON:				
Methane	0.32	0.32	0.10	0.15
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	8.07	1.29	N.D.	N.D.
n-Pentane	9.53	1.53	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	1.09	0.21	0.09	0.15
3-Methylpentane	0.09	N.D.	N.D.	N.D.
n-Hexane	0.23	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	15.54	3.25	22.28	20.68
Cyclohexane	1.54	N.D.	N.D.	N.D.
n-Heptane	0.56	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	11.29	2.33	22.30	4.85
Octanes or cycloheptanes	0.33	N.D.	0.77	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	2.35	N.D.	1.60	N.D.
m-, p-Xylene	2.86	1.38	2.45	4.42
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	53.80	10.31	49.59	30.25
Total w/o C1-C4	53.48	9.99	49.49	30.10

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	60	61	62	63
HYDROCARBON:				
Methane	0.32	0.27	0.27	0.25
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	N.D.
n-Pentane	N.D.	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	N.D.	6.82	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	0.32	7.08	0.27	0.25
Total w/o C1-C4	0.00	6.82	0.00	0.00

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	64	65	66	67
HYDROCARBON:				
Methane	0.25	0.25	0.34	0.26
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	N.D.
n-Pentane	N.D.	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	0.76	0.88	0.59	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	1.01	1.13	0.93	0.26
Total w/o C1-C4	0.76	0.88	0.59	0.00

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	68	69	70	71
HYDROCARBON:				
Methane	0.27	N.D.	0.29	0.30
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	N.D.
n-Pentane	N.D.	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	0.91	N.D.	N.D.	1.81
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	1.18	0.00	0.29	2.11
Total w/o C1-C4	0.91	0.00	0.00	1.81

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	72	73	74	75
HYDROCARBON:				
Methane	0.60	0.28	0.20	0.29
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	N.D.
n-Pentane	N.D.	N.D.	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	0.98	1.93	1.53	0.93
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	1.58	2.21	1.73	1.22
Total w/o C1-C4	0.98	1.93	1.53	0.93

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	76	77	78	79
HYDROCARBON:				
Methane	0.31	0.30	0.13	0.19
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	0.33	N.D.	N.D.
n-Pentane	N.D.	0.33	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	0.12	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	0.61	N.D.	N.D.
Cyclohexane	N.D.	N.D.	N.D.	N.D.
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	0.57	2.37	1.16	0.61
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	0.88	4.06	1.29	0.80
Total w/o C1-C4	0.57	3.76	1.16	0.61

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	80	81	82	83
HYDROCARBON:				
Methane	0.22	0.25	0.37	0.19
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	N.D.	N.D.	N.D.	2.07
n-Pentane	N.D.	N.D.	N.D.	2.51
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.	N.D.	0.35
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	N.D.	N.D.	N.D.	6.46
Cyclohexane	N.D.	N.D.	N.D.	0.47
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	1.09	1.49	N.D.	7.48
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	2.52
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	1.31	1.73	0.37	22.04
Total w/o C1-C4	1.09	1.49	0.00	21.85

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	84	85	86	87
HYDROCARBON:				
Methane	0.30	0.38	0.61	0.34
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	3.99	0.86	N.D.	1.02
n-Pentane	4.78	1.07	N.D.	1.05
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	1.94	1.49	N.D.	0.15
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	0.11	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	6.90	2.64	N.D.	2.04
Cyclohexane	0.71	N.D.	N.D.	N.D.
n-Heptane	0.39	N.D.	N.D.	N.D.
Methylcyclohexane	0.29	N.D.	N.D.	N.D.
Toluene	4.08	1.53	0.60	1.41
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	1.42	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	24.91	7.98	1.20	6.02
Total w/o C1-C4	24.60	7.59	0.60	5.68

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	88	89	90	91
HYDROCARBON:				
Methane	0.31	0.35	0.31	0.30
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	N.D.	N.D.	N.D.	N.D.
n-Butane	N.D.	N.D.	N.D.	N.D.
Isopentane	1.22	0.82	0.46	0.19
n-Pentane	1.25	0.82	0.38	0.22
2,2-Dimethylbutane	N.D.	N.D.	N.D.	N.D.
Cyclopentane + 2-Methylpentane	0.20	0.13	N.D.	N.D.
3-Methylpentane	N.D.	N.D.	N.D.	N.D.
n-Hexane	N.D.	N.D.	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.	N.D.	N.D.
Benzene	2.54	2.50	0.52	N.D.
Cyclohexane	N.D.	N.D.	N.D.	0.47
n-Heptane	N.D.	N.D.	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.	N.D.	N.D.
Toluene	1.64	1.40	0.77	3.29
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	N.D.	N.D.	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.	N.D.	N.D.
o-Xylene	N.D.	N.D.	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.	N.D.	N.D.
C3 Benzenes	N.D.	N.D.	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	7.17	6.02	2.44	4.46
Total w/o C1-C4	6.85	5.68	2.14	4.16

KASITSNA BAY WATER SAMPLES

WATER SAMPLE #	92	93
HYDROCARBON:		
Methane	0.30	0.28
Ethane	N.D.	N.D.
Propane	N.D.	N.D.
Isobutane	N.D.	N.D.
n-Butane	N.D.	N.D.
Isopentane	0.34	N.D.
n-Pentane	0.24	N.D.
2,2-Dimethylbutane	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.
3-Methylpentane	N.D.	N.D.
n-Hexane	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.
Benzene	0.85	N.D.
Cyclohexane	N.D.	N.D.
n-Heptane	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.
Toluene	3.18	1.44
Octanes or cycloheptanes	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.
Ethylbenzene	N.D.	N.D.
m-, p-Xylene	N.D.	N.D.
o-Xylene	N.D.	N.D.
Isopropylbenzene	N.D.	N.D.
C3 Benzenes	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.
Total Hydrocarbons	4.91	1.73
Total w/o C1-C4	4.61	1.44

APPENDIX F

WATER-SOLUBLE HYDROCARBONS FROM REGULAR GASOLINE

DILUTION FACTOR	**NO DILUTION	0.10	0.01	.005
HYDROCARBON:				
Methane	1.30	2.94	3.62	2.70
Ethane	N.D.	N.D.	N.D.	N.D.
Propane	N.D.	N.D.	N.D.	N.D.
Isobutane	3.30	0.33	N.D.	N.D.
n-Butane	34.80	3.48	0.45	0.32
Isopentane	39.90	3.99	0.24	0.08
n-Pentane	57.70	5.77	0.23	N.D.
2,2-Dimethylbutane	6.10	0.61	N.D.	N.D.
Cyclopentane + 2-Methylpentane	60.50	6.05	0.39	0.64
3-Methylpentane	36.20	3.62	0.15	N.D.
n-Hexane	42.80	4.28	N.D.	N.D.
Methylcyclopentane	93.10	9.31	0.42	0.19
Benzene	491.90	49.19	11.18	1.37
Cyclohexane	89.50	8.95	N.D.	N.D.
n-Heptane	86.20	8.62	N.D.	N.D.
Methylcyclohexane	68.20	6.82	N.D.	N.D.
Toluene	2253.10	225.31	16.37	5.07
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Oct nes o cycloheptanes	N.D.	N.D.	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.	N.D.	N.D.
Ethylbenzene	193.60	19 36	N.D.	N.D.
m-, p-Xylene	1036.90	103.69	9.80	3.99
o-Xylene	451.70	45.17	3.32	1.39
Isopropylbenzene	9.50	0.95	N.D.	N.D.
C3 Benzenes	333.90	33.39	3.45	1.05
o-Methylethylbenzene	65.30	6.53	N.D.	N.D.
1,2,4-Trimethylbenzene	269.00	26.90	1.92	3.66
1,2,3-Trimethylbenzene	N.D.	N.D.	N.D.	N.D.
Total Hydrocarbons	5724.50	575.26	51.54	20.46
Total w/o C1-C4	5685.10	568.51	47.47	17.44

**1 drop of gasoline in approx. 200 ml water

REGULAR GASOLINE SAMPLES

DILUTION FACTOR	.0025	.0013
HYDROCARBON:		
Methane	3.06	3.02
Ethane	N.D.	N.D.
Propane	N.D.	N.D.
Isobutane	N.D.	N.D.
n-Butane	0.22	N.D.
Isopentane	N.D.	N.D.
n-Pentane	N.D.	N.D.
2,2-Dimethylbutane	N.D.	N.D.
Cyclopentane + 2-Methylpentane	N.D.	N.D.
3-Methylpentane	N.D.	N.D.
n-Hexane	N.D.	N.D.
Methylcyclopentane	N.D.	N.D.
Benzene	1.23	0.77
Cyclohexane	N.D.	N.D.
n-Heptane	N.D.	N.D.
Methylcyclohexane	N.D.	N.D.
Toluene	1.05	1.59
Octanes or cycloheptanes	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.
Octanes or cycloheptanes	N.D.	N.D.
Ethylbenzene	N.D.	N.D.
m-, p-Xylene	2.01	0.92
o-Xylene	0.70	N.D.
Isopropylbenzene	N.D.	N.D.
C3 Benzenes	N.D.	N.D.
o-Methylethylbenzene	N.D.	N.D.
1,2,4-Trimethylbenzene	N.D.	N.D.
1,2,3-Trimethylbenzene	N.D.	N.D.
Total Hydrocarbons	8.27	6.30
Total w/o C1-C4	4.99	3.28

Appendix G

RESULTS OF ANALYSIS OF VARIANCE TESTS

Variable Tested	Factor	Degrees of Freedom	F Ratio	Significance
Total Hydrocarbon Concentration	Background and Control Experiments (Sample Nos. 1-12, 27-43, 60-71)	2, 32	0.89	0.41
Fish Depth	All Six Experiments	5, 1263	329.8	0.00[a]
Duration-of-Return	Treatment 1 vs Control 1	1, 12	0.94	0.34
Duration-of-Return	Treatment 2 vs Control 2	1, 12	0.14	0.71
Duration-of-Return	Treatment 3 vs Control 3	1, 34	161.2	0.00
Swim Speed	Time Periods before, during, and after exposure to hydrocarbon concentrations >1 ppb for Treatment 3	2, 799	600.9	0.00

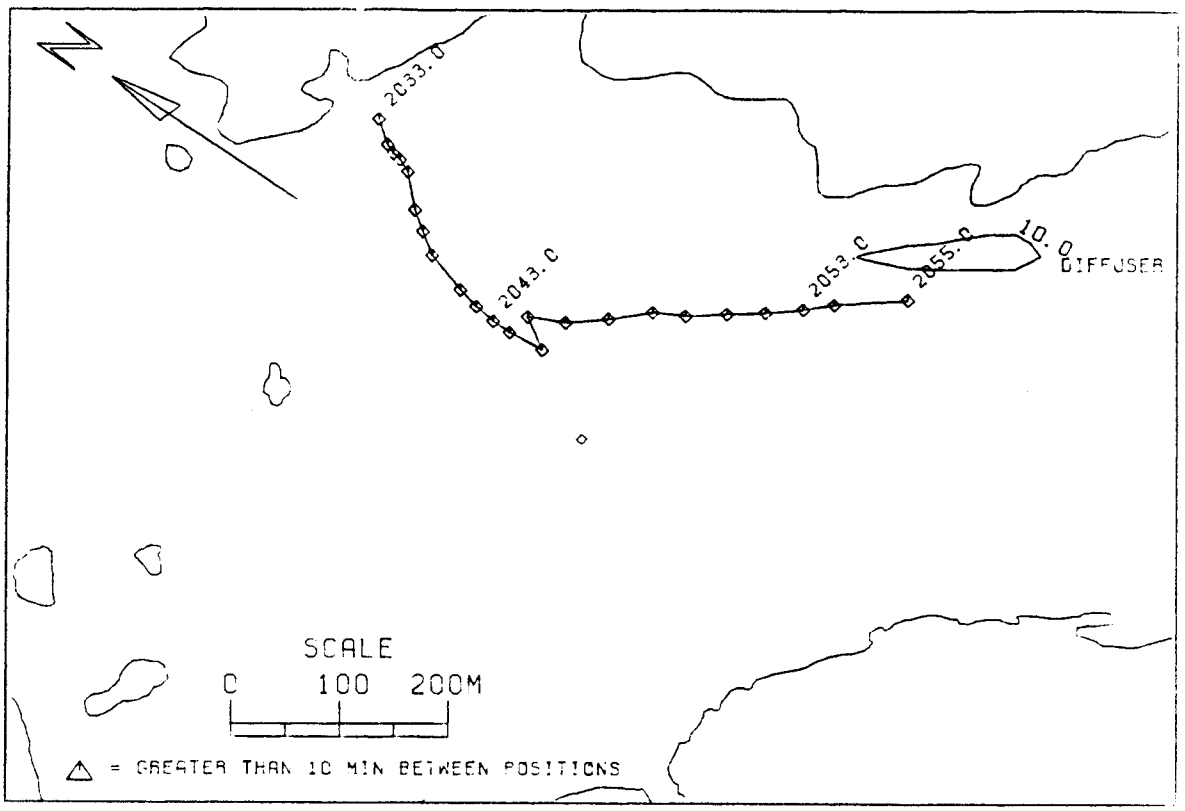
[a] Results of Multiple Range Test indicated differences among Treatments (T) and Controls (C) are as follows:

C3 T2 T1 C1 C2 T3

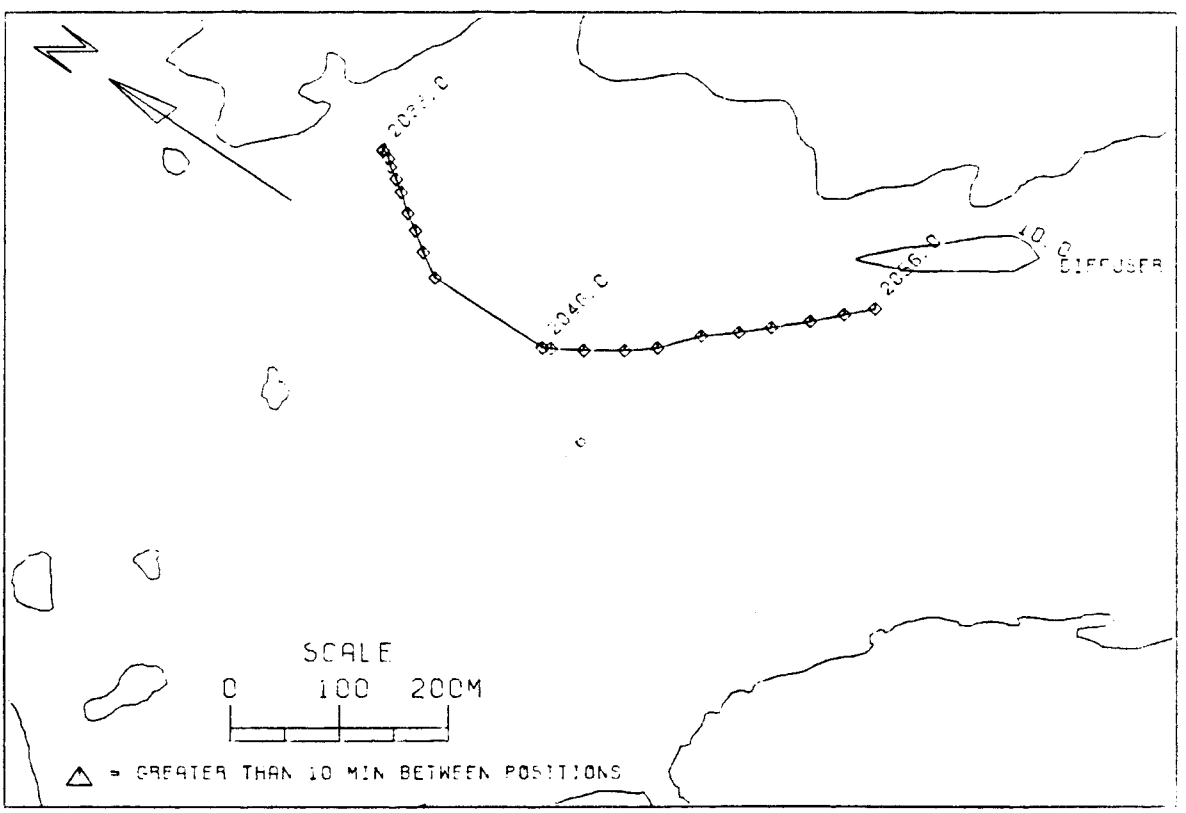
Experiments not connected by an underline are significantly ($P < 0.05$) different, those connected by an underline are not significantly different.

APPENDIX H

PLOTS OF HORIZONTAL MOVEMENTS OF ADULT PINK SALMON DURING CONTROL EXPERIMENTS



JAKOLOF BAY, FISH 03, CONTROL NO. 1, 7/19/88



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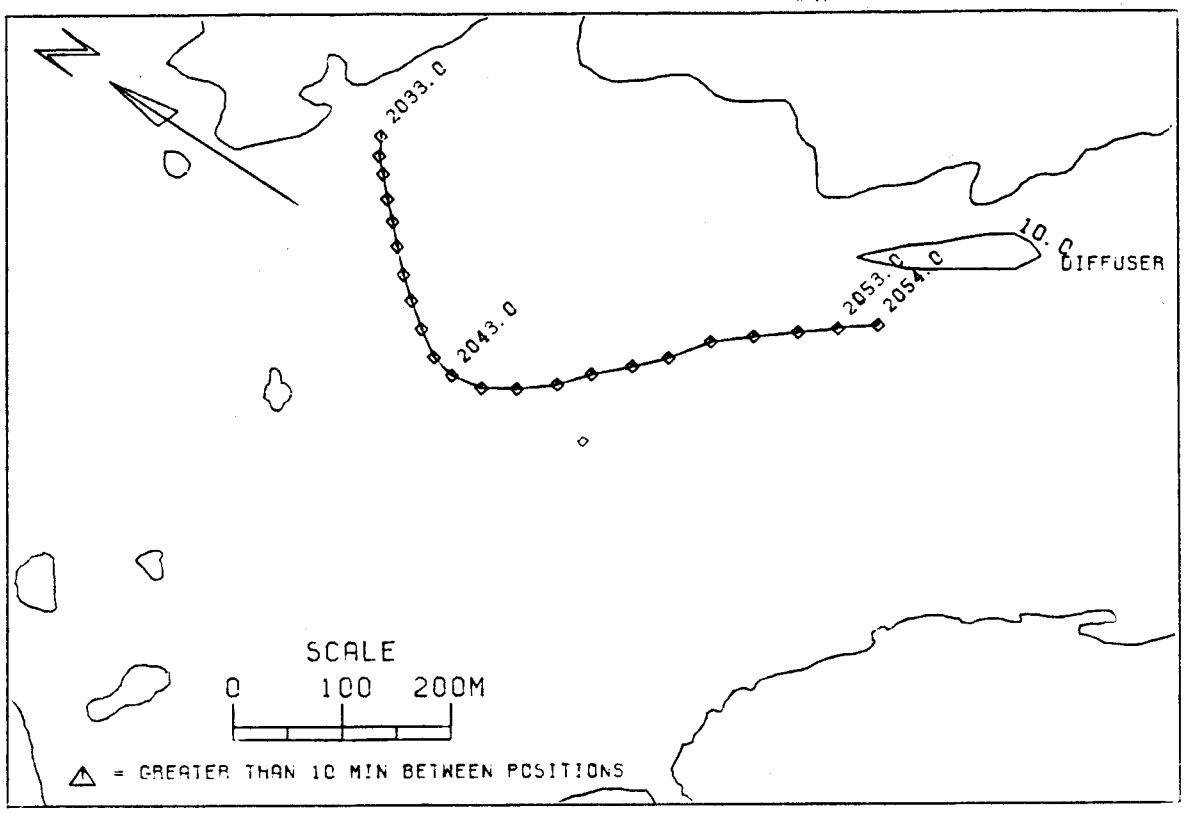

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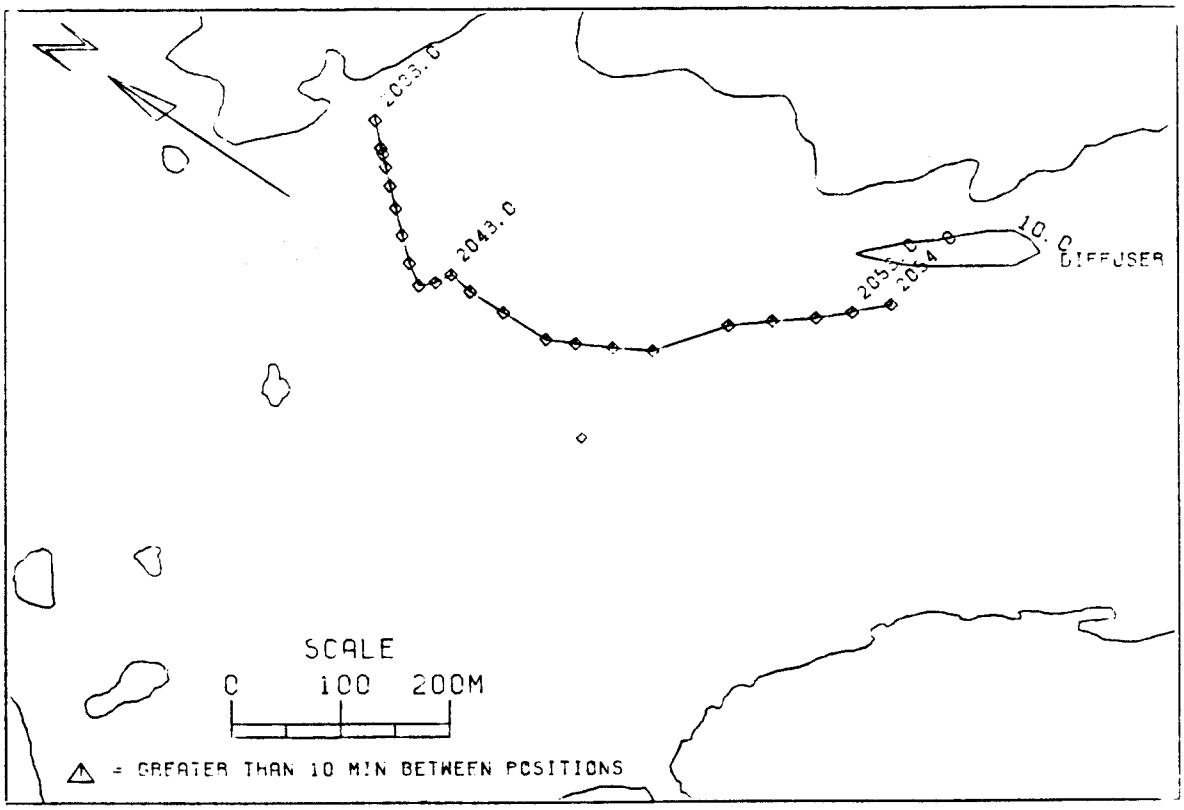

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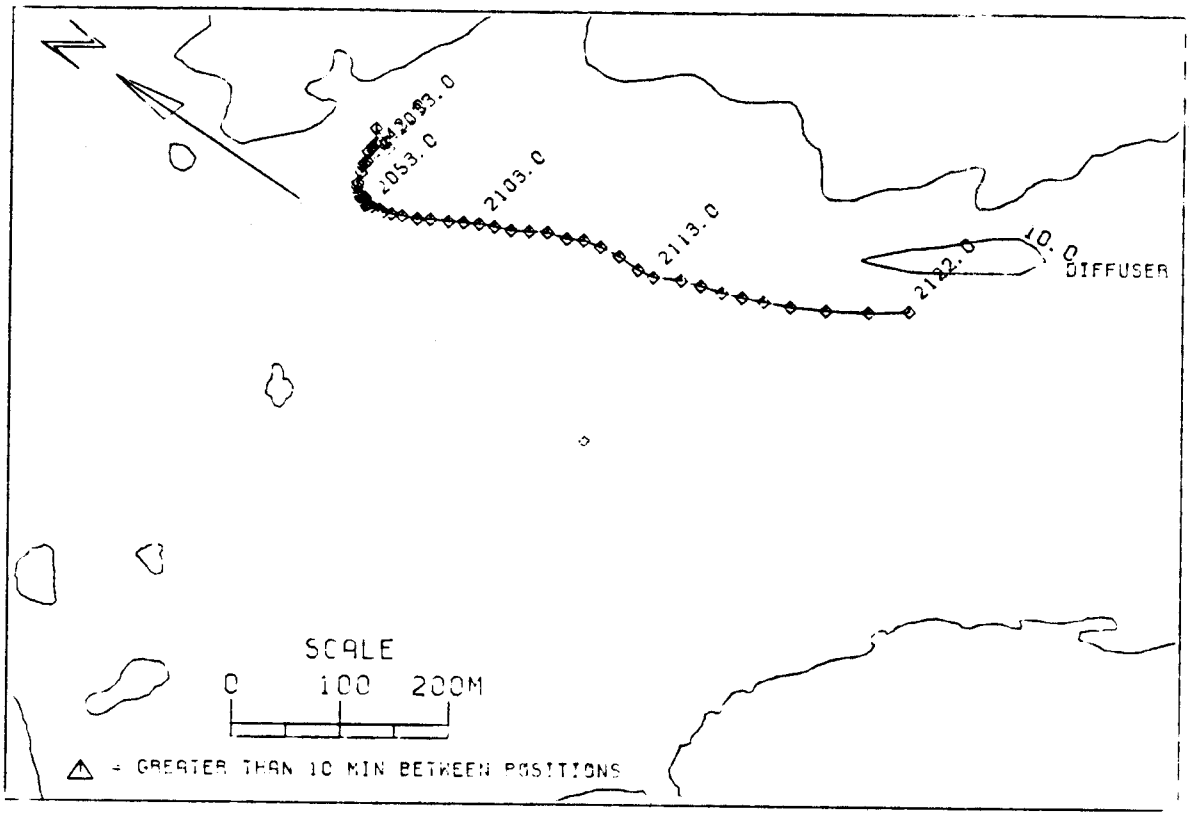

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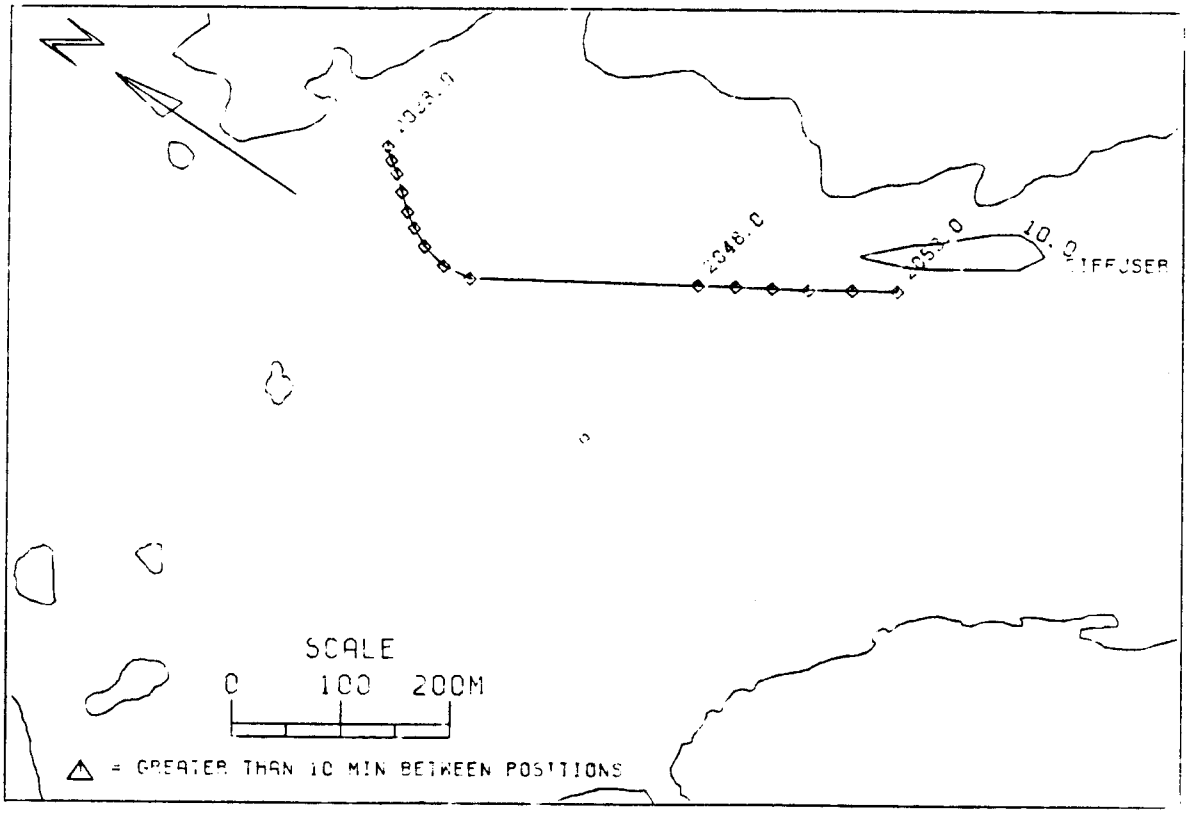
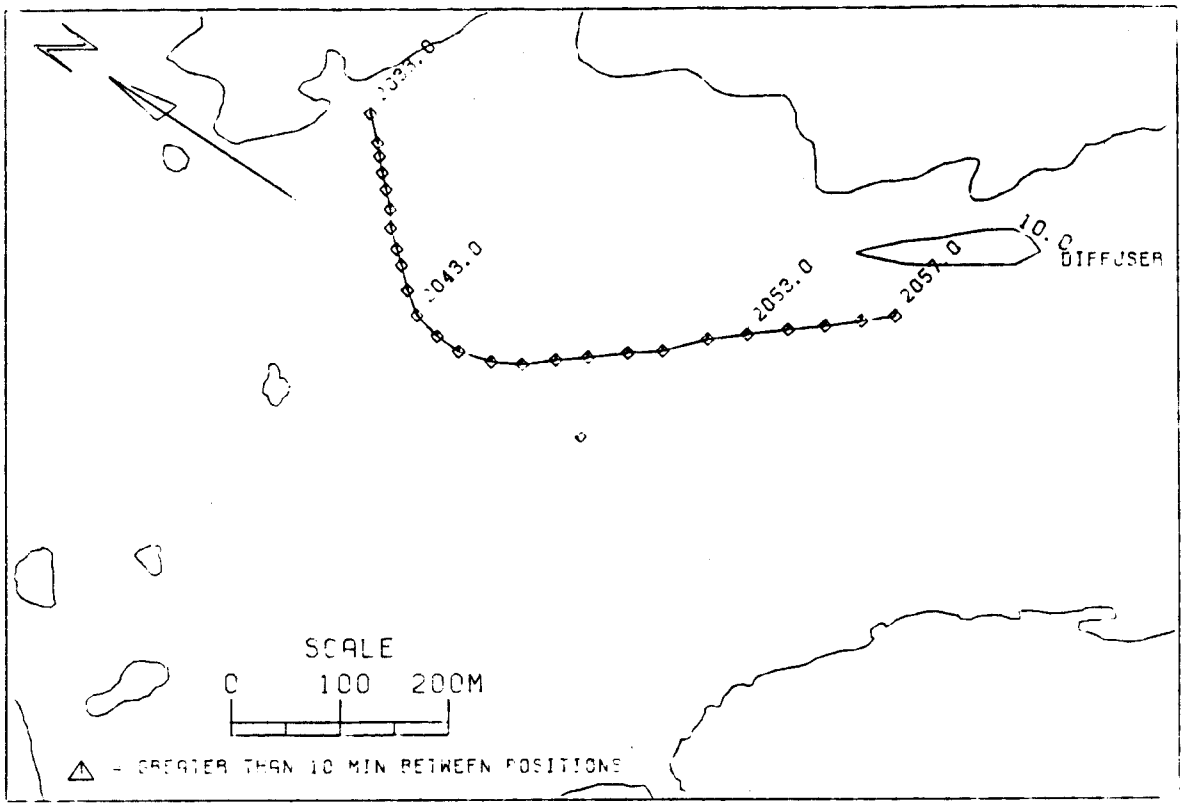


JAKOLOF BAY, FISH 08, CONTROL NO. 1, 7/19/88



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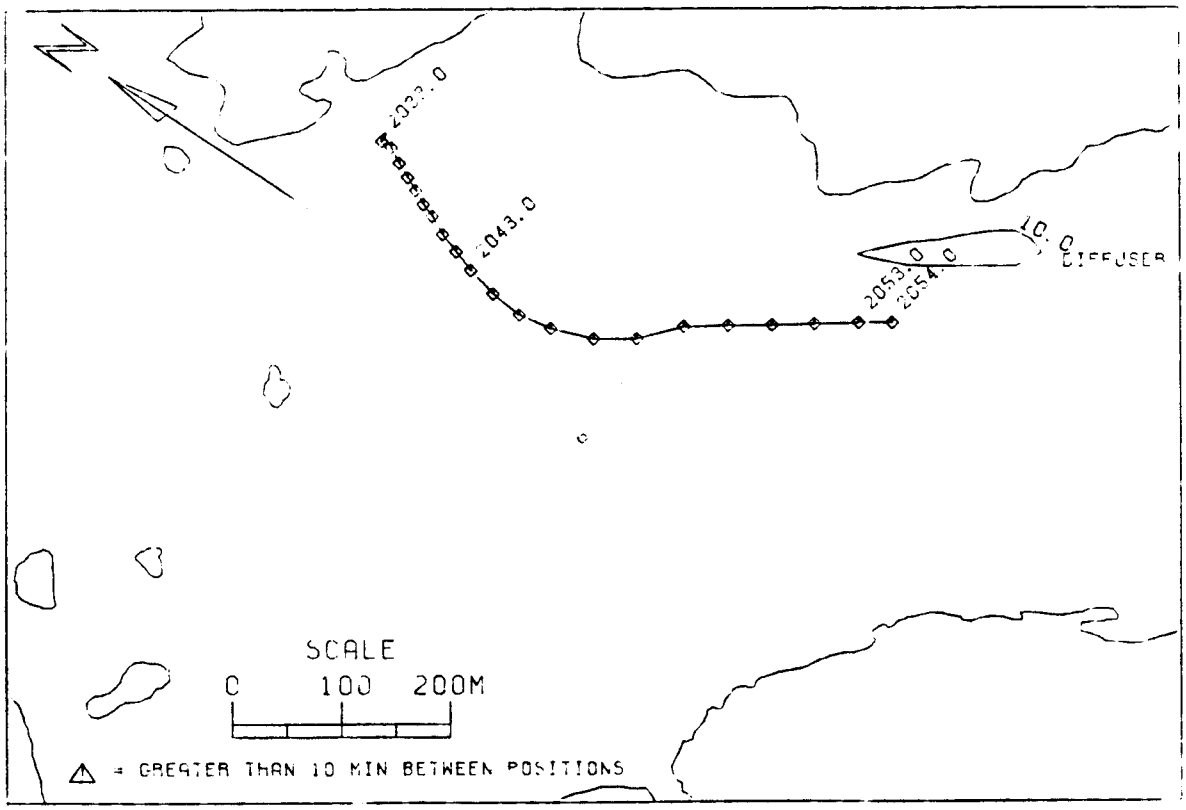
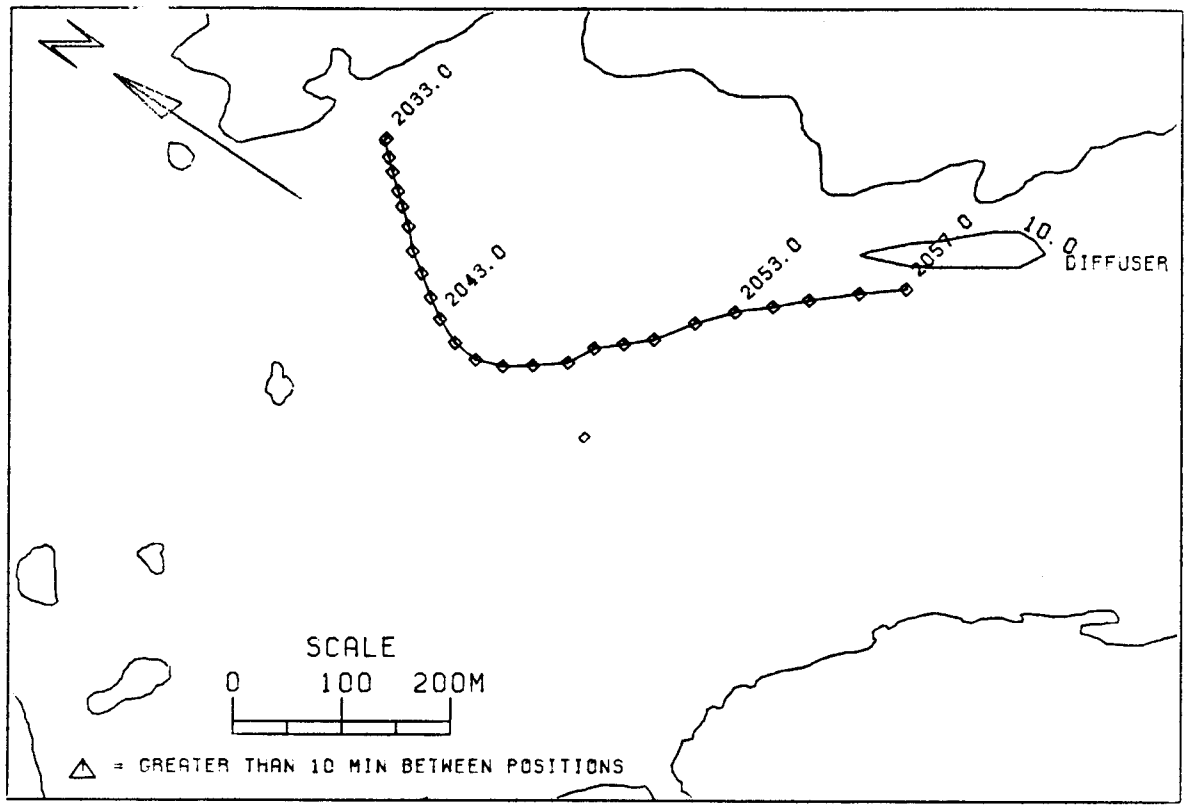
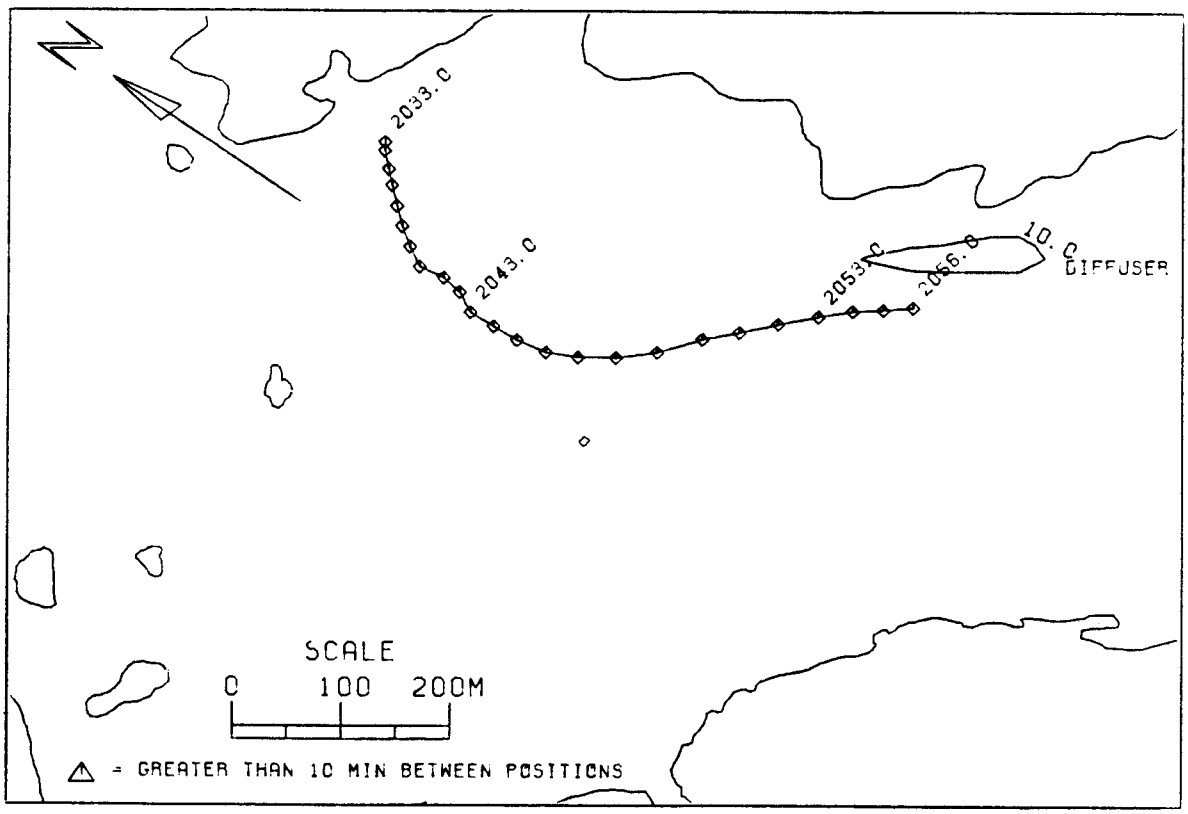


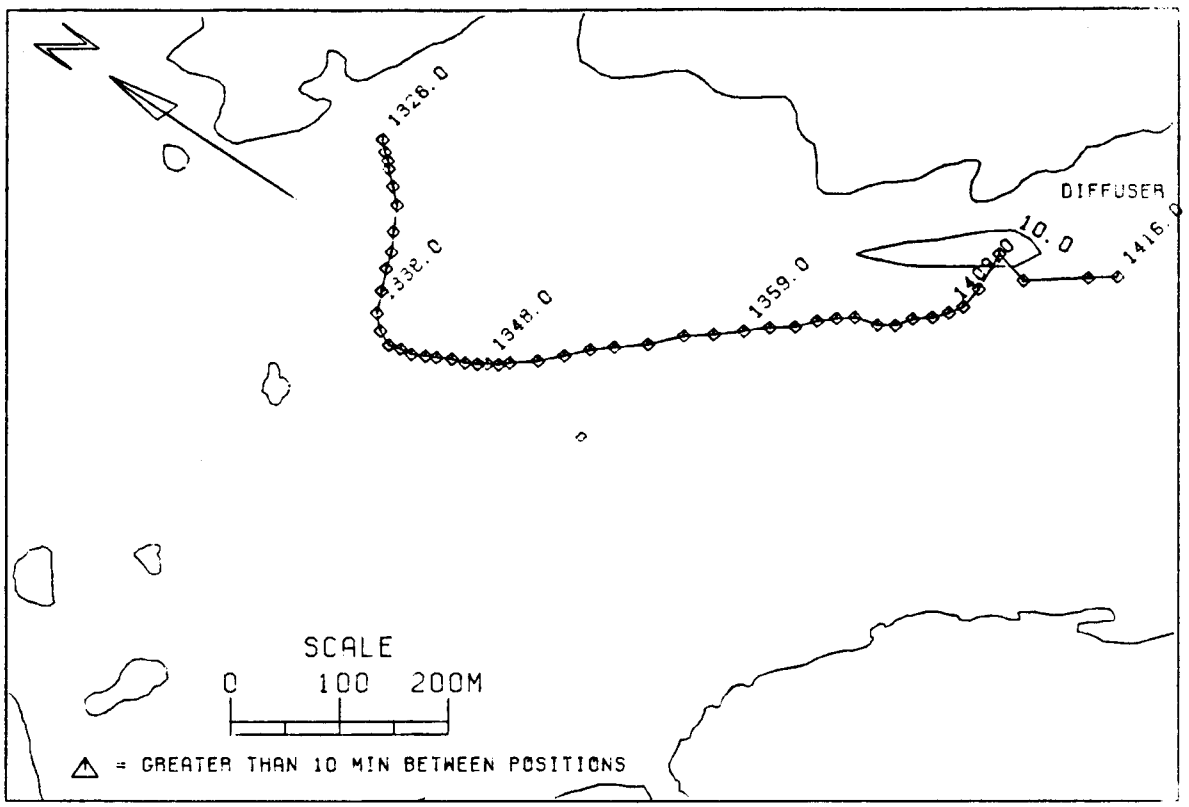
JAKOLOF BAY, FISH 10, CONTROL NO 1, 7/19/88



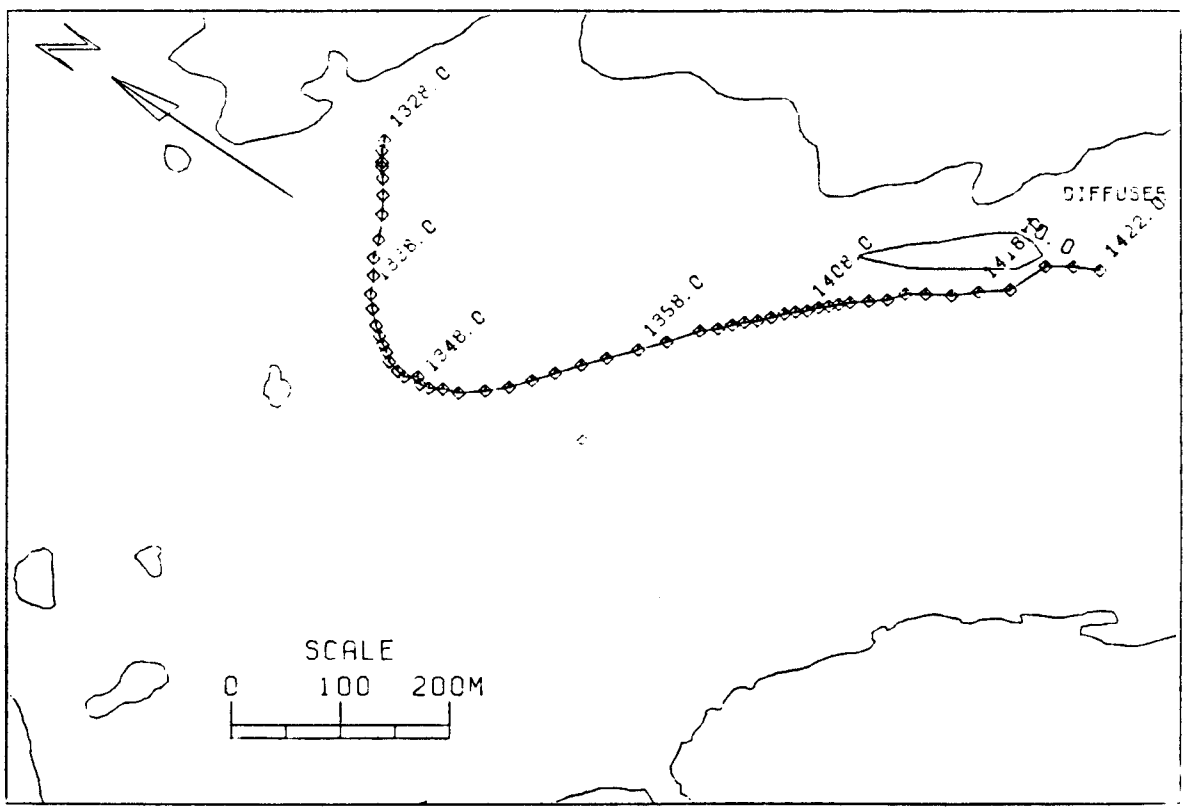
JAKOLOF BAY, FISH 11, CONTROL NO. 1, 7/19/88



JAKOLOF BAY, FISH 12, CONTROL NO. 1, 7/19/88



JAKOLOF BAY, FISH 33, CONTROL NO. 2, 7/24/88



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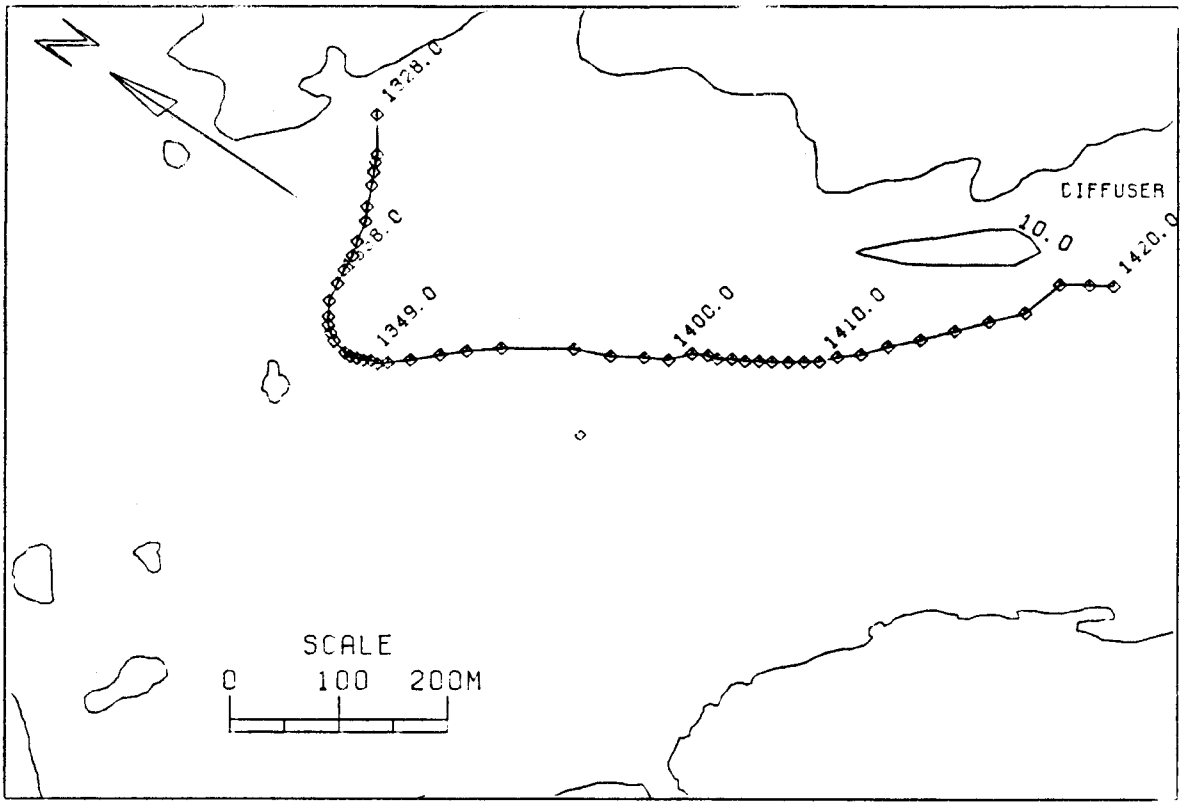

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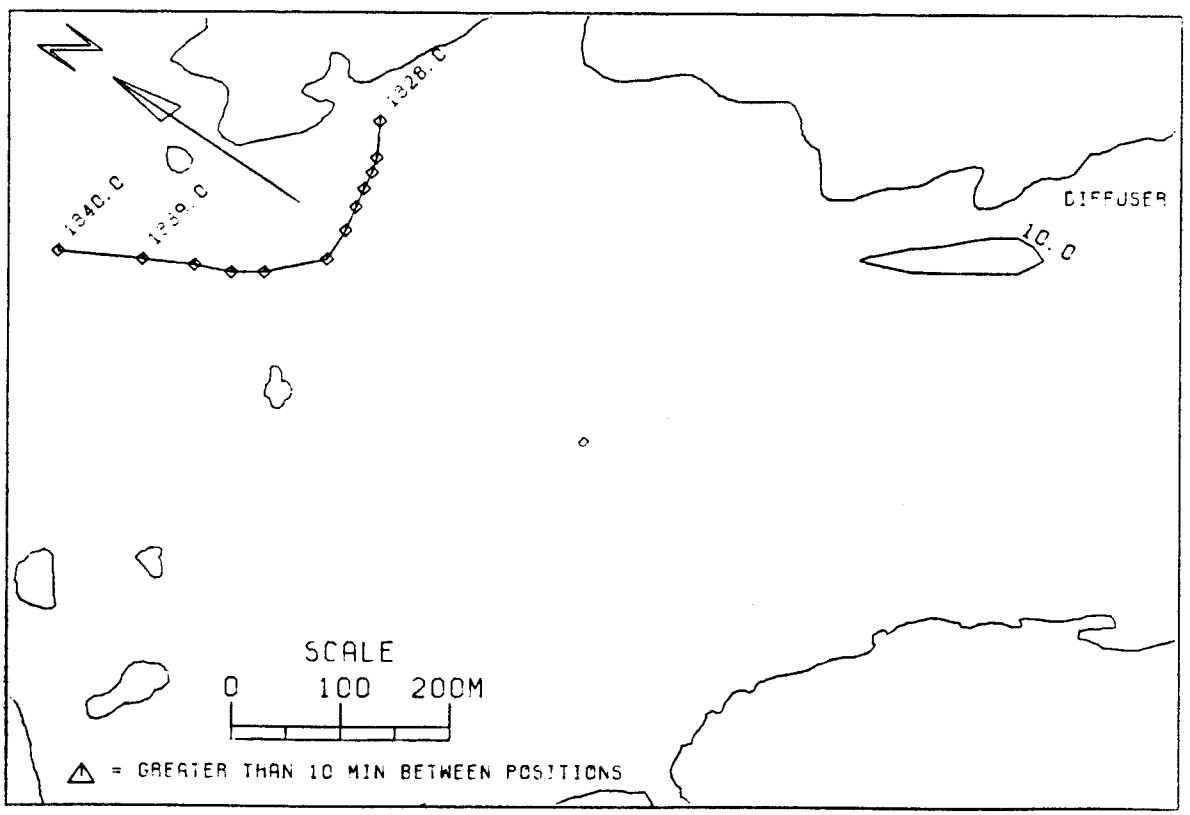

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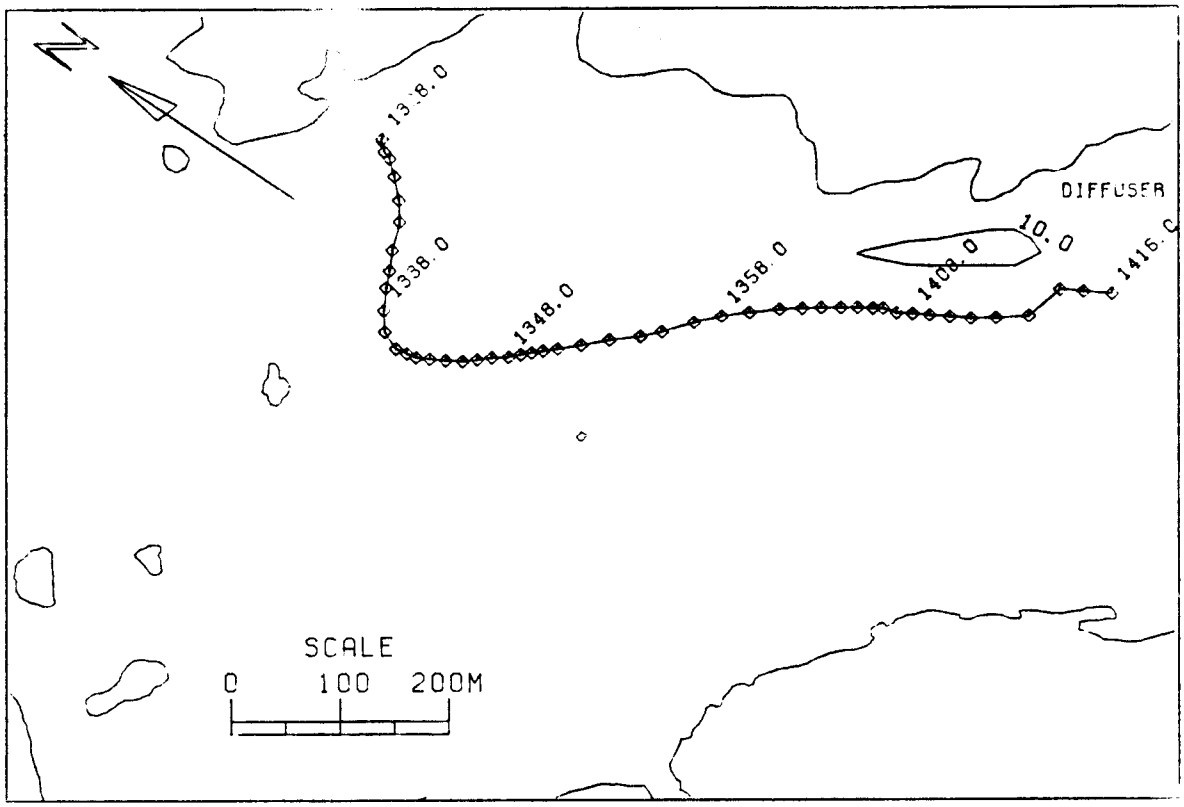

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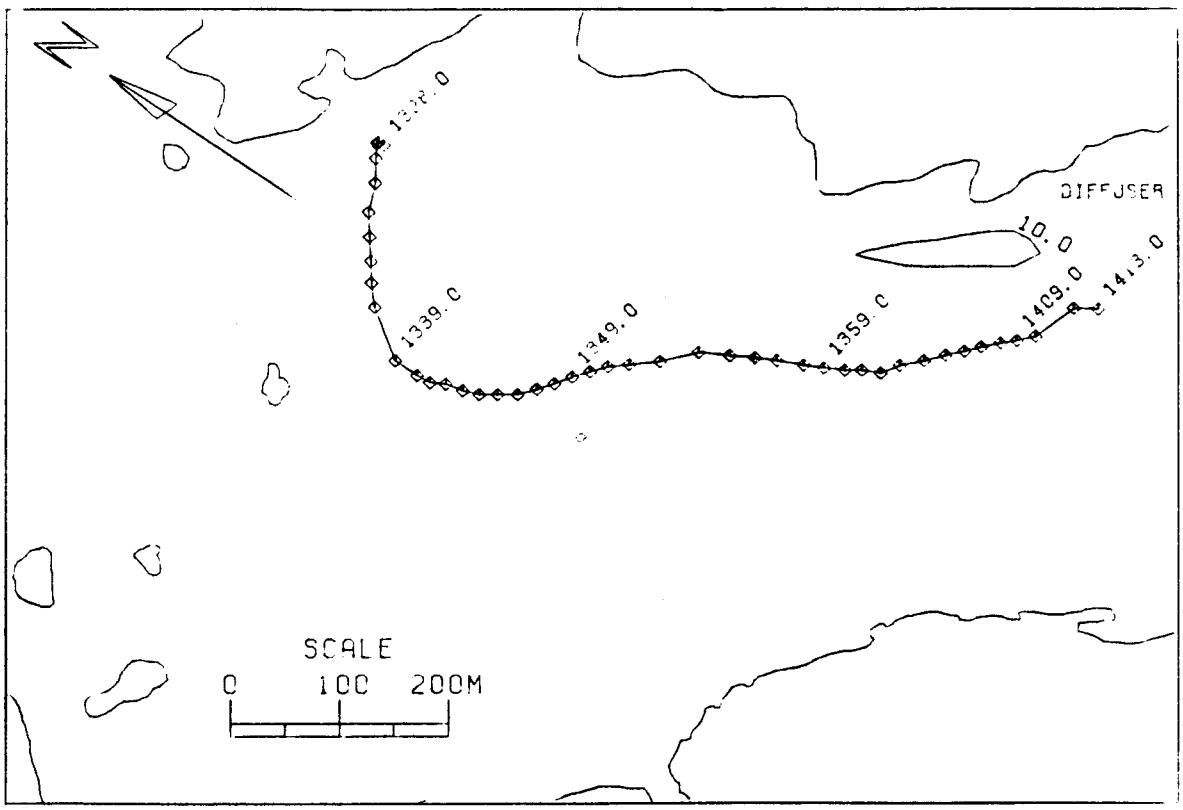

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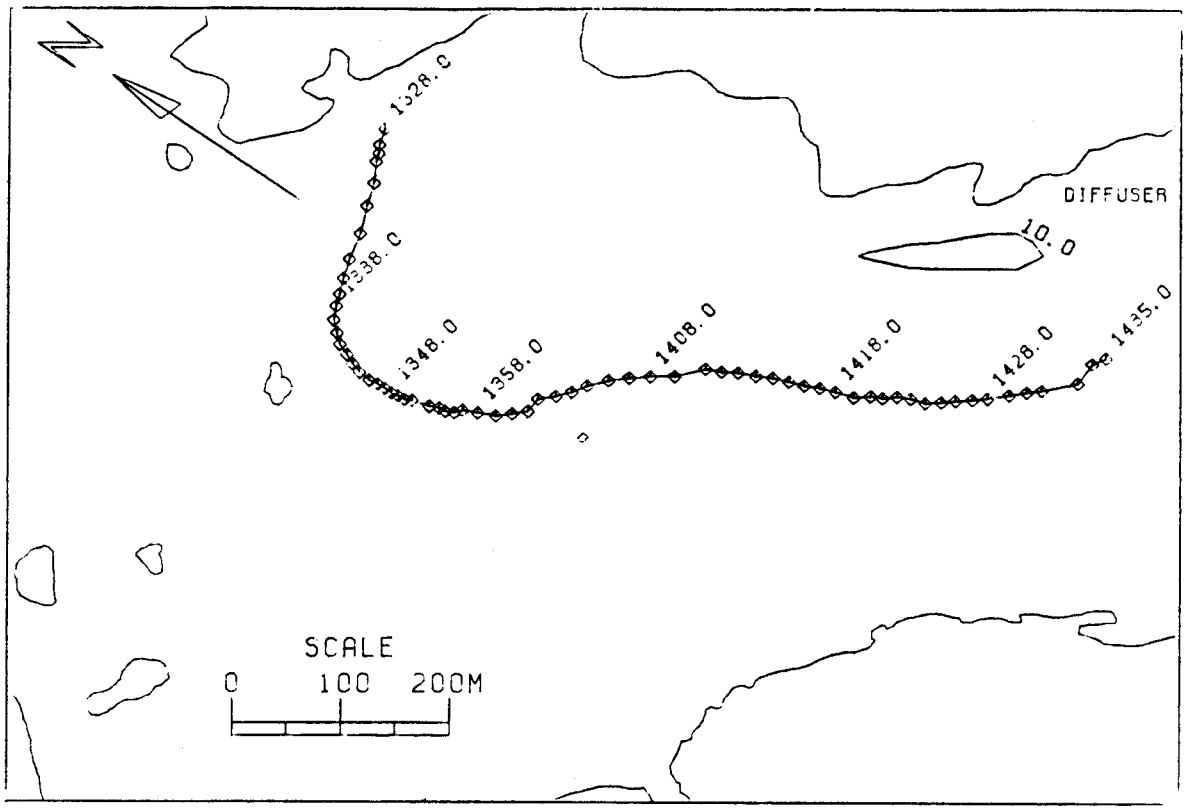

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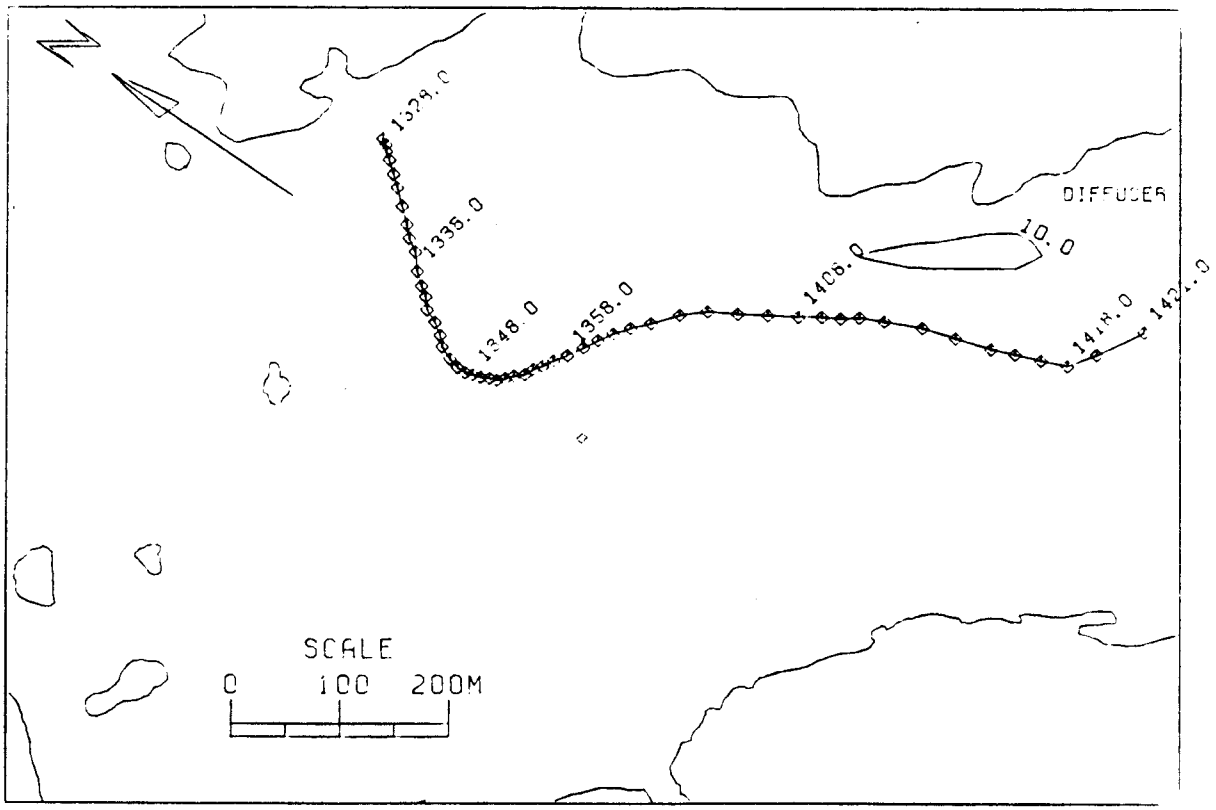

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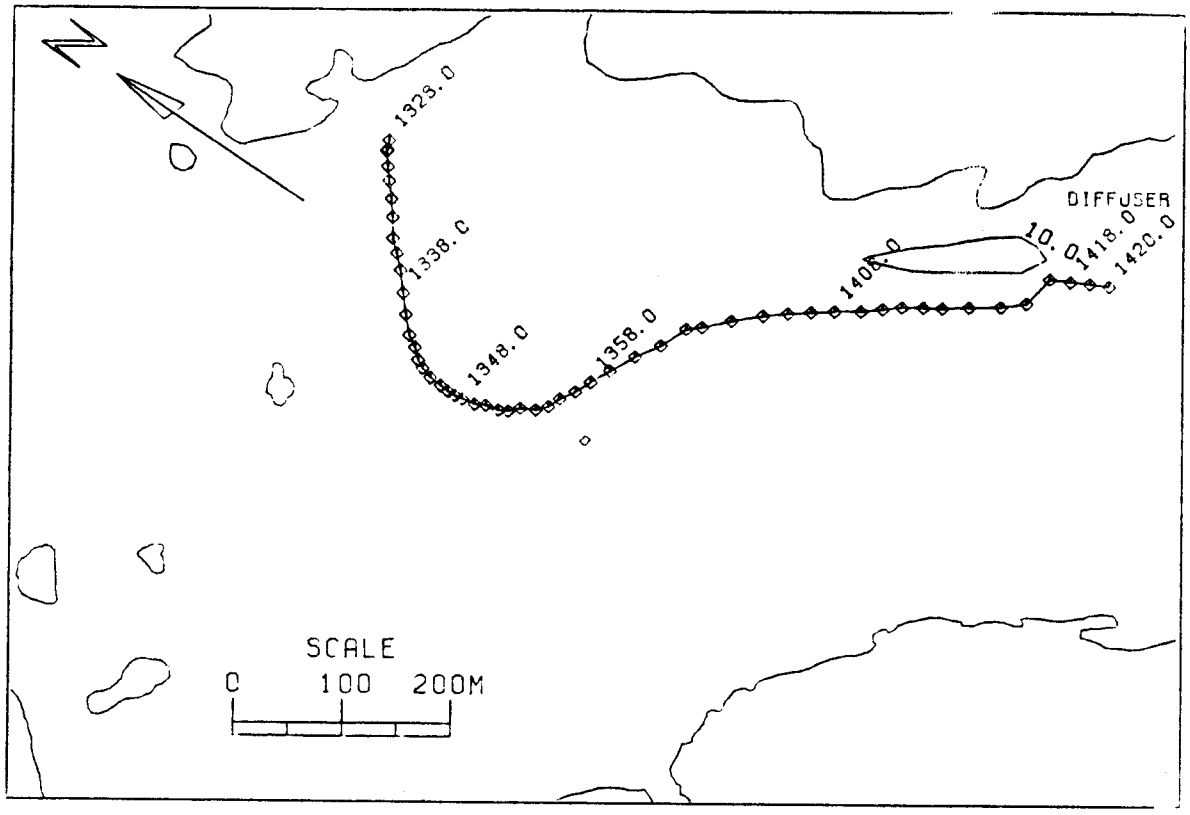

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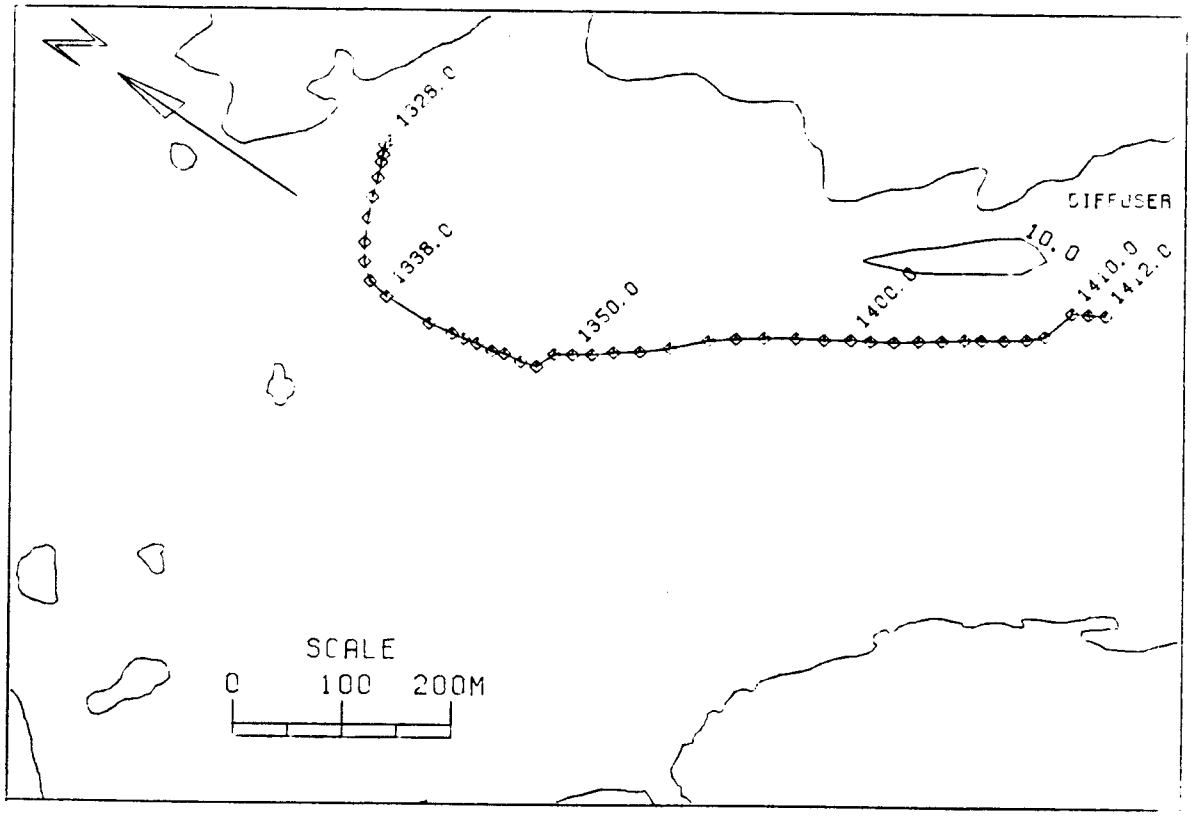

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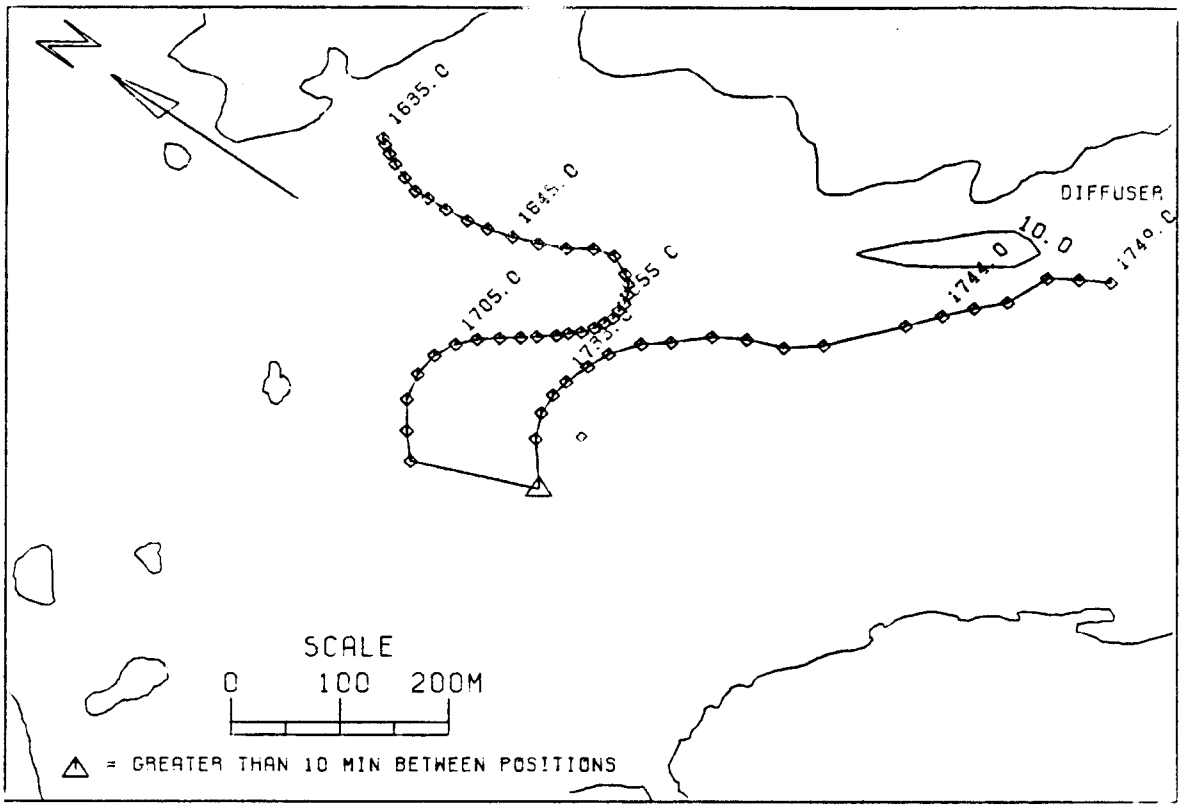

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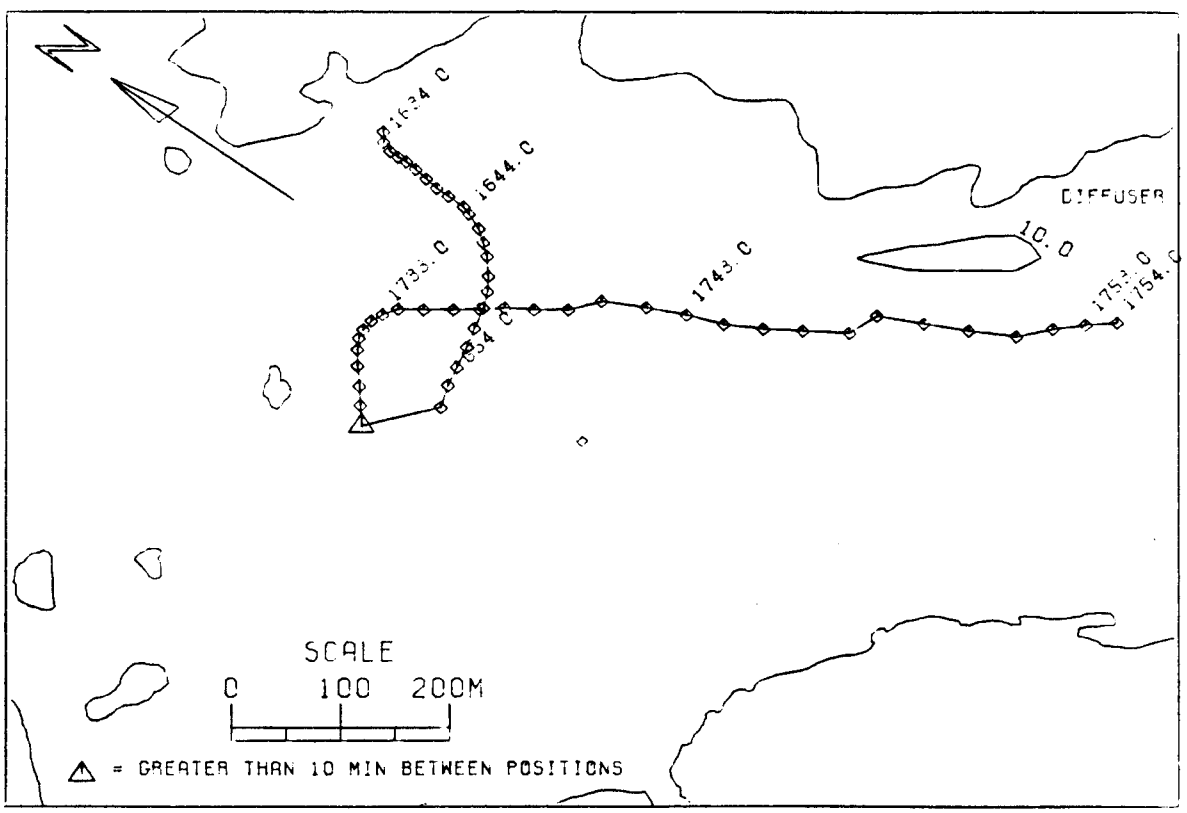

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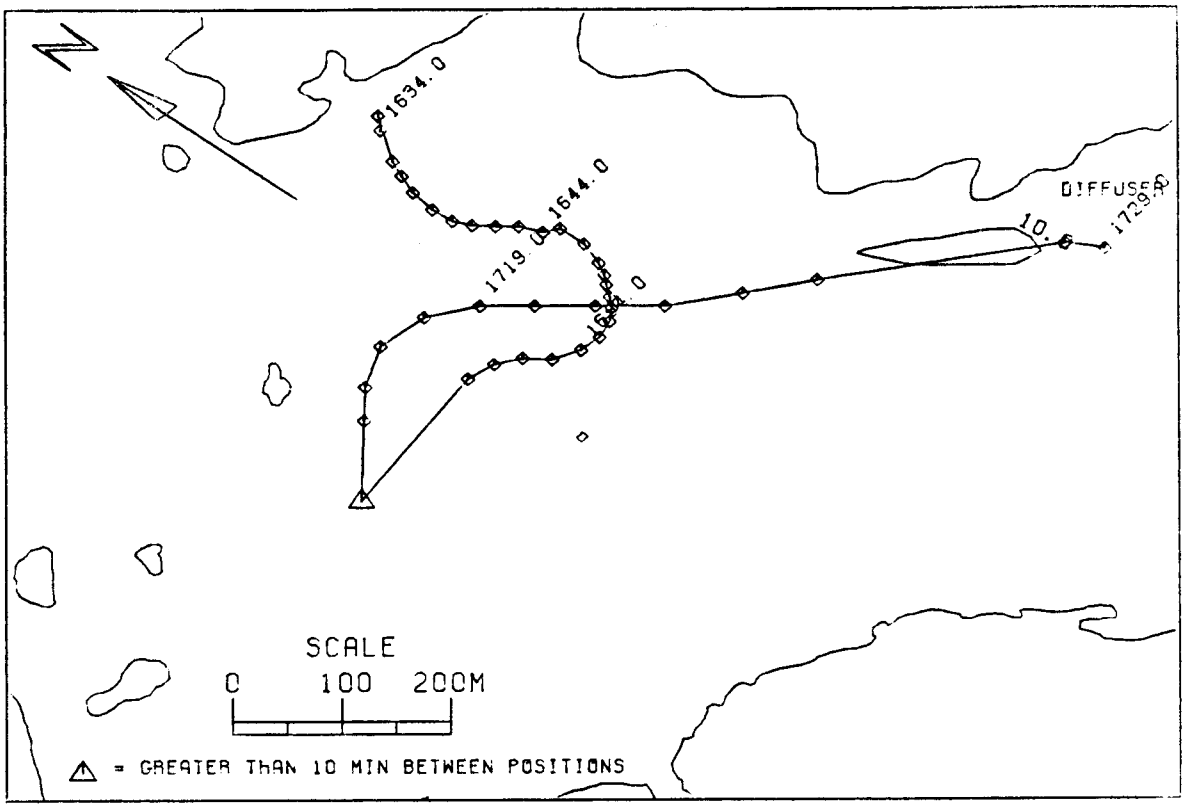

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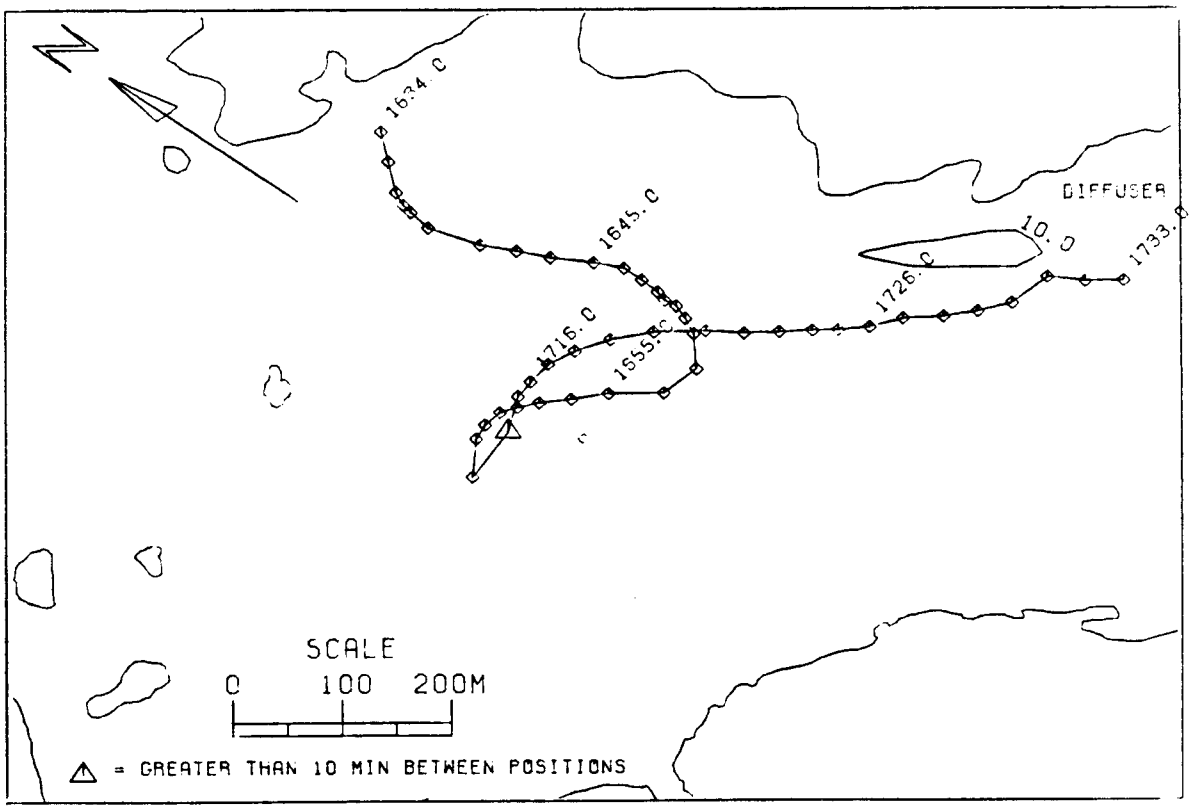

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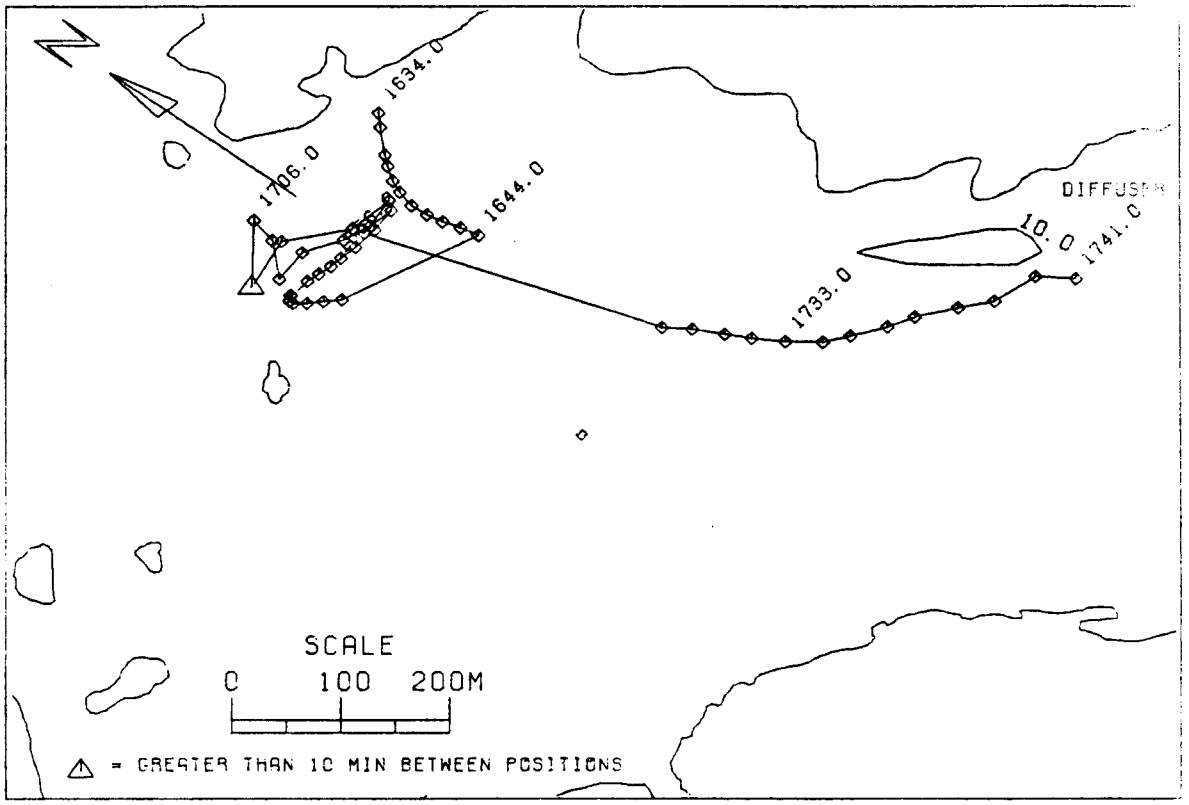

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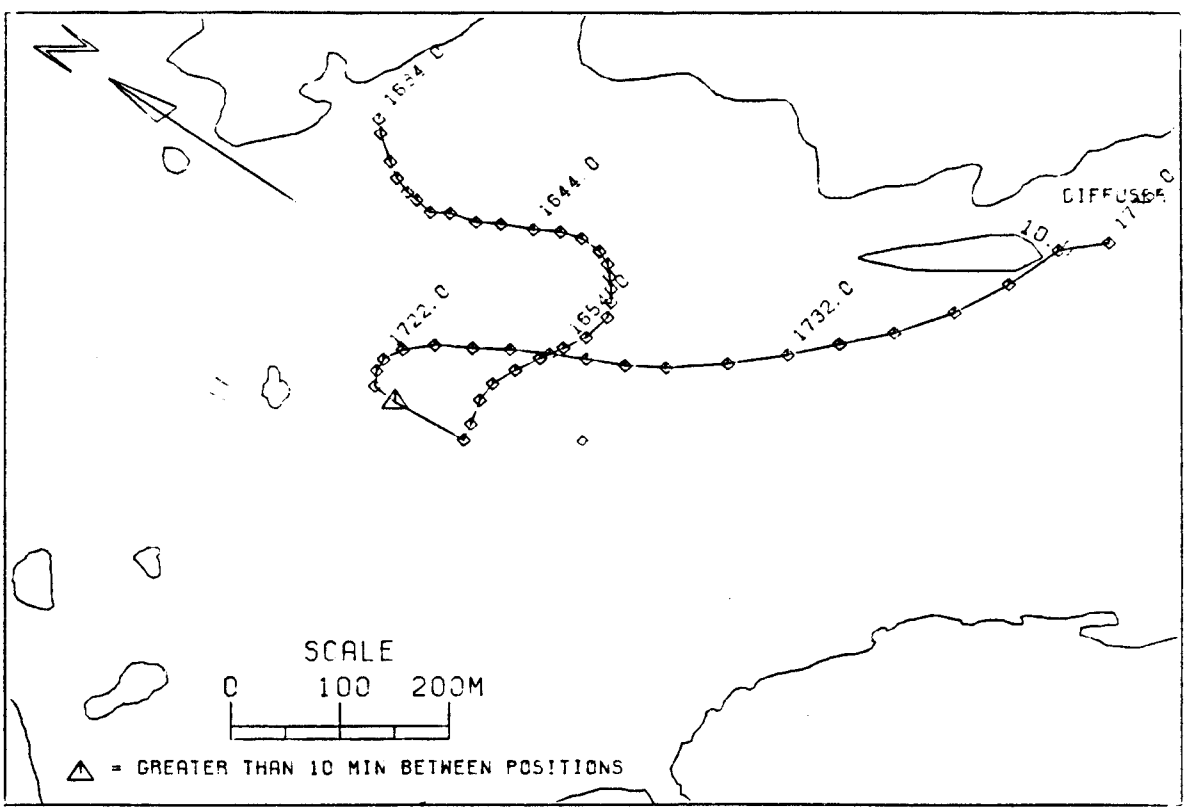

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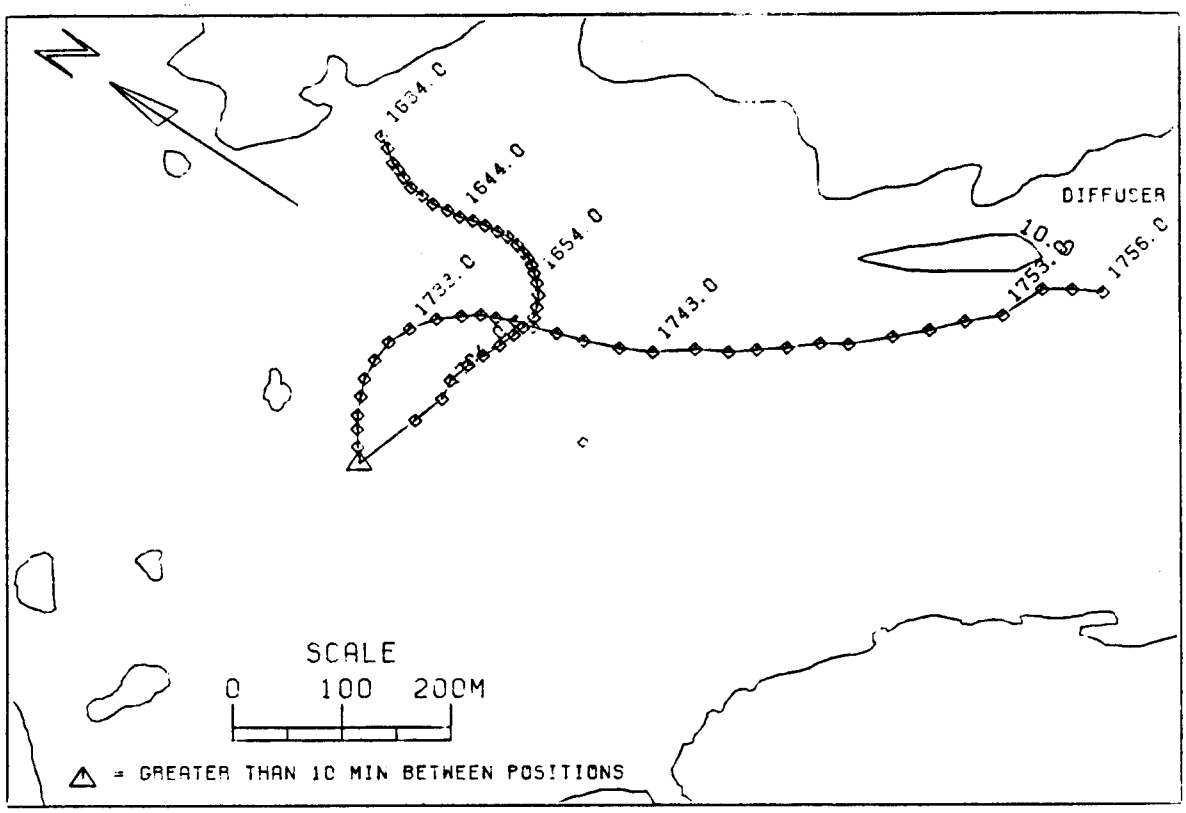

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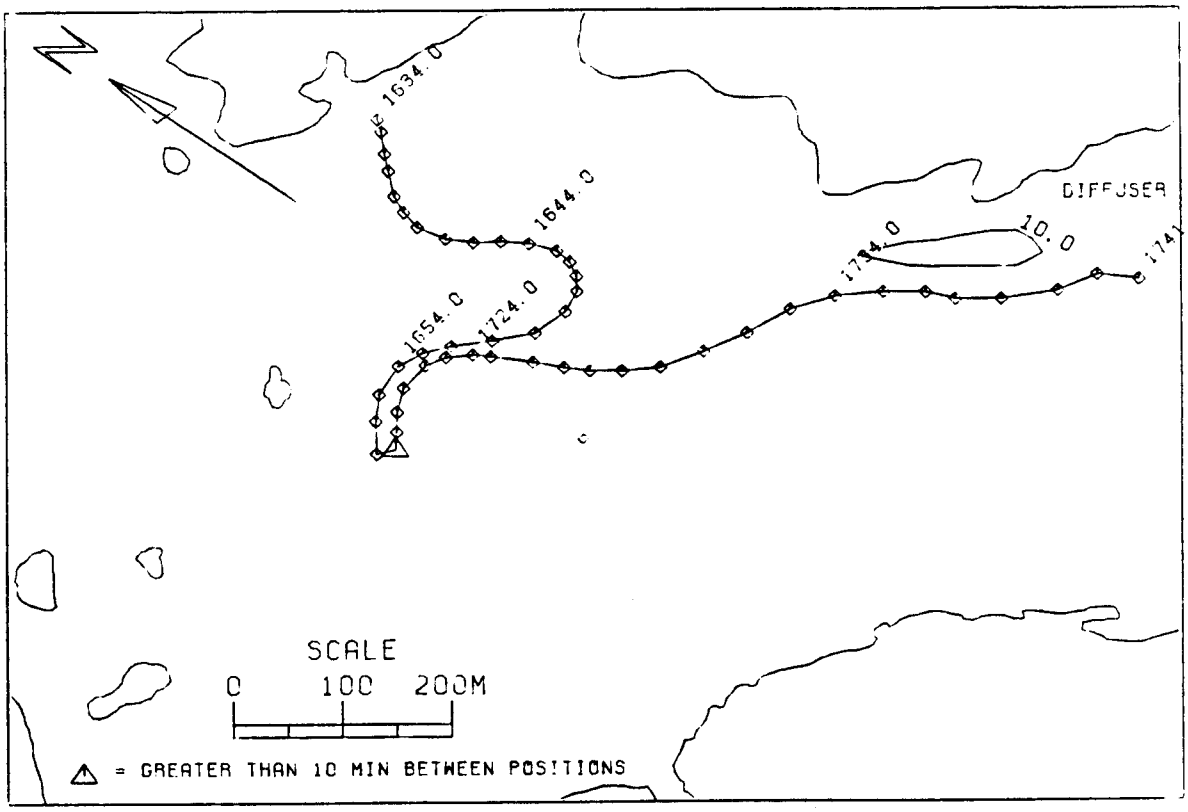

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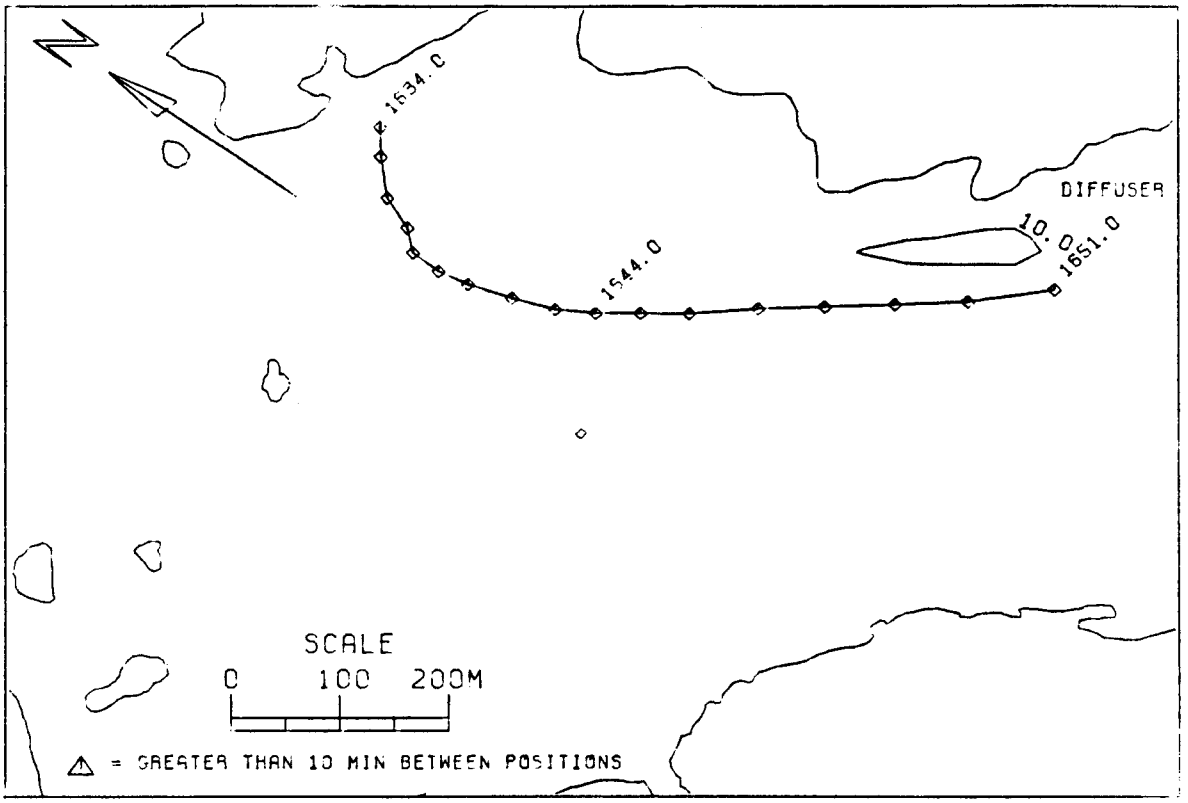

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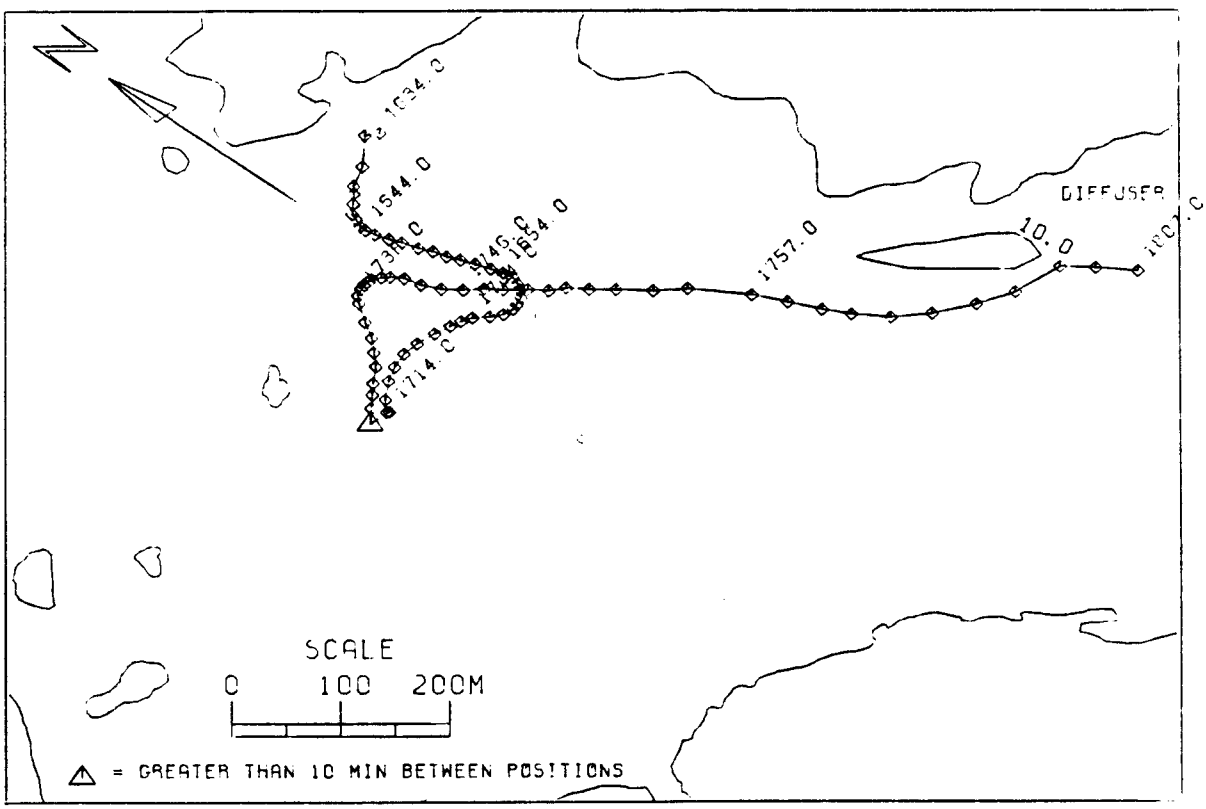

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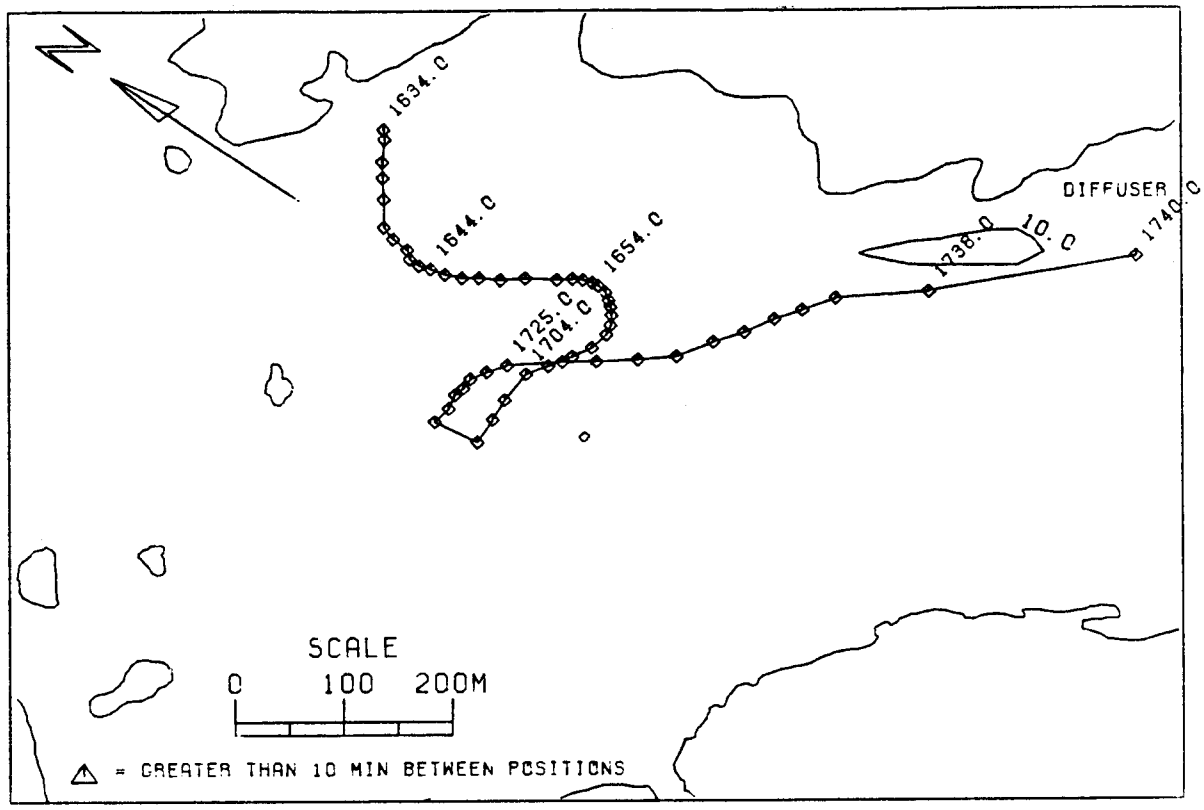

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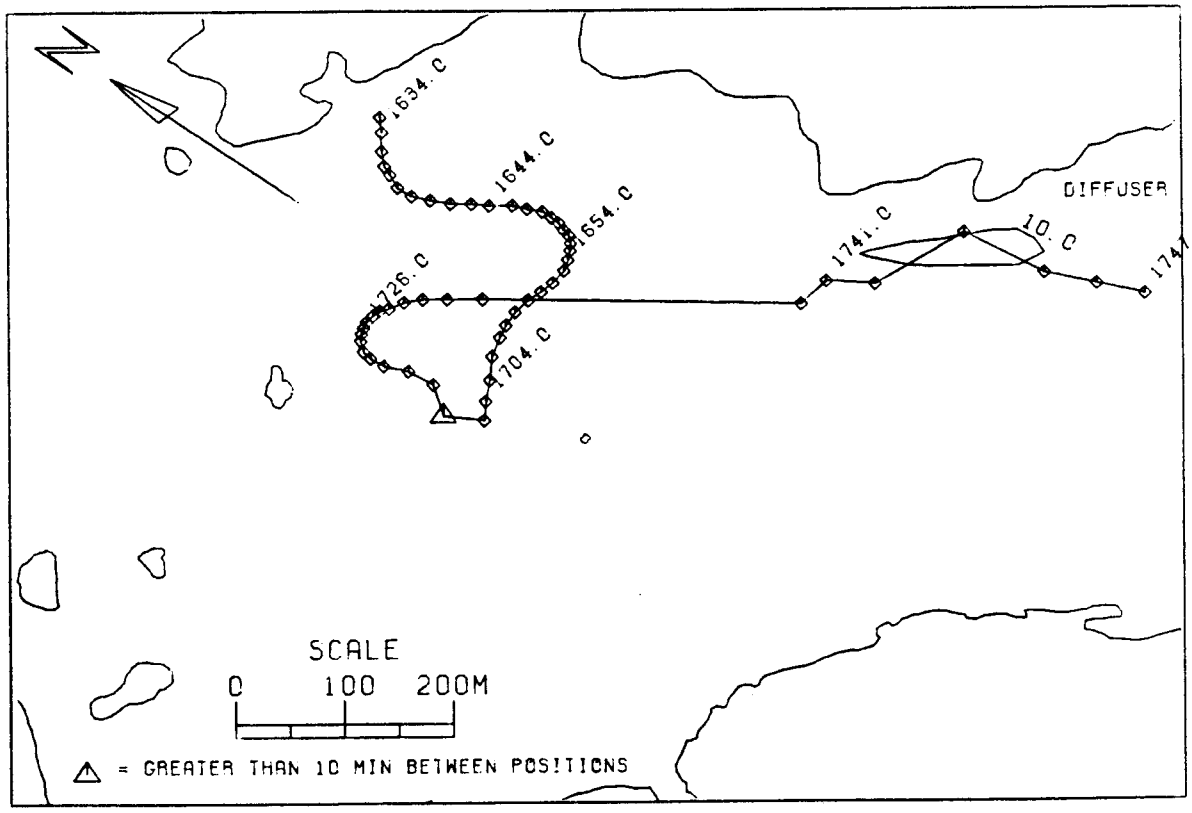

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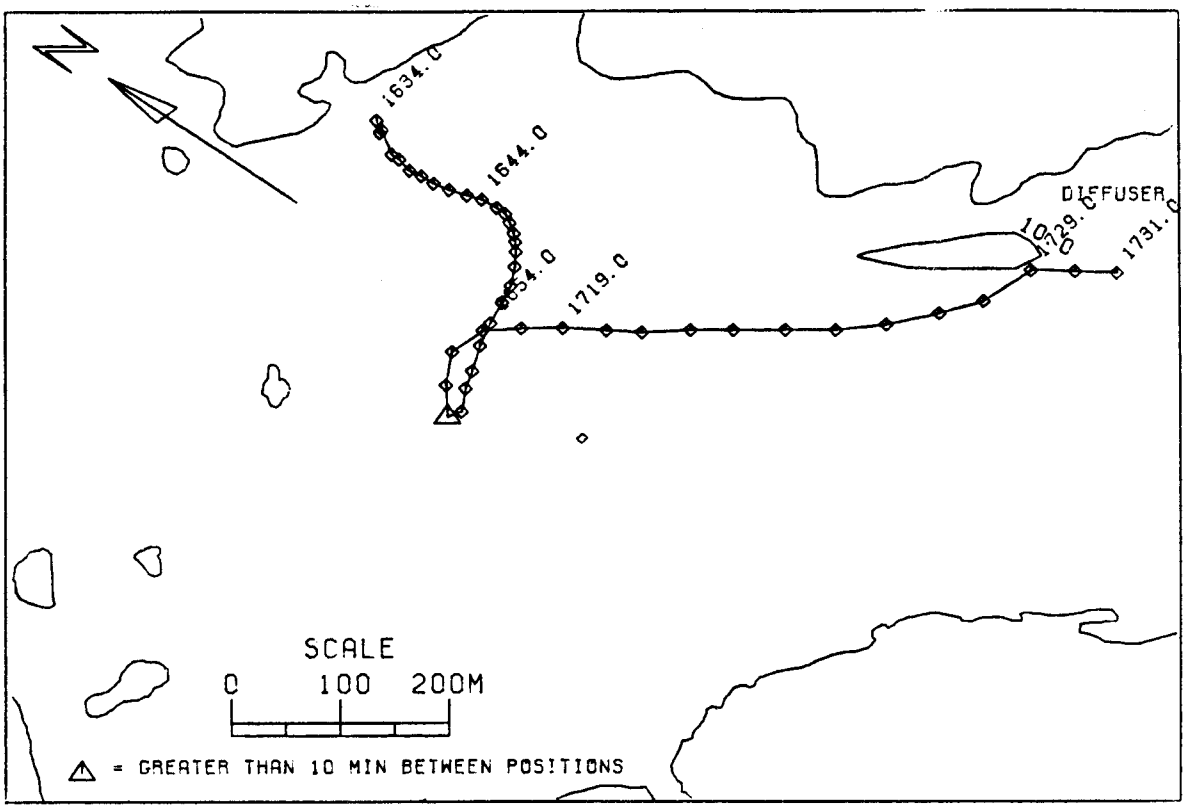

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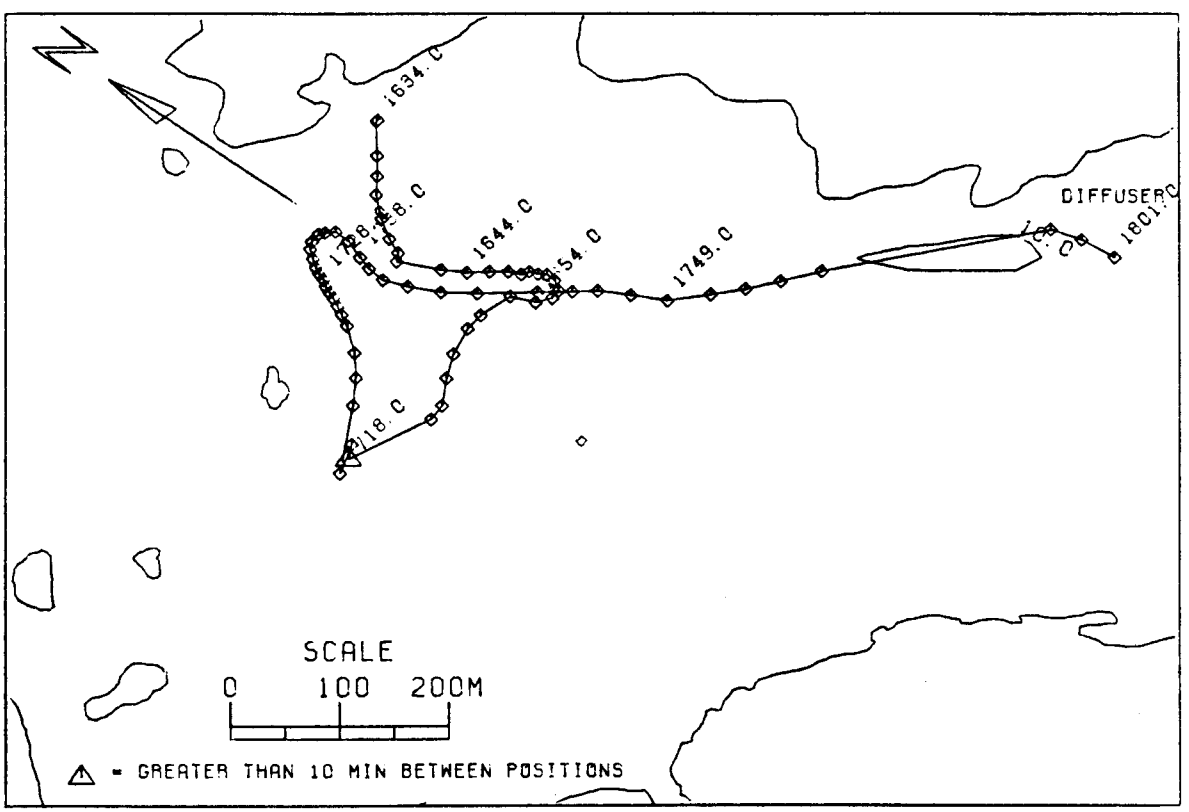

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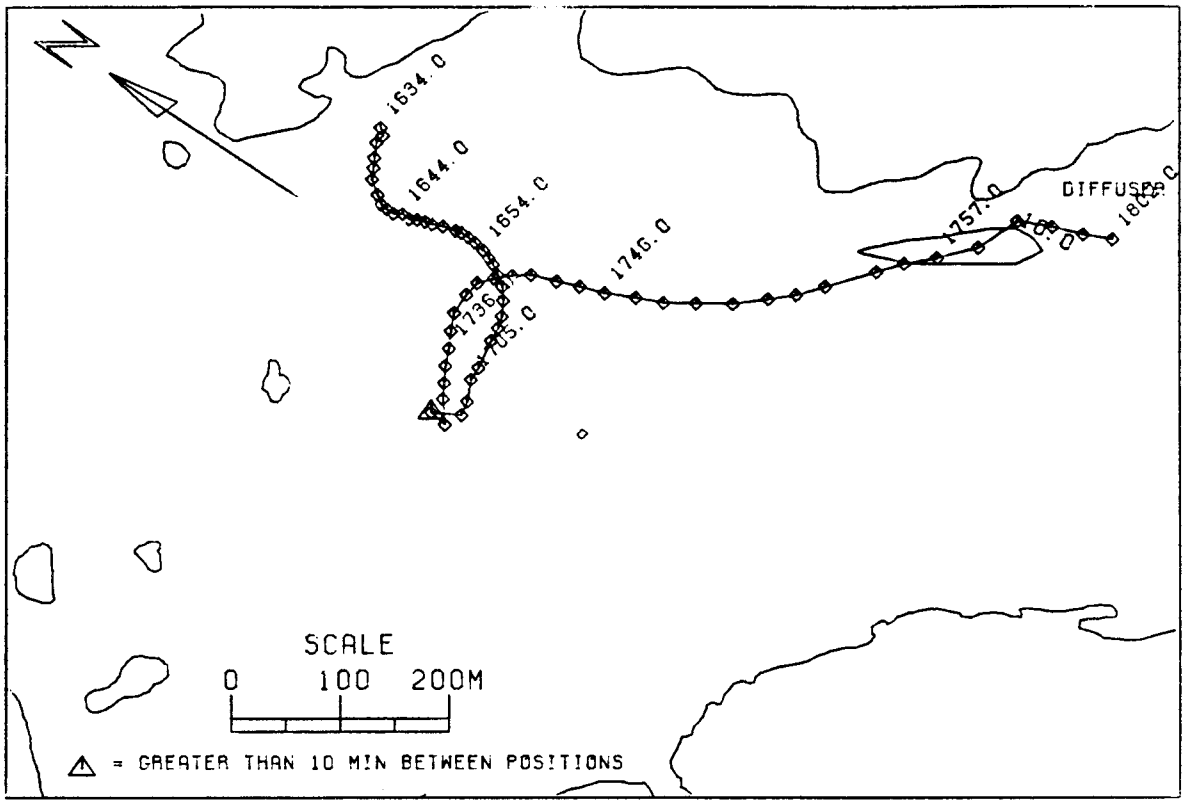

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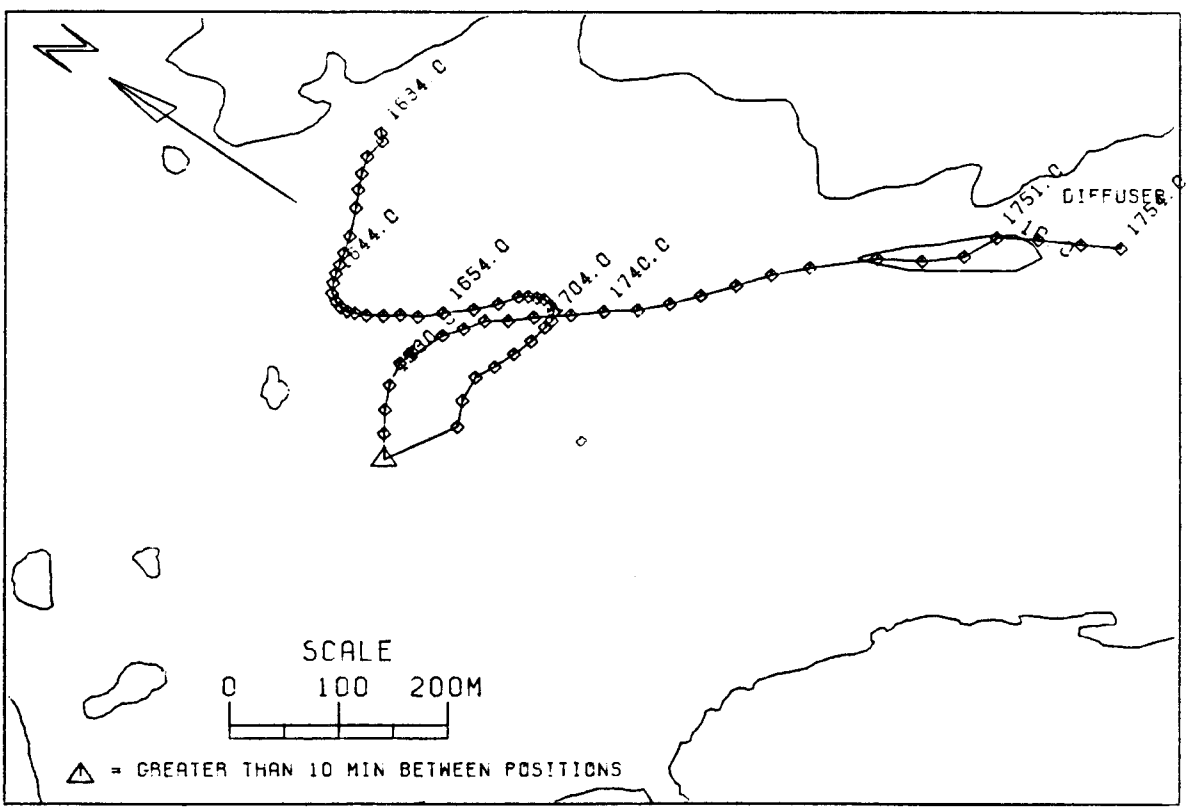

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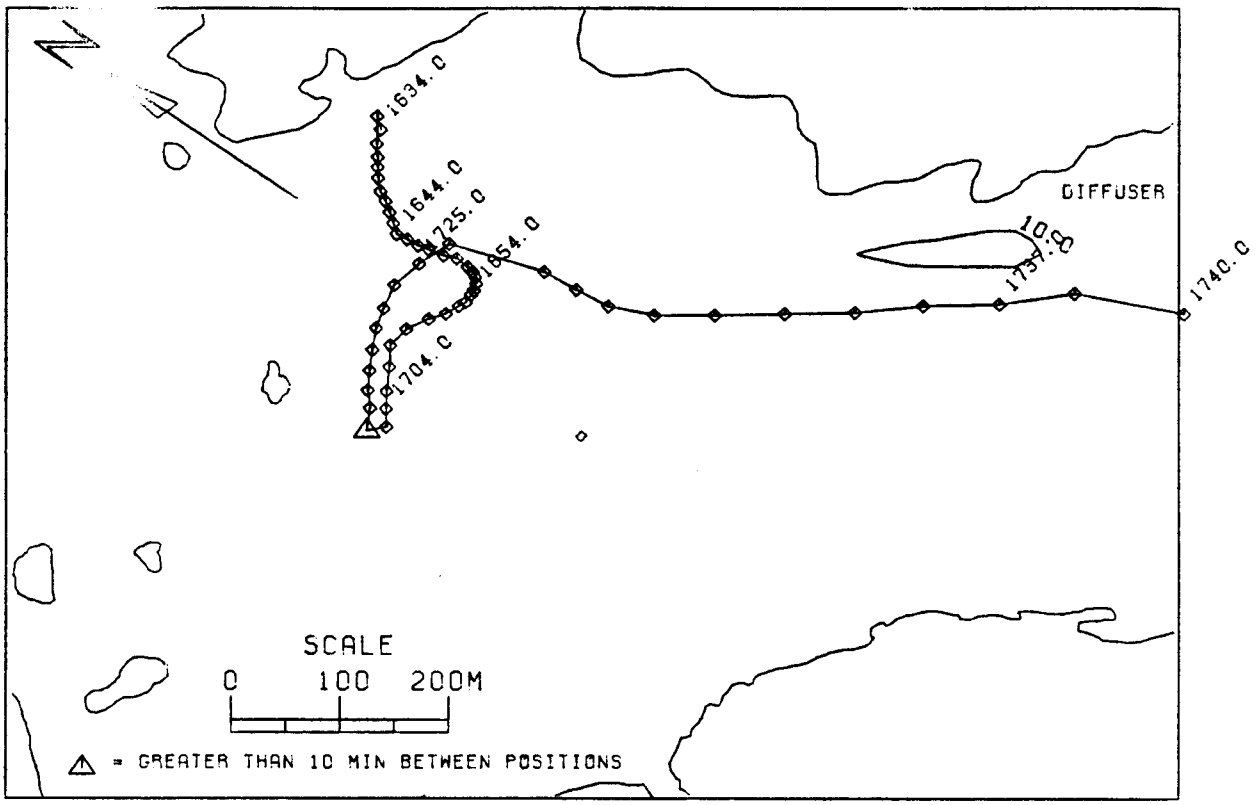

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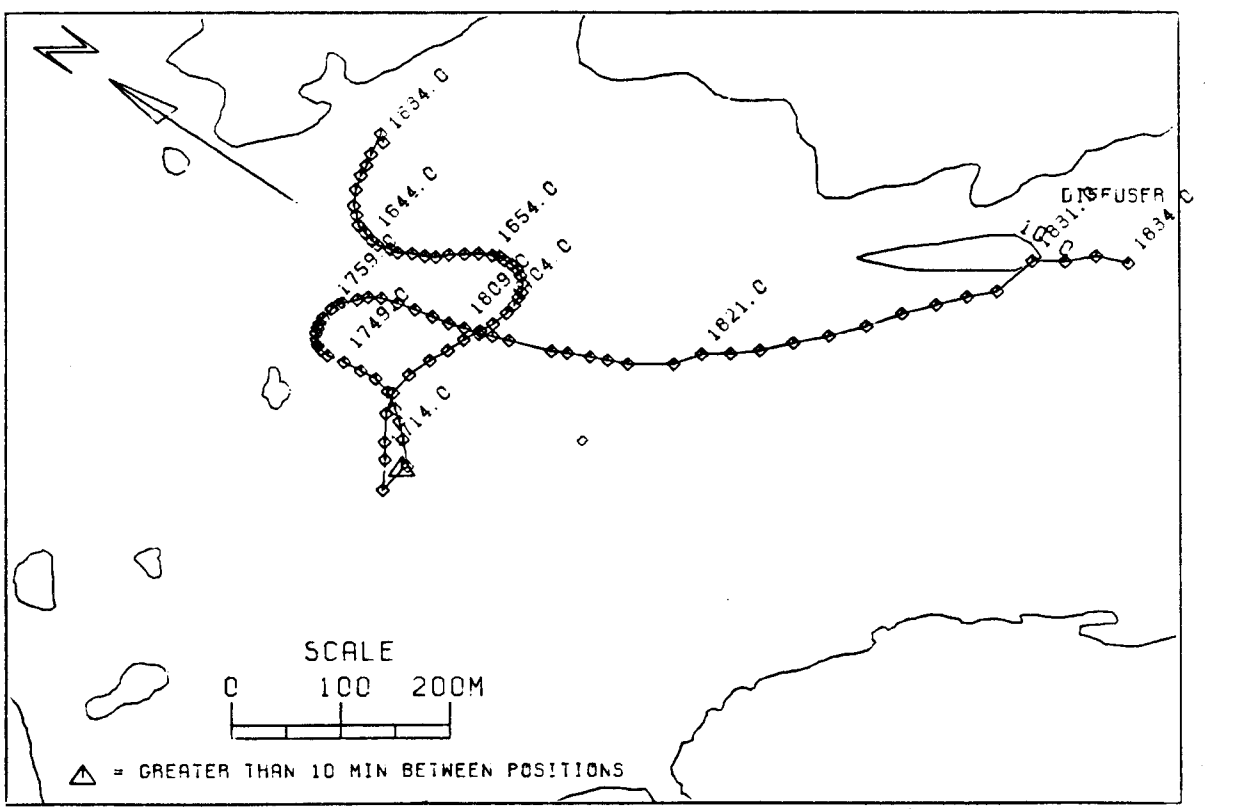
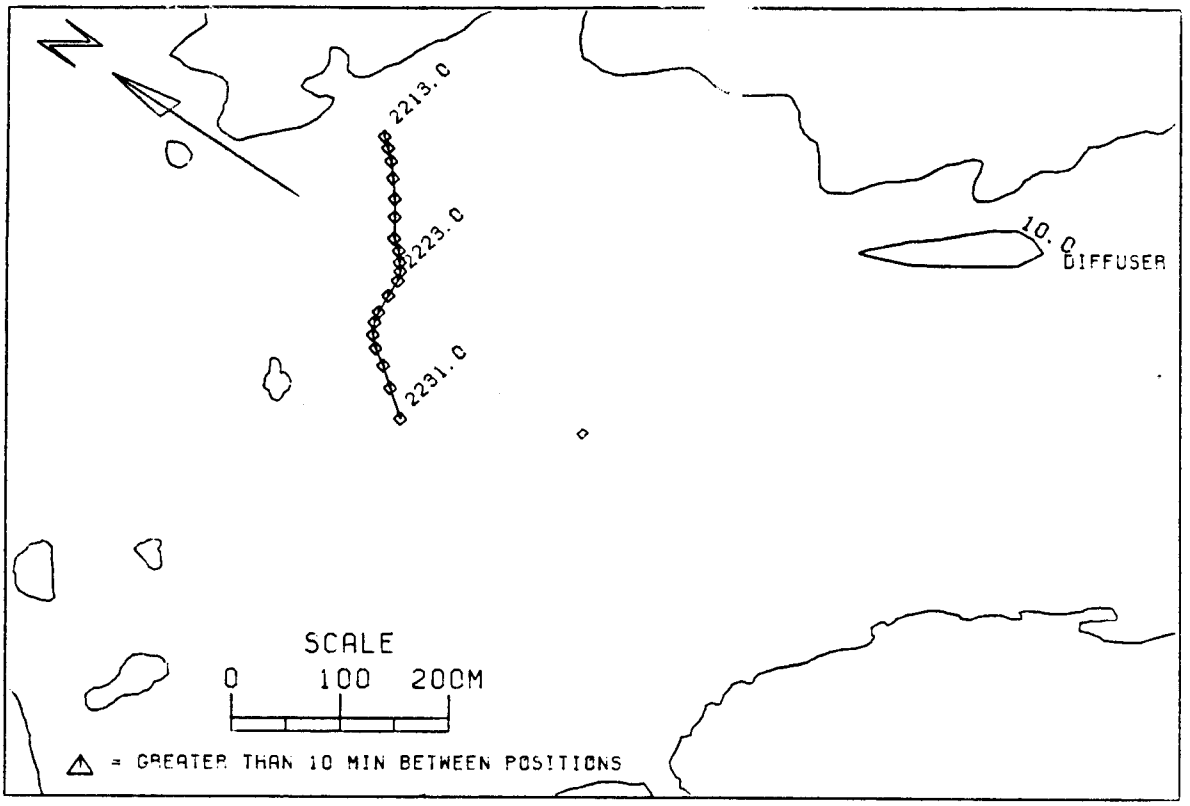


JAKOLOF BAY, FISH 72, CONTROL NO. 3, 7/28/88

APPENDIX I

PLOTS OF HORIZONTAL MOVEMENTS OF ADULT PINK SALMON DURING TREATMENT EXPERIMENTS



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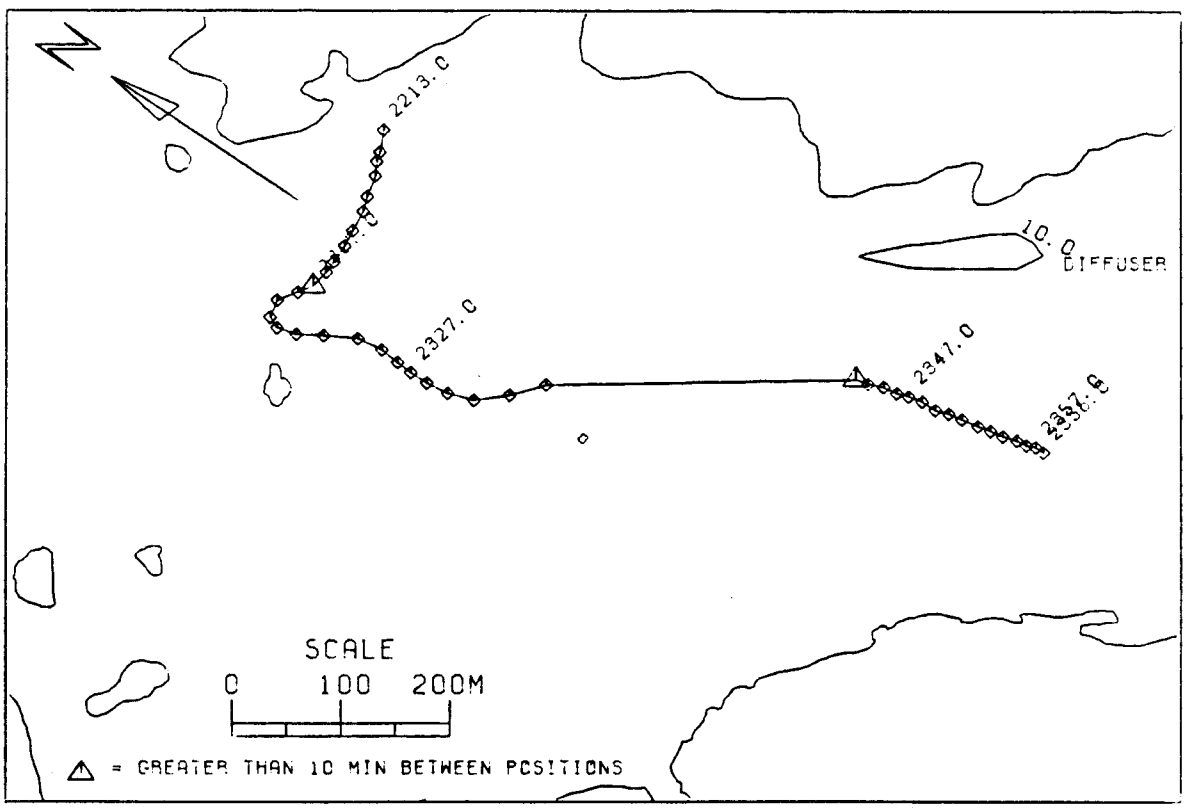

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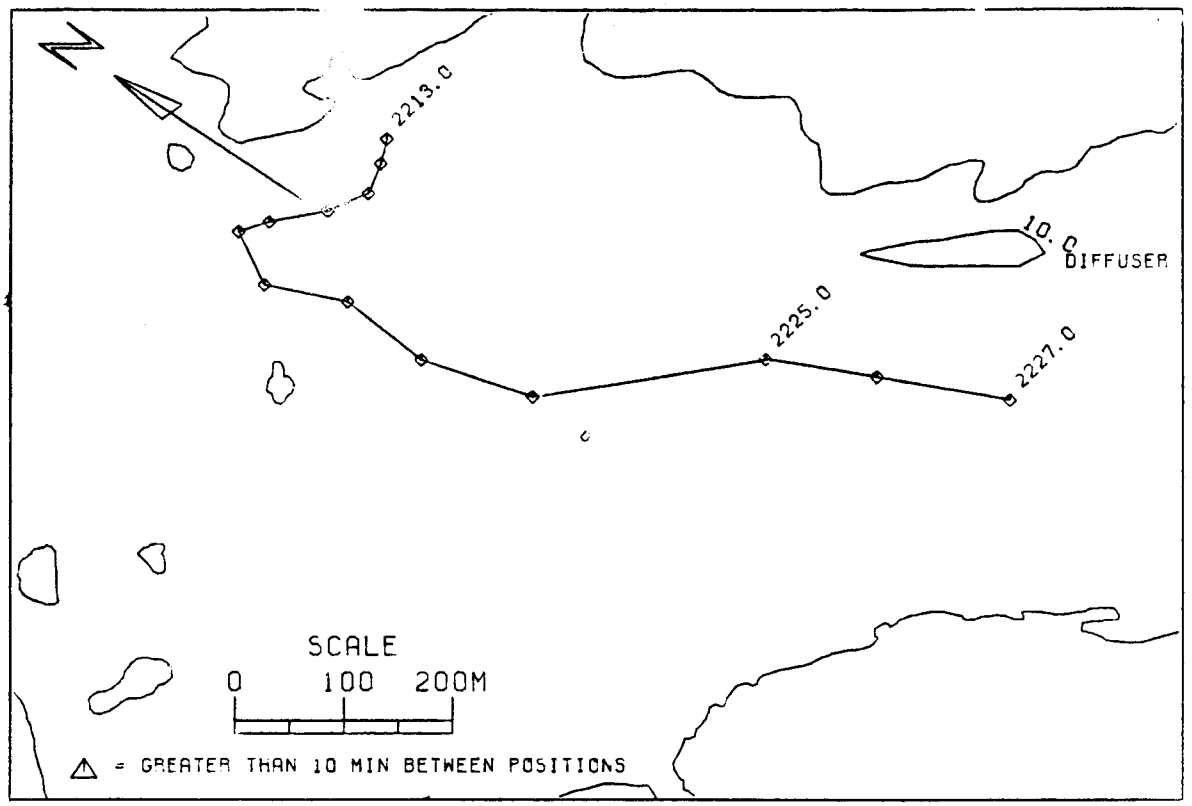

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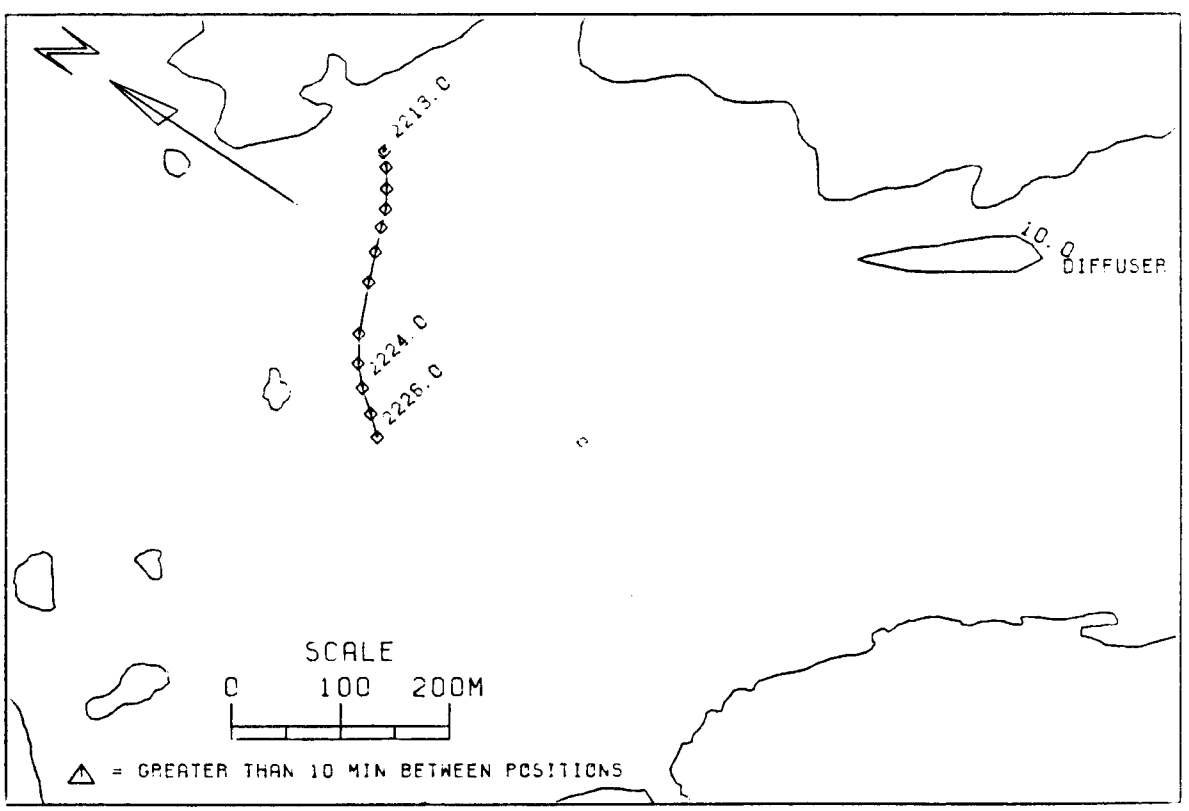

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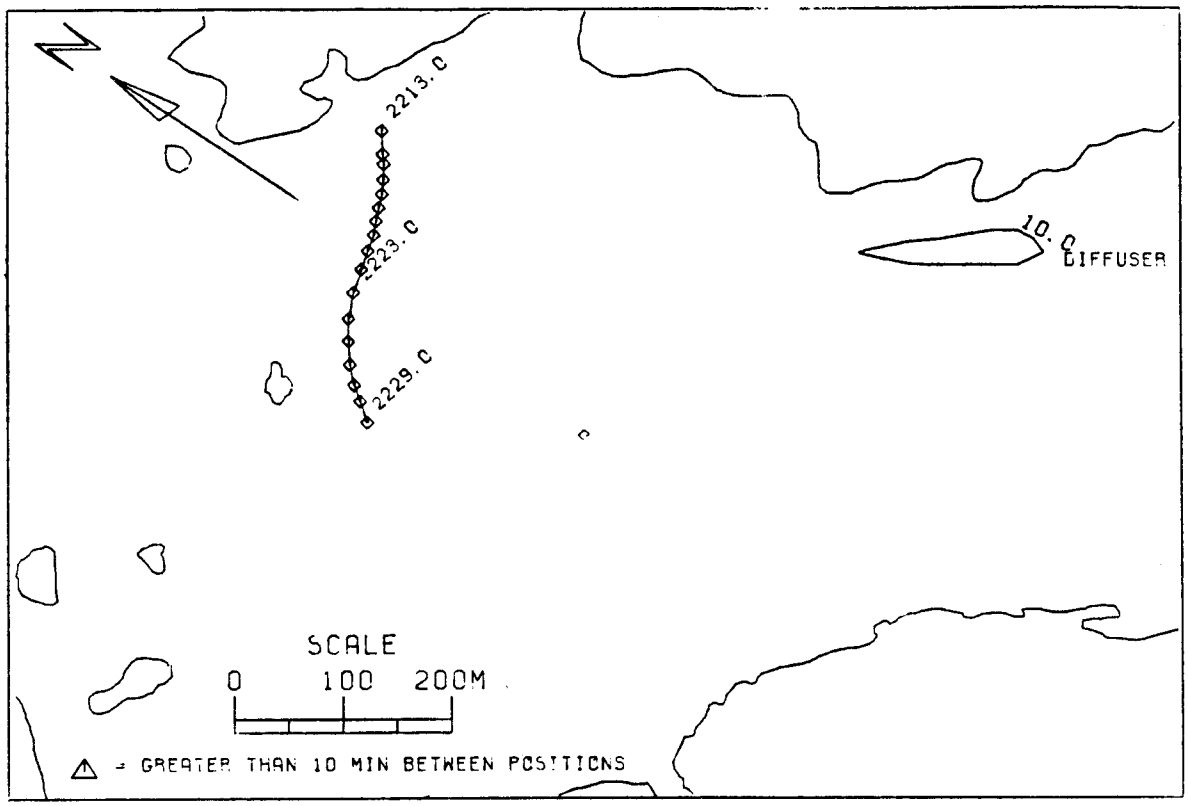

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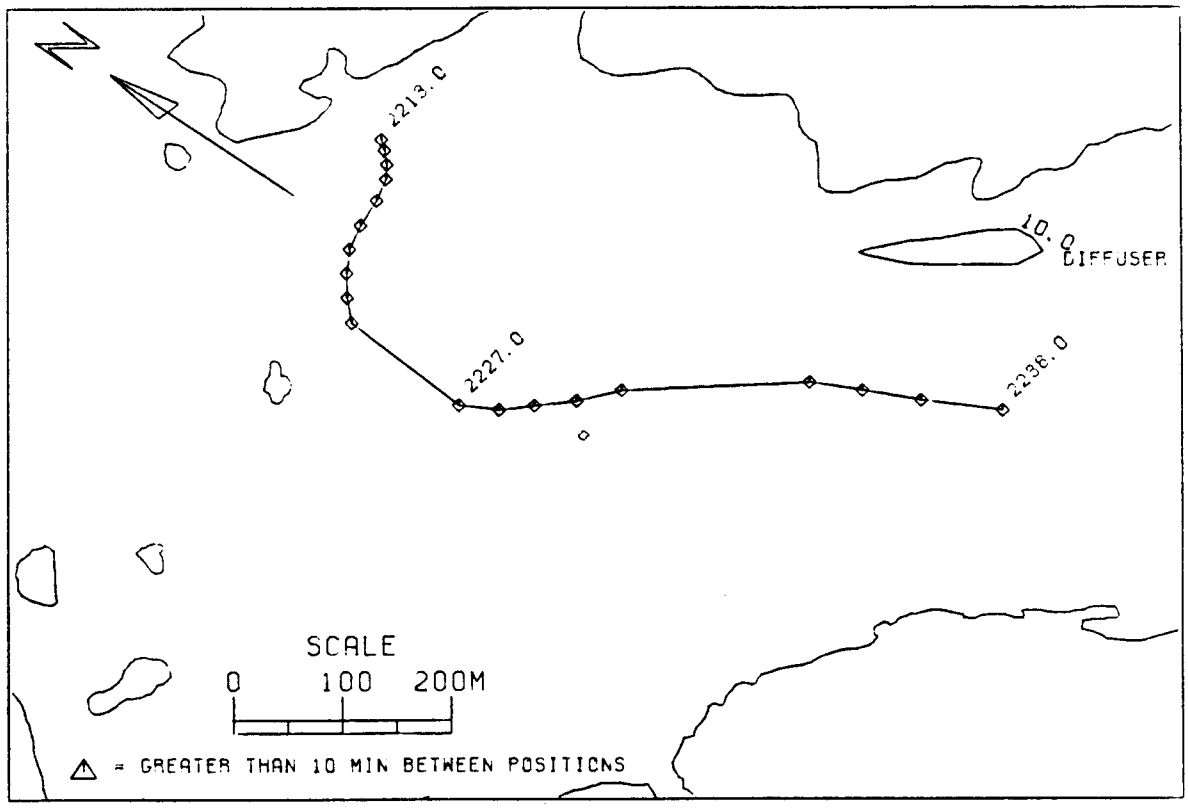

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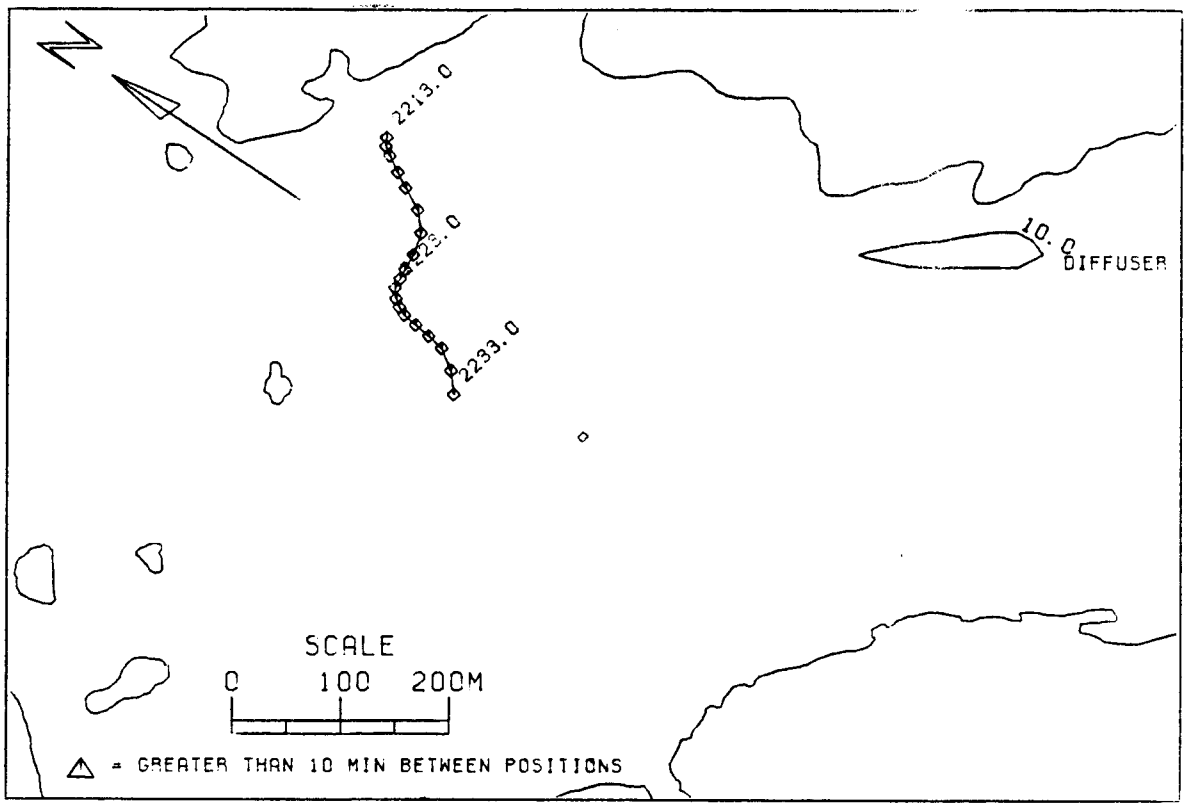

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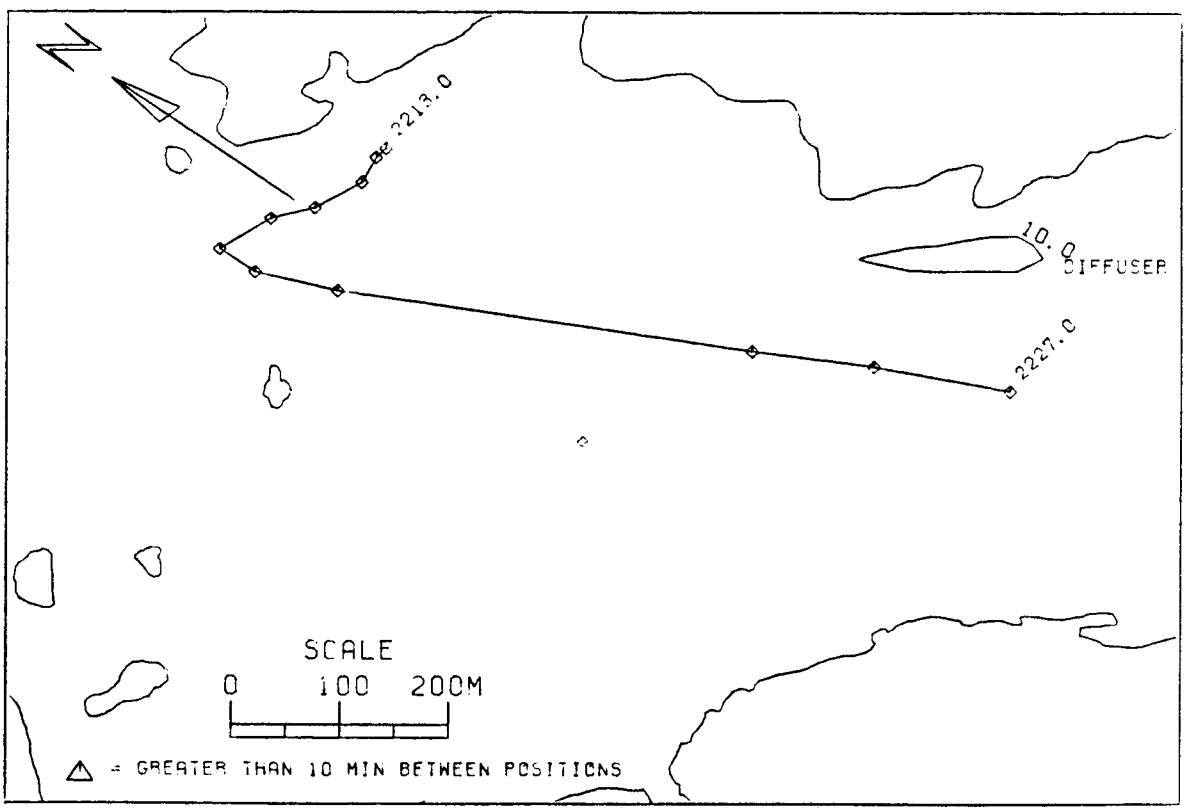

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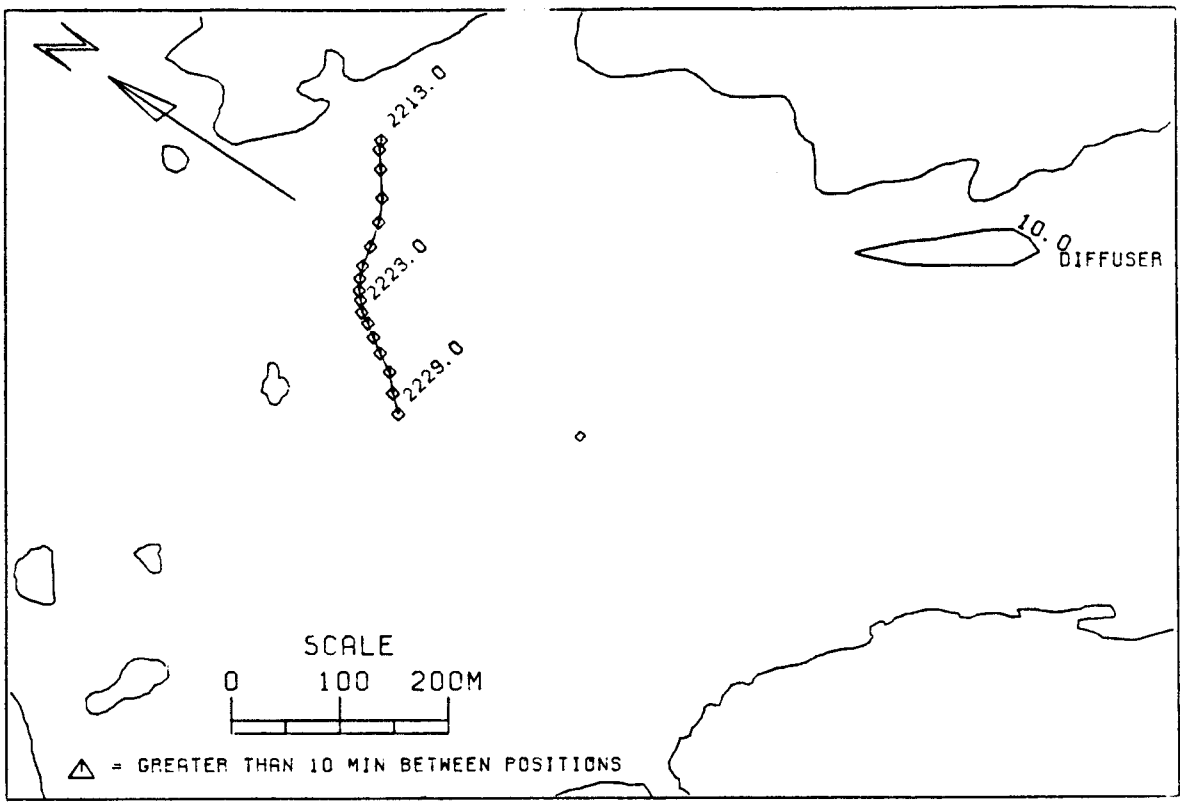

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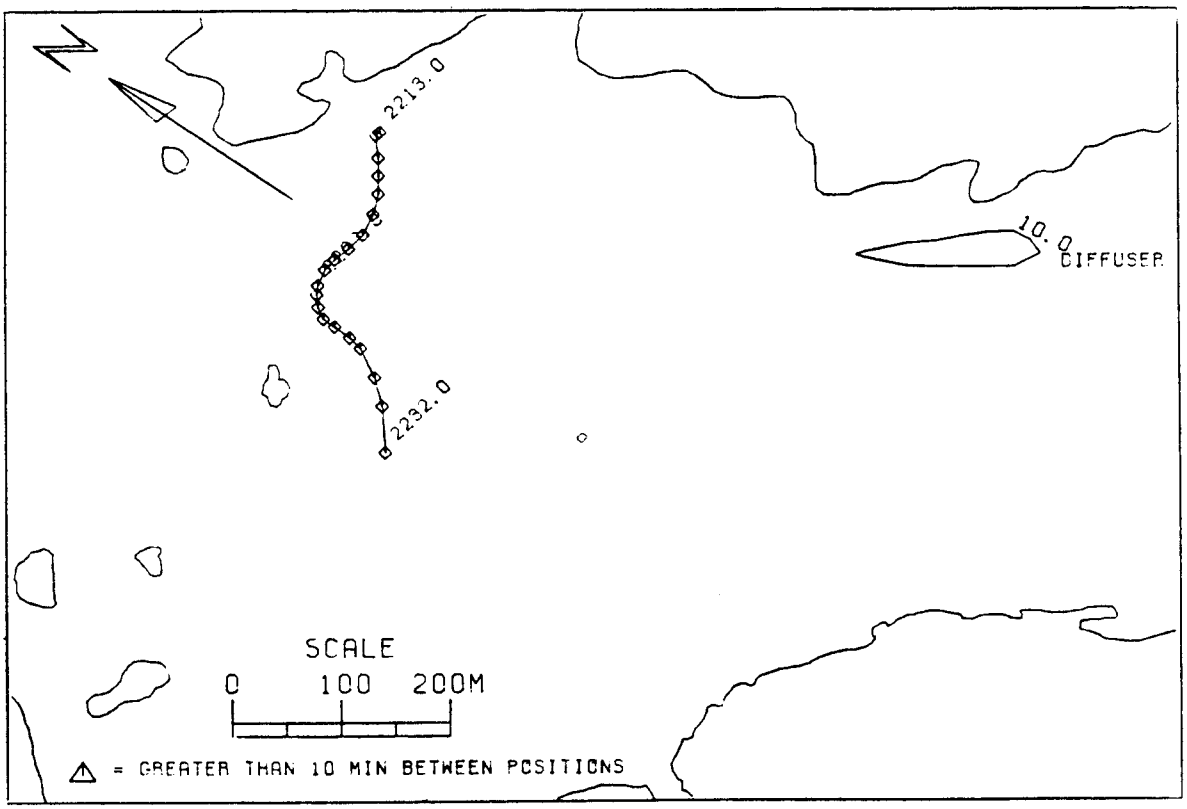

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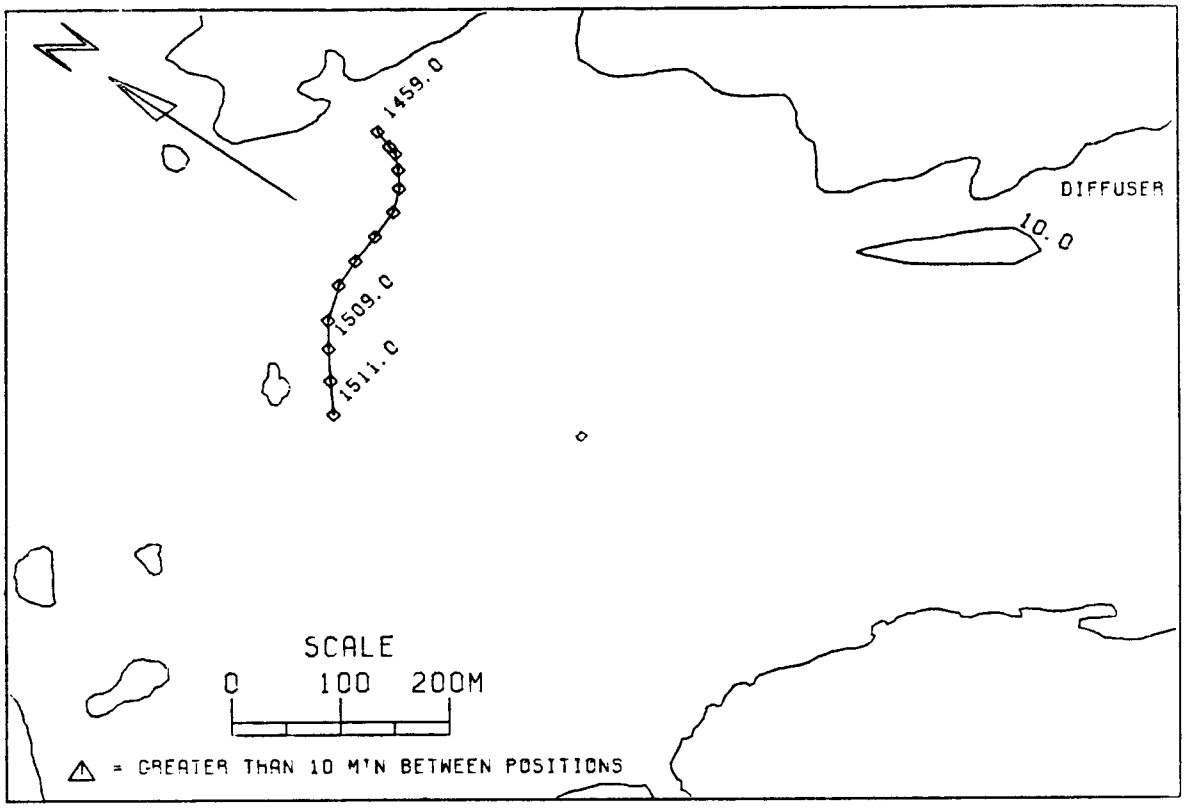

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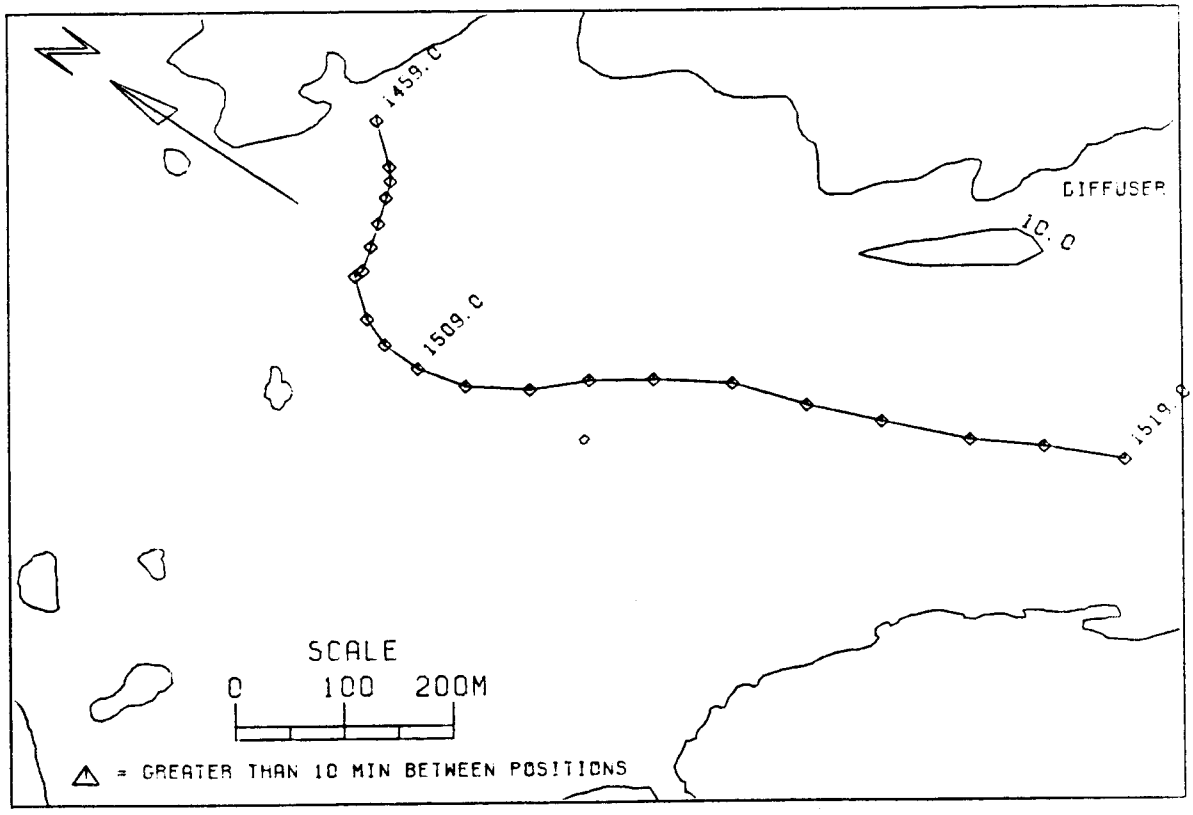
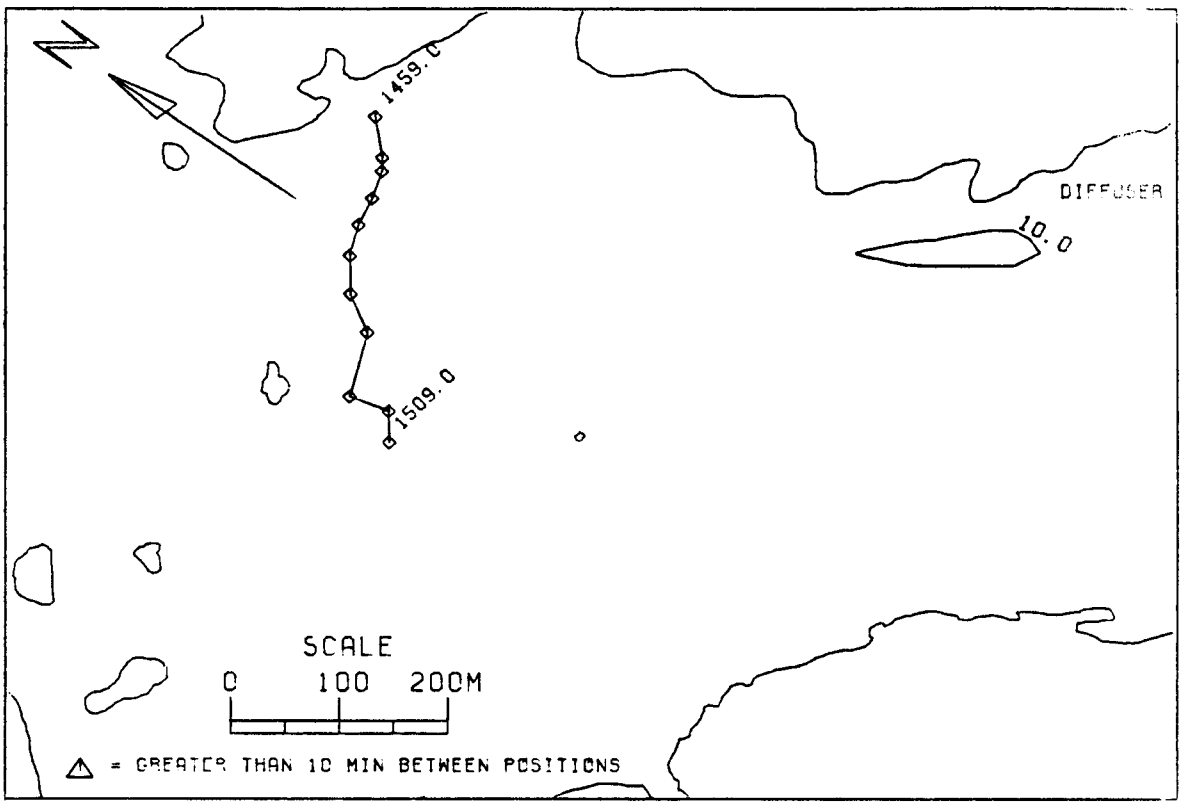


JAKOLOF BAY. FISH 44. TREAT. NO. 2, 7/25/88



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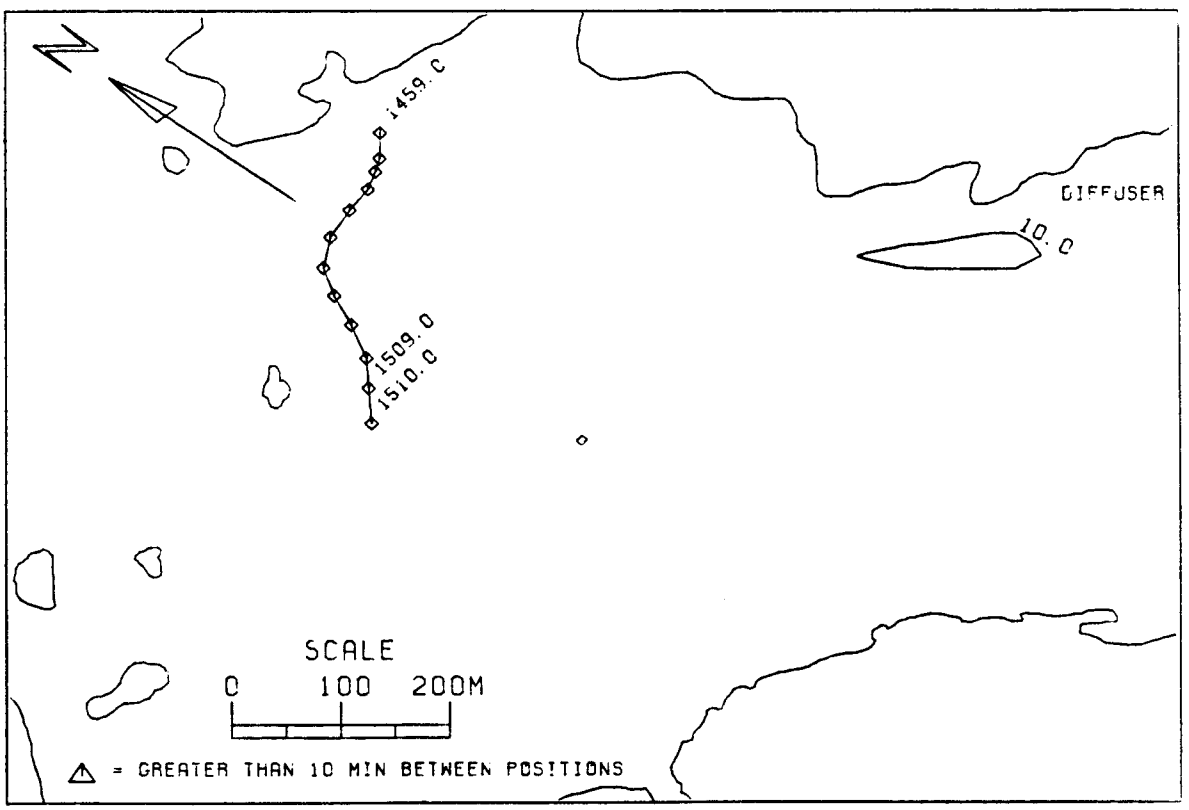

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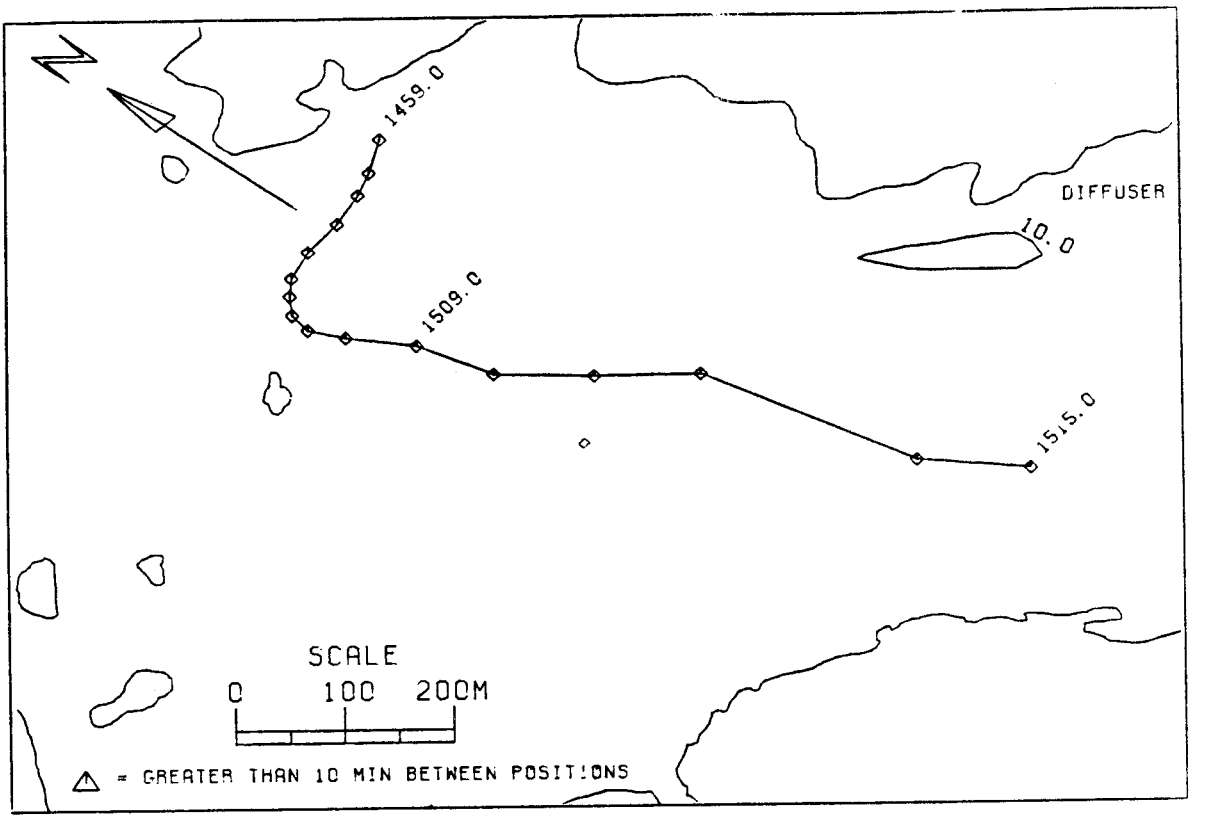

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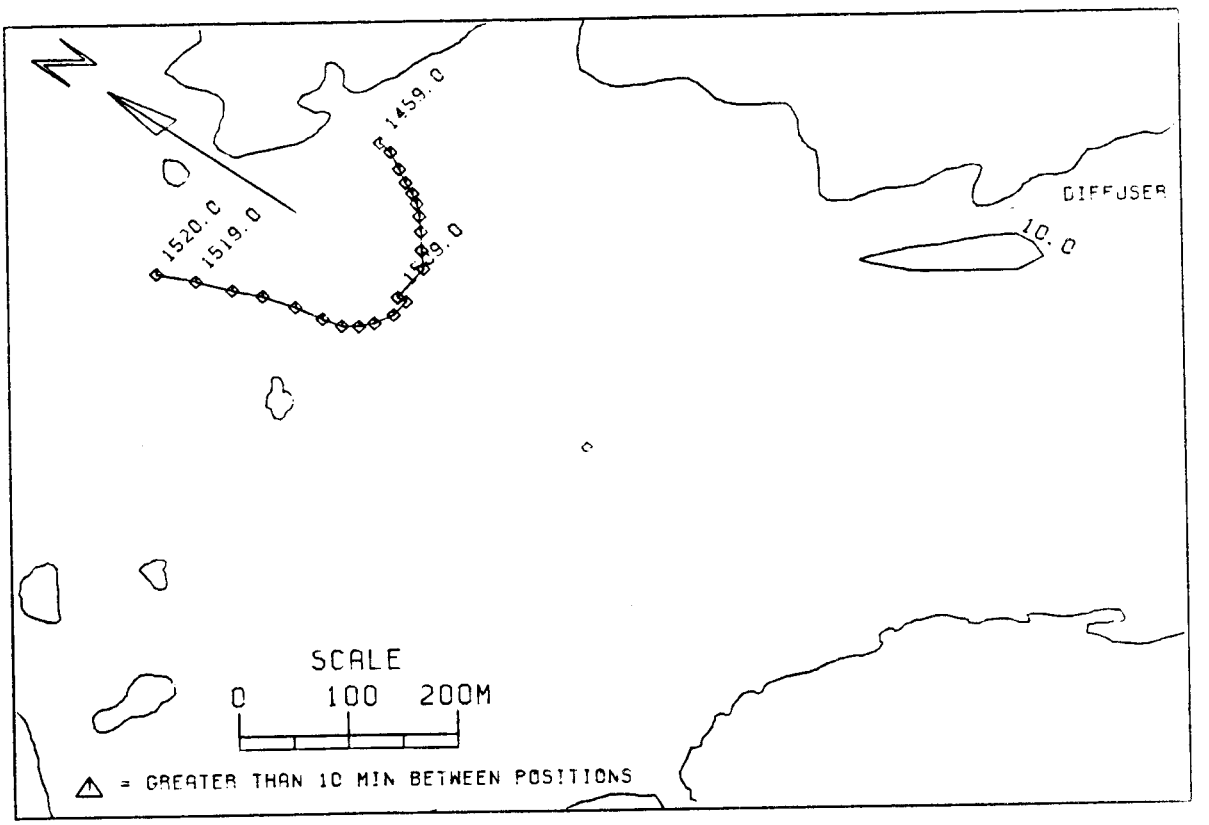

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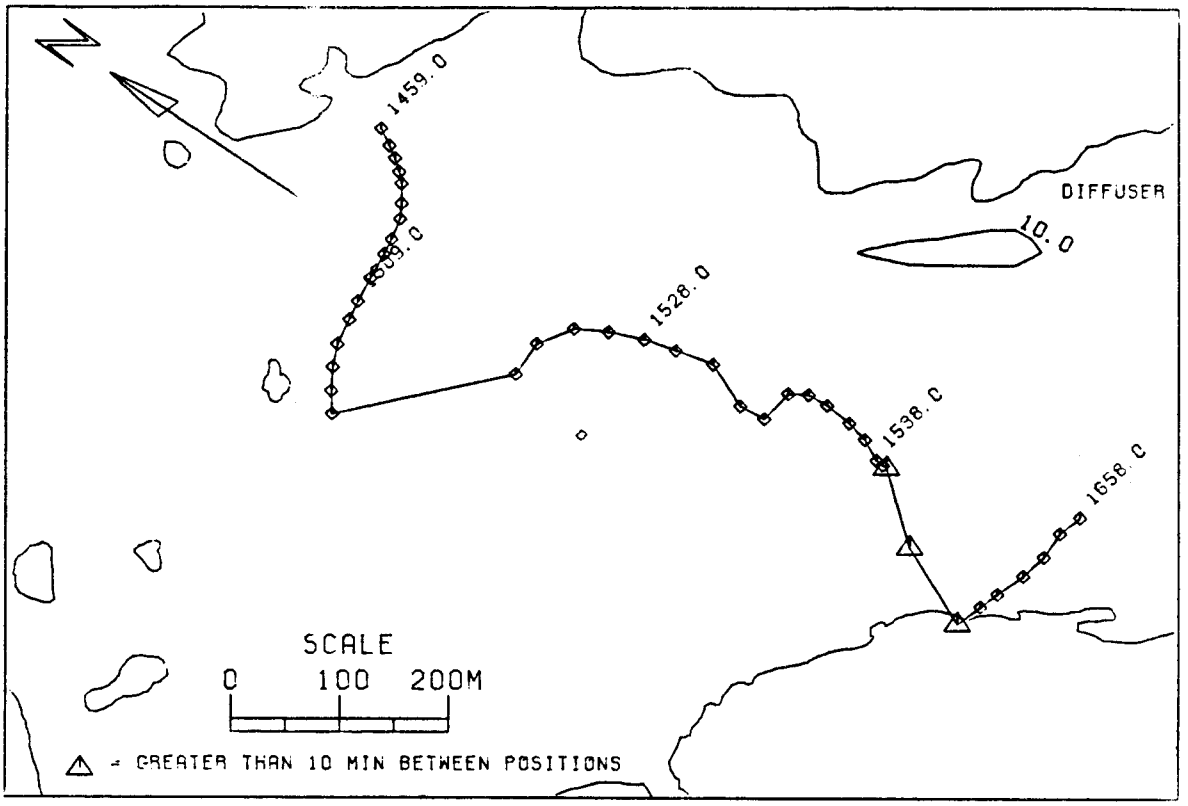
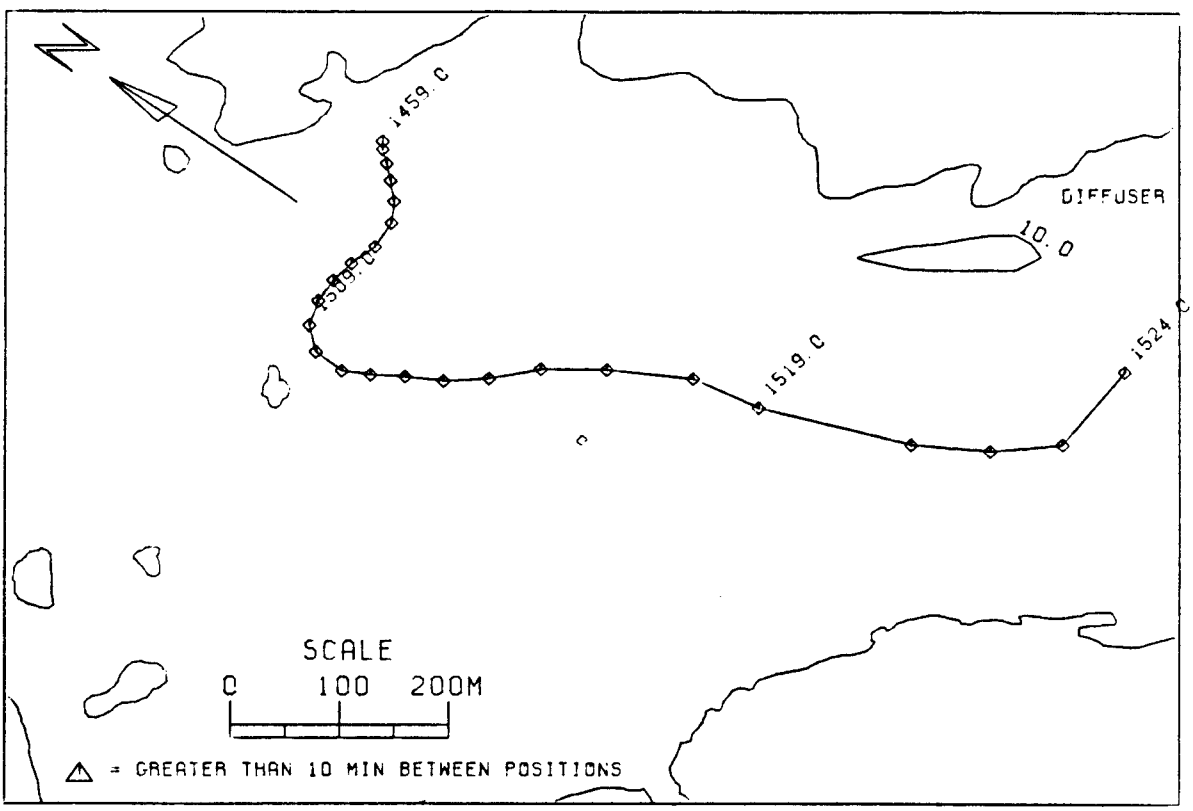
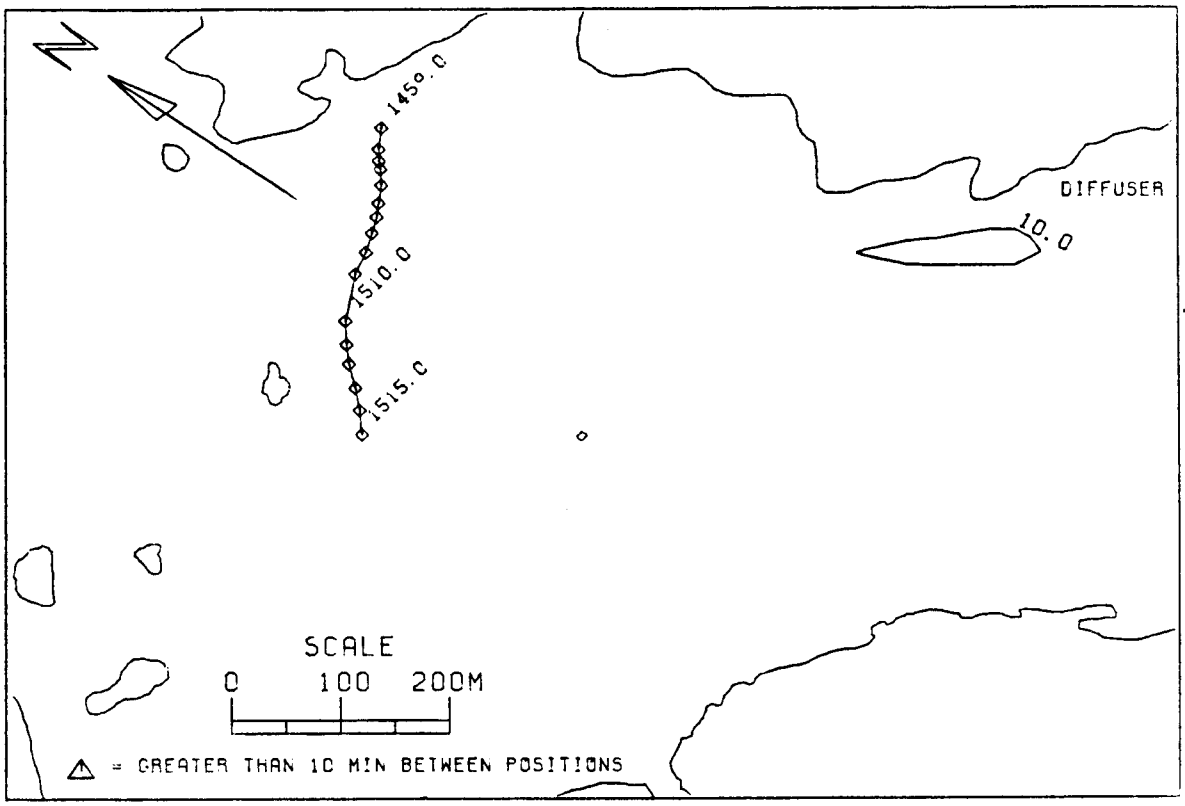


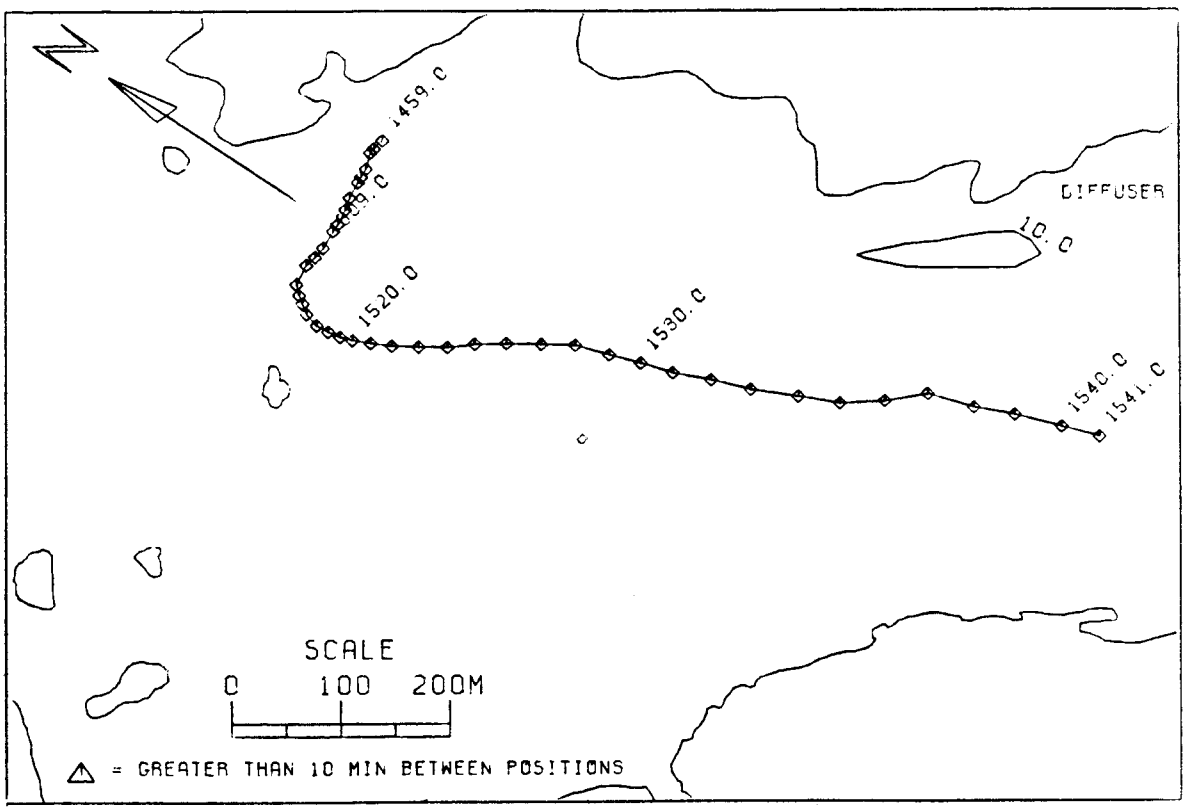
JAKOLOF BAY, FISH 49, TREAT. NO. 2, 7/25/88



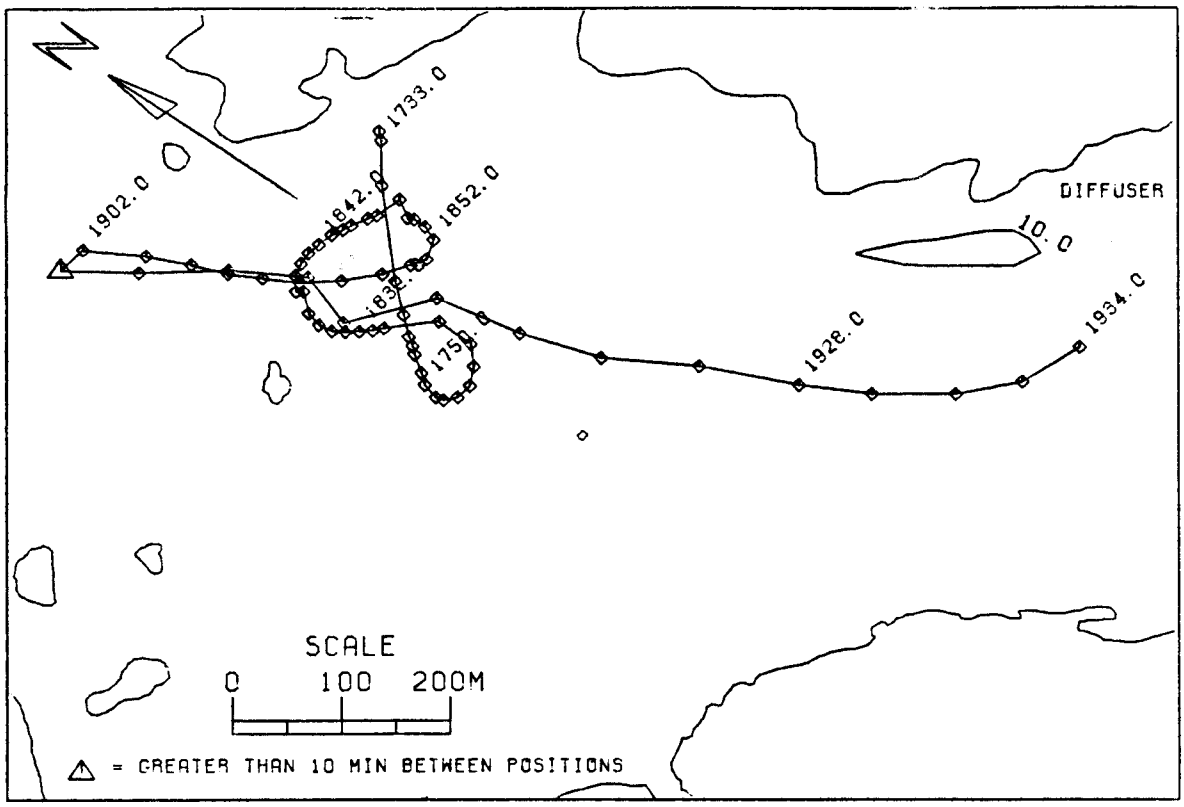
JAKOLOF BAY, FISH 50, TREAT. NO. 2, 7/25/88



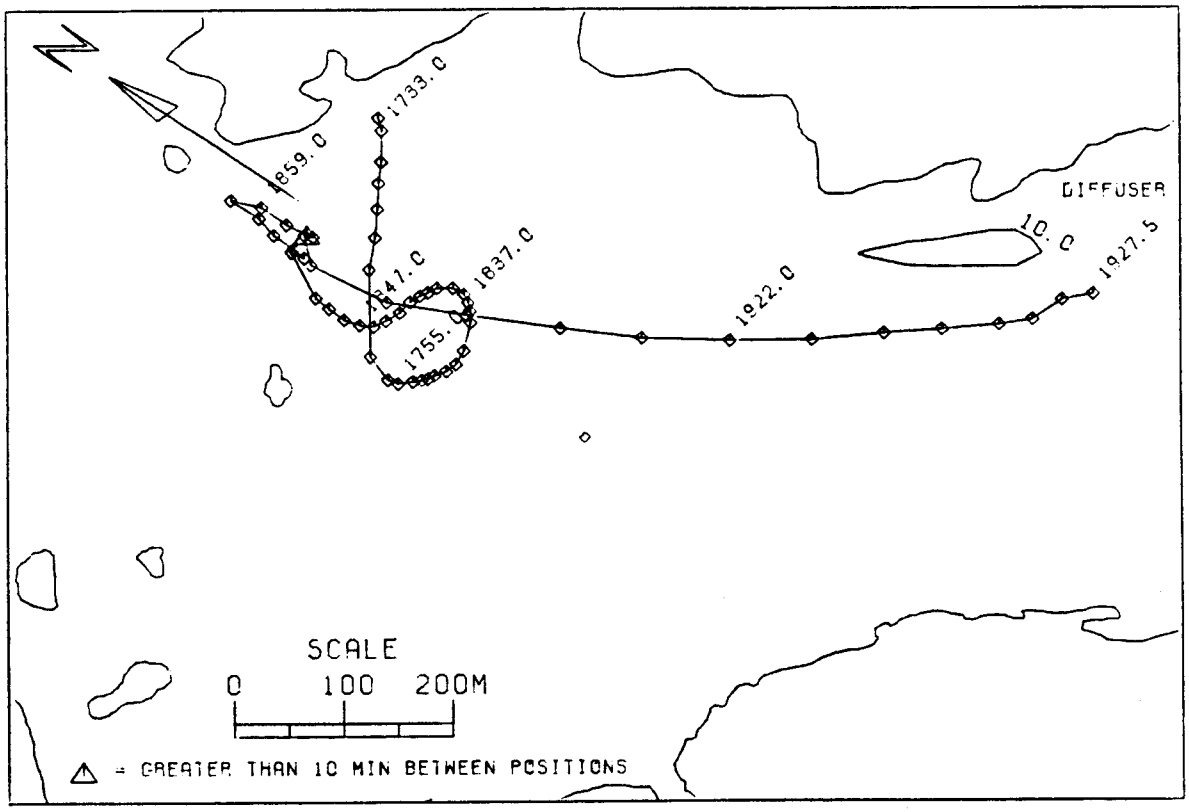
JAKOLOF BAY, FISH 51, TREAT. NO. 2, 7/25/88



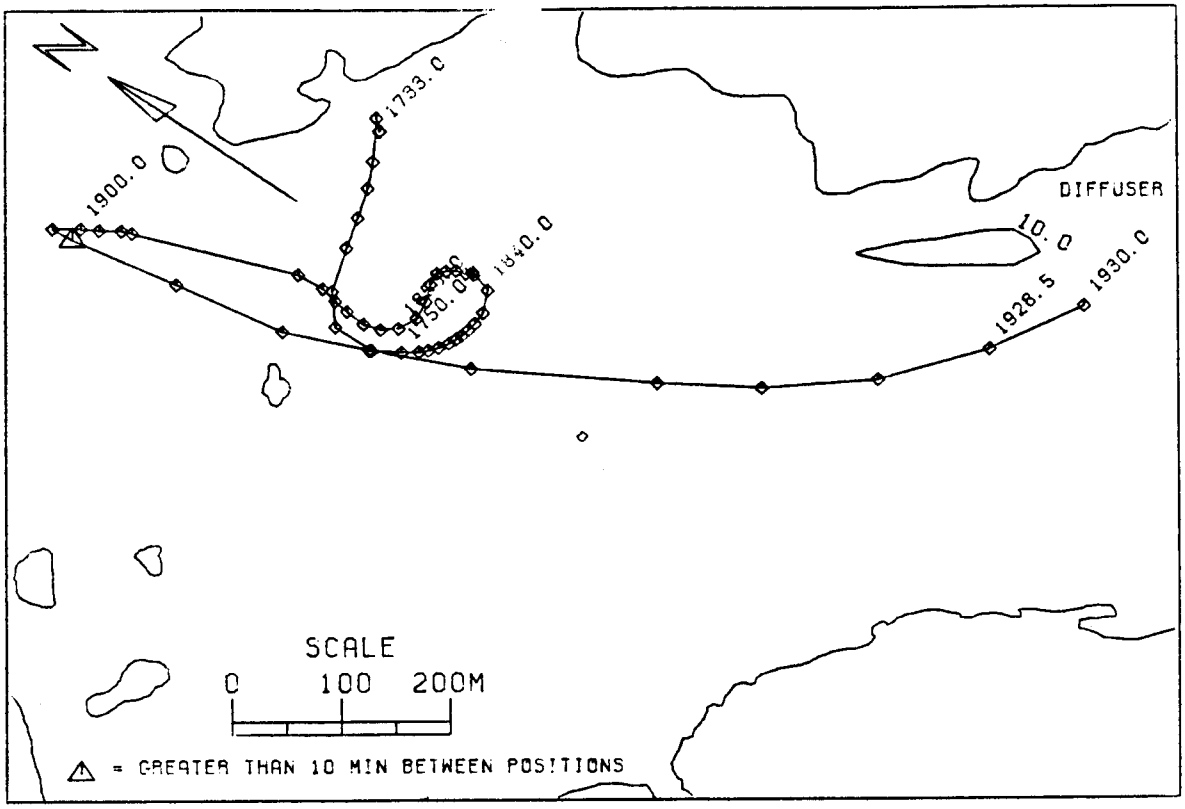
JAKOLOF BAY, FISH 52, TREAT. NO. 2, 7/25/88



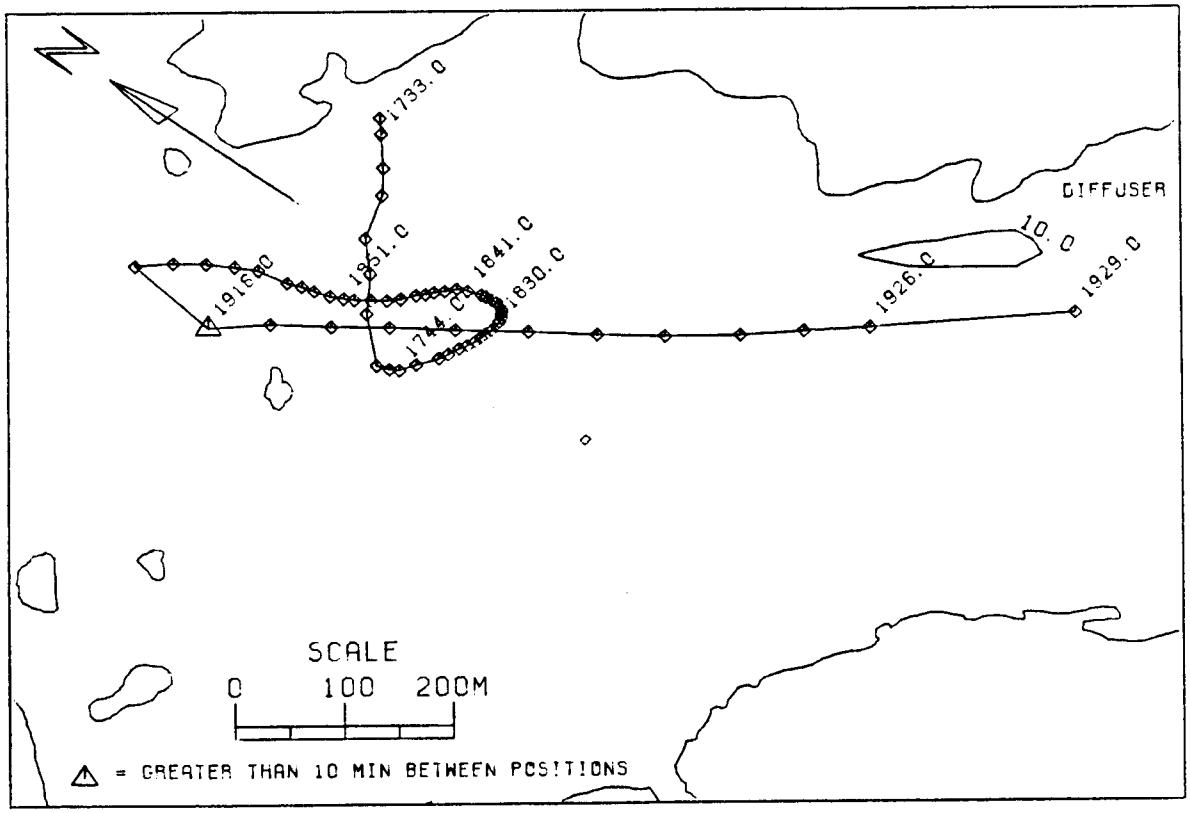
JAKOLOF BAY, FISH 73, TREAT. NO. 3, 7/29/88



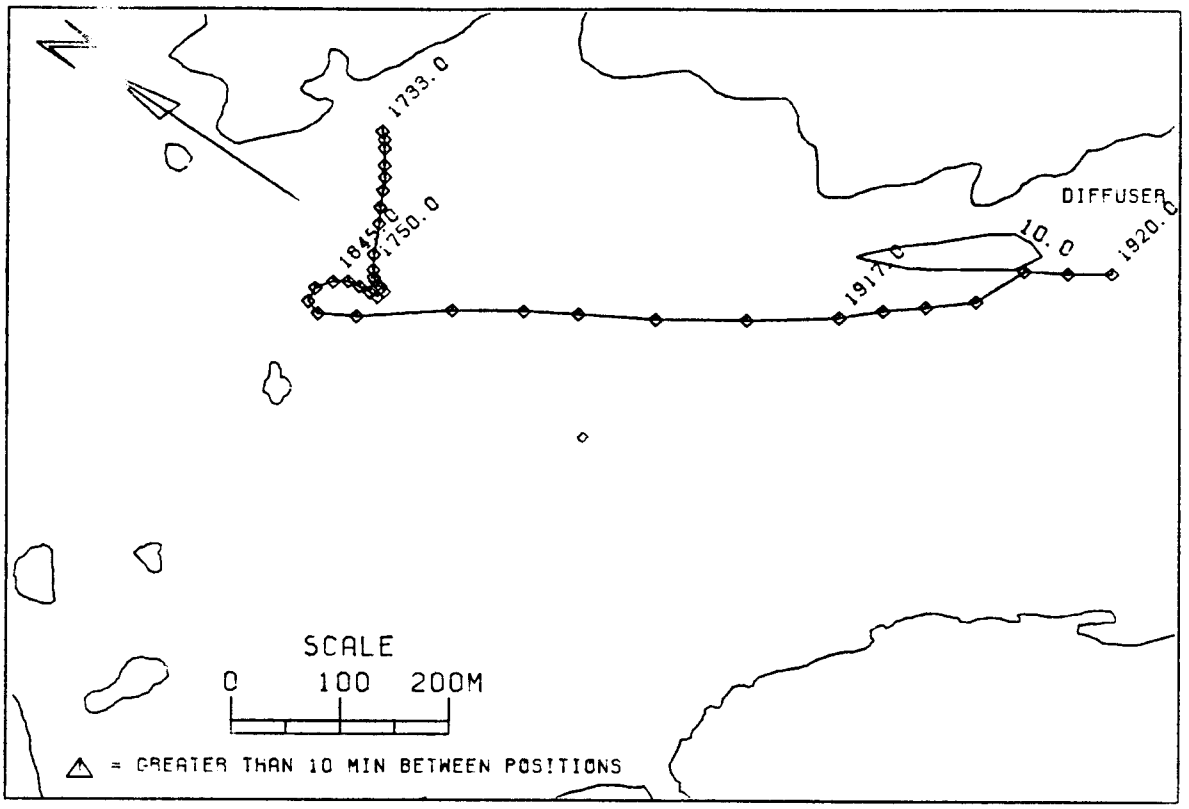
JAKOLOF BAY, FISH 74, TREAT. NO. 3, 7/29/88



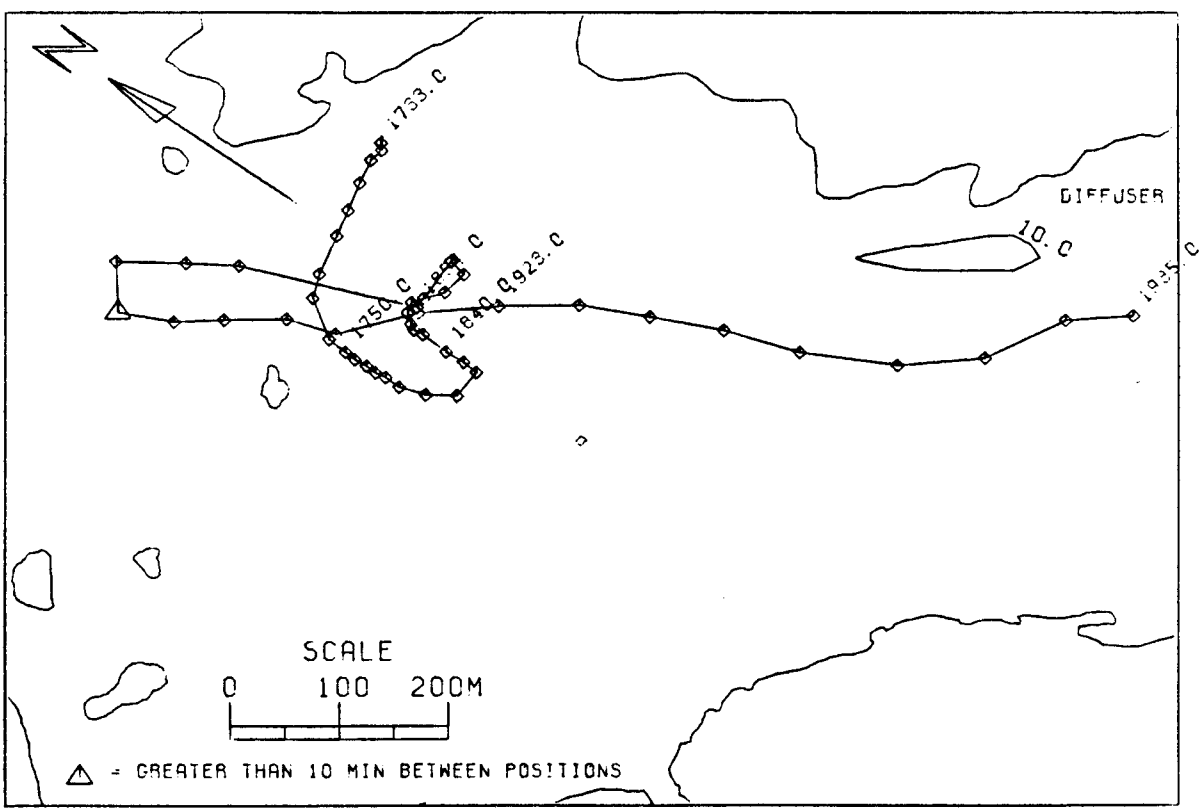
JAKOLOF BAY, FISH 75, TREAT. NO. 3, 7/29/88



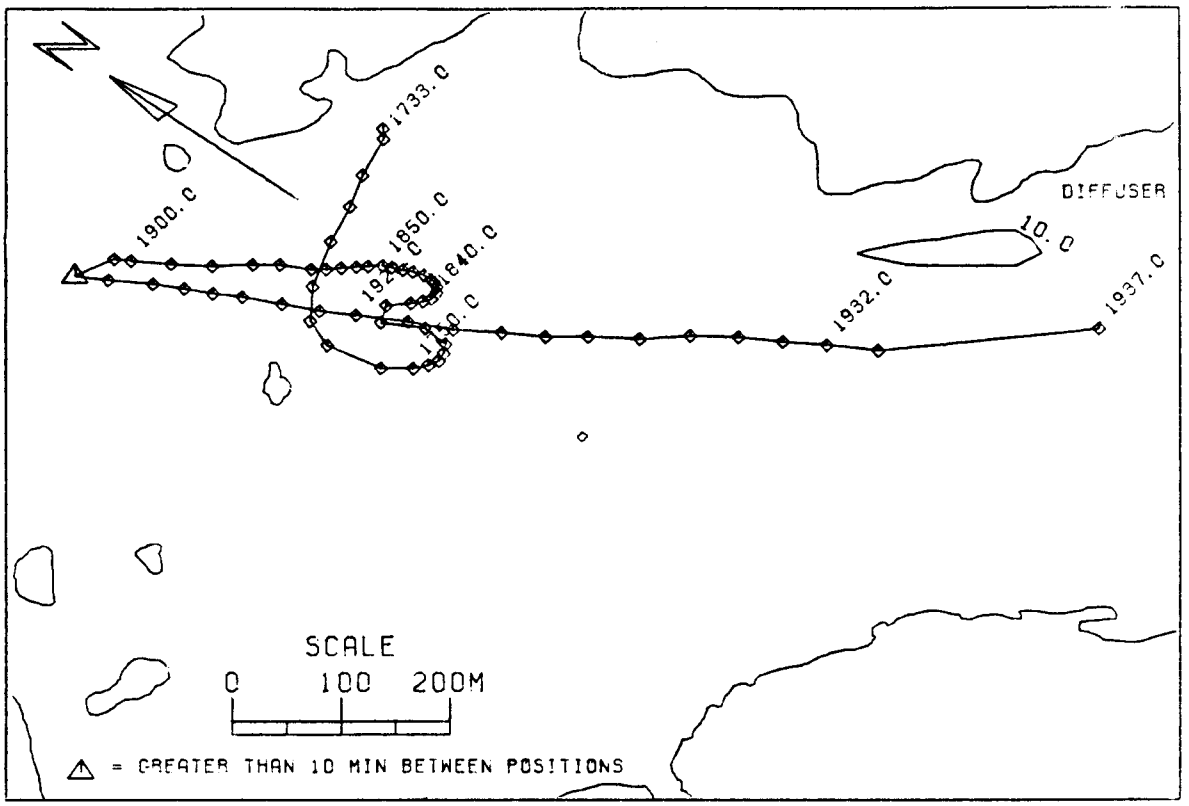
JAKOLOF BAY, FISH 76, TREAT. NO. 3, 7/29/88



JAKOLOF BAY, FISH 77, TREAT. NO. 3, 7/29/88



JAKOLOF BAY, FISH 78, TREAT. NO. 3, 7/29/88



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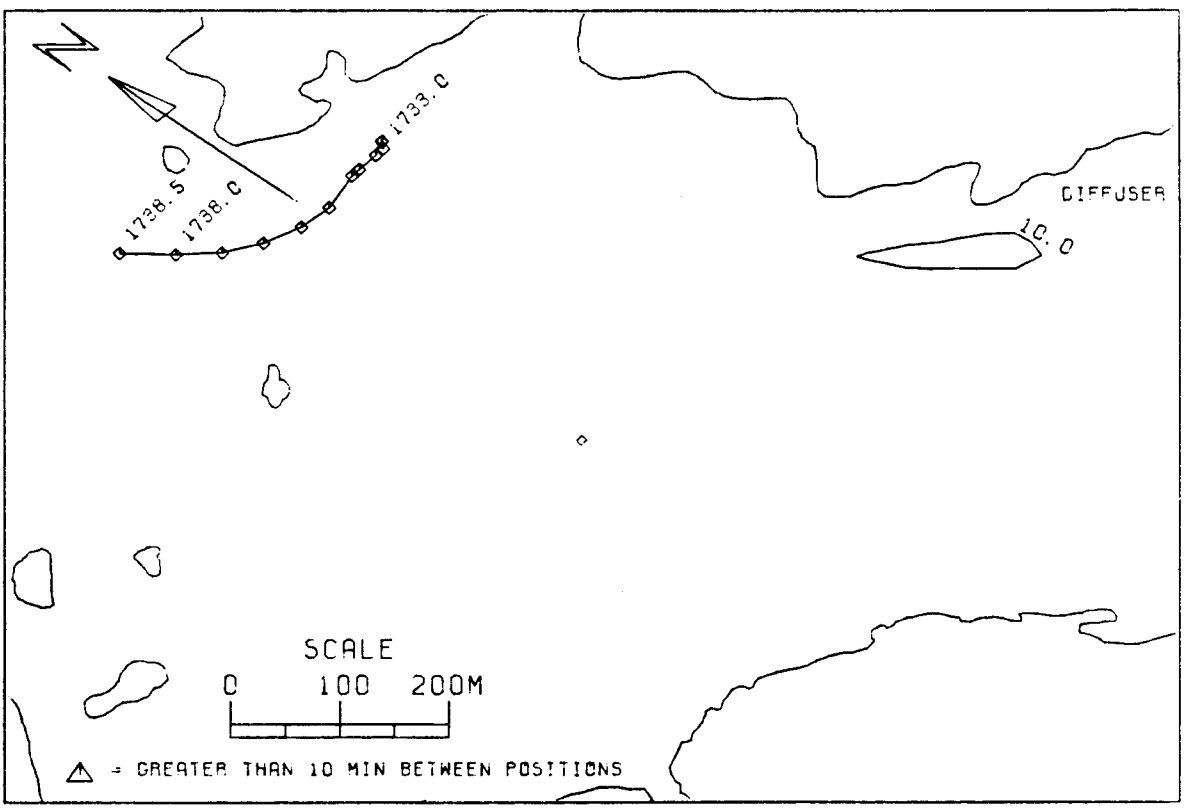
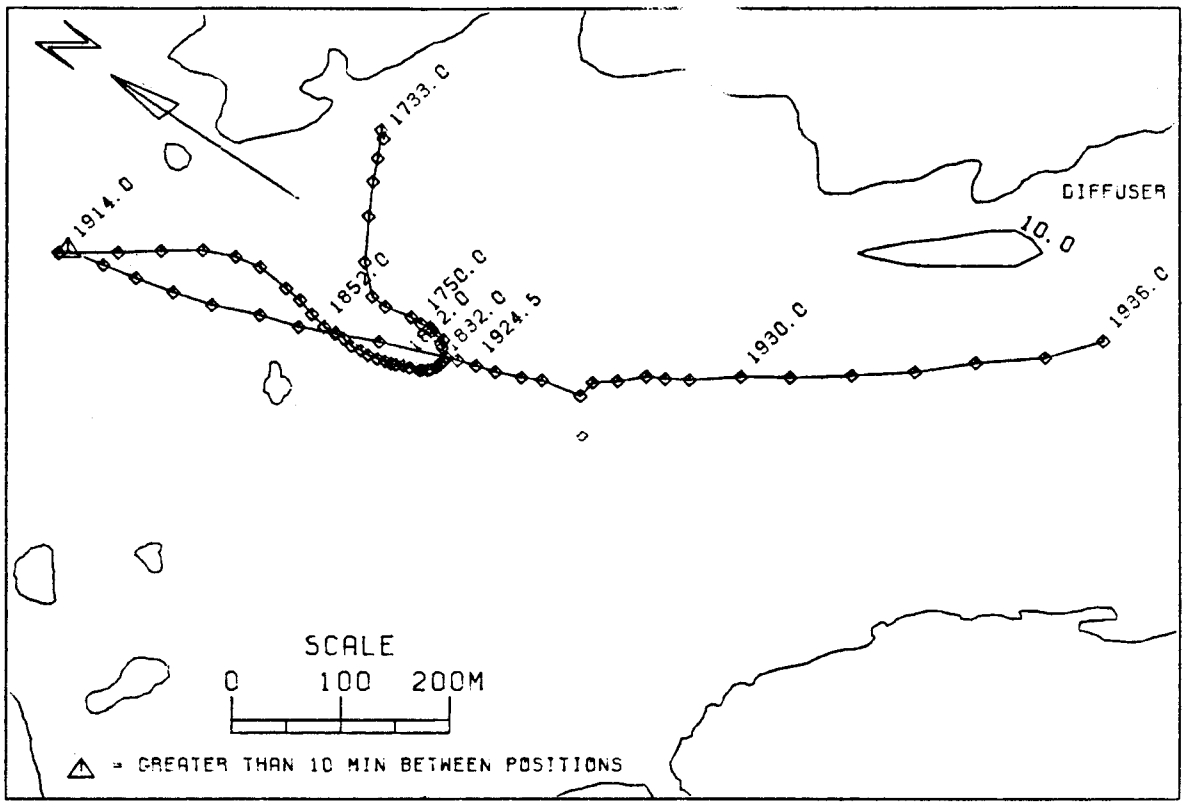
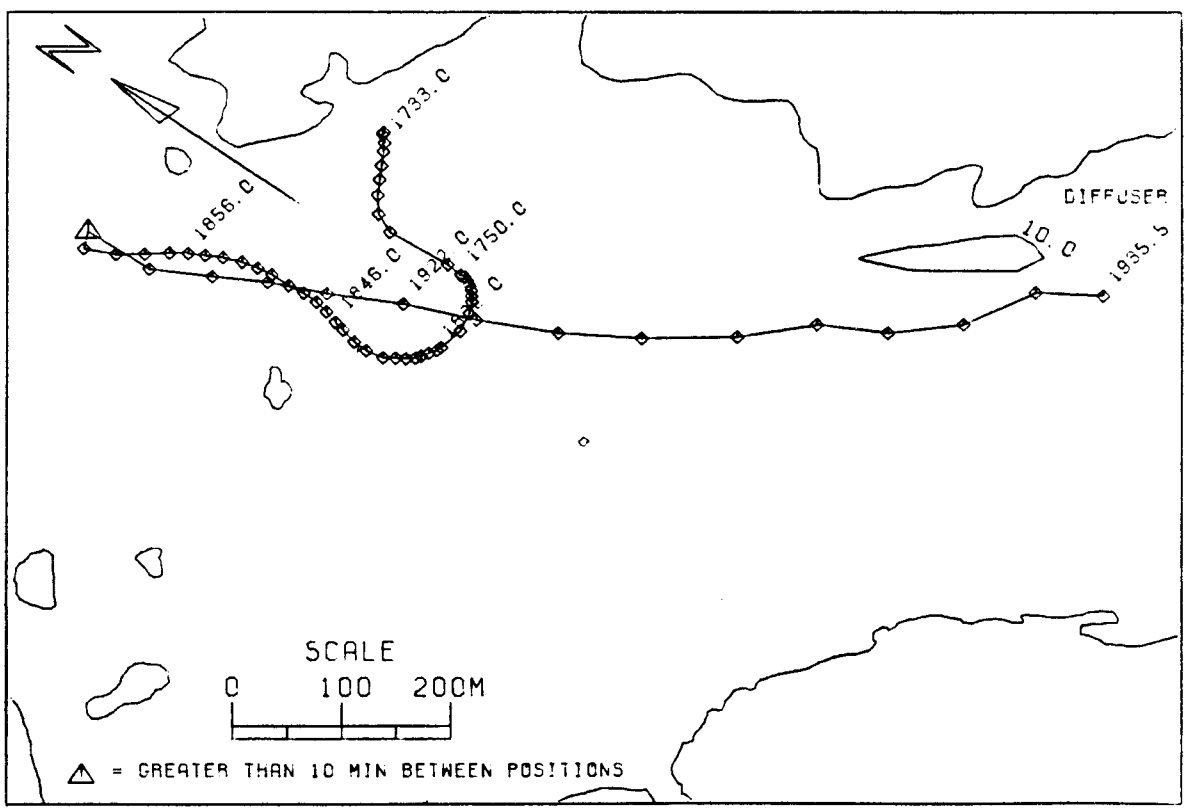


JAKOLOF BAY, FISH 80, TREAT. NO. 3, 7/29/88



JAKOLOF BAY, FISH 81, TREAT. NO. 3, 7/29/88



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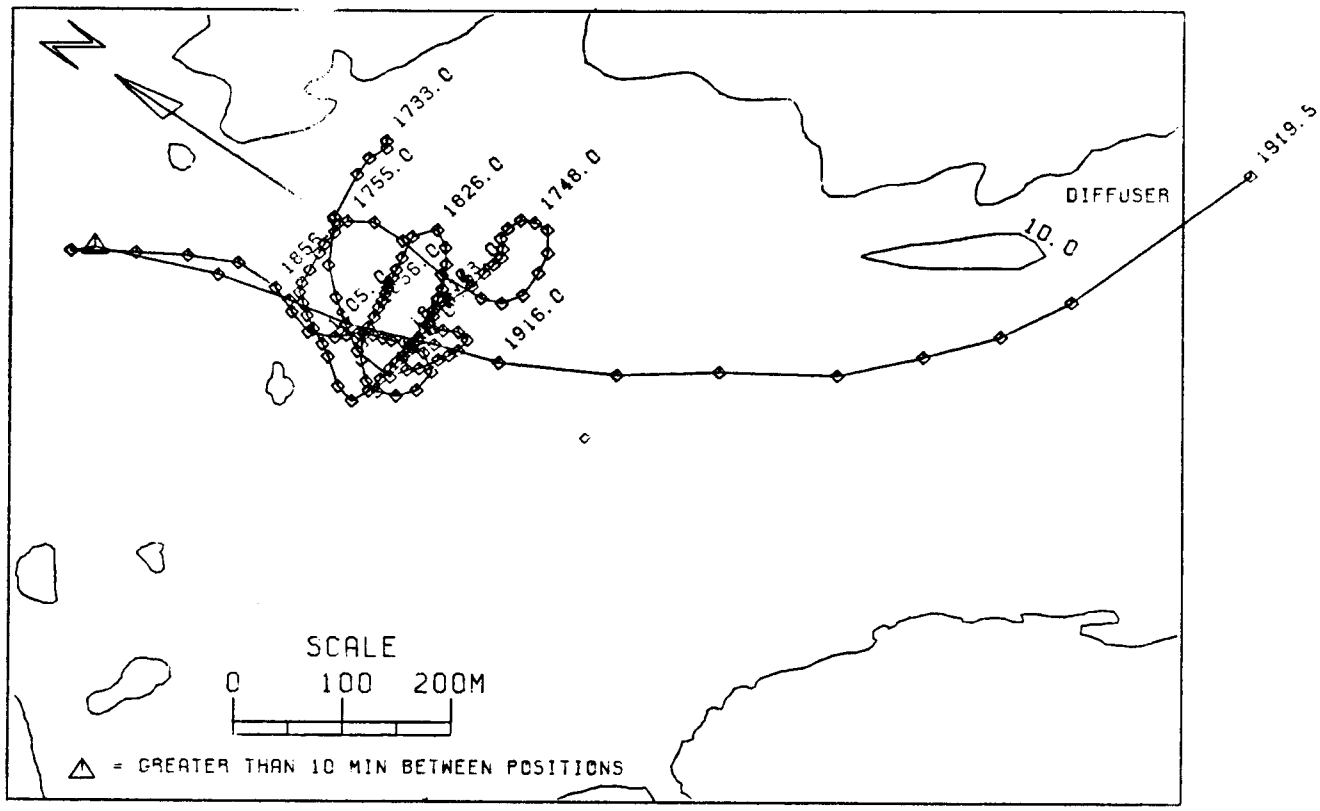

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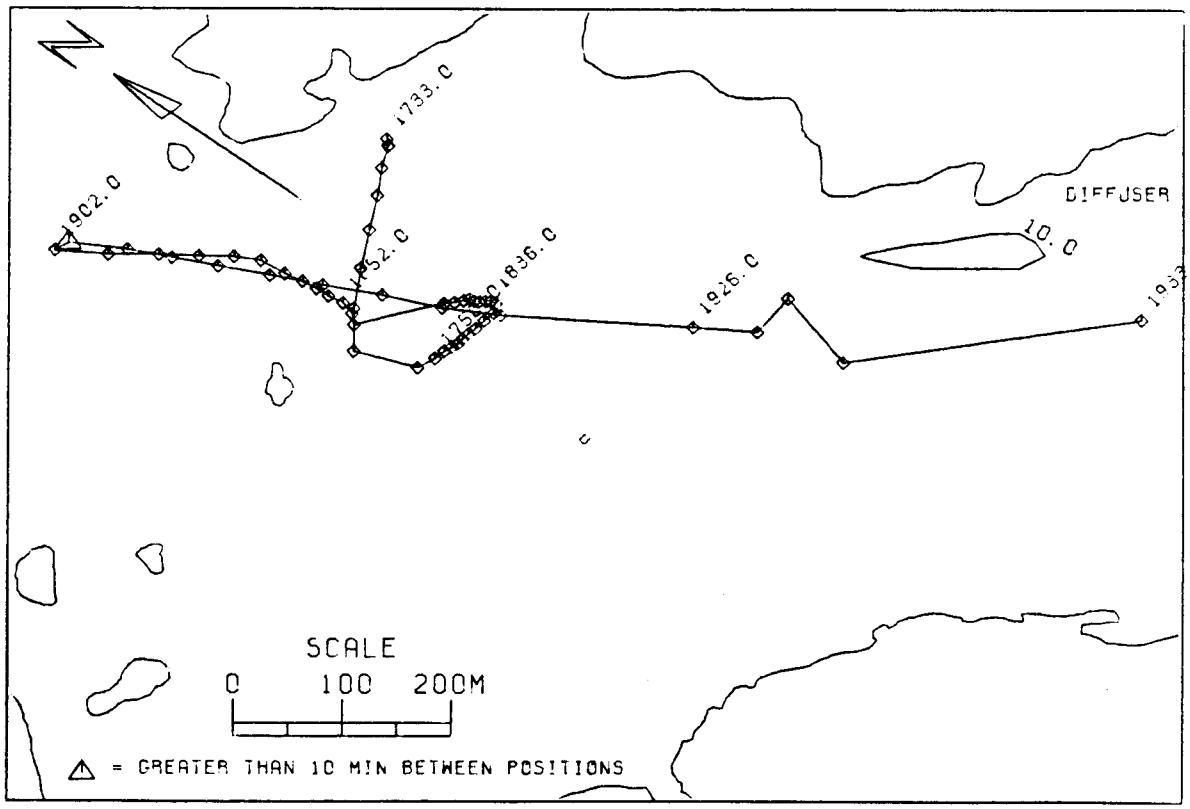

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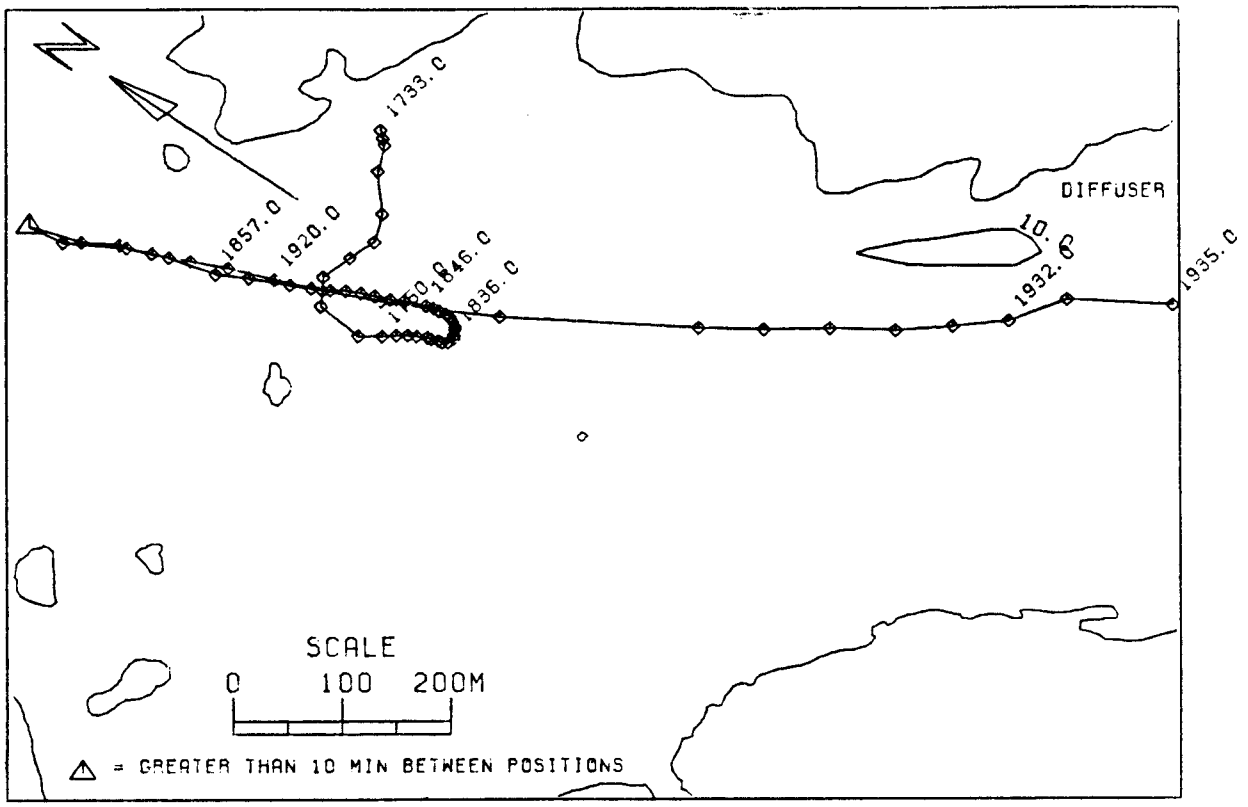

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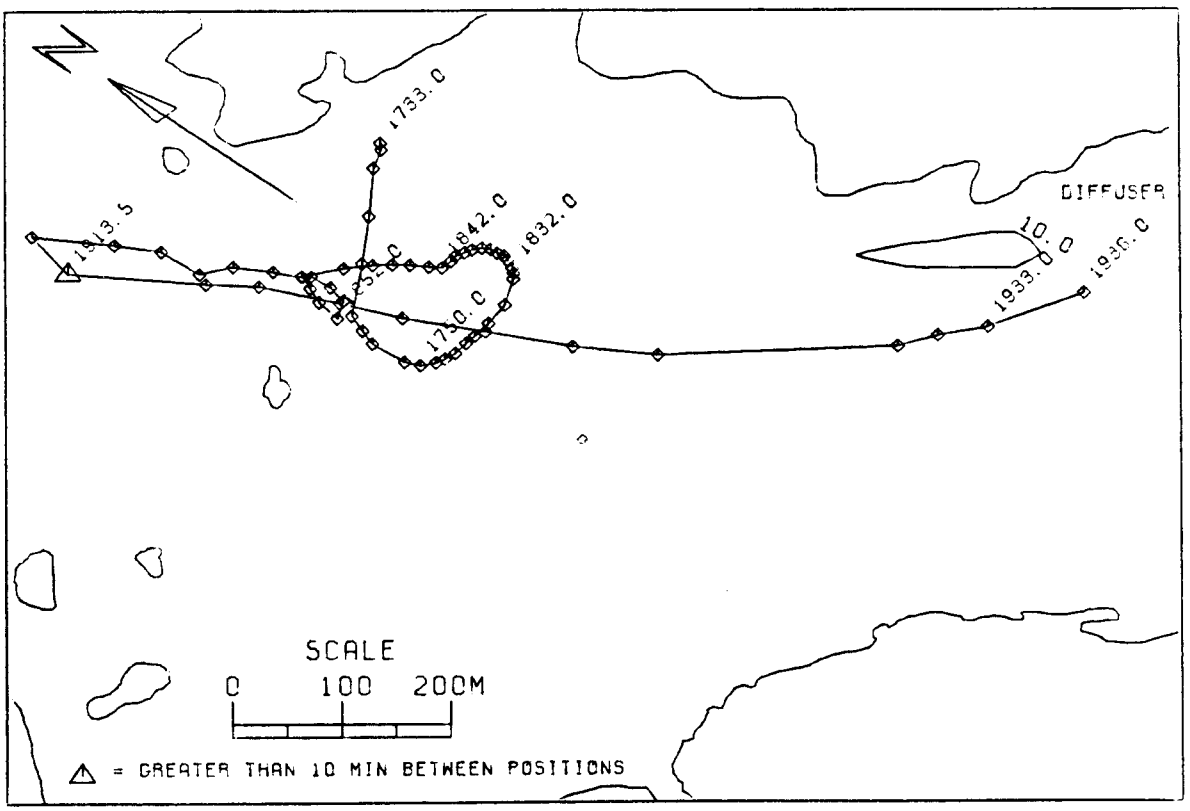

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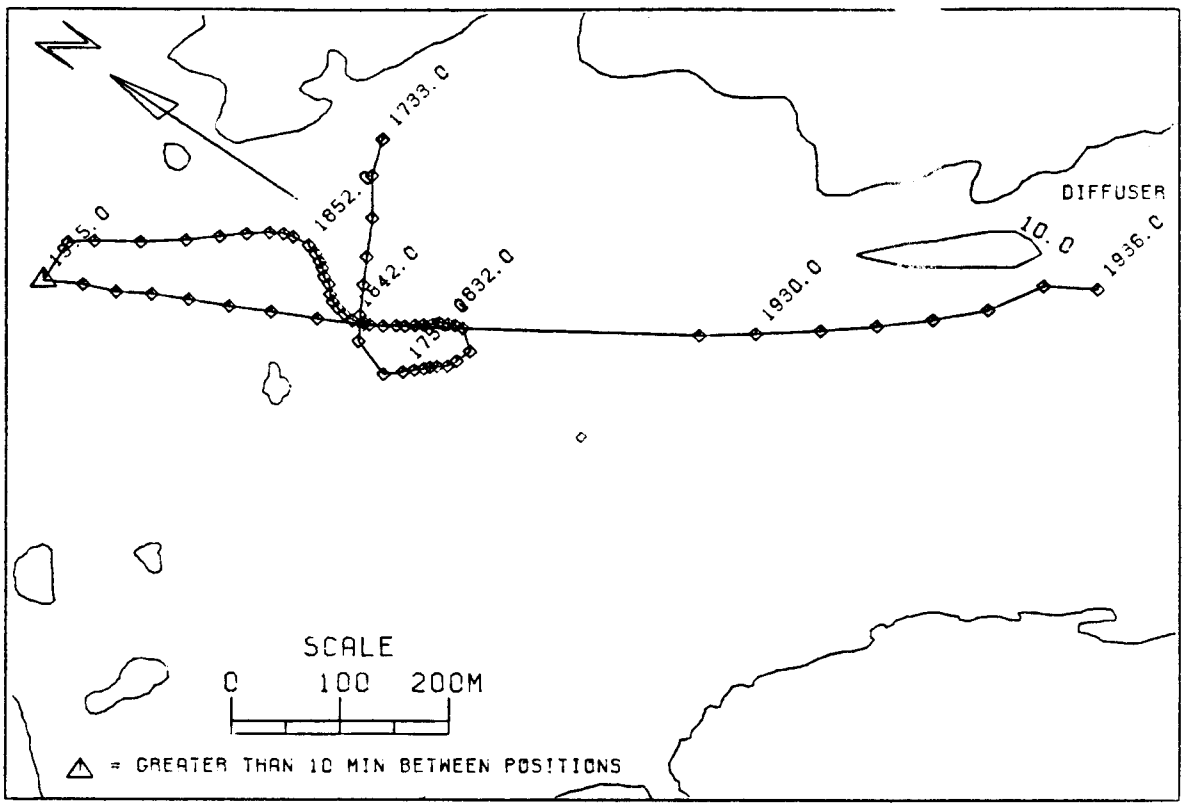

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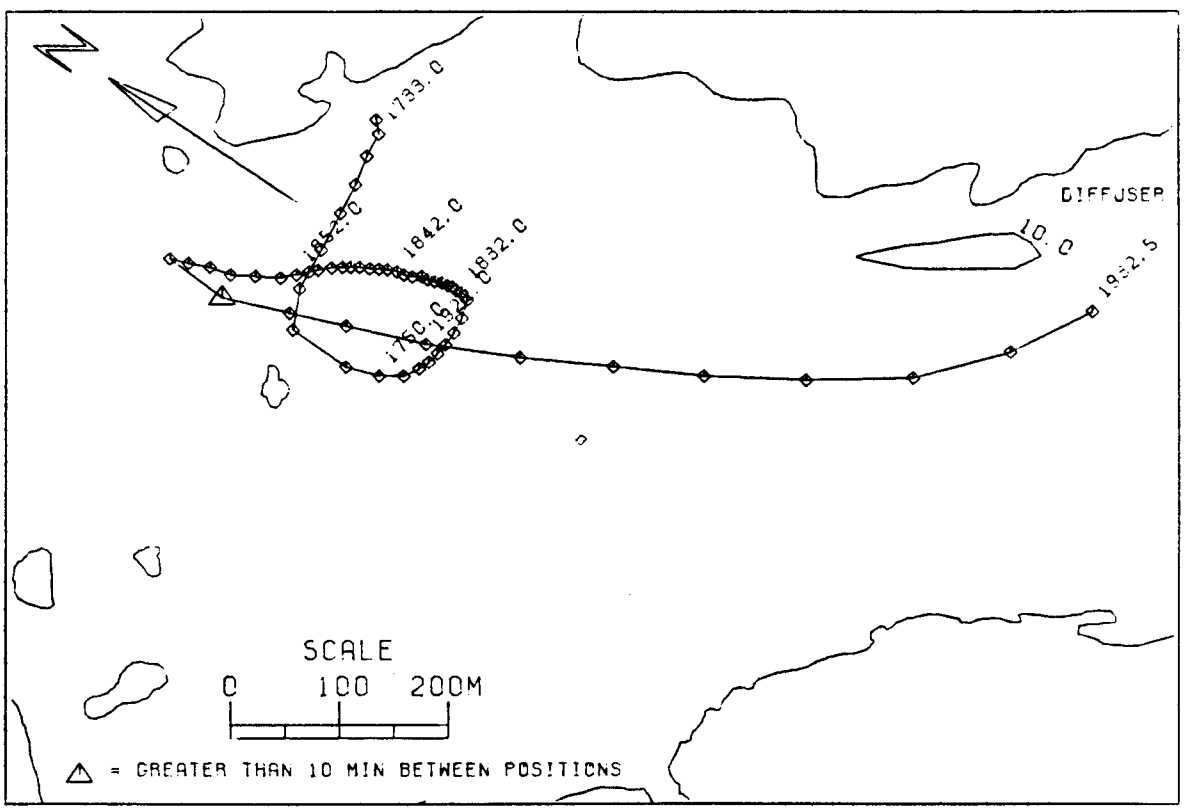

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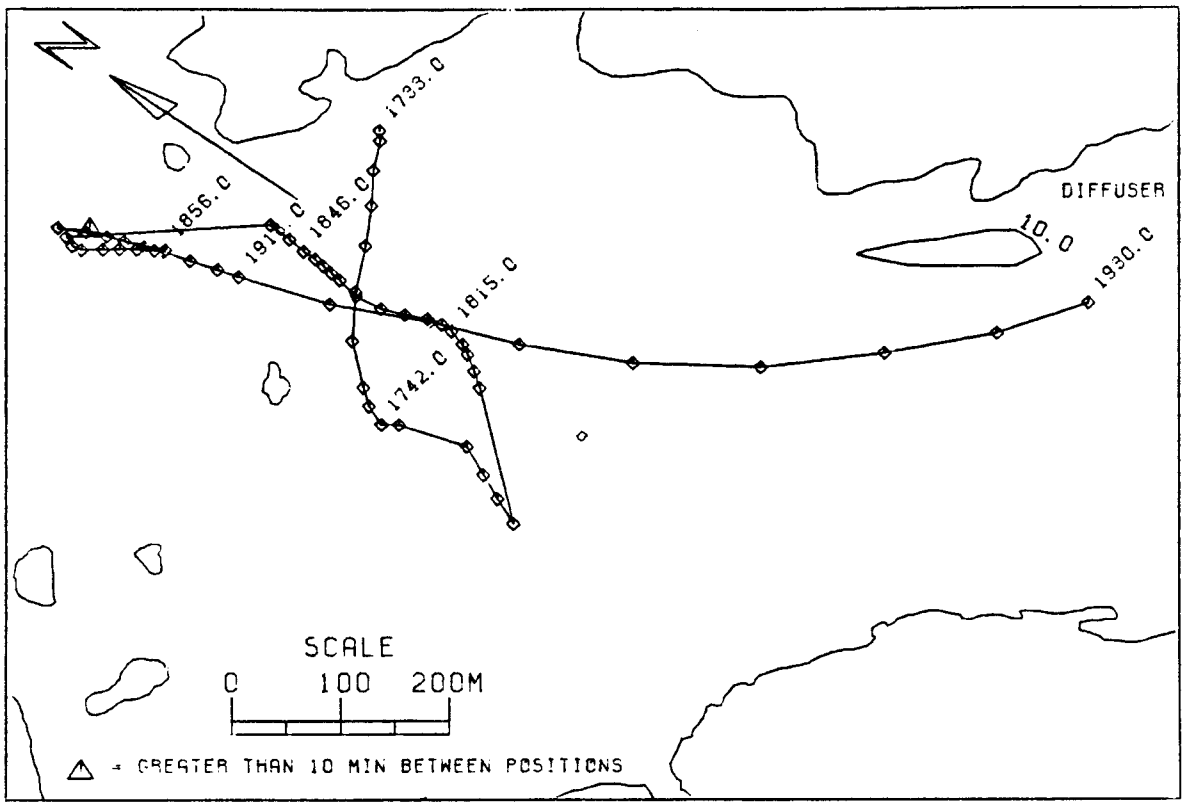

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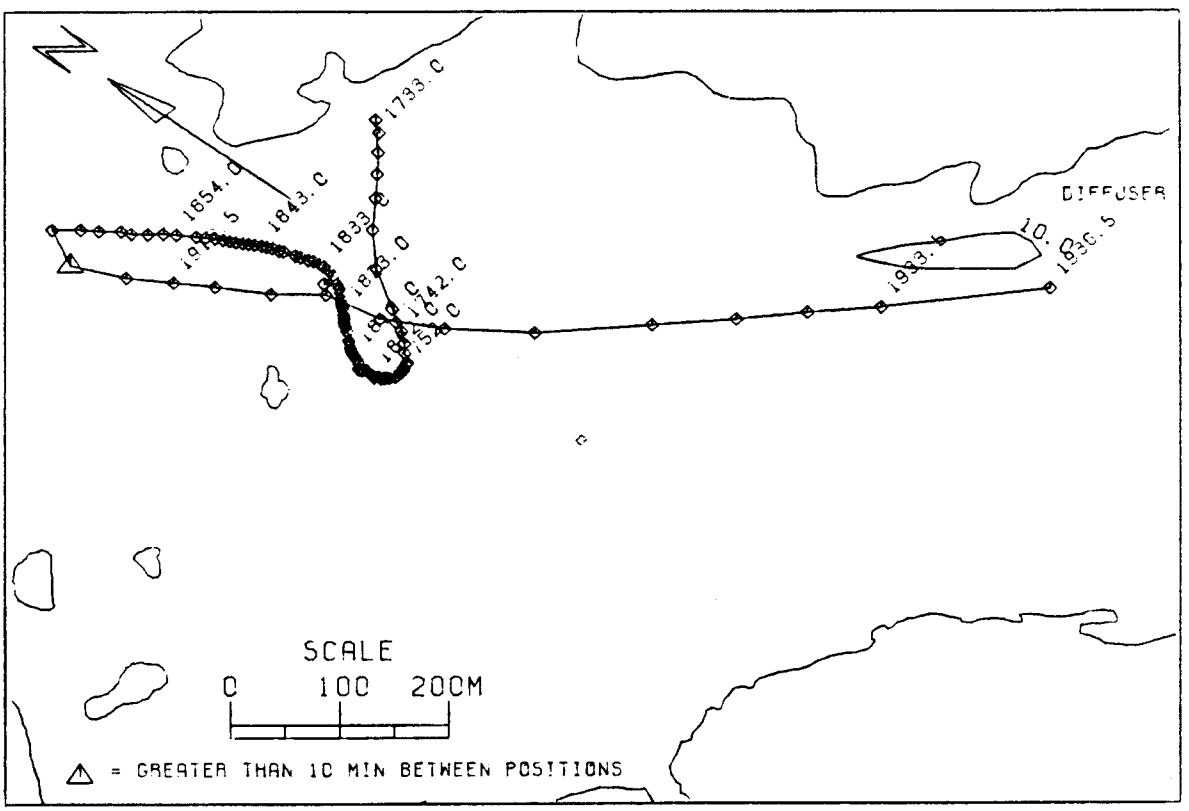

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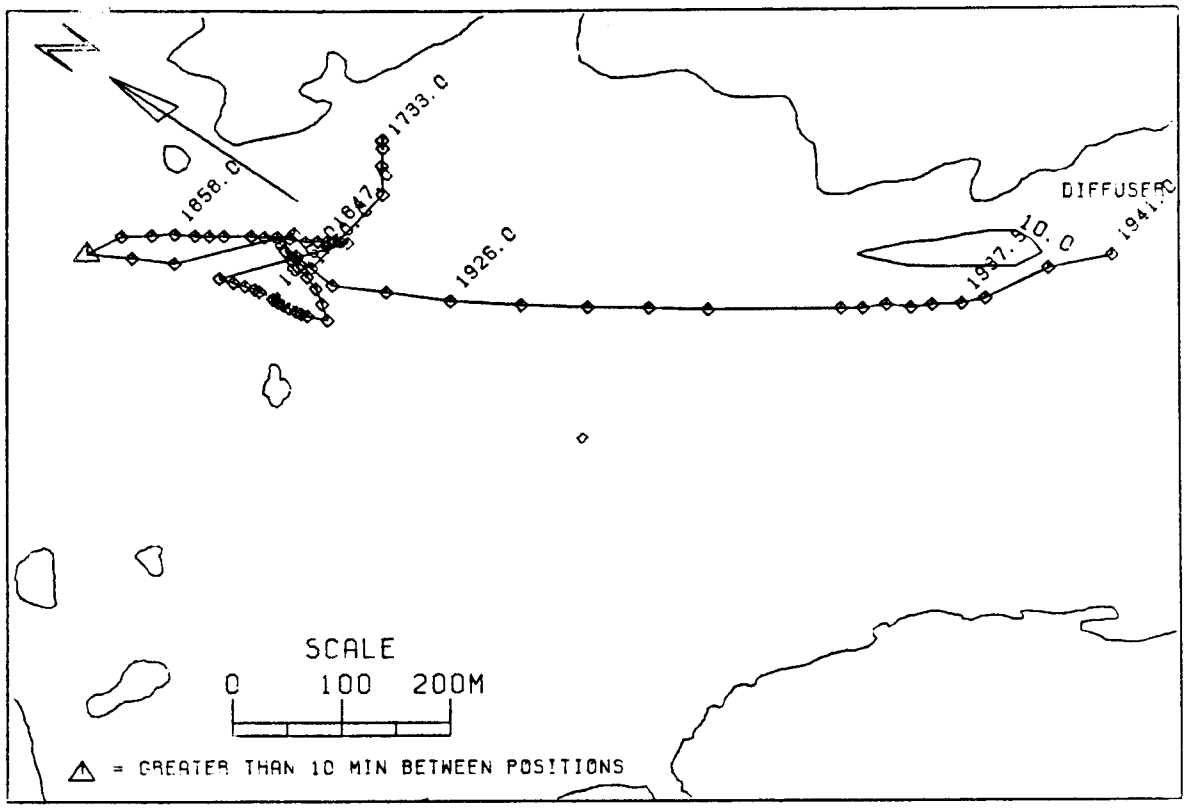

JAKOLOF BAY, FISH 91, TREAT. NO. 3, 7/29/88

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

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