229225

JUP

# Vertical Distribution of Juvenile Chum Salmon (*Oncorhynchus keta*) in Relation to a Thermal Discharge Into Port Moody Arm, Burrard Inlet, British Columbia.

I.K. Birtwell, R.P. Fink, J.S. Korstrom, B.J. Fink,
J.A. Tanaka and D.I. Tiessen

Department of Fisheries and Oceans
Science Branch, Pacific Region
610 Derwent Way, Annacis Island,
New Westminster, B.C.
V3M 5P8

1998

## Canadian Technical Report of Fisheries and Aquatic Sciences 2235

Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

Canada

## Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1 - 456 in this series were issued as Technical reports of the Fisheries Research Board of Canada. Numbers 457 - 714 were issued as Department of the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

## Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon regional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences 2235

1998

# VERTICAL DISTRIBUTION OF JUVENILE CHUM SALMON (*ONCORHYNCHUS KETA*) IN RELATION TO A THERMAL DISCHARGE INTO PORT MOODY ARM, BURRARD INLET, BRITISH COLUMBIA.

by

I.K. Birtwell, R.P. Fink[1], J.S. Korstrom,
B.J. Fink, J.A. Tanaka and D.I. Tiessen

Department of Fisheries and Oceans,
Science Branch,
Marine Environment and Habitat Science Division,
Freshwater Habitat Section,
610 Derwent Way,
New Westminster,
B.C. V3M 5P8

1.Global Fisheries Consultants Limited, 13069 Marine Drive, White Rock, B.C. V4A 1E5

Cat. No. Fs 97-6/2235E ISSN 0706-6457

Correct citation for this publication:

Birtwell, I.K., R.P. Fink, J.S. Korstrom, B.J. Fink, J.A Tanaka, and D.I. Tiessen. 1998. Vertical distribution of juvenile chum salmon (*Oncorhynchus keta*) in relation to a thermal discharge into Port Moody Arm, Burrard Inlet, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2235: xii + 99 p.

## TABLE OF CONTENTS

## TABLE OF CONTENTS (contd.)

# PREFACE

This report is one in a series that describe the results of field and laboratory studies on the effect of heated sea water on juvenile chum salmon (*Oncorhynchus keta*). The studies were initiated in response to potential increases in the thermal discharge from British Columbia Hydro and Power Authority's (B.C. Hydro) Burrard Generating Station, into the marine waters of Port Moody Arm, Burrard Inlet, B.C. This gas-fired steam-electric station operates under a permit from the provincial government, and utilises a once-through sea water cooling system. The permit allows for the discharge of up to 1.7 million $m^3$ daily of heated cooling waters ($\leq 27$ °C), drawn from, and discharged to, Port Moody Arm. An environmental impact study to assess any effects due to the thermal discharge was a requirement of an amendment to the provincial permit. An environmental assessment study plan was submitted by B.C. Hydro to federal and provincial regulatory authorities in 1996, and it was approved in 1997.

The Department of Fisheries and Oceans entered into a co-operative research venture with B.C. Hydro on selected aspects of the environmental assessment. Other studies investigated the effects of the thermal effluent on the growth of juvenile chum salmon, the heat budget of Port Moody Arm and the input from mud flats, an assessment of the potential effects of the effluent on migrating and resident fish, and the potential effects on planktonic organisms drawn into the plant and those entrained in the thermal effluent plume. Reports on these studies were provided to B.C. Hydro in December 1997, and those undertaken by the Department of Fisheries and Oceans are also to be published in the scientific literature.

The Department of Fisheries and Oceans undertook two studies in 1997:

1) The behaviour of chum salmon in response to heated sea water was investigated in the laboratory using a water column simulator that mimicked conditions the fish may encounter in Port Moody Arm. Their behaviour was examined under controlled conditions during a changing thermal regime and under thermally-stratified conditions. The response of the fish to food, their swimming, and school positions were quantified in relation to the experimental conditions.

2) "Preference-avoidance" cages (6.0 m x 0.5 m x 0.5 m) were used in Port Moody Arm to examine the vertical distribution of chum salmon at a reference location and at sites 70 m, 250 m, and 1200 m from the heated cooling water discharge. The results were related to the ambient aquatic conditions to reveal differences or similarities in the vertical distribution of salmon with proximity to the discharge location, and to identify variables that accounted for these changes.

This report documents the results of the second study.

# ABSTRACT

Birtwell, I.K., R.P. Fink, J.S. Korstrom, B.J. Fink, J.A. Tanaka and D.I. Tiessen. 1998. Vertical distribution of juvenile chum salmon (*Oncorhynchus keta*) in relation to a thermal discharge into Port Moody Arm, Burrard Inlet, British Columbia. Can Tech. Rep. Fish. Aquat. Sci. 2235: 99 p.

The vertical distribution of juvenile chum salmon (*Oncorhynchus keta*) was examined in waters receiving a thermal discharge from a gas-fired steam-electric generating plant in Port Moody Arm, Burrard Inlet, British Columbia. It was anticipated that the innate surface water orientation of these fish during their early sea life could be modified by the daily discharge of up to 1.7 million $m^3$ of heated ($\leq 27$ °C) cooling water into this 6.5 km shallow arm of Burrard Inlet.

Aluminum-framed 6.0 m x 0.5 m x 0.5 m "preference/avoidance" cages were deployed at 4 locations (a reference site west of the thermal discharge, and at 70 m, 250 m, and 1200 m east) in Port Moody Arm. The volitional movement of separate groups of 60 fish in each cage was examined on 12 to 16 occasions at each site between June 25 and August 22 1997. The timing of this investigation coincided with the latter stages of the period that juvenile chum salmon use Burrard Inlet. The technique permitted the vertical distribution of salmon held in the waters of Port Moody Arm to be determined at 1 m depth intervals within the enclosed 6 m column. The porous exterior of the cages facilitated water flow through the apparatus thus maintaining the natural vertical stratification. Temperature, salinity, dissolved oxygen, total gas pressure (TGP), pH, oxidation-reduction potential, and light intensity were measured at 0.5 m intervals from the surface to 5.5 m depth before and after each exposure period. In addition, Secchi depth visibility was also determined immediately adjacent to each cage at the start and end of an experiment (approximately 20 h). The fish distribution and water quality data were analysed to reveal correlations and relationships between these data.

All of the juvenile chum salmon that were used in the field experiments survived. Between June and July, most of the fish were located in the uppermost chamber of the apparatus at all of the sites. The distributions in August were more variable and revealed a downward shift over the 6 m depth. Overall, fewer mean numbers of fish were present in the uppermost waters proximal (70 m) to the thermal discharge, but on comparing all data, there was no statistically-significant difference in the vertical distribution of chum salmon among the experimental sites.

Only two water quality variables were significantly different among the study sites. Temperature at 2.5 m and 3.5 m depths was significantly higher at site 2 and site 3 (70 m and 250 m east of the discharge, respectively), but at 3.5 m only site 2 was different from the other sites. Dissolved oxygen was significantly lower at 0.5 m and 1.5 m depths at site 2 than at the other sites. Both these results were considered to reflect the effect of the thermal plume which contained waters of higher temperature but lower dissolved oxygen relative to ambient waters at the same depth. The levels of dissolved oxygen were depressed relative to the supersaturated waters (dissolved oxygen and TGP) more distant from the thermal discharge, but remained close to optimal values (90% to 100% of air saturation) for salmon and other aquatic organisms.

Forward stepwise regression was used to determine the water quality characteristics most related to the recorded vertical distribution of the caged chum salmon. At the reference site, dissolved oxygen, pH, TGP, and depth were shown to be correlated with fish distribution. At the sites 70 m and 250 m from the thermal discharge, only depth and light intensity were significantly correlated. At 1200 m, fish distribution was correlated with temperature, pH, TGP, and depth. Combining the data for all sites, temperature, dissolved oxygen, pH, TGP, and depth were the primary water quality variables related to the observed vertical distribution of the caged salmon. Time of year was the predominant variable shown to influence the presence of fish in the uppermost (0 - 1 m) waters of Port Moody Arm: fewer fish occupied the surface waters in August than in earlier months.

The Burrard Generating Station operated intermittently during the summer of 1997, and therefore the volume and temperature of water discharged varied considerably during our 2-month experimental period (497 to 1194 $m^3 \cdot d^{-1}$ at 18.7 °C to 26.7 °C). This variation, and the relatively cool surface waters of the inlet during the early part of the study contributed to the variation in the aquatic characteristics among sites. Water temperature at the study sites rarely attained levels that proved to be acutely lethal in laboratory studies, and were frequently within laboratory-derived preferred or tolerated ranges. Temperatures were highest in July. Even when surface water temperatures in Port Moody Arm were at or above levels found to evoke avoidance responses by chum salmon in laboratory studies (EC50 value 20.2 °C) some portion of the caged fish continued to occupy the upper water column. Both non-thermal and thermal cues were probably associated with this preference of caged fish for the seasonally-warm surface waters of Port Moody Arm both within the thermal plume and at the nearby reference station.

Under the conditions that existed in Port Moody Arm during June to August 1997, we concluded that the thermal plume did not affect the vertical distribution of juvenile chum salmon in a statistically significant manner. The chum salmon tended to occupy their preferred surface water habitats in which temperatures occasionally exceeded optimal values determined under laboratory conditions.

**Key words**: chum salmon, (*Oncorhynchus keta*), vertical distribution, volitional movement, thermal discharge, in-situ experiments

# RESUMÉ

Birtwell, I.K., R.P. Fink, J.S. Korstrom, B.J. Fink, J.A. Tanaka and D.I. Tiessen. 1998. Vertical distribution of juvenile chum salmon (*Oncorhynchus keta*) in relation to a thermal discharge into Port Moody Arm, Burrard Inlet, British Columbia. Can Tech. Rep. Fish. Aquat. Sci. 2235: 99 p.

La distribution verticale du saumon kéta juvénile (*Oncorhynchus keta*) a été étudiée dans des eaux recevant une décharge thermique provenant d'une centrale alimentée au gaz naturel dans le bras Port Moody, bras Burrard, Colombie-Britannique. Il a été postulé que l'orientation spontanée de ces poissons dans l'eau de surface au début de leur vie marine pouvait être modifiée par les décharges quotidiennes pouvant atteindre 1,7 milliard de litres d'eau de refroidissement (# 27 EC) dans ce bras peu profond et long de 6,5 km qui ouvre sur le bras Burrard.

Des cages de type «préférence/évitement» à cadre d'aluminium et mesurant 6,0 m x 0,5 m x 0,5 m ont été déployées dans le bras Port Moody à 4 sites (un site témoin à l'ouest de la décharge thermique et trois sites localisés respectivement à 70 m, à 250 m et à 1 200 m à l'est de la décharge). Le déplacement volontaire de groupes distincts de 60 poissons a été examiné plusieurs fois (12 à 16 reprises) au moyen de ce dispositif à chaque site entre le 25 juin et le 22 août 1997. L'investigation a coïncidé avec la fin de la période où les saumons juvéniles fréquentent le bras Burrard. La technique employée a permis de déterminer la distribution verticale des saumons à intervalles de profondeur de 1 m à l'intérieur de la colonne d'eau de 6 m ainsi délimitée. L'extérieur poreux des cages facilitait l'écoulement de l'eau à travers le dispositif, préservant ainsi la stratification verticale naturelle. Les caractéristiques de l'eau (température, salinité, teneur en oxygène dissous, pression totale des gaz [PTG], pH, potentiel d'oxydoréduction et éclairement) ont été déterminées à intervalles de 0,5 m jusqu'à une profondeur de 5,5 m, et la transparence de l'eau a été mesurée au disque de Secchi, juste à côté de chaque cage, au début et à la fin de chaque période d'observation (approximativement 20 h). On a analysé les données en vue de déterminer les éventuels liens et corrélations entre la distribution des poissons et les variables mesurées.

De juin à juillet, la plupart des poissons se tenaient dans la chambre supérieure du dispositif à tous les sites, et les poissons ont survécu dans toutes les expériences. Au mois d'août, les distributions étaient plus variables et ont révélé un déplacement vers le bas sur toute la colonne d'eau de 6 m de profondeur. Globalement, un nombre moins élevé de poissons a été recensé dans les eaux les plus superficielles au site le plus proche de la décharge thermique (70 m), mais la comparaison de toutes les données n'a pas révélé de différence statistiquement significative dans la distribution verticale des saumons kétas entre les divers sites d'observation.

Seules deux variables aquatiques accusaient une différence significative entre les sites d'observation. La température aux profondeurs de 2,5 m et de 3,5 m était significativement plus élevée aux sites 2 et 3 (respectivement à 70 m et à 250 m à l'est de la décharge), mais à la profondeur de 3,5 m, seul le site 2 présentait une différence comparativement aux autres sites. La teneur de l'eau en oxygène dissous était significativement plus faible aux profondeurs de 0,5 m et de 1,5 m au site 2 comparativement aux autres sites. Il est admis que ces deux résultats reflétaient l'effet du panache thermique composé d'eau plus chaude et moins oxygénée comparativement aux eaux ambiantes à la même profondeur. La teneur en oxygène était plus faible comparativement à celle des eaux sursaturées plus distantes de la décharge thermique, mais restait proche des valeurs optimales (90 à 100 % de saturation d'air).

Les caractéristiques aquatiques les plus fortement reliées à la distribution des poissons ont été déterminées au moyen de la méthode de régression ascendante. Au site de référence, la distribution des poissons était corrélée avec la teneur en oxygène dissous, le pH, la PTG et la profondeur. Aux sites distants de 70 m et de 250 m de la décharge thermique, elle n'était corrélée qu'avec la profondeur et l'éclairement, respectivement. À 1 200 m, la distribution des poissons était corrélée avec la température, le pH, la PTG et la profondeur. Pour l'ensemble des sites, la température, la teneur en oxygène, le pH, la PTG et la profondeur étaient les principales variables aquatiques associées à la distribution verticale des saumons en cage. La période de l'année constituait la principale variable déterminante de la présence de poissons dans les eaux les plus superficielles (0 à 1 m) du bras Port Moody : le nombre de poissons fréquentant les eaux de surface était en effet plus faible au mois d'août qu'aux mois précédents.

Au cours de la période expérimentale de 2 mois de l'été de 1997, la centrale thermique était en opération de manière intermittente. Les quantités d'eau chaude déchargées ont donc varié en débit (497 à 1 194 m$^3$·d$^{-1}$) et en température (18,7 à 26,7 °C). Cette fluctuation, conjuguée à la température relativement basse des eaux de surface du bras de mer au début de l'étude, a contribué à la variation des caractéristiques aquatiques entre les sites. Les conditions thermiques aux sites d'observation n'ont que rarement atteint des niveaux correspondant à un effet létal aigu sur les poissons au laboratoire, et étaient souvent comprises dans les intervalles de préférence ou de tolérance déterminés au laboratoire. Les températures étaient maximales au mois de juillet. Même lorsque les eaux de surface du bras Port Moody affichaient une température supérieure ou égale aux seuils associés à des réponses d'évitement chez le saumon kéta au laboratoire (CE50 de 20,2 °C), un certain nombre des poissons en cage s'y tenaient quand même. Des indices thermiques aussi bien que non thermiques étaient probablement associés à cette préférence des poissons en cage pour les eaux de surface à réchauffement saisonnier du bras Port Moody dans le panache thermique ou au site témoin adjacent.

Dans les conditions prévalant dans le bras Port Moody de juin à août 1997, l'analyse des données recueillies nous a permis de conclure que la décharge thermique n'avait pas de répercussion statistiquement significative sur la distribution verticale des saumons kétas juvéniles. Les poissons avaient tendance à occuper leurs habitats préférés d'eau de surface, où les températures excèdent parfois les valeurs optimales déterminées au laboratoire.

**Mots clés :** saumon kéta, *Oncorhynchus keta*, distribution verticale, déplacement volontaire, décharge thermique, expériences *in situ*

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF FIGURES (contd.)

# INTRODUCTION

The significance of temperature changes due to thermal discharges from nuclear and electric generating stations into fresh and marine waters received much attention over 20 years ago (Neill and Magnuson 1974; Coutant 1975; International Atomic Energy Agency 1975; Spigarelli 1975; Spigarelli et al. 1982; Langford 1990). Studies focused on the responses of fish to temperature primarily because of its' fundamental importance in the life of poikilothermic aquatic organisms as a controlling, limiting, and directive factor (Fry 1947; Brett 1952; Coutant 1977; Reynolds 1977; Olla et al. 1980; Houston 1982; Coutant 1987; Langford 1990).

In 1996 additional site-specific environmental impact information was required by federal and provincial government regulatory agencies in response to the initiative of B.C. Hydro to upgrade their natural gas-fired steam-electric Burrard Generating Station (BGS) located on the north shore of Port Moody Arm, in Burrard Inlet, British Columbia, Canada. The plant draws sea water from Port Moody Arm to cool steam condensers and subsequently returns the "once through" cooling waters (maximum temperature 27 °C) at flows up to 1.7 million $m^3$ daily into sub-surface waters. Discharge flows are directed eastwards and towards the head of this relatively shallow 6.5 km arm of Burrard Inlet.

The purpose of this study was to address some of the concerns of the regulatory bodies and provide information on the effects of temperature change on juvenile chum salmon (*Oncorhynchus keta*). Because of the importance of temperature in the life of fish and the potential for ambient conditions to be changed by the thermal discharge (Seaconsult Marine Research Ltd. 1995) our 1997 field study used in-situ experiments while a companion study (Birtwell et al. 1998) examined behavioural responses of chum salmon juveniles to a variable thermal environment in a laboratory setting. Attention was focused on behavioural responses, particularly because of the relatively narrow thermal preference of juvenile salmon (Brett 1952), and the requirement for thermoregulatory behaviour to optimise metabolic function (Brett 1971; Coutant 1977, 1987).

Despite the fundamental adaptive significance of behaviour to survival of salmon (Mace 1983; Piercey et al. 1985; Macdonald et al. 1987; Birtwell and Kruzynski 1989), there is a paucity of information, especially in relation to thermal change in marine and estuarine environments, on fish behaviour. Because warmer water is generally located at the water surface, and juvenile salmon are surface orientated during their early sea life (Mason 1974; Birtwell 1977; Birtwell and Harbo 1980; Birtwell et al. 1983; McGreer and Vigers 1983; Birtwell and Kruzynski 1987; Macdonald et al. 1987; Birtwell and Kruzynski 1989), there is a likelihood that juvenile salmon frequenting the waters of Port Moody Arm would utilise surface waters therein, including those influenced by the discharge of heated water from the BGS.

Chum salmon were chosen as the test species due to their abundance and prevalence (March to August) in the contiguous waters of Burrard Inlet (Nelles 1978; Macdonald and Chang 1993). In 1997, a total of 528,000 juvenile salmon were released from hatcheries into the waters of Port Moody Arm and Indian Arm, in Burrard Inlet. These releases comprised 66,000 coho salmon

(*Oncorhynchus kisutch*), 184,000 chinook salmon (*Oncorhynchus tshawytscha*), and 278,000 chum salmon (M. Johnson, Department of Fisheries and Oceans, Vancouver, B.C., unpublished information). Port Moody Arm supports a diverse aquatic community and serves as an important nursery area for juvenile salmonids (Macdonald and Chang 1993). Populations of coho (*Oncorhynchus kisutch*) and chum salmon, and steelhead trout (*Oncorhynchus mykiss)* in Mossom and Noon's Creeks are supported by volunteer hatcheries. One of the unnamed tributaries on the south shore has a small run of chum salmon. In addition to salmon, the major streams support small populations of cutthroat trout (*Oncorhynchus clarki*). Spawning populations occur in local streams and rivers (see Figure 1), and progeny of these fish will utilise the waters of Port Moody Arm and potentially encounter the thermal plume created by the heated cooling water discharged by the BGS.

Chum salmon have been used previously in behaviour experiments that have assessed the effects of pollutants discharged into estuarine and marine waters (Birtwell 1977, 1978; Birtwell and Harbo 1980; Birtwell and Kruzynski 1989). Although juvenile chum salmon avoided lethal concentrations of pulp mill effluent in surface waters over 3 h, over 24 h some fish died (Birtwell and Kruzynski 1989). These authors considered that the innate behaviour of juvenile salmon to occupy the uppermost surface waters resulted in their exposure to lethal concentrations of effluents and the death of some individuals. A similar response and effect was recorded by McGreer and Vigers (1983) in their study of the vertical distribution of chum salmon in Neroutsos Inlet, B.C. which was affected by effluent from the Port Alice pulp mill.

We speculated that juvenile chum salmon would occupy surface waters in the marine environment of Burrard Inlet, and that their dispersion in the water column would be related to the prevailing conditions. Because of the variable nature of the waters around the thermal discharge location, and the tendency of the heated cooling water to occupy surface waters (Seaconsult Marine Research Ltd. 1995) we employed an experimental cage technique (Birtwell 1977; McGreer and Vigers 1983) to assess the influence of the discharge on the vertical distribution of chum salmon.

Coincident with the field investigation, several laboratory experiments were conducted (Birtwell et al. 1998, Korstrom et al. 1998) in order to examine chum salmon behaviour in response to temperature change under controlled conditions, thereby facilitating direct comparisons with results from the field experiments. A Water Column Simulator (WCS) (Birtwell and Kruzynski 1987), was employed which provided a 4500-L flow-through sea water aquarium under natural photoperiod. In addition acute lethal thermal resistance bioassays were undertaken to determine the time to death for juvenile salmon exposed to a single high temperature (25°C) in the presence or absence of dissolved gas supersaturation.

## STUDY LOCATION

The BGS is located on the north shore of Port Moody Arm approximately 10 km east of Vancouver, near the town of Ioco, B.C. Port Moody Arm is a comparatively shallow arm of Burrard Inlet, contiguous with the Strait of Georgia and the Pacific Ocean (Figure 1). It is 6.5

km long and has an average depth at low tide of 8.8 m. The Arm itself has only limited fresh water input (Waldichuk 1965). The nearest indirect fresh water influences include the Indian River, located at the head of the adjacent Indian Arm, and the Seymour River, both of which discharge from the north shore into Burrard Inlet, west of the BGS. Several local streams contribute fresh water to the eastern end of Port Moody Arm. The most important of these are Mossom and Noon's Creeks, located 1.5 km and 4.2 km east of the plant, respectively, on the north shore of the Arm. Several minor tributary streams as well as Schoolhouse Brook enter from the south shore (Figure 1). The topography of both the northern and southern shores of Port Moody Arm in the immediate vicinity of the BGS is relatively steep and, in consequence, there are few important salmonid streams in the immediate vicinity of the discharge.

## MATERIALS AND METHODS

### Fish husbandry

Three thousand juvenile chum salmon (fork length 38.6 ± 2.1 mm, weight 0.41 ± 0.09 g) were obtained from the Seymour River Volunteer Hatchery in North Vancouver, B.C., and transported in a covered, double-walled 800-L polyethylene container by truck to the BGS. Transport water was 200 L sea water (22 ‰ salinity; 10 °C) mixed with 500 L fresh water (Seymour Hatchery source) at 5.5 °C, to give approximately isotonic conditions of 9‰ salinity at 7 °C. Dissolved oxygen saturation (± 0.1% air saturation) was monitored every 5 min during transport using an Oxyguard Handi Mark III™ meter. A 12-volt battery-powered air pump added compressed air to the transport tank through a submerged air stone to maintain dissolved oxygen levels above 80% of air saturation values throughout the transport period.

Following transport the fish were vaccinated in the transport tank against *Vibrio* using Biovax 1300 *Vibrio anguillarum-ordalii* Bacterin (Alpharma, Bellevue, WA). The tank was drained to a volume of 200 L to which was added 2 L of the attenuated bacteria. Fish were kept in the vaccine under continuously aerated conditions for 1 h.

Fish were subsequently removed with soft-mesh nylon nets and transferred to a covered 6850-L fibreglass holding tank (3 m diameter, 1.2 m height). Sea water from a 5 m-deep submerged intake structure in Port Moody Arm, west of the thermal discharge, was pumped approximately 100 m through 7.6 mm PVC pipe to a PVC control valve and from there, delivered continuously through a 1.2 m x 10 cm dissolved gas equilibration column packed with plastic rings (Owseley 1981), to the holding tank at a flow of 25 to 40 $L \cdot min^{-1}$.

The fish were fed Moore Clark (Vancouver, B.C.) semi-moist food (#1, #2, and #3 starter feed, and 1.5 mm pellet) at a ration of 5% body $weight \cdot d^{-1}$ using an automatic belt feeder (Zeigler Brothers Inc., Gardners, PA). The total fish weight in the holding tank was estimated from the number of fish received from the hatchery multiplied by their initial weight. Ration was continually adjusted for estimated growth (5%$\cdot$d$^{-1}$), mortality, and fish removed for cage studies, as well as being periodically adjusted following determination of growth rate (every 3 weeks).

An outbreak of *Vibrio anguillarum-ordalii* in the holding tank, 2.5 weeks after arrival at the holding facilities, was successfully treated using 30 mg Tribrissen$\cdot$kg fish $^{-1}\cdot$d $^{-1}$ (Syndel Laboratories Ltd., Vancouver, B.C.) mixed with #2 feed. During the 7-d medication period, the food ration was decreased from 5% to 2% body weight$\cdot$d$^{-1}$. Following treatment daily mortality was <0.05%$\cdot$d$^{-1}$. Fish were held for an additional 10 d following the end of treatment before being used in the first cage study.

## Experimental protocol

### Apparatus

The vertical distribution of juvenile chum salmon was assessed in Port Moody Arm using apparatus developed by Birtwell (1977). The apparatus comprises a 6-chamber aluminum-framed cage (Figure 2) with an outer marine-aluminum frame surrounded by a black vinyl (5 mm mesh) covering. The cage measures 6 m in length and 0.25 m$^2$ in cross section. Each 1 m cage chamber has an internal volume of 0.25 m$^3$ and a gate mechanism permits or prevents access to adjacent compartments. This operation was carried out by moving a lever connected to all gates; thus they were opened or closed simultaneously. Two 3 m x 0.5 m aluminum-reinforced sections of one side of the 6-m apparatus are removable and permit access to the individual 1 m compartments Two aluminum-clad Styrofoam™ floats (~0.1 m$^3$ each) support the upper end of the apparatus just above the water surface, and at the study sites it was anchored to the sea floor with adjustable 30 m long (19 mm diameter) braided nylon ropes and 3.5 kg galvanised iron Danforth style anchors. The apparatus was operated in the vertical position from the water surface and allowed the distribution of fish to be determined at 1 m intervals in the enclosed water column. Four identical cages were used in the experiments.

### Experimental sites

Four near-shore sites in the vicinity of the BGSs' thermal discharge were selected for study following a field inspection and a review of information on the dispersion of the thermal plume. A reference site located 250 m west, and three experimental sites 70 m, 250 m, and 1200 m east, of the thermal discharge location were chosen (Figure 1). Each week of the study, a single cage was anchored at each site and the distribution of juvenile chum salmon within the apparatus determined on a daily basis.

### Transfer of fish and in-situ experimentation

Naive fish from the stock tanks were placed in the apparatus and their position subsequently determined the following day. Two fish transfers from the stock tank were required to provide fish to the apparatus at the 4 sites for each experiment. To minimise the handling and transportation stress on the fish, separate transfer operations were completed for every two cages serviced.

Each time new fish were required for the cages (4 times per week, over four separate weeks), approximately 125 fish were removed from the stock tank using soft-mesh dip nets, and equally divided among two opaque 60-L insulated plastic containers holding 30 L of sea water at the same temperature as the water in the stock tank. The lids were closed and the containers taken by truck and then placed aboard a 3 m aluminum boat. The fish were transported to each of two cages in sequence. During the initial weeks of the study dissolved oxygen saturation remained close to air saturated values in the transport containers, and no additional aerated water was required during transport. During the final week of the study, and with fish of larger size, it was necessary to add aerated sea water to maintain dissolved oxygen concentrations above 75% air saturation. Water temperature in the containers did not change appreciably during the transfer process. The time fish spent in transit was between 15 and 30 min.

The procedure for placing the fish into the apparatus followed that reported by Birtwell (1977), and McGreer and Vigers (1983). Prior to fish delivery, the cages were raised to the horizontal position and placed on a Styrofoam™ and plywood "service" float. The float was positioned beneath, and at the opposite end to, the attached floatation compartments, and moved to a position which preserved at least 10 cm depth of water in each compartment. The two 3 m long side doors permitted full access to the 6 individual 1-m long compartments. Ten fish were removed from the insulated transport container by dip net and placed into each of the 6 compartments. The side doors were subsequently closed, the apparatus removed from its' support float, and then slowly lowered to the vertical position with the interior (between compartment) doors still closed. The cage was left undisturbed for at least 15 min before the inter-compartment gates were opened with as little disturbance as possible. After the cages were stocked, any surplus fish remaining in the transport container (usually between 5 and 10 individuals) were released to Port Moody Arm, their otherwise-intended natural environment.

Each cage was left undisturbed overnight with all interior doors open, and then examined the following day to determine the vertical distribution of the fish. In order to fix the position of the fish within the 1 m compartments before enumeration, the interior gates were closed in the following manner. Each cage was approached at low speed (<1 knot) and usually from down wind or down current. An operator leaning over the bow of the boat quickly closed the interior doors by operating the lever mechanism. Given the number of occasions that the majority of fish were recorded in the uppermost compartment, this method of closure was considered to be satisfactory. The cage was raised to the horizontal position, placed on its' "service" float and the outer access doors opened for fish retrieval. Fish from each chamber were netted with a soft-mesh dip net, counted, examined for general health and any signs of gas bubble trauma, and then released at the site.

### Water quality characterisation

At each station and on each occasion, while one study team undertook to service the cages, a second team measured water temperature, salinity, dissolved oxygen, pH, oxidation-reduction potential, and total gas pressure (TGP), as well as light intensity and Secchi disc visibility depth in the immediate vicinity of each cage. Measurements were taken at the surface, 0.5 m, 1.5 m, 2.5 m, 3.5 m , 4.5 m, and 5.5 m, corresponding with the centre of each of the vertical 1 m chambers of the cage apparatus. Certain water quality characteristics were measured using a hand-held Hydrolab Surveyor 4 (Hydrolab Corporation Ltd., Houston, TX) with separate transmitter unit on a fixed 25 m cable, and photosynthetically-active radiation (PAR) in $\mu$Einsteins$\cdot s^{-1} \cdot m^{-2}$ was measured with a Li-Cor LI 193SB spherical quantum sensor (Li-Cor Environmental Division, Lincoln, NE). Water clarity was examined using a 30 cm diameter white Secchi disk. Total gas pressure (TGP) was determined using a Model 300C tensionometer (Alpha Designs Ltd., Victoria, B.C., ± 1 mm Hg accuracy), and by applying the calculations provided by Colt (1984).

In addition, a near-continuous temperature record (15 min intervals) was provided by Optic Stowaway or Tidbit portable data loggers (Onset Computer Corp. Pocasset, MA) positioned inside each apparatus on a side wall and at the centre of each 1 m chamber. The stored information in the loggers was downloaded to an AST 486 computer each week using Onset Computers' Logbook™ Version 2.04 software. Temperature data files were transferred to Microsoft Excel™ 5.0 for editing, statistical analyses, and graphing.

## Data analyses

For each of the cage studies, the daily counts of fish within each cage chamber, and for each site were tabulated in Excel along with all corresponding water quality measurements, and analysed for significant differences and relationships. The fish counts were transformed to percent counts to correct for minor errors in counting fish added to the apparatus, and individual water quality parameters were normalised through log-transformation.

Fish distribution data (arcsine transformation) were analysed to reveal any differences between sites and depths, and to relate distributions at each site and over the study area to the measured variables. Correlation analyses were carried out to identify variables that were significantly related to each other, and to fish distribution by site, depth, and on the combined data set. Analysis of variance (ANOVA) was used to examine the interrelationships of water characteristics and fish distribution. All possible pair-wise comparisons were examined using Tukeys' HSD method (Devore 1991). Forward step-wise regression analysis was undertaken to identify the variables most associated with the fish distribution. The statistical analyses utilised Systat Version 5.0 (Systat Inc. 1992).

## RESULTS

### Fish distribution

Reference Site 1

The distribution of chum salmon at the reference location (Site 1), 70 m east of outfall (Site 2) and 1200 m east of outfall (Site 4) was determined on 16 occasions from June 25 to August 22 1997. The distribution of fish at (Site 3) 250 m east of outfall was determined on 12 occasions between July 07 and August 22. The number of fish recorded in each of the cage compartments for all of the sites is shown in Tables 1 - 4 and the mean weekly position (n = 4 observations) is depicted in Figures 3 - 6.

In June the fish displayed a strong surface orientation at the reference site and >80% were in the uppermost 1 m. In July when we recorded the highest surface water temperatures, the majority of the test fish were still in the uppermost waters, but their distribution was more variable. By late August there was even greater dispersion and 30% were found in the deepest compartment; a significant contrast to earlier observation periods. When data for all the experiments at all time periods are combined, 62% of fish were determined to be in the uppermost 1 m of the water column.

Experimental Site 2, 70 m east of the thermal discharge

This site was the closest to the thermal discharge, and during 2 experimental periods (July 8-11 and August 19-22), fewer fish were in the uppermost waters relative to those at the reference site on the same dates. The data for the salmon distribution recorded on 14 occasions from June 25 to August 22, 1997 are presented in Table 2, and illustrated in Figure 4. Combining all the data from the experiments resulted in an average of 47% in the surface 1 m, 15% less than at the reference site.

Experimental Site 3, 250 m east of the thermal discharge

The fish distribution data obtained on 12 occasions from July 8 to August 22 1997 are presented in Table 3 and Figure 5. As determined at the reference site, the majority of fish were located in the uppermost waters with the exception of the determinations made in August when the fish occupied greater depths. At this location 54% of fish occupied the uppermost 1 m of the water column (all experiments combined).

Experimental Site 4, 1200 m east of the thermal discharge

The same pattern of fish distribution recorded at the other sites was revealed at this location which was the most distant site we used from the thermal discharge of the BGS. The majority of fish occupied the uppermost waters from June 25 to July 18, but in August (19 to 22), there was a downward shift and more fish occupied the deeper compartments of the 6 m water column. The data are presented in Table 4, and Figure 6. Combining all data for experiments from June 25 to August 22 1997, 51% of fish were recorded in the top 1 m of the water column.

## Fish size

The mean (weekly) fork lengths of experimental fish are presented in Table 5, and length-frequency histograms of the same data are shown in Figure 7. There was an expected and substantial increase in the size of the fish as the trials continued throughout the 8-week study period. Fish used in August (fork length = 130 ± 9 mm) were almost double the length of those used in June (fork length = 70 ± 7 mm).

## Water quality characteristics

Determinations of all water quality variables measured at the experimental cage sites are shown in Tables 5 to 9, and the weekly maximum mean and minimum measured values for temperature, dissolved oxygen, salinity, TGP, and pH are illustrated in Figures 8 to 22. No adjustments of experimental schedules were made to standardise activities to accommodate for tidal state or time of day. In addition, when an experiment was terminated at a particular site and another one started immediately thereafter, only one determination of aquatic characteristics was made to reveal conditions at the end and start of the respective tests.

Sea water temperatures recorded by data loggers in each of the cage chambers are presented in Figures 23 to 36. Only brief comments will be made on some of the salient variables, as the intent of these determinations was to relate them to fish distribution rather than examine differences in aquatic characteristics among sites and depths in Port Moody Arm.

### Temperature

Temperature change at all sites reflected seasonal climatic changes and the influence of local weather patterns, and reached maximum values in July. The maximum recorded temperatures from the cage data loggers approximated 22.5 °C, 23.5 °C, 23.3 °C, and 24 °C for the reference location and sites 70 m, 250 m, and 1200 m from the discharge location, respectively (Figures 23 - 36). Throughout the study period mean temperatures were rarely above 20 °C in surface waters, and the greatest depths over which these conditions existed was at site 2, 70 m from the thermal discharge. The influence of the thermal plume on the vertical temperature gradient in the upper water column is evident in Figures 8 - 10. Water temperature in sub-surface waters was slightly higher at the 70 m experimental location (Site 2) than in shallower layers, (refer also to Figures 26, 27, 30, and 31). This effect was most notable during July (Figures 8 and 9) but was virtually undetectable during the week of August 18 to 22 (Figure 10). A similar pattern was observed at the 250 m station (Site 3) where the mean temperature of subsurface waters to a depth of 3.5 m was sometimes higher than that found at the surface and also higher than for similar water depths at the reference site. This trend diminished during August when only slightly higher sub-surface temperatures were observed.

### Salinity

Salinity in the upper water column at the reference location (Site 1) generally increased with depth and also over time during the study period, reflecting seasonal and climatic changes. The highest salinity was recorded in August when fresh water influence was low, and somewhat cooler, windy conditions prevailed. Surface water salinity at the 70 m, 250 m, and 1200 m sites showed a similar pattern, though with more variation, than that at the reference site (Figures 11-13). The entrainment of deeper, more saline water, together with the mixing energy associated with the BGS discharge, resulted in a higher mean surface salinity at Site 2, 70 m from the thermal discharge (18.5 ‰) during the second week in July (Figure 11) than was measured at the reference site (14 ‰). This effect was much less noticeable at other times during the summer. During the third week of August (Figure 13), very little vertical change in salinity was recorded in the upper 5.5 m of the water column.

### Dissolved oxygen

Dissolved oxygen levels were frequently above 100% air saturation at all sites during the study period (Figures 14 - 16). Minimum mean values were recorded at 5.5 m depth and were close to 75% of air saturation. There was a marked increase in dissolved oxygen with proximity to the surface. In addition, there was a general increase in dissolved oxygen saturation at depth during the summer, from mean values around 85%, to 90% - 95% at 5.5 m. Dissolved oxygen saturation in the upper 2 m of the water column was generally lower at the 70 m site (Site 2) than at the reference site (Site 1) or the 250 m and 1200 m locations (Sites 3 and 4). These differences in dissolved oxygen saturation (usually between 10% and 15%) at Site 2 compared with the reference and other sites generally decreased with increasing depth and were relatively minor at depths of 3.5 m and greater. High dissolved oxygen saturation values (125% to 145%) may have been associated with peak phytoplankton photosynthetic activity. At Site 4 several high dissolved oxygen levels were determined at different depths (Figures 14 - 0.5 m, Figure 15 - 2.5 m, and Figure 16 - 1.5 m) which may reflect localised changes in plankton populations. The lowest oxygen saturation levels recorded during this investigation were those at 5.5 m depth at reference Site 1 (69%) and at Site 4 1200 m east of thermal discharge location (68%).

### Total gas pressure (TGP)

Throughout the study period at depths shallower than 4.5 m, TGP was elevated above 100%, and differed little among sites (Figures 17 - 19). Highest values occurred in July, and the maximum (125.2%) was recorded at Site 4 farthest from the heated cooling water discharge. However, at this time mean values typically lay between 110% and 115% at all sites. Mean values of dissolved gas saturation (%) decreased with increasing depth at all stations and all periods during the study. This may reflect the influence of surface-oriented photosynthetic activity and the general heating of surface waters by solar radiation, which also peaked during the same time period. Near-surface TGP levels at all sites within Port Moody Arm from July 14-18, 1997, exceeded levels considered safe for salmonid growth and survival (Fiddler and Miller 1997).

### pH

All pH values recorded during this investigation ranged between 7.7 to 8.9 pH units. Variation in pH with depth and among sites generally reflected changes in salinity over the study period. They were most variable in surface waters, and less so at depth (Figures 20 - 22). Maximum differences in pH between waters at the reference Site 1 and those at Site 2, 70 m east of thermal discharge in any one week at any one depth, were typically 0.2 - 0.3 pH units. The pattern of slight decreases in pH with increasing depth in the water column was generally similar at each study site, and appeared to change with time more so than among the study sites. The highest values for pH (>8.5, Figure 21) coincided with a period of high algal production that we observed between July 14 and 18 (Figure 15) when dissolved carbon dioxide would be expected to be low.

## Fish distribution and aquatic characteristics

Over the study period the caged chum salmon tended to display a distinct preference for the upper 1 m depth compartment of the cages regardless of location. However, because of the large variation in the data for each site ANOVA did not reveal significant ($p < 0.05$) differences among the sites at each depth interval except for that at 4.5 m. The percentage of fish at this depth for Sites 2 and 4 were different than that at the reference Site 1, and at Site 4, 1200 m from the outfall. The low proportion of the test fish to which these analyses apply (Tables 1 - 4; Figures 3 - 6), decreases the significance of the result.

Correlation analysis provided a relative indication of the variables that were correlated with fish distribution. The results of these analyses applied to the total data set, by site, and by depth are presented in Tables 10 - 12.

Depth, dissolved oxygen, pH and salinity were the variables most strongly correlated with the distribution of fish for the combined data set (Table 10). Depth and salinity were negatively correlated.

When the data were analysed by experimental site (Table 11), depth was the most strongly (and negatively) correlated of the variables examined in relation to the vertical distribution of the caged fish. At the reference site dissolved oxygen, salinity, and pH were also strong factors. At Site 2, 70 m from the thermal discharge depth was the only variable that was strongly correlated with the vertical distribution of the salmon. At Site 3, 250 m from the outfall dissolved oxygen, and pH were also strongly correlated. At Site 4, 1200 m from the outfall, depth, dissolved oxygen, salinity, pH, and light intensity were highly correlated with the chum salmon distribution.

The results of the correlation analyses presented in Table 12 show how different variables are correlated with the percentage of fish at different depths over the study area. Time was a significant variable for each depth but 1.5 m. It was negatively correlated with the percentage of fish in the uppermost 1 m, reflecting the downward shift in fish distribution from July to August.

Temperature, salinity, and light intensity were all negatively correlated. Temperature was again a significant correlate at 2.5 m depth, and pH at 5.5 m.

Forward step-wise regression analysis was undertaken to examine the variables most associated with the distribution of chum salmon. The results of these analyses applied to data for each site, each depth over the study area, and for the combined data set are shown in Tables 13, 14 and 15, respectively. Few variables were associated with the distributions at Sites 2 and 3, 70 m and 250 m from the outfall reflecting the more variable nature of the environment and distribution of the fish. At the reference Site 1 and at 1200 m from the outfall 4 variables were associated with the variance in the data; TGP, depth, and pH were common to both sites.

When the data were analysed by depth to reveal any horizontal associations of variables with the presence of fish, a range of variables was identified, as shown in Table 14. The majority of fish were typically in the uppermost 1 m of the water column, hence the regression results for this depth probably have greatest significance to fish distribution overall than do the results for deeper waters. Time was the only variable that was selected for the 1 m depth interval, reflecting the decreasing number of fish over the time of the experiments, especially the downward shift that occurred between July and August.

Table 15 provides the overall assessment of the factors most related to the distribution of the fish. Temperature (+), dissolved oxygen (+), pH (+), TGP (–) and depth (–) were the main variables.

Analysis of Variance was used to identify any significant differences among the aquatic characteristics, by depth. Temperature, and dissolved oxygen were the variables selected at the 2.5 m and 3.5 m, and 0.5 and 1.5 m depths respectively. Tukeys' HSD test was used to reveal at which depths these significant differences occurred.

Temperature at 2.5 m depth was different and higher at Sites 2 and 3 closest to the outfall, while at 3.5 m depth, the temperature at Site 2, 70 m from the discharge, was different than that at the other sites. The results relate to the presence of the thermal discharge plume and the rise of warm water towards the surface. Figure 8 illustrates this trend.

Dissolved oxygen was significantly lower and different at 0.5 m and 1.5 m depths at Site 2, than at the same depths at the other sites. Figures 14 - 16 illustrate the depression but only in August were values below 100% of air saturation levels. Dissolved oxygen supersaturation typically occurred at all study sites at 0.5 m and 1.0 m depths.

# DISCUSSION

## Thermal discharge and fish distribution

### Thermal discharge

The quantity and temperature of heated cooling water discharged to Port Moody Arm varied considerably during the course of our investigation in response to the operational requirements of the BGS. Data presented in Table 16 show the number of generating units in operation (out of 6), plant electrical output, daily water flow, and cooling water discharge temperature, for the periods during the summer of 1997 when our experimental cages were in the waters of Port Moody Arm. The most consistent output of heat occurred during the experiments conducted in August. However, it was in July that the ambient surface water temperatures were at maximum values. At this time the plant was discharging approximately 35% less heated cooling water at a mean temperature of 25.4 °C, compared with the larger discharge of 25.2 °C water in late August (Table 16). The highest temperatures among the study sites coincided with a period of stable warm weather from July 14 to 18, a time when the cooling water discharge volume was at a minimum for the month, but the discharge temperature was between 24 °C and 27 °C.

The temperatures we determined at Sites 2 and 3 (70 m and 250 m east of outfall respectively) reflected the influence of the thermal discharge from the BGS in that subsurface temperatures were elevated relative to temperatures at the same depth at the other sites (refer to Figures 23 - 36). This is an atypical situation for thermally-stratified waters wherein warmer waters overlie cooler waters due to respective density differences. In contrast, sea water temperatures recorded at Sites 1 (reference) and 4 (1200 m east of outfall) typically decreased to a greater extent, relative to changes at Sites 2 and 3, with increasing depth from the water surface (Figures 8 - 10).

### Fish presence, distribution, and aquatic characteristics

During our 8-week study when the BGS operated intermittently there was no statistically significant reduction in the numbers of caged chum salmon that occupied the surface waters among sites up to 1200 m from the stations' heated cooling water discharge. That only slightly fewer numbers of fish utilised the uppermost waters close to the discharge was not surprising as the range of temperatures that the fish were exposed to rarely exceeded the 50% avoidance level to high temperature that was determined in the laboratory (Birtwell et al. 1998). The laboratory-derived temperature representing the upper lethal limit, the 50% avoidance value, and the "preferred" range for chum salmon are provided on the temperature profile graphs presented in Figures 23 - 36. Most frequently the fish had access to waters at preferred temperatures (13.7 °C to 17.9 °C; Birtwell et al. 1998) within the 6 m water column of the test apparatus. Only in mid-July, at the site 70 m from the thermal discharge was this rarely so. The 50% avoidance response thresholds identified on the thermal profiles in Figures 23 to 36 provide information of the frequency of occasions when temperatures were optimal to stressful for the chum salmon during experimentation. At the reference site temperatures were at the 50% avoidance level for but a few hours during experiments in July, but at the other sites the duration of such temperature elevations were greater, and maximum temperatures approached (but rarely exceeded) the ultimate upper lethal limit of 23.8 °C determined in laboratory experiments in fresh water by Brett (1952).

### *Surface water orientation*

The occupation of surface waters by chum salmon even when temperatures were at levels above the laboratory-derived avoidance thresholds (for 50% of the population) was not unexpected. Westerberg (1984) and Döving et al. (1985) considered that fine-scale hydrographic features (e.g. thermal microstructure) may provide a necessary reference system for successful orientation by salmon in coastal regions. The innate behavioural trait of chum salmon to orientate to the water surface during their early sea life has been documented in a number of studies. Macdonald and Chang (1993) collected chum salmon in shallow beach seines close to shore in Burrard Inlet. Mason (1974) observed chum salmon in shallow waters (<1 m) of a coastal stream and estuary, and both Beak Consultants Ltd. (1981) and Healey (1982) caught juvenile chum salmon in shallow waters in the estuaries of the Fraser and Nanaimo Rivers, respectively. Piercey et al. (1985) and Macdonald et al. (1987), using underwater observations also documented the shallow-water habit of salmonids in the Campbell River estuary. At later stages in their life chum salmon occupy a much greater range of depths in marine waters. In off-shore waters in the Gulf of Alaska, Manzer (1964) found no conclusive evidence regarding the vertical distribution of chum salmon (of different sizes and ages up to 4 years) and temperature, although at night they were always caught above the thermocline (June and July).

### *Avoidance behaviour*

Recently we determined, under laboratory conditions, the preference of chum salmon juveniles to occupy waters <1 m from the water surface, to avoid increasing temperatures and yet voluntarily feed in waters >6 °C above their upper lethal limit (Birtwell et al. 1998; Korstrom et al. 1998). It is, therefore, not surprising that in our field experiments the juvenile chum salmon displayed the same surface water orientation and that a significant portion of the test populations utilised the uppermost part of the water column when temperatures approached or exceeded those which caused avoidance responses in laboratory experiments (Birtwell et al. 1998). Our lack of knowledge on the exposure of individual fish to the warm surface waters limits definitive statements about the potential consequences to the test fish of exposure to elevated temperatures. However, the results of both laboratory (Birtwell et al. 1998) and field studies provide supportive information and reveal that the chum salmon will use warm surface waters, even above avoidance response thresholds. Whether this relates to a greater tolerance of warmer waters due to the progressive acclimation of the fish in the in-situ experiments to higher ambient temperatures which favoured occupancy of warmer waters, or the response of these fish to additional natural stimuli is not clear.

In the field it has only been in relation to the discharge of acutely toxic effluents that the strong surface-water orientation behaviour of juvenile salmon has been disrupted (Birtwell and Harbo 1980; McGreer and Vigers 1983; Birtwell and Kruzynski 1989), a contrasting situation to that which occurred in Port Moody Arm adjacent to the heated cooling water discharge from the BGS. Although juvenile salmon avoided concentrations of pulp mill effluent in surface waters over 3 h, they did not do so over 24 h resulting in the death of some individuals (Birtwell and Kruzynski 1989). Aquatic conditions proximal (70 m) to the thermal discharge from the BGS did not present similar constraints on the vertical orientation of chum salmon, and no fish died during experimentation. Accordingly these results contrast with the findings of McGreer and Vigers (1983), and Birtwell and Kruzynski (1989) adjacent to discharges of toxic industrial effluent. Gray (1990) investigated the avoidance response of juvenile chinook salmon in a raceway to simulate the discharge of heated water into a riverine situation. Although the temperature causing avoidance increased with acclimation temperature the mean difference between that causing avoidance and the ambient level was 9 °C to 11°C. Contrary to some findings in the field (when other cues, such as food, will evoke feeding responses), Gray (1990) found no evidence of thermal attraction. Thus it was concluded that juvenile chinook encountering low temperature discharges in nature (< 9 °C above ambient) may orientate and remain in low velocity discharge currents: the consequences of such occupation being detrimental if combined with other stressors.

### *Thermal effects and temperature preference*

Over the duration of the study sea water temperatures in Port Moody Arm were frequently close to preferred temperature levels for juvenile chum salmon observed under laboratory conditions (Birtwell et al. 1998). This was especially so at the reference site, but less so for the site 70 m from the outfall and others further east towards the shallow head of the Arm. In August temperatures were generally higher at the site 1200 m from the thermal discharge compared to those at the reference site and Site 3, 250 m east of the discharge, which were similar to each other. Notwithstanding these differences, temperatures close to those preferred by chum salmon were available throughout most of the study period within Port Moody Arm.

In the laboratory chum salmon in sea water displayed an acute preference for temperatures ranging between 13.7 °C and 17.9 °C, with a 50% response range from 12.2 °C to 20.2 °C (Birtwell et al. 1998; Korstrom et al. 1998). Brett (1952) determined that the mode of preferred temperatures of juvenile chum salmon lay between 14 °C and 15 °C irrespective of prior acclimation to temperatures of 10 °C, 15 °C or 20 °C. However mean (± S.D.) preferred values ranged between 13.9 ± 1.1 °C, 14.1 ± 1.0 °C and 14.6 ± 1.3 °C, for fish acclimated to 10 °C, 15 °C, and 20 °C respectively. Considering variation in the responses among individuals, populations, and species to temperature (Konecki et al. 1995; Beacham and Withler 1991; McGeer et al. 1991), the thermal preference determinations by Brett (1952) and ourselves (Birtwell et al. 1998) revealed behavioural thermoregulatory responses of chum salmon that were proximal to those temperatures considered to optimise physiological performance. This result is in accordance with the expectations from other studies and the opinion that the final temperature preferendum of a fish relates to efficient metabolic function (Brett 1971; Coutant 1977). The final temperature preferendum is the temperature around which fish aggregate given an opportunity to do so in a gradient of sufficient extent (Fry 1947). The thermal preferendum can be elevated by such factors as starvation (Javaid and Anderson 1967), physiological activities (Crawshaw 1977), prior thermal history (Reynolds and Casterlin 1980), age (Kwain and McCauley 1978), and infections (Reynolds and Casterlin 1976), but not to circadian activity (Reynolds 1977), aside from mediation by non-thermal factors (Giattina and Garton 1982).

The significance of the preferred temperature and behavioural thermoregulation lies in the potential exploitation of habitats and niche selection, and the maximising of metabolic and physiological functions that have adaptive and survival value (Coutant 1977; Reynolds and Casterlin 1976; Coutant 1977; Crawshaw 1977; Reynolds 1977; Magnuson et al. 1979; Giattina and Garton 1982; Spigarelli et al. 1983). Thus chum salmon would be expected to seek temperatures between 13.7 °C and 17.9°C in marine waters, based on laboratory results (Brett 1952; Birtwell et al. 1998). This selection would, of course, be subject to modification by other factors. Because of this, Coutant(1977) suggested that the temperature for optimum physiological and ecological performance would lie between the physiological optimum and the ultimate upper incipient limit.

The results we obtained during in-situ experimentation in Port Moody Arm, tend to support the opinion of Coutant (1977), and it is likely that cues other than temperature exerted an influence on the vertical distribution of the chum salmon. The age (size) of fish was different among experiments and the results we obtained for the vertical distribution in August indicated an overall downward shift of these larger individuals relative to younger and smaller individuals we examined in June and July. In the laboratory we determined that there was a consistent pattern of behaviour with respect to the response of juvenile chum salmon of differing sizes to elevated temperatures (Birtwell et al. 1998). At the termination of these experiments the fish were smaller than those used in the caged experiments in Port Moody Arm in August. Accordingly, it is possible that had the laboratory experiments employed fish of similar size to those used in the field in August, we may have seen a shift in the depths preferred by this size of chum salmon. It is also possible that the chum salmon in the August field experiments were responding to natural stimuli that were not present during the laboratory experiments, and progressive acclimation to the ambient conditions.

At the beginning of the experimental period temperatures within the "preferred" range were available at the water surface where the majority of fish were found. This behaviour persisted when temperatures exceeded this range, however we have no information on the duration of time that each individual fish may have spent in the warmer waters. The fish displayed thermoregulatory behaviour, resistance to temperatures exceeding lethal limits for variable periods of time and fed in these waters, under laboratory conditions (Birtwell et al. 1998). It is therefore not unexpected that the chum salmon continued to occupy their preferred surface water habitat over much of the study period despite changes in ambient thermal structure, nor is it unexpected that temperature was positively correlated with fish presence. The temperature levels were not consistently at extreme levels and did not evoke statistically significant avoidance responses by the chum salmon.

The absence of significant avoidance responses in the water column around the thermal discharge into Port Moody Arm indicates that fish would be expected to occupy the area around the outfall. Laboratory studies determined that these fish would feed in waters with temperatures above their upper lethal limit (Birtwell et al. 1998). Hence it would be expected that the fish would exploit the waters around the discharge for thermoregulatory purposes and the optimisation of physiological and ecological performance (Coutant 1977).

Studies on the distribution of fish around thermal discharges have revealed the attraction of fish at certain times of the year, consistent with the optimisation of metabolism. Elser (1965) reported that fishing (especially for catfish) in heated water was better during the cooler 9 months of the year than in the 3 summer months, implying attraction to warmer waters. Neill and Magnuson (1974) recorded concentrations of fish around a thermal discharge, but the distributions did not reverse with season or time of day, and were related to body temperatures of fish and their thermal preferences. Similarly, Kelso and Minns (1975) reported that a thermal plume had little effect on pelagic fish and speculated that the fish were either not available to the elevated temperatures or they failed to respond to increased surface temperatures. However, in later studies Spigarelli (1975) reported that rainbow trout were in thermal discharges for variable periods. This finding supports the seasonal changes in fish populations in reference and thermal plume areas, reported by Spigarelli et al. (1982). They found concentrations of fish in the plume area to be up to two orders of magnitude greater than those at reference areas during late spring and early summer. Thereafter, the reference area had a maximum of 10 times the numbers of fish in the plume location during late summer and early fall. Because of thermal preferences large numbers of predatory salmon were in the thermal plume at times of low food densities. This impoverished energetic situation of plume residence was considered to be offset at distance from the discharge by the high concentrations of forage fish prey.

Adaptation to thermal discharges is revealed by Spigarelli and Thommes (1979) who determined that the temperature of fish increased with the thermal discharge temperature. The maximum temperature exceeded the ambient temperature by 10 °C, while the population mean differed by 2 °C to 6 °C. Unlike the behavioural studies on chum salmon (Birtwell et al. 1998), these results reveal the integration of temperatures experienced by the fish, and provide less insight into temporary use of waters at elevated levels. That fish were captured with body temperatures exceeding ambient by up to 10 °C, implies longer residence than was recorded for chum salmon in 24 °C to 30 °C waters (Birtwell et al. 1998). Thus fish have been documented to utilise thermal plumes and to distribute themselves according to thermal preferences.

### Dissolved gas saturation

Throughout the study dissolved oxygen was frequently at levels in excess of air saturated values. The heating of sea water drawn into the electric-generating plant for cooling purposes will result in supersaturation of gases within these waters. However, the water drawn into the plant is from depths where dissolved oxygen levels tends to be lower than in surface waters. Although supersaturation of dissolved gases would have occurred in waters adjacent to the thermal discharge as a consequence of this heating, the TGP levels were probably reduced due to the entrainment of the deeper less dissolved gas-saturated water. Hence, it is not apparent that the thermal discharge from the BGS resulted in a direct elevation of TGP in the waters of Port Moody Arm at this location. Any role that the discharge may have played in promoting planktonic algal growth, which may be linked to the elevated levels of TGP in Port Moody Arm through enhanced primary productivity, has not been determined. The dissolved oxygen and TGP values we determined imply that Port Moody Arm tends to be eutrophic and subject to algal blooms (L. Nikl, Department of Fisheries and Oceans, New Westminster, B.C., pers. comm.).

Because the caged chum salmon favoured the upper surface waters of the Arm, there is the potential for long term residency in such waters to result in adverse effects on their health. The levels of gas supersaturation in the shallower surface waters utilised by the chum salmon exceeded proposed guidelines of about 103% and 110% for sea level conditions in waters with depths <1 m and >1 m respectively, to safeguard fish from gas bubble trauma (GBT), (Fidler and Miller 1997). Although juvenile salmon may avoid dissolved gas supersaturated conditions, especially by moving deeper and avoiding GBT (Shrimpton et al. 1989), there is no guarantee that this would happen when other cues are present in the natural environment that have the potential to override such avoidance responses. Fidler and Miller (1997) state that for waters <1 m depth the level of TGP that will afford protection for juvenile salmon will be associated with the partial pressure of dissolved oxygen ($pO_2$) in the water and the depth of water occupied by the fish. When the waters are supersaturated with dissolved oxygen (a higher $pO_2$ than at air saturation levels), as typically occurred in the surface waters of Port Moody Arm during our studies, the safe limits for exposure to TGP and protection from symptoms of GBT are increased. Thus the occupancy of shallow surface waters which were supersaturated with dissolved oxygen in Port Moody Arm could provide some protective benefit from the elevated TGP levels in these waters, aside from the benefit of moving deeper in the water column. A TGP level of 103% at sea level at 100% air saturation ($pO_2 = 157$ mm Hg), 0 m depth, is considered to safeguard juvenile salmon from GBT (Fidler and Miller 1997). Thus in the absence of ambient elevated $pO_2$ levels, and with prolonged occupancy of water depths <1 m, it would be expected that there could be some negative effects on the health of chum salmon. The results of analyses relating fish distribution to aquatic variables revealed that TGP was negatively and significantly associated with their presence, implying that fish tended to select, or coincidentally favour waters lower in TGP, and shallower depths (see Table 15).

Meekin and Turner (1974) report that juvenile chinook salmon and steelhead trout could withstand 16 h exposure to 135% nitrogen supersaturation. However, their tests were conducted with dissolved oxygen levels less than 100%. In tests with oxygen and nitrogen supersaturation (116% and 124% respectively) chinook, coho and steelhead died quicker than at similar nitrogen levels (122%). This finding suggests that both dissolved gasses contribute to the mortality of the fish, and seems to contrast with the deductions of Fidler and Miller (1997) regarding the protection from GBT provided by elevated levels of dissolved oxygen and the results of Rucker (1976) for coho salmon. The experiments of Meekin and Turner (1974) were conducted at a constant, relatively low temperature (around 10 °C to 12 °C). Ebel et al. (1971) concluded that an increase in temperature over ambient would be detrimental to migrating juvenile salmonids during periods of nitrogen supersaturation. It cannot be ruled out, therefore, that at highly stressful temperatures concomitant elevated TGP levels (naturally occurring or otherwise), especially of nitrogen and oxygen, would create additional stress on fish in contrast to either factor acting alone. Such findings have been reported by Marcello and Fairbanks (1974) revealing the potential for waters of sub-optimal quality to be occupied because of , for example, thermoregulatory behaviour. They report that Atlantic menhaden (*Brevoortia tyranus*) were attracted to the thermally heated waters discharged from a nuclear power plant and they died from exposure to elevated TGP levels. Meldrim et al. (1973) noted that golden shiner usually avoided gas supersaturation of 110% but when temperature increases of 5°C to 10°C were associated with the supersaturation, thermal preference overrode the avoidance response.

## Fish presence in sub-optimal habitats

Chum salmon occupation of the surface waters of Port Moody Arm close to the thermal discharge implies that the waters were not lethal to the fish over a short period of time (approximately 20 h), when they were given access from the surface to 6 m depth. We do not know the residence time of fish in waters with temperatures above their potential lethal limit in Port Moody Arm, but we determined that they would use less thermally-stressful waters which were supersaturated with dissolved gasses, and briefly feed in waters at temperatures up to 30 °C during laboratory experiments (Birtwell et al. 1998). It is also probable that fish would be exposed to "chlorine-produced oxidants" in waters emanating from the plant (Greenbank et al. 1998), but we have no information on the potential interaction with sublethal temperatures, TGP, and contaminants on the fish in the field. Greenbank et al. (1998) reported that chum salmon growth rate was reduced by 24% and 45% in two separate 20 d growth studies when fish were exposed to 50% heated cooling water from the BGS in contrast to chum salmon growth in control waters (the overall health and performance of fish surviving extended periods in heated cooling water was not evaluated in this particular investigation).

Caution must be exercised in the interpretation of our findings that juvenile salmon occurred in insignificantly different numbers in the surface waters proximal to, and distal from, the BGS heated water discharge. It has been determined that fish do not always avoid sub-optimal waters and accordingly presence *per se* is but an extremely coarse indicator of environmental quality (Birtwell and Kruzynski 1989; Birtwell et al. 1994, 1997; Korstrom et al. 1997).

Neill and Magnuson (1974) in their comprehensive examination of the effects of thermal discharges in the laboratory and field, state that thermoregulatory behaviour of fish was not overridden by feeding behaviour in either location. Even though planktonic food was more abundant in the thermal outfall area fish would only make forays into waters with extreme temperatures to feed (Neill and Magnuson 1974). However, in the laboratory, temperature limited the acquisition of a maximum daily meal, and as recorded for chum salmon (Birtwell et al. 1998), fish (yellow perch) spent significantly less time (<5%) in waters above their lethal limit and the duration of forays became <30 s. Two fish died during feeding experiments in which the perch obtained food in waters 3 °C above the upper lethal limit. Similarly, Munson et al. (1980) recorded the death (50% to 65%) of rainbow trout feeding in temperatures above their lethal limit. The fish were habituated to feeding at the end of a 2.4 m channel in which a thermal gradient occurred: food being provided in the hotter waters. In a thermal gradient from the acclimation temperature to 30 °C to 36 °C (up to 24 °C above acclimation temperature), some of the fish died while attempting to feed. Complete inhibition of motivation to feed was not achieved. Thus the motivation to feed, even in lethal waters, overrode the expected thermoregulatory response: a contrast with the conclusion of Neill and Magnuson (1974).

It is not known whether feeding in waters at temperatures that are just above potentially lethal limits or above those optimal for physiological and metabolic function (at a sublethal exposure, as may have occurred in July in Port Moody Arm) had a detrimental effect on chum salmon survival. It is possible that the thermal input in the early spring could favour growth and survival, assuming all other factors are appropriate, by elevating temperatures to levels that are metabolically optimal. Clearly, if exposure to elevated temperatures results in prolonged stress, inefficient utilisation of energy and reductions in growth, increased risk of predation and disease, then the advantages of obtaining food in the thermally enriched waters are minimal. Wissmar and Simenstad (1988) state that the metabolic costs of maintenance are in delicate balance with food intake and growth. If food were impoverished in the preferred, yet thermally-heated, surface waters the energetic costs of capture in high temperature waters could limit growth. Donaldson and Foster (1941) found that juvenile sockeye salmon refused to feed at temperatures increased from 17.2 °C to 25.6 °C, but resumed feeding when temperatures returned to 21.1 °C. Similarly, Brett et al. (1982), found that 19 °C was the optimum temperature for the growth of juvenile chinook salmon fed on maximum ration, but above this level feeding and growth decreased. They also state that at 60% of maximum daily ration, the optimum temperature for growth decreased to 14.8 °C. Their studies did not permit opportunity for the fish to balance the thermoregulatory requirements against the energetic and metabolic demands of feeding and growth. Feeding in higher temperature waters may not be as detrimental in thermally-stratified environments which permit fish to thermoregulate and maximise performance. In this context, the movement of sockeye salmon into warmer surface waters to feed followed by a return to colder waters in lakes, is considered to be adaptive and energetically advantageous (Biette and Geen 1980). The advantage occurring because of the lower maintenance requirements at colder temperatures and, therefore, the greater the proportion of food conversion for growth (Brett 1971). However, in the examination of chum salmon confined to a 6 m portion of the water column in Port Moody Arm it was not possible to ascertain such vertical migratory behaviour. Experience from studies with chum salmon at other locations (Birtwell and Kruzynski (1989) suggests that they do not undergo similar vertical migrations to those of lake dwelling juvenile sockeye, during their early sea life.

While the dispersion of food in the wild is unlikely to be available only in the surface waters (1 m - 2 m) where the juvenile chum salmon prefer to reside, their presence there suggests proximity to food. It has been suggested by Coutant (1987) that there may be marked differences in feeding behaviour in steep gradients and that fish may feed on uncharacteristic prey. Spigarelli and Thommes (1979) documented the reduced growth and condition in ictalurids in "thermally-enriched" areas because of strong thermal attraction and inadequate food. However Spigarelli and Smith (1976) found no evidence of such an effect on rainbow trout from thermal plume and reference areas implying an ample supply of food for "plume-resident" fish. Quite obviously there are site-specific differences among the reported findings, but the pattern of attraction to thermal discharges at certain times of the year is common to all.

Chum salmon are opportunistic and selective predatory sight feeders consuming a variety of items that reflect abundance in fresh water and sea water (Higgs et al. 1995). If, through the discharge of heated waters, the upper surface water temperatures exceed preferred levels, reduced abundance may occur as the fish move to avoid these temperatures, but motivation to feed in addition to responding to other cues will, seemingly, encourage occupancy of surface waters for brief periods. The field experiments of McGreer and Vigers (1983) and Birtwell and Kruzynski (1989) determined that juvenile chum salmon may succumb to conditions in vertically-stratified waters where lethal conditions persisted close to the water surface: a result similar to that reported by Munson et al. (1980). Prolonged occupancy in waters heated above ambient could be detrimental through exposure to elevated levels of TGP, aside from exposure to other stressors. The mortality of Atlantic menhaden in the thermal plume of a nuclear power plant was related to elevations in TGP and the thermoregulatory responses of the fish which chose to occupy the plume region (Marcello and Fairbanks 1974). Thus the effects of thermal change on juvenile chum salmon in Port Moody Arm would be expected to follow a seasonal trend of attraction to, and occupancy of, waters at the preferred temperature, followed by a movement from increasing temperatures, from spring through to late summer. The timing, duration and magnitude of these events being related to many factors in addition to the discharge volume and temperature of heated water from the BGS.

## SUMMARY AND CONCLUSIONS

The vertical distribution of chum salmon was not affected in a statistically significant manner with proximity to the discharge of thermal effluent from the BGS during July and August 1997. These fish preferred to occupy the shallow waters close to the surface during their early marine life and we anticipated that warm water from the plant would rise to the surface and disrupt this adaptive behaviour, thereby displacing them from their preferred habitat. In this way we expected that the distribution of fish would be affected depending not only on the climatic conditions and proximity to the discharge location, but also on the operating conditions at the BGS. Although fewer fish were in the uppermost surface waters close to the thermal discharge there was sufficient variation in the data to negate any potential statistical significance. However, a seasonal component to their distribution was recorded as the larger fish tended to be in deeper waters in August at all study locations including the reference site.

The waters of Port Moody Arm were typically supersaturated with dissolved gasses reflective of the primary productivity and thermal input from both natural (solar) and other sources. However, adjacent to the discharge of heated cooling water, TGP was occasionally reduced to levels approaching optimal values for salmon. Thus, there did not appear to be a direct effect of the BGS heated water discharge on TGP in Port Moody Arm at this location.

Temperature was significantly elevated at sites close to the discharge (70 m and 250 m east), and in general at sites towards the shallow head of the Port Moody Arm. Throughout most of the study period (June to August) temperatures at levels preferred by chum salmon (13.7 °C to 17.9 °C) were present within 6 m of the water surface, and were frequently less than the level that caused 50% avoidance (20.2 °C) in laboratory studies (Birtwell et al. 1998). At the reference site temperatures in the uppermost 1 m of the water column that were favoured by the chum salmon, were always less than the upper lethal limit of 23.8 °C that was determined by Brett (1952) in laboratory experiments, and rarely at levels that would have been expected to evoke avoidance behaviour. Temperatures in waters to the east of the outfall were generally higher and exceeded the laboratory-derived avoidance threshold more frequently, and approached the potentially lethal level in July. At Site 4, 1200 m east of the thermal discharge location, the potentially lethal level was exceeded briefly, perhaps reflecting the shallowness of the area and the possible thermal input from extensive mud flats towards, and at the head of, Port Moody Arm. Even though the temperature of surface waters in Port Moody Arm were frequently higher than those that were found to cause avoidance responses in laboratory experiments, juvenile chum salmon continued to use these waters. It is unclear as to whether this use represented brief excursions into these waters to feed, an ability to tolerate the warmer water due to progressive thermal acclimation, a response to natural ambient stimuli or a combination of all of these. While experiments conducted in the laboratory by Brett (1952) and Birtwell et al. (1998) did not mimic all the cues likely to be found in the wild, they did reveal that elevated temperatures, such as the highest ones recorded in Port Moody Arm are likely avoided by juvenile chum salmon, and that prolonged occupation of such waters can result in their death. Irrespective of the reasons why juvenile chum salmon chose to occupy the waters close to the surface concern is warranted if these fish continue to reside in depths <1 m due to the potential for harmful effects on their health caused by the interaction of temperature and TGP (notwithstanding the potential protection from TGP in shallow waters due to the presence of supersaturated levels of dissolved oxygen).

At each of the four stations in Port Moody Arm investigated in this study, including a reference station removed from the direct influence of the BGS cooling water discharge, chum salmon continued to use surface waters despite supersaturated conditions for TGP and temperatures which were frequently 18°C to 21°C. The innate behavioural trait to occupy surface waters during estuarine residence and early sea life may compromise survival if other non-thermal cues become dominant factors. In this circumstance, they could override thermal stimuli that would otherwise favour survival and the optimisation of metabolic and physiological functions. Although chum salmon demonstrated an avoidance of potentially lethal high temperatures in laboratory experiments (Birtwell et al. 1998), they were also motivated to feed in such waters (to 30°C). To this extent we do not know the effects of repeated excursions into waters that are potentially lethal, nor the consequences of longer occupancy of waters that are potentially stressful at the sub-lethal level (combined effects of temperature and elevated TGP) on the health and performance of individuals and the crucial link to survival. In addition, it is possible that a thermal discharge could elevate temperatures above ambient to those in the preferred range during certain times of the year. Under these circumstances fish would be encouraged to move from cooler waters, as may occur in the spring and early summer. Assuming adequate food supplies, these conditions would favour growth (and possibly survival), but at the same time extended residence could result in exposure to elevated TGP. This latter effect may be mediated behaviourally through the occupation of deeper waters, but this would remove the fish from their preferred surface water habitat.

The intermittent operation of the Burrard Thermal Generating Plant would impose a similarly fluctuating thermal regime in Port Moody Arm because of the rapid (1 to 2 d) tidal-induced replacement of water in this water body (Waldichuk 1965). It is speculated that such an operating regime could probably reduce potential impacts on chum salmon during the spring and early summer, but might increase the risk of adverse effects such as thermal shock in winter and temporary habitat displacement in summer. Thus, the judicious discharge of heated cooling water could favour salmonid survival during spring and early summer if other environmental factors (biological, physical, and chemical) were appropriate for maintaining health and performance.

## ACKNOWLEDGEMENTS

This research was funded under a collaborative agreement with B.C. Hydro, and we are particularly indebted to Peter Calder, Al Brotherston,, and Tony Cohen (B.C. Hydro), Richard Addison, Julie Henderson, Gail Huscroft, and Gus Cormier (DFO), for their facilitation of the administrative tasks. We appreciate the efforts of Mark Johnson and Lee Nikl who assisted in the procurement of fish, and the staff of the Seymour River Volunteer Hatchery who reared them. Invaluable assistance with statistical analyses was provided by Brett Hodson. Mike Bradford, Lee Nikl, and Mark Johnson provided boats for the study. Jeff Greenbank and Mu Zhen Lu cared for the stock fish. Gordon Miller and Pam Olson provided assistance in obtaining literature. We are also grateful to Don McLeay for his thorough and meticulous review of the report.

## REFERENCES

Beacham, T. D., and R. E. Withler. 1991. Genetic variation in mortality of chinook salmon, *Oncorhynchus tshawytscha* (Walbrum), challenged with high water temperatures. Aquaculture and Fisheries Management 22: 125-133.

Beak Consultants Ltd. 1981. Environmental statement of proposed improvement to the Fraser River shipping channel. Public Works Canada, Vancouver, BC: 635 p.

Biette, R. M., and G. H. Geen. 1980. Growth of underyearling salmon (*Oncorhynchus nerka*) under constant and cyclic temperatures inn relation to live zooplankton ration size. Can. J. Fish. Aquat. Sci. 37: 203-210.

Birtwell, I. K. 1977. A field technique for studying the avoidance of fish to pollutants. p. 69-86. In: Proc. 3rd Aquatic Toxicity Workshop, Halifax, NS, Nov. 2-3, 1976. Envir. Prot. Serv. Tech. Rep. No. EPS-5-AR-77-1.

Birtwell, I. K. 1978. Studies on the relationship between juvenile chinook salmon and water quality in the industrialised estuary of the Somass River. p. 57-78. In: B. C. Sheppard, and R. M. J. Ginetz (eds.), Proceedings of the 1977 Northwest Pacific Chinook and Coho Workshop. Fish Mar. Serv. Tech. Rep. 759.

Birtwell, I. K., and R. M. Harbo. 1980. Pulp mill impact studies at Port Alberni and Port Mellon, British Columbia. Trans. Tech. Sect. Can. Pulp Pap. Assoc. 81: 85-88.

Birtwell, I. K., and G. M. Kruzynski. 1987. Laboratory apparatus for studying the behavior of organisms in vertically stratified waters. Can. J. Fish. Aquat. Sci. 44: 1343-1350.

Birtwell, I. K., and G. M. Kruzynski. 1989. *In situ* and laboratory studies on the behavior and survival of Pacific salmon (genus *Oncorhynchus*). Hydrobiologia 188/189: 543-560.

Birtwell, I. K., A. P. Farrell, R. Fink, J. S. Korstrom, and S. Spohn. 1997. Responses of adult salmon to hypoxic waters and toxicants. p. 35-36. In: R. C. Pierce, and D. Williams (eds.), Book of Abstracts: Department of Fisheries and Oceans Green Plan Toxic Chemicals Program Wrap-Up Conference, Ottawa, ON, Jan. 28 – 31, 1997.

Birtwell, I. K., J.S. Korstrom, R.P. Fink, J.A. Tanaka, D.I. Tiessen, and B.J. Fink. 1998. Distribution and feeding responses of juvenile chum salmon (Oncorhynchus keta) to thermal change in sea water. Can Tech Rep. Fish Aquat. Sci. (In preparation)

Birtwell, I. K., K. Hyatt, J. Korstrom, G. M Kruzynski, C. M Langton, G. E. Piercey, and S. Spohn. 1994. Behavior and physiological responses of adult sockeye (Oncorhynchus nerka) salmon to simulated estuarine conditions and salt water hypoxia. p. 243-245. In: D. D. MacKinley (ed.), High Performance Fish: Proceedings of an International Fish Physiology Symposium, University of British Columbia, Vancouver. American Fisheries Society and Fish Physiology Association.

Birtwell, I. K., S. Nelles, and R. M. Harbo. 1983. A brief investigation of fish in the surface waters of the Somass River estuary, Port Alberni, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 1744: 31p.

Brett, J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. J. Fish. Res. Board Can. 9: 265-323.

Brett, J. R. 1971. Energetic response of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon (*Oncorhynchus nerka*). Am. Zool. 11: 99-113.

Brett, J. R., W. C. Clarke, and J. E. Shelbourn. 1982. Experiments on thermal requirements for growth and food conversion efficiency of juvenile chinook salmon, *Oncorhynchus tshawytscha*. Can. Tech. Rep. Fish. Aquat. Sci. 1127: iv + 29p.

Colt, J. 1984. Computation of dissolved gas concentrations in water as functions of temperature, salinity, and pressure. Spec. Publ. No. 14. American Fisheries Society, Washington, DC. 154 p.

Coutant, C. C. 1975. Temperature selection by fish – a factor in power-plant impact assessments. p.575-597. In: Environmental Effects of Cooling Systems at Nuclear Power Plants. IAEA-SM-187/11, Vienna, Austria.

Coutant, C. C. 1977. Physiological considerations of future thermal additions for aquatic life. P 251 - 266. In M. Marios (ed.) Proceedings of the World Conference Towards a Plan of Action for Mankind, Vol. 3. Biological Balance and Thermal Modifications. Pergamon Press, NY.

Coutant, C. C. 1987. Thermal preference: when does an asset become a liability? Envir. Biol. Fish. 18: 161-172.

Crawshaw, L. I. 1977. Physiological and behavioral reactions of fishes to temperature change. J. Fish. Res. Board Can. 34: 730-734.

Devore, J. L. 1991. Probability and Statistics for Engineering and the Sciences. 3rd ed. Brooks/Cole Publishing Company, Pacific Grove, CA: 716 p.

Donaldson, L. R., and F. J. Foster. 1941. Experimental study on the effect of various water temperatures on the growth, food utilization, and mortality rate of fingerling sockeye salmon. Trans. Am. Fish. Soc. 70: 339-346.

Döving, K. B., H. Westerberg, and P. B. Johnson. 1985. Role of olfaction in the behavioural and neuronal responses of Atlantic salmon, *Salmo salar*, to hydrographic stratification. Can. J. Fish. Aquat. Sci. 42: 1658-1667.

Ebel, W. J., E. M. Dawley, and B. H. Monk. 1971. Thermal tolerance of juvenile Pacific salmon and steelhead trout in relation to supersaturation of nitrogen gas. Fish. Bull. 69: 833-843.

Elser, H. J. 1965. Effect of a warmed-water discharge on angling in the Potomac River, Maryland, 1961-1962. Prog. Fish. Cult. 27: 79-86.

Fidler, L. E., and S. B. Miller. 1997. British Columbia water quality guidelines for the protection of aquatic biota from dissolved gas supersaturation - technical report. Prepared by Aspen Applied Sciences Limited for the B.C. Ministry of Environment, Lands, and Parks; Environment Canada, and Department of Fisheries and Oceans. Vancouver, B.C. 100 p + Appendices.

Fry, F. E. J. 1947. Effects of the environment on animal activity. Univ. Toronto Stud. Biol. Ser. 55. Publ. Ont. Fish. Res. Lab. 68: 1-62.

Giattina, J. D., and R. R. Garton. 1982. Graphical model of thermoregulatory behavior by fishes with a new measure of eurythermality. Can. J. Fish. Aquat. Sci. 39: 524-528.

Gray, R. H. 1990. Fish behavior and environmental assessment. Envir. Tox. Chem. 9: 53-67.

Greenbank, J. D., R. P. Fink, and Mu Zhen Lu. 1998. Burrard Generating Station cooling water effects study: effect of cooling water on growth of juvenile chum salmon (*Oncorhynchus keta*). B.C. Hydro, Port Moody, B.C. 101 p.

Healey, M. C. 1982. Timing and relative intensity of size-selective mortality of juvenile chum salmon (*Oncorhynchus keta*) during early sea life. Can. J. Fish. Aquat. Sci. 39: 952-957.

Higgs, D. A., J. A. MacDonald, C. D. Levings, B. S. Dosanjh. 1995. Nutrition and feeding habits in relation to life history stage. p. 160-315. In: C. Groot, L. Margolis, W. C. Clarke. Physiological Ecology of Pacific Salmon. UBC Press, Vancouver, BC.

Houston, A. H. 1982. Thermal Effects Upon Fishes. NRCC Associate Committee on Scientific Criteria for Environmental Quality. NRCC No. 18566: 200 p. Ottawa, ON.

International Atomic Energy Agency. 1975. Environmental Effects of Cooling Systems at Nuclear Power Plants. IAEA-SM-187, Vienna, Austria. 829 p.

Javaid, M. Y., and J. M. Anderson. 1967. Influence of starvation on selected temperature of some salmonids. J. Fish. Res. Board Can. 24: 1515-1519.

Kelso, J. R. M, and C. K. Minns. 1975. Summer distribution of the nearshore fish community near a thermal generating station as determined by acoustic census. J. Fish. Res. Board Can. 32: 1409-1418.

Konecki, J. T., C. A. Woody, and T. P. Quinn. 1995. Critical thermal maxima of coho salmon (*Oncorhynchus kisutch*) fry under field and laboratory acclimation regimes. Can. J. Zool. 73: 993-996.

Korstrom, J. S., R. Fink, S. Spohn, and I. K. Birtwell. 1997. Sublethal toxicological stress in adult sockeye salmon (*Oncorhynchus nerka*) exposed to a combination of sodium pentacholorophenate and fresh water hypoxia. Can. Data Rep. Fish. Aquat. Sci. 1006: viii + 77

Korstrom, J. S., R. P. Fink, J. A. Tanaka, D. I .Tiessen, B. J. Fink, and I. K. Birtwell. 1998. The influence of lethal temperature and food on the behavior of juvenile chum salmon (Oncorhynchus keta) under simulated marine conditions. Can. Data Rep. Fish. Aquat. Sci. (in press): 70 p.

Kwain, W., and R. W. McCauley. 1978. Effects of age and overhead illumination on temperature preferred by underyearling rainbow trout, *Salmo gairdneri*, in a vertical temperature gradient. J. Fish. Res. Board Can. 35: 1430-1433.

Langford, T. E. L. 1990. Ecological Effects of Thermal Discharges. Elsevier Applied Science, London, England: 468 p.

Macdonald, J. S., and B. D. Chang. 1993. Seasonal use by fish of nearshore areas in an urbanized coastal inlet in south-western British Columbia. Northwest Sci. 67: 63-77.

Macdonald, J. S., I. K. Birtwell, and G. M. Kruzynski. 1987. Food and habitat utilization by juvenile salmonids in the Campbell River estuary. Can. J. Fish. Aquat. Sci. 44: 1233-1246.

Mace, P.M.. 1983. Bird predation on juvenile salmonids in the Big Qualicum River, Vancouver Island. Can. Tech. Rep. Fish. Aquat. Sci. 1117: 79 p.

Magnuson, J. J., L. B. Crowder, and P. A. Medvick. 1979. Temperature as an ecological resource. Amer. Zool. 19: 331-343.

Manzer, J. I. 1964. Preliminary observations on the vertical distribution of Pacific salmon (Genus *Oncorhynchus*) in the Gulf of Alaska. J. Fish. Res. Board Can. 21: 891-903.

Mason, J. C. 1974. Behavioral ecology of chum salmon fry (*Oncorhynchus keta*) in a small estuary. J. Fish. Res. Board Can. 31: 83-92.

Marcello, R. A., and R. B. Fairbanks. 1974. Gas bubble disease mortality of Atlantic menhaden, *Brevoortia tyrannus*, at a coastal nuclear power plant. p. 75-80. In: D. H. Fickeisen, and M. J. Schneider, eds. Gas Bubble Disease. USERDA CONF-741033. Energy Research and Development Administration, Oak Ridge, TN.

McGeer, J. C., L. Barany, and G. K. Iwama. 1991. Physiological response to challenge tests in six stocks at coho salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 48: 1761-1771.

McGreer, E. R., and G. A. Vigers. 1983. Development and validation of an in-situ fish preference-avoidance technique for environmental monitoring of pulp mill effluents. In: W. E. Bishop, R. D. Cardwell, and B. C. Heidolph (eds.). Aquatic Toxicology and Hazard Assessment: 6th symposium: 519-529. ASTM STP 802, American Society for Testing and Materials, Philidelphia, PA.

Meekin, T. K., and B. K. Turner. 1974. Tolerance of salmonid eggs, juveniles, and squawfish to supersaturated nitrogen, p. 78-126. In: Nitrogen Supersaturation Investigations in the Mid-Columbia River. Report 12, Olympia, WA.

Meldrim, J. W., J. J. Gift, and B. R. Petrosky. 1973. Responses of several fresh water fishes to water containing various levels of gas supersaturation. I. A comparison of two different methods for achieving supersaturation. II. The effect of increased temperature associated with gas supersaturation on the response. Ichthyological Associates, mimeo report: 15 p.

Munson, B. H., J. H. McCormick, and H. L. Collins. 1980. Influence of thermal challenge on conditioned feeding forays of juvenile rainbow trout. Trans. Am. Fish. Soc. 109: 116-121.

Neill, W. H., and J. J. Magnuson. 1974. Distributional ecology and behavioral thermoregulation of fishes in relation to heated effluent from a power plant at Lake Monona, Wisconsin. Trans. Am. Fish. Soc. 103: 663-710.

Nelles, S. 1978. Comments on juvenile salmonid utilization of Burrard Inlet and Vancouver Harbour. Fisheries and Marine Service Internal Report, Department of Fisheries and Environment, Vancouver, BC: 20 p.

Olla, B. L., Pearson, W. H, and A. L. Studholme. 1980. Applicability of behavioral measures in environmental stress assessment. Rapp. P.-v. Réun. Cons. int. Explor. Mer 179: 162-173.

Owseley, D. E. 1981. Nitrogen gas removal using packed columns, p 71 - 82. In L. J. Allen and E. C. Kinney (eds.) Proceedings of the Bio-Engineering Symposium for Fish Culture. Fish Culture Section of the American Fisheries Society. FCS Publ. 1.

Piercey, G. E., I. K. Birtwell, H. Herunter, M. Kotyk, G. M. Kruzynski, J. S. MacDonald, and K. Seaman. 1985. Data report on physical habitat characteristics and observations of fish at two regions in the estuary of the Campbell River, British Columbia, 1984. Can. Data Rep. Fish. Aquat. Sci. 551: 107p.

Reynolds, W. W. 1977. Temperature as a proximate factor in orientation behavior. J. Fish. Res. Board Can. 34: 734-739.

Reynolds, W. W., and M. E. Casterlin. 1976. Thermal preferenda and behavioral thermoregulation in three centrachid fishes. p. 185-190. In: B. W. Esch, and R. W. McFarlane (eds.). Thermal Ecology II. Springfield, Va., Technical Information Service.

Reynolds, W. W., and M. E. Casterlin. 1980. The role of temperature in the environmental physiology of fishes. p. 497-518. In: M. A. Ali (ed.), Environmental Physiology of Fishes. Plenum Press, New York, NY.

Rucker, R.R. 1976. Gas bubble disease of salmonids: variation in oxygen-nitrogen ratios with constant total gas pressure. p. 85-88. In: D. H. Fickeisen and M. J. Schneider (eds.), Gas Bubble Disease. CONF-741033. Technical Information Centre, Energy Research and Development Administration, Springfield, VA.

Seaconsult Marine Research Ltd. 1995. Receiving water impact assessment for the Burrard Thermal Generating Plant. Vancouver, B.C. 58 p.

Shrimpton, J. M., Randall, D. J, and L. E. Fidler. 1989. Assessing the effects of positive buoyancy on rainbow trout (*O. mykiss*) held in gas supersaturated water. Can. J. Zool. 68: 969-973.

Spigarelli, S. A. 1975. Behavioral responses of Lake Michigan fishes to a nuclear power plant discharge. p. 479-498. In: Environmental Effects of Cooling Systems at Nuclear Power Plants, IAEA-SM-187/18, Vienna, Austria.

Spigarelli, S. A., and D. W. Smith. 1976. Growth of salmonid fishes from heated and unheated areas of Lake Michigan – measured by RNA-DNA ratios. p. 100-105. In: G. W. Esch, and R. W. McFarlane (eds.), Thermal Ecology II. ERDA Symposium Series, CONF-750425. Augusta, GA.

Spigarelli, S. A., and M. M. Thommes. 1979. Temperature selection and estimated thermal acclimation by rainbow trout in a thermal plume. J. Fish. Res. Board Can. 36: 366-376.

Spigarelli, S. A., M. M. Thommes, and W. Prepejchal. 1982. Feeding, growth, and fat deposition by brown trout in constant and fluctuating temperatures. Trans. Am. Fish. Soc. 111: 199-209.

Spigarelli, S. A., M. M. Thommes, W. Prepejchal, and R. M. Goldstein. 1983. Selected temperatures and thermal experience of brown trout, *Salmo trutta*, in a steep thermal gradient in nature. Envir. Biol. Fish 8: 137-149.

Systat Inc. 1992. SYSTAT for Windows, Version 5.0. Evanston, IL: 750 p.

Waldichuk, M. 1965. Water exchange in Port Moody, British Columbia, and its effect on waste disposal. J. Fish. Res. Board Can. 22: 801-822.

Westerberg, H. 1984. The orientation of fish and the vertical stratification at fine and microstructure scales. p. 179-204. In: J. D. McCleave, G. P. Arnold, J. J. Dodson, and W. H. Neill (eds.), Mechanisms of Migration in Fishes. Plenum Publishing Corp., New York, NY.

Wissmar, R. C., and C. A. Simenstad. 1988. Energetic constraints of juvenile chum salmon (*Oncorhynchus keta*) migrating in estuaries. Can. J. Fish. Aquat. Sci. 45: 1555-1560.

# TABLES 1 to 16

# AND

# FIGURES 1 to 36

Table 1. Number of chum salmon juveniles recovered from each depth at the Reference Site (1)*.

| | | Depth (m)** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Week No. | Date | 0.5 | 1.5 | 2.5 | 3.5 | 4.5 | 5.5 | Total |
| 1 | 25-Jun-97 | 58 | 2 | 0 | 0 | 0 | 0 | 60 |
| | 25-Jun-97 | 49 | 1 | 6 | 1 | 1 | 2 | 60 |
| | 26-Jun-97 | 56 | 1 | 2 | 0 | 1 | 0 | 60 |
| | 26-Jun-97 | 50 | 8 | 1 | 1 | 0 | 0 | 60 |
| 2 | 8-Jul-97 | 38 | 16 | 3 | 1 | 2 | 0 | 60 |
| | 9-Jul-97 | 47 | 6 | 0 | 7 | 0 | 0 | 60 |
| | 10-Jul-97 | 30 | 26 | 1 | 0 | 1 | 1 | 59 |
| | 11-Jul-97 | 27 | 30 | 2 | 0 | 1 | 0 | 60 |
| 3 | 15-Jul-97 | 58 | 1 | 1 | 0 | 0 | 0 | 60 |
| | 16-Jul-97 | 33 | 16 | 4 | 2 | 2 | 3 | 60 |
| | 17-Jul-97 | 38 | 15 | 6 | 1 | 0 | 0 | 60 |
| | 18-Jul-97 | 47 | 11 | 2 | 0 | 0 | 0 | 60 |
| 4 | 19-Aug-97 | 16 | 5 | 9 | 6 | 2 | 22 | 60 |
| | 20-Aug-97 | 21 | 11 | 10 | 4 | 4 | 10 | 60 |
| | 21-Aug-97 | 14 | 9 | 5 | 2 | 3 | 27 | 60 |
| | 22-Aug-97 | 11 | 18 | 7 | 5 | 3 | 16 | 60 |
| | Mean | 37.06 | 11.00 | 3.69 | 1.88 | 1.25 | 5.06 | |
| | SD | 15.97 | 8.78 | 3.16 | 2.33 | 1.29 | 8.84 | |

* Data in columns represent the number of fish (out of 60) recovered from each cage chamber following overnight acclimation with free access to all depths between the surface and 6 meters

** Depth values (0.5, 1.5, 2.5, 3.5, 4.5, 5.5) represent the aproximate center of each cage chamber

Table 2. Number of chum salmon juveniles recovered from each depth 70 m east of outfall (Site 2)*.

| | | Depth (m)** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Week No. | Date | 0.5 | 1.5 | 2.5 | 3.5 | 4.5 | 5.5 | Total |
| 1 | 25-Jun-97 *** | 31 | 12 | 5 | 7 | 3 | 2 | 60 |
| | 25-Jun-97 *** | 23 | 10 | 5 | 13 | 2 | 7 | 60 |
| 2 | 8-Jul-97 | 39 | 7 | 7 | 0 | 5 | 2 | 60 |
| | 9-Jul-97 | 22 | 18 | 8 | 5 | 5 | 2 | 60 |
| | 10-Jul-97 | 40 | 5 | 4 | 6 | 4 | 1 | 60 |
| | 11-Jul-97 | 32 | 13 | 3 | 8 | 1 | 1 | 58 |
| 3 | 15-Jul-97 | 41 | 5 | 4 | 3 | 2 | 5 | 60 |
| | 16-Jul-97 | 12 | 20 | 10 | 1 | 10 | 7 | 60 |
| | 17-Jul-97 | 23 | 9 | 13 | 1 | 6 | 9 | 61 |
| | 18-Jul-97 | 3 | 16 | 10 | 9 | 4 | 17 | 59 |
| 4 | 19-Aug-97 | 28 | 14 | 8 | 3 | 7 | 0 | 60 |
| | 20-Aug-97 | 32 | 2 | 3 | 4 | 3 | 16 | 60 |
| | 21-Aug-97 | 36 | 6 | 5 | 4 | 5 | 4 | 60 |
| | 22-Aug-97 | 32 | 6 | 8 | 7 | 2 | 5 | 60 |
| | Mean | 28.33 | 10.08 | 6.92 | 4.25 | 4.50 | 5.75 | |
| | SD | 11.63 | 5.88 | 3.18 | 2.86 | 2.47 | 5.67 | |

* Data in columns represent the number of fish (out of 60) recovered from each cage chamber following overnight acclimation with free access to all depths between the surface and 6 meters

** Depth values (0.5, 1.5, 2.5, 3.5, 4.5, 5.5) represent the aproximate center of each cage chamber

*** June 25 station at 100 meters downstream from outfall

Table 3. Number of chum salmon juveniles recovered from each depth 250 m east of outfall (Site 3).*

| | | Depth (m)** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Week No. | Date | 0.5 | 1.5 | 2.5 | 3.5 | 4.5 | 5.5 | Total |
| 2 | 8-Jul-97 | 40 | 8 | 5 | 3 | 3 | 0 | 59 |
| | 9-Jul-97 | 43 | 12 | 4 | 1 | 0 | 0 | 60 |
| | 10-Jul-97 | 44 | 11 | 2 | 1 | 1 | 1 | 60 |
| | 11-Jul-97 | 42 | 14 | 1 | 2 | 0 | 0 | 59 |
| 3 | 15-Jul-97 | 49 | 0 | 6 | 1 | 1 | 3 | 60 |
| | 16-Jul-97 | 38 | 13 | 1 | 5 | 1 | 2 | 60 |
| | 17-Jul-97 | 14 | 14 | 20 | 6 | 5 | 1 | 60 |
| | 18-Jul-97 | 37 | 9 | 3 | 4 | 3 | 3 | 59 |
| 4 | 19-Aug-97 | 8 | 10 | 20 | 15 | 5 | 2 | 60 |
| | 20-Aug-97 | 26 | 5 | 15 | 4 | 0 | 15 | 65*** |
| | 21-Aug-97 | 14 | 9 | 23 | 7 | 1 | 6 | 60 |
| | 22-Aug-97 | 39 | 13 | 2 | 3 | 1 | 2 | 60 |
| | Mean | 32.83 | 9.83 | 8.50 | 4.33 | 1.75 | 2.92 | |
| | SD | 13.75 | 4.11 | 8.44 | 3.89 | 1.82 | 4.17 | |

* Data in columns represent the number of fish (out of 60) recovered from each cage chamber following overnight acclimation with free access to all depths between the surface and 6 meters

** Depth values (0.5, 1.5, 2.5, 3.5, 4.5, 5.5) represent the aproximate center of each cage chamber

*** Fish miscounted during retrieval, counts presented as recorded.

Table 4. Number of chum salmon juveniles recovered from each depth 1200 m east of outfall (Site 4).*

| | | Depth (m)** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Week No. | Date | 0.5 | 1.5 | 2.5 | 3.5 | 4.5 | 5.5 | Total |
| 1 | 26-Jun-97 | 30 | 16 | 7 | 5 | 1 | 1 | 60 |
| | 26-Jun-97 | 42 | 8 | 6 | 1 | 2 | 1 | 60 |
| 2 | 8-Jul-97 | 41 | 3 | 1 | 1 | 3 | 11 | 60 |
| | 9-Jul-97 | 35 | 22 | 1 | 1 | 1 | 1 | 61*** |
| | 10-Jul-97 | 52 | 5 | 1 | 1 | 0 | 1 | 60 |
| | 11-Jul-97 | 23 | 27 | 6 | 2 | 2 | 0 | 60 |
| 3 | 15-Jul-97 | 46 | 5 | 2 | 2 | 4 | 1 | 60 |
| | 16-Jul-97 | 39 | 10 | 7 | 1 | 1 | 2 | 60 |
| | 17-Jul-97 | 38 | 5 | 5 | 9 | 1 | 2 | 60 |
| | 18-Jul-97 | 34 | 8 | 8 | 4 | 4 | 2 | 60 |
| 4 | 19-Aug-97 | 16 | 14 | 14 | 6 | 3 | 7 | 60 |
| | 20-Aug-97 | 11 | 6 | 19 | 5 | 6 | 13 | 60 |
| | 21-Aug-97 | 12 | 14 | 10 | 7 | 8 | 9 | 60 |
| | 22-Aug-97 | 12 | 18 | 1 | 9 | 17 | 3 | 60 |
| | Mean | 30.79 | 11.50 | 6.29 | 3.86 | 3.79 | 3.86 | |
| | SD | 13.69 | 7.24 | 5.34 | 3.01 | 4.39 | 4.28 | |

* Data in columns represent the number of fish (out of 60) recovered from each cage chamber following overnight acclimation with free access to all depths between the surface and 6 meters

** Depth values (0.5, 1.5, 2.5, 3.5, 4.5, 5.5) represent the aproximate center of each cage chamber

*** An extra fish was inadvertently included during intitial cage deployment

Table 5. Fork length of fish used in the cage experiments.

| Lengths at Week Ending: | | | | | | | |
|---|---|---|---|---|---|---|---|
| June 26, 1997 | | July 11, 1997 | | July 18, 1997 | | Aug 22, 1997 | |
| 77 | 77 | 75 | 85 | 91 | 85 | 128 | 112 |
| 79 | 72 | 60 | 91 | 79 | 89 | 139 | 130 |
| 75 | 68 | 80 | 82 | 90 | 81 | 125 | 125 |
| 75 | 70 | 70 | 74 | 90 | 83 | 124 | 129 |
| 78 | 75 | 81 | 88 | 61 | 78 | 131 | 122 |
| 65 | 70 | 78 | 65 | 69 | 79 | 133 | 122 |
| 72 | 66 | 84 | 98 | 86 | 80 | 142 | 127 |
| 55 | 64 | 82 | 88 | 59 | 83 | 140 | 127 |
| 73 | 67 | 80 | 90 | 71 | 82 | 118 | 146 |
| 60 | 81 | 85 | 82 | 81 | 70 | 142 | 135 |
| 72 | 70 | 83 | 76 | 86 | 86 | 131 | 141 |
| 66 | 61 | 81 | 82 | 76 | 84 | 145 | 114 |
| 55 | 73 | 85 | 70 | 78 | 78 | 130 | 121 |
| 76 | 66 | 85 | 83 | 86 | 92 | 133 | 129 |
| 77 | 74 | 67 | 83 | 78 | 86 | 127 | 127 |
| Mean | 70.30 | | 80.43 | | 80.57 | | 129.83 |
| SD | 6.75 | | 8.10 | | 8.14 | | 8.66 |

# Table 6. Characteristics of Reference Site (1) by time and depth.

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE\cdot s^{-1}\cdot m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jun-25 | 9:30 | Surface | 15.4 | 112 | 9.4 | 16.0 | 8.6 |  | na |  |  | 762 | n/a |
|  |  | 0.5 | 15.3 | 110 | 9.3 | 16.2 | 8.6 |  | 93.0 | 57 | 107.5 |  |  |
|  |  | 1.5 | 15.3 | 101 | 8.5 | 17.0 | 8.5 |  | 38.0 | 59 | 107.7 |  |  |
|  |  | 2.5 | 14.7 | 78 | 6.6 | 19.6 | 8.2 |  | 24.0 | 29 | 103.8 |  |  |
|  |  | 3.5 | 14.0 | 77 | 6.5 | 20.0 | 8.1 |  | 15.0 | 27 | 103.5 |  |  |
|  |  | 4.5 | 12.3 | 74 | 6.3 | 22.3 | 8.2 |  | 10.0 | 15 | 102.0 |  |  |
|  |  | 5.5 | 12.5 | 69 | 6.0 | 22.7 | 8.1 |  | 7.0 | 12 | 101.6 |  |  |
| Jun-26 | 9:50 | Surface | 15.8 | 113 | 9.4 | 16.3 | 8.6 |  | 156.0 |  |  | 764 | 3.5 |
|  |  | 0.5 | 15.8 | 109 | 9.1 | 16.3 | 8.6 |  | 82.0 | 50 | 106.5 |  |  |
|  |  | 1.5 | 16.4 | 101 | 8.2 | 18.4 | 8.5 |  | 56.0 | 56 | 107.3 |  |  |
|  |  | 2.5 | 16.1 | 94 | 7.6 | 19.5 | 8.3 |  | 24.0 | 33 | 104.3 |  |  |
|  |  | 3.5 | 13.8 | 81 | 6.8 | 22.2 | 8.2 |  | 33.0 | 32 | 104.2 |  |  |
|  |  | 4.5 | 12.9 | 84 | 7.2 | 22.6 | 8.1 |  | 23.0 | 11 | 101.4 |  |  |
|  |  | 5.5 | 12.3 | 80 | 6.8 | 23.0 | 8.1 |  | 17.0 | 12 | 101.6 |  |  |
| Jul-07 | 14:05 | Surface | 17.2 | 121 | 10.2 | 21.1 | 8.3 | 384 | 85.1 |  |  | 766 | 2.5 |
|  |  | 0.5 | 17.2 | 118 | 9.9 | 21.8 | 8.3 | 384 | 24.0 | 80 | 110.4 |  |  |
|  |  | 1.5 | 16.7 | 117 | 9.7 | 22.1 | 8.2 | 384 | 11.3 | 95 | 112.4 |  |  |
|  |  | 2.5 | 14.9 | 102 | 8.7 | 23.4 | 8.1 | 388 | 11.8 | 73 | 109.5 |  |  |
|  |  | 3.5 | 12.9 | 77 | 6.8 | 28.9 | 7.9 | 392 | 11.2 | 31 | 104.0 |  |  |
|  |  | 4.5 | 12.6 | 70 | 6.3 | 29.0 | 7.8 | 392 | 10.4 | 3 | 100.4 |  |  |
|  |  | 5.5 | 12.3 | 69 | 6.1 | 29.8 | 7.9 | 389 | 6.7 | -5 | 99.3 |  |  |
| Jul-08 | 11:10 | Surface | 16.0 | 108 | 9.8 | 16.3 | 8.1 | 419 | 36.5 |  |  | 761 | 2.0 |
|  |  | 0.5 | 16.1 | 113 | 10.1 | 20.3 | 8.1 | 421 | 23.3 | 45 | 105.9 |  |  |
|  |  | 1.5 | 15.3 | 105 | 9.5 | 21.4 | 8.1 | 422 | 10.9 | 59 | 107.8 |  |  |
|  |  | 2.5 | 14.3 | 94 | 8.6 | 22.0 | 8.0 | 423 | 5.3 | 39 | 105.1 |  |  |
|  |  | 3.5 | 14.3 | 89 | 8.2 | 22.2 | 7.9 | 423 | 6.0 | 39 | 105.1 |  |  |
|  |  | 4.5 | 13.1 | 84 | 7.9 | 22.6 | 7.8 | 423 | 2.9 | 18 | 102.4 |  |  |
|  |  | 5.5 | 12.3 | 82 | 7.8 | 22.9 | 7.8 | 424 | 2.2 | 9 | 101.2 |  |  |

Table 6. Characteristics of Reference Site (1) by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE{\cdot}s^{-1}{\cdot}m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-09 | 11:05 | Surface | 15.8 | 105 | 9.8 | 11.4 | 7.9 | 373 | 185.3 | | | 762 | 1.8 |
| | | 0.5 | 15.7 | 116 | 10.6 | 17.5 | 8.2 | 371 | 73.7 | 55 | 107.2 | | |
| | | 1.5 | 14.0 | 104 | 9.7 | 20.2 | 8.1 | 374 | 20.4 | 47 | 106.2 | | |
| | | 2.5 | 13.7 | 96 | 9.0 | 20.8 | 8.1 | 374 | 25.9 | 45 | 105.9 | | |
| | | 3.5 | 14.1 | 92 | 8.5 | 21.4 | 8.0 | 375 | 20.7 | 39 | 105.1 | | |
| | | 4.5 | 14.2 | 91 | 8.4 | 21.7 | 8.0 | 375 | 20.3 | 33 | 104.3 | | |
| | | 5.5 | 13.6 | 89 | 8.3 | 21.8 | 8.0 | 375 | 12.0 | 31 | 104.1 | | |
| Jul-10 | 11:30 | Surface | 15.6 | 130 | 11.8 | 15.0 | 8.4 | 406 | 166.1 | | | 764 | 2.3 |
| | | 0.5 | 15.6 | 119 | 10.9 | 16.7 | 8.4 | 406 | 78.7 | 66 | 108.6 | | |
| | | 1.5 | 15.1 | 113 | 10.3 | 18.1 | 8.3 | 407 | 25.6 | 64 | 108.4 | | |
| | | 2.5 | 15.8 | 99 | 9.0 | 20.7 | 8.1 | 410 | 15.3 | 54 | 107.1 | | |
| | | 3.5 | 15.2 | 98 | 8.8 | 21.2 | 8.0 | 410 | 12.7 | 49 | 106.4 | | |
| | | 4.5 | 15.1 | 98 | 8.8 | 21.5 | 8.0 | 409 | 8.5 | 40 | 105.2 | | |
| | | 5.5 | 14.4 | 95 | 8.7 | 21.6 | 8.0 | 408 | 5.2 | 39 | 105.1 | | |
| Jul-11 | 9:45 | Surface | 14.9 | 129 | 12.0 | 13.3 | 8.6 | 369 | 181.8 | | | 766 | 2.5 |
| | | 0.5 | 15.2 | 131 | 12.1 | 15.0 | 8.5 | 371 | 78.2 | 74 | 109.7 | | |
| | | 1.5 | 16.9 | 135 | 12.0 | 17.5 | 8.5 | 375 | 81.1 | 90 | 111.7 | | |
| | | 2.5 | 16.0 | 113 | 10.0 | 19.1 | 8.2 | 380 | 45.8 | 62 | 108.1 | | |
| | | 3.5 | 16.0 | 104 | 9.3 | 20.0 | 8.1 | 382 | 12.4 | 60 | 107.8 | | |
| | | 4.5 | 15.2 | 94 | 8.5 | 21.1 | 8.0 | 384 | 9.1 | 39 | 106.0 | | |
| | | 5.5 | 15.1 | 89 | 8.2 | 21.6 | 8.0 | 386 | 8.6 | 30 | 103.9 | | |
| Jul-14 | 13:00 | Surface | 21.7 | 138 | 11.5 | 13.1 | 8.7 | 359 | 117.3 | | | 763 | 2.5 |
| | | 0.5 | 19.6 | 141 | 12.1 | 13.2 | 8.7 | 356 | 96.9 | 107 | 114.0 | | |
| | | 1.5 | 18.6 | 150 | 12.9 | 16.6 | 8.6 | 361 | 47.0 | 122 | 116.0 | | |
| | | 2.5 | 17.4 | 108 | 9.5 | 19.3 | 8.0 | 370 | 48.5 | 84 | 111.0 | | |
| | | 3.5 | 16.9 | 99 | 8.8 | 19.9 | 7.9 | 372 | 72.2 | 38 | 108.9 | | |
| | | 4.5 | 16.4 | 87 | 7.9 | 20.6 | 7.9 | 373 | 70.7 | 47 | 106.2 | | |
| | | 5.5 | 15.0 | 83 | 7.7 | 20.8 | 7.8 | 375 | 22.8 | 34 | 104.5 | | |

## Table 6. Characteristics of Reference Site (1) by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | uE·s$^{-1}$·m$^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-15 | 13:35 | Surface | 21.1 | 131 | 10.6 | 14.1 | 8.5 | 358 | 126.3 | | | 767 | 3.3 |
| | | 0.5 | 21.1 | 131 | 10.6 | 14.1 | 8.6 | 362 | 66.2 | 95 | 112.4 | | |
| | | 1.5 | 20.3 | 135 | 11.1 | 14.5 | 8.6 | 367 | 34.2 | 108 | 114.1 | | |
| | | 2.5 | 17.0 | 100 | 8.6 | 19.3 | 8.1 | 382 | 21.5 | 84 | 111.0 | | |
| | | 3.5 | 16.5 | 99 | 8.8 | 19.8 | 7.9 | 387 | 14.5 | 62 | 108.1 | | |
| | | 4.5 | 15.6 | 98 | 8.8 | 20.0 | 8.0 | 389 | 11.8 | 36 | 104.7 | | |
| | | 5.5 | 15.4 | 91 | 8.1 | 21.0 | 7.8 | 392 | 9.8 | 29 | 103.8 | | |
| Jul-16 | 11:20 | Surface | 19.5 | 143 | 11.9 | 15.1 | 8.6 | 361 | 955.0 | | | 765 | 2.5 |
| | | 0.5 | 19.5 | 143 | 12.1 | 15.2 | 8.7 | 357 | 212.0 | 97 | 112.6 | | |
| | | 1.5 | 19.2 | 136 | 11.8 | 15.7 | 8.6 | 360 | 53.0 | 105 | 113.7 | | |
| | | 2.5 | 17.1 | 131 | 11.4 | 16.9 | 8.4 | 363 | 46.0 | 93 | 112.1 | | |
| | | 3.5 | 18.0 | 118 | 10.2 | 17.9 | 8.2 | 366 | 23.0 | 100 | 113.0 | | |
| | | 4.5 | 17.6 | 113 | 9.8 | 18.5 | 8.1 | 369 | 14.0 | 73 | 109.5 | | |
| | | 5.5 | 17.1 | 104 | 9.1 | 19.1 | 8.0 | 372 | 11.0 | 60 | 107.8 | | |
| Jul-17 | 10:45 | Surface | 19.3 | 134 | 11.3 | 15.6 | 8.7 | 379 | 587.0 | | | 763 | 3.0 |
| | | 0.5 | 19.3 | 133 | 11.3 | 15.6 | 8.7 | 381 | 282.0 | 93 | 112.2 | | |
| | | 1.5 | 19.2 | 133 | 11.2 | 15.8 | 8.6 | 382 | 110.0 | 99 | 113.0 | | |
| | | 2.5 | 18.4 | 124 | 10.6 | 17.0 | 8.5 | 386 | 49.0 | 102 | 113.4 | | |
| | | 3.5 | 16.9 | 112 | 9.7 | 17.5 | 8.3 | 390 | 51.0 | 96 | 112.6 | | |
| | | 4.5 | 17.2 | 108 | 9.4 | 18.2 | 8.2 | 399 | 39.0 | 68 | 108.9 | | |
| | | 5.5 | 16.8 | 107 | 9.3 | 18.5 | 8.1 | 401 | 26.0 | 60 | 107.9 | | |
| Jul-18 | 8:45 | Surface | 19.7 | 133 | 11.3 | 16.3 | 8.6 | 376 | 1022.0 | | | 769 | 3.8 |
| | | 0.5 | 19.7 | 133 | 11.2 | 16.3 | 9.9 | 380 | 494.0 | 88 | 111.4 | | |
| | | 1.5 | 19.5 | 118 | 10.2 | 16.5 | 8.6 | 384 | 275.0 | 96 | 112.5 | | |
| | | 2.5 | 18.7 | 114 | 9.8 | 17.7 | 8.3 | 392 | 105.0 | 88 | 111.4 | | |
| | | 3.5 | 18.1 | 100 | 8.7 | 18.5 | 8.1 | 396 | 93.0 | 60 | 107.8 | | |
| | | 4.5 | 15.2 | 95 | 8.6 | 19.0 | 8.1 | 399 | 41.0 | 35 | 104.6 | | |
| | | 5.5 | 15.0 | 96 | 8.8 | 19.7 | 7.9 | 403 | 34.0 | 25 | 103.3 | | |

# Table 6. Characteristics of Reference Site (1) by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | uE$\cdot$s$^{-1}\cdot$m$^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug-18 | 14:45 | Surface | 21.1 | 122 | 9.5 | 22.9 | 8.5 | 341 | 1430.0 | | | 769 | 3.5 |
| | | 0.5 | 20.5 | 129 | 10.3 | 23.0 | 8.5 | 340 | 430.0 | 86 | 111.2 | | |
| | | 1.5 | 18.8 | 127 | 10.3 | 23.1 | 8.5 | 342 | 432.0 | 94 | 112.2 | | |
| | | 2.5 | 18.6 | 130 | 10.7 | 23.1 | 8.5 | 344 | 234.0 | 78 | 110.1 | | |
| | | 3.5 | 16.5 | 111 | 9.7 | 23.4 | 8.3 | 349 | 65.0 | 53 | 106.9 | | |
| | | 4.5 | 15.2 | 93 | 8.3 | 23.7 | 8.2 | 353 | 65.0 | 29 | 103.7 | | |
| | | 5.5 | 14.7 | 93 | 8.4 | 23.7 | 8.2 | 356 | 34.0 | 10 | 101.3 | | |
| Aug-19 | 11:00 | Surface | 19.6 | 122 | 9.9 | 23.0 | 8.4 | 381 | 1153.0 | | | 763 | 3.5 |
| | | 0.5 | 19.6 | 125 | 10.0 | 23.0 | 8.4 | 382 | 948.0 | 75 | 109.8 | | |
| | | 1.5 | 19.3 | 132 | 10.6 | 23.1 | 8.4 | 382 | 203.0 | 84 | 111.0 | | |
| | | 2.5 | 16.3 | 102 | 8.6 | 23.6 | 8.2 | 386 | 260.0 | 34 | 104.5 | | |
| | | 3.5 | 15.8 | 93 | 8.0 | 23.7 | 8.1 | 387 | 143.0 | 28 | 103.7 | | |
| | | 4.5 | 15.6 | 89 | 7.8 | 23.8 | 8.1 | 388 | 91.0 | 11 | 101.4 | | |
| | | 5.5 | 15.6 | 86 | 7.5 | 23.8 | 8.1 | 388 | 54.0 | 11 | 101.4 | | |
| Aug-20 | 10:35 | Surface | 18.7 | 129 | 10.6 | 23.2 | 8.5 | 359 | 192.4 | | | 759 | 3.0 |
| | | 0.5 | 18.7 | 130 | 10.6 | 23.3 | 8.5 | 362 | 95.8 | 91 | 112.0 | | |
| | | 1.5 | 18.5 | 129 | 10.6 | 23.3 | 8.5 | 365 | 85.0 | 90 | 111.9 | | |
| | | 2.5 | 17.8 | 117 | 9.8 | 23.5 | 8.4 | 368 | 46.5 | 79 | 110.4 | | |
| | | 3.5 | 16.5 | 102 | 8.7 | 23.8 | 8.2 | 371 | 59.4 | 52 | 106.9 | | |
| | | 4.5 | 16.3 | 98 | 8.4 | 23.8 | 8.2 | 373 | 26.2 | 37 | 104.9 | | |
| | | 5.5 | 15.7 | 96 | 8.3 | 23.9 | 8.2 | 374 | 17.8 | 30 | 104.0 | | |
| Aug-21 | 10:45 | Surface | 18.7 | 113 | 9.1 | 23.2 | 8.3 | 385 | 498.0 | | | 768 | 3.5 |
| | | 0.5 | 18.5 | 114 | 9.3 | 23.2 | 8.4 | 380 | 341.0 | 55 | 107.2 | | |
| | | 1.5 | 17.8 | 115 | 9.5 | 23.5 | 8.4 | 381 | 139.0 | 60 | 107.8 | | |
| | | 2.5 | 17.1 | 102 | 8.6 | 23.7 | 8.3 | 382 | 77.0 | 39 | 105.1 | | |
| | | 3.5 | 15.9 | 96 | 8.3 | 23.9 | 8.2 | 383 | 48.0 | 29 | 103.8 | | |
| | | 4.5 | 15.6 | 97 | 8.4 | 23.9 | 8.3 | 383 | 23.0 | 16 | 102.1 | | |
| | | 5.5 | 15.5 | 99 | 8.7 | 23.9 | 8.3 | 383 | 16.0 | 17 | 102.2 | | |

Table 6. Characteristics of Reference Site (1) by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | uE·s$^{-1}$·m$^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug-22 | 10:45 | Surface | 18.0 | 120 | 9.9 | 23.5 | 8.4 | 361 | 685.0 | | | 765 | 3.3 |
| | | 0.5 | 18.0 | 119 | 10.0 | 23.5 | 8.4 | 362 | 302.0 | 67 | 108.8 | | |
| | | 1.5 | 17.7 | 115 | 9.7 | 23.6 | 8.3 | 365 | 201.0 | 76 | 109.9 | | |
| | | 2.5 | 17.4 | 108 | 9.1 | 23.7 | 8.3 | 368 | 129.0 | 50 | 106.5 | | |
| | | 3.5 | 17.1 | 104 | 8.9 | 23.7 | 8.3 | 371 | 121.0 | 32 | 104.2 | | |
| | | 4.5 | 16.4 | 95 | 8.3 | 23.8 | 8.2 | 374 | 78.0 | 22 | 102.9 | | |
| | | 5.5 | 15.6 | 93 | 8.2 | 24.0 | 8.2 | 376 | 34.0 | 16 | 102.1 | | |

Table 7. Characteristics of Site 2 (70 meters east of outfall), by time and depth.

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | uE·s$^{-1}$·m$^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-07 | 14:55 | Surface | 18.4 | 94 | 7.7 | 23.3 | 8.1 | 376 | 134.8 | | | 766 | 2.8 |
| | | 0.5 | 17.1 | 101 | 8.5 | 22.7 | 8.2 | 373 | 92.5 | 85 | 111.1 | | |
| | | 1.5 | 17.0 | 98 | 8.3 | 22.6 | 7.9 | 378 | 73.5 | 86 | 111.2 | | |
| | | 2.5 | 17.3 | 96 | 8.2 | 22.1 | 7.9 | 375 | 53.8 | 90 | 111.7 | | |
| | | 3.5 | 18.3 | 94 | 8.1 | 22.3 | 8.0 | 375 | 29.1 | 84 | 111.0 | | |
| | | 4.5 | 15.8 | 84 | 7.9 | 22.4 | 7.9 | 378 | 15.0 | 79 | 110.3 | | |
| | | 5.5 | 12.2 | 75 | 7.1 | 23.0 | 7.8 | 381 | 9.9 | 58 | 107.6 | | |
| Jul-08 | 11:40 | Surface | 17.9 | 99 | 8.5 | 21.7 | 7.9 | 404 | 29.2 | | | 761 | 2.0 |
| | | 0.5 | 17.5 | 98 | 8.5 | 21.8 | 7.9 | 406 | 21.7 | 67 | 108.8 | | |
| | | 1.5 | 17.2 | 97 | 8.3 | 22.5 | 7.9 | 409 | 14.7 | 80 | 110.5 | | |
| | | 2.5 | 18.1 | 94 | 7.9 | 22.7 | 7.9 | 410 | 15.4 | 76 | 110.0 | | |
| | | 3.5 | 16.9 | 94 | 7.9 | 23.2 | 7.9 | 412 | 9.9 | 75 | 109.9 | | |
| | | 4.5 | 15.3 | 88 | 7.6 | 23.0 | 7.8 | 412 | 7.6 | 64 | 108.4 | | |
| | | 5.5 | 13.1 | 82 | 7.5 | 23.3 | 7.9 | 413 | 4.0 | 43 | 105.7 | | |
| Jul-09 | 11:35 | Surface | 17.1 | 99 | 8.8 | 15.0 | 8.0 | 322 | 553.0 | | | 760 | 3.0 |
| | | 0.5 | 18.0 | 98 | 8.5 | 20.3 | 8.0 | 290 | 193.0 | 67 | 108.8 | | |
| | | 1.5 | 18.4 | 94 | 8.0 | 20.7 | 7.9 | 261 | 69.0 | 83 | 110.9 | | |
| | | 2.5 | 18.2 | 89 | 7.8 | 21.9 | 7.9 | 256 | 53.0 | 82 | 110.8 | | |
| | | 3.5 | 16.6 | 88 | 7.7 | 22.1 | 7.9 | 256 | 14.0 | 75 | 109.9 | | |
| | | 4.5 | 15.0 | 87 | 7.6 | 21.7 | 7.9 | 255 | 10.0 | 53 | 107.0 | | |
| | | 5.5 | 14.4 | 83 | 7.5 | 22.3 | 7.9 | 262 | 6.0 | 49 | 106.4 | | |
| Jul-10 | 12:00 | Surface | 17.1 | 108 | 9.4 | 18.5 | 8.3 | 350 | 181.2 | | | 764 | 2.5 |
| | | 0.5 | 17.6 | 106 | 9.2 | 19.2 | 8.2 | 319 | 101.4 | 83 | 110.9 | | |
| | | 1.5 | 19.0 | 100 | 8.5 | 19.8 | 8.0 | 275 | 48.5 | 93 | 112.2 | | |
| | | 2.5 | 18.8 | 98 | 8.2 | 20.2 | 8.0 | 259 | 27.2 | 96 | 112.6 | | |
| | | 3.5 | 18.7 | 94 | 8.0 | 21.6 | 8.0 | 254 | 9.6 | 98 | 112.8 | | |
| | | 4.5 | 16.3 | 89 | 7.7 | 21.8 | 7.9 | 257 | 10.6 | 71 | 109.3 | | |
| | | 5.5 | 14.9 | 84 | 7.7 | 22.0 | 8.0 | 260 | 5.8 | 59 | 107.7 | | |

Table 7. Characteristics of Site 2 (70 meters east of Outfall), by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | uE$\cdot$s$^{-1}\cdot$m$^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-11 | 10:15 | Surface | 15.8 | 128 | 11.7 | 14.0 | 8.6 | 357 | 283.0 | | | 765 | 2.5 |
| | | 0.5 | 16.1 | 129 | 11.8 | 14.1 | 8.5 | 346 | 367.0 | 72 | 109.4 | | |
| | | 1.5 | 17.3 | 117 | 10.3 | 17.6 | 8.3 | 294 | 98.0 | 83 | 110.8 | | |
| | | 2.5 | 18.3 | 105 | 9.4 | 19.8 | 8.0 | 240 | 55.0 | 83 | 110.8 | | |
| | | 3.5 | 18.9 | 97 | 8.3 | 20.8 | 8.0 | 224 | 24.0 | 82 | 110.7 | | |
| | | 4.5 | 17.0 | 92 | 8.2 | 21.7 | 8.0 | 230 | 19.0 | 62 | 108.1 | | |
| | | 5.5 | 16.9 | 82 | 7.5 | 22.2 | 7.8 | 231 | 6.0 | 54 | 107.0 | | |
| Jul-14 | 13:30 | Surface | 21.9 | 134 | 10.4 | 12.9 | 8.7 | 341 | 161.0 | | | 762 | 2.5 |
| | | 0.5 | 21.2 | 133 | 10.7 | 13.0 | 8.7 | 334 | 82.3 | 97 | 112.7 | | |
| | | 1.5 | 21.2 | 120 | 9.5 | 16.6 | 8.4 | 339 | 89.6 | 108 | 114.2 | | |
| | | 2.5 | 19.6 | 99 | 7.8 | 20.5 | 7.9 | 347 | 49.2 | 113 | 114.8 | | |
| | | 3.5 | 18.7 | 92 | 7.6 | 20.8 | 7.9 | 347 | 47.1 | 100 | 113.1 | | |
| | | 4.5 | 17.1 | 88 | 7.6 | 20.8 | 7.9 | 350 | 31.6 | 73 | 109.6 | | |
| | | 5.5 | 15.8 | 83 | 7.4 | 21.1 | 7.9 | 352 | 50.8 | 59 | 107.7 | | |
| Jul-15 | 14:05 | Surface | 21.0 | 121 | 9.8 | 13.8 | 8.6 | 367 | 106.7 | | | 767 | 3.5 |
| | | 0.5 | 21.1 | 121 | 9.7 | 13.9 | 8.6 | 368 | 38.9 | 77 | 110.0 | | |
| | | 1.5 | 21.1 | 112 | 9.1 | 16.3 | 8.5 | 377 | 29.6 | 88 | 111.5 | | |
| | | 2.5 | 20.2 | 94 | 7.5 | 20.4 | 8.1 | 383 | 21.2 | 82 | 110.7 | | |
| | | 3.5 | 18.1 | 90 | 7.3 | 21.1 | 7.9 | 383 | 22.6 | 78 | 110.2 | | |
| | | 4.5 | 17.5 | 89 | 7.6 | 21.3 | 7.9 | 383 | 12.1 | 52 | 106.8 | | |
| | | 5.5 | 16.8 | 89 | 7.6 | 21.5 | 7.8 | 384 | 5.5 | 43 | 105.6 | | |
| Jul-16 | 12:00 | Surface | 20.6 | 135 | 10.6 | 16.0 | 8.5 | 321 | 439.0 | | | 765 | 3.5 |
| | | 0.5 | 20.9 | 127 | 10.4 | 17.0 | 8.4 | 326 | 238.0 | 110 | 114.3 | | |
| | | 1.5 | 20.8 | 121 | 9.9 | 17.8 | 8.3 | 334 | 230.0 | 119 | 115.5 | | |
| | | 2.5 | 20.9 | 119 | 9.6 | 18.5 | 8.2 | 338 | 153.0 | 117 | 115.2 | | |
| | | 3.5 | 21.3 | 111 | 9.2 | 18.6 | 8.2 | 343 | 91.0 | 114 | 114.8 | | |
| | | 4.5 | 19.3 | 105 | 8.5 | 19.4 | 8.0 | 348 | 59.0 | 96 | 112.5 | | |
| | | 5.5 | 17.8 | 95 | 8.4 | 20.1 | 7.9 | 349 | 47.0 | 79 | 110.3 | | |

Table 7. Characteristics of Site 2 (70 meters east of Outfall), by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE \cdot s^{-1} \cdot m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-17 | 11:25 | Surface | 21.3 | 116 | 9.2 | 17.5 | 8.3 | 376 | 1263.0 | | | 761 | 3.0 |
| | | 0.5 | 21.5 | 120 | 9.6 | 17.2 | 8.4 | 374 | 691.0 | 115 | 115.1 | | |
| | | 1.5 | 21.8 | 117 | 9.4 | 17.4 | 8.3 | 376 | 202.0 | 120 | 115.8 | | |
| | | 2.5 | 21.5 | 113 | 9.1 | 17.8 | 8.3 | 374 | 137.0 | 117 | 115.4 | | |
| | | 3.5 | 20.5 | 111 | 8.8 | 18.1 | 8.2 | 375 | 88.0 | 108 | 114.2 | | |
| | | 4.5 | 20.0 | 116 | 9.4 | 18.3 | 8.1 | 377 | 23.0 | 94 | 112.4 | | |
| | | 5.5 | 18.9 | 96 | 8.1 | 19.4 | 8.1 | 381 | 30.0 | 80 | 110.5 | | |
| Jul-18 | 9:20 | Surface | 20.8 | 111 | 9.0 | 18.0 | 8.4 | 362 | 720.0 | | | 769 | 4.5 |
| | | 0.5 | 20.3 | 114 | 9.2 | 17.7 | 8.4 | 362 | 290.0 | 96 | 112.5 | | |
| | | 1.5 | 21.0 | 110 | 8.9 | 18.2 | 8.3 | 365 | 86.0 | 104 | 113.5 | | |
| | | 2.5 | 21.2 | 107 | 8.7 | 18.1 | 8.3 | 368 | 44.0 | 100 | 113.0 | | |
| | | 3.5 | 20.6 | 107 | 8.6 | 19.2 | 8.1 | 371 | 30.0 | 83 | 110.8 | | |
| | | 4.5 | 19.6 | 98 | 8.5 | 19.8 | 8.0 | 372 | 20.0 | 71 | 109.2 | | |
| | | 5.5 | 17.8 | 96 | 8.2 | 19.8 | 8.0 | 376 | 34.0 | 51 | 106.6 | | |
| Aug-18 | 14:10 | Surface | 21.3 | 102 | 8.0 | 23.3 | 8.2 | 329 | 1346.0 | | | 769 | 2.5 |
| | | 0.5 | 20.9 | 104 | 8.2 | 23.2 | 8.2 | 330 | 909.0 | 80 | 110.4 | | |
| | | 1.5 | 19.7 | 104 | 8.4 | 23.2 | 8.2 | 332 | 298.0 | 79 | 110.3 | | |
| | | 2.5 | 19.4 | 102 | 8.5 | 23.2 | 8.2 | 335 | 108.0 | 70 | 109.1 | | |
| | | 3.5 | 18.7 | 102 | 8.4 | 23.4 | 8.2 | 338 | 64.0 | 64 | 108.3 | | |
| | | 4.5 | 17.4 | 93 | 8.0 | 23.7 | 8.2 | 340 | 44.0 | 46 | 106.0 | | |
| | | 5.5 | 16.6 | 93 | 8.1 | 23.6 | 8.2 | 343 | 36.0 | 37 | 104.8 | | |
| Aug-19 | 11:35 | Surface | 19.5 | 86 | 6.9 | 23.6 | 8.1 | 335 | 1443.0 | | | 763 | 3.8 |
| | | 0.5 | 19.0 | 86 | 7.1 | 23.7 | 8.1 | 341 | 1017.0 | 53 | 106.9 | | |
| | | 1.5 | 18.1 | 86 | 7.1 | 23.4 | 8.1 | 346 | 431.0 | 49 | 106.4 | | |
| | | 2.5 | 17.4 | 86 | 7.1 | 23.8 | 8.1 | 349 | 366.0 | 37 | 104.8 | | |
| | | 3.5 | 17.2 | 87 | 7.3 | 23.9 | 8.0 | 351 | 203.0 | 27 | 103.5 | | |
| | | 4.5 | 16.3 | 80 | 7.1 | 24.1 | 8.1 | 352 | 134.0 | 13 | 101.7 | | |
| | | 5.5 | 16.0 | 78 | 6.9 | 24.3 | 8.1 | 351 | 74.0 | 3 | 100.4 | | |

Table 7. Characteristics of Site 2 (70 meters east of Outfall), by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE{\cdot}s^{-1}{\cdot}m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug-20 | 11:10 | Surface | 19.6 | 93 | 7.6 | 24.0 | 8.2 | 366 | 632.0 | | | 758 | 4.3 |
| | | 0.5 | 19.6 | 98 | 7.9 | 23.9 | 8.2 | 369 | 382.0 | 69 | 109.1 | | |
| | | 1.5 | 18.6 | 94 | 7.8 | 23.8 | 8.2 | 379 | 370.0 | 69 | 109.1 | | |
| | | 2.5 | 17.5 | 95 | 8.0 | 24.5 | 8.2 | 380 | 231.0 | 53 | 107.0 | | |
| | | 3.5 | 18.4 | 95 | 8.0 | 24.0 | 8.2 | 381 | 161.0 | 52 | 106.9 | | |
| | | 4.5 | 17.6 | 90 | 8.0 | 23.8 | 8.2 | 381 | 111.0 | 34 | 104.5 | | |
| | | 5.5 | 15.8 | 89 | 8.0 | 24.1 | 8.2 | 382 | 85.0 | 26 | 103.4 | | |
| Aug-21 | 11:25 | Surface | 18.8 | 90 | 7.5 | 23.9 | 8.2 | 387 | 389.0 | | | 767 | 4.3 |
| | | 0.5 | 18.6 | 91 | 7.5 | 23.8 | 8.2 | 386 | 331.0 | 54 | 107.0 | | |
| | | 1.5 | 18.5 | 91 | 7.6 | 24.0 | 8.2 | 388 | 150.0 | 48 | 106.3 | | |
| | | 2.5 | 17.8 | 91 | 7.7 | 24.0 | 8.2 | 389 | 135.0 | 37 | 104.8 | | |
| | | 3.5 | 17.6 | 94 | 7.9 | 23.8 | 8.2 | 389 | 90.0 | 30 | 103.9 | | |
| | | 4.5 | 15.7 | 93 | 8.0 | 23.9 | 8.2 | 389 | 66.0 | 24 | 103.1 | | |
| | | 5.5 | 15.6 | 89 | 7.8 | 24.0 | 8.2 | 388 | 41.0 | 10 | 101.3 | | |
| Aug-22 | 11:30 | Surface | 18.4 | 92 | 7.6 | 24.0 | 8.2 | 365 | 721.0 | | | 765 | 4.3 |
| | | 0.5 | 19.5 | 94 | 7.7 | 24.0 | 8.2 | 365 | 237.0 | 59 | 107.7 | | |
| | | 1.5 | 18.6 | 97 | 8.0 | 23.9 | 8.2 | 369 | 355.0 | 53 | 106.9 | | |
| | | 2.5 | 17.5 | 93 | 8.0 | 23.8 | 8.2 | 372 | 221.0 | 45 | 105.9 | | |
| | | 3.5 | 16.4 | 94 | 8.1 | 24.3 | 8.2 | 368 | 146.0 | 35 | 104.6 | | |
| | | 4.5 | 16.0 | 93 | 8.1 | 24.1 | 8.2 | 329 | 99.0 | 26 | 103.4 | | |
| | | 5.5 | 15.1 | 90 | 7.9 | 24.2 | 8.2 | 322 | 71.0 | 16 | 102.1 | | |

Table 7. Characteristics of Site 2 (70 meters east of outfall), by time and depth.

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | uE·s$^{-1}$·m$^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-07 | 14:55 | Surface | 18.4 | 94 | 7.7 | 23.3 | 8.1 | 376 | 134.8 | | | 766 | 2.8 |
| | | 0.5 | 17.1 | 101 | 8.5 | 22.7 | 8.2 | 373 | 92.5 | 85 | 111.1 | | |
| | | 1.5 | 17.0 | 98 | 8.3 | 22.6 | 7.9 | 378 | 73.5 | 86 | 111.2 | | |
| | | 2.5 | 17.3 | 96 | 8.2 | 22.1 | 7.9 | 375 | 53.8 | 90 | 111.7 | | |
| | | 3.5 | 18.3 | 94 | 8.1 | 22.3 | 8.0 | 375 | 29.1 | 84 | 111.0 | | |
| | | 4.5 | 15.8 | 84 | 7.9 | 22.4 | 7.9 | 378 | 15.0 | 79 | 110.3 | | |
| | | 5.5 | 12.2 | 75 | 7.1 | 23.0 | 7.8 | 381 | 9.9 | 58 | 107.6 | | |
| Jul-08 | 11:40 | Surface | 17.9 | 99 | 8.5 | 21.7 | 7.9 | 404 | 29.2 | | | 761 | 2.0 |
| | | 0.5 | 17.5 | 98 | 8.5 | 21.8 | 7.9 | 406 | 21.7 | 67 | 108.8 | | |
| | | 1.5 | 17.2 | 97 | 8.3 | 22.5 | 7.9 | 409 | 14.7 | 80 | 110.5 | | |
| | | 2.5 | 18.1 | 94 | 7.9 | 22.7 | 7.9 | 410 | 15.4 | 76 | 110.0 | | |
| | | 3.5 | 16.9 | 94 | 7.9 | 23.2 | 7.9 | 412 | 9.9 | 75 | 109.9 | | |
| | | 4.5 | 15.3 | 88 | 7.6 | 23.0 | 7.8 | 412 | 7.6 | 64 | 108.4 | | |
| | | 5.5 | 13.1 | 82 | 7.5 | 23.3 | 7.9 | 413 | 4.0 | 43 | 105.7 | | |
| Jul-09 | 11:35 | Surface | 17.1 | 99 | 8.8 | 15.0 | 8.0 | 322 | 553.0 | | | 760 | 3.0 |
| | | 0.5 | 18.0 | 98 | 8.5 | 20.3 | 8.0 | 290 | 193.0 | 67 | 108.8 | | |
| | | 1.5 | 18.4 | 94 | 8.0 | 20.7 | 7.9 | 261 | 69.0 | 83 | 110.9 | | |
| | | 2.5 | 18.2 | 89 | 7.8 | 21.9 | 7.9 | 256 | 53.0 | 82 | 110.8 | | |
| | | 3.5 | 16.6 | 88 | 7.7 | 22.1 | 7.9 | 256 | 14.0 | 75 | 109.9 | | |
| | | 4.5 | 15.0 | 87 | 7.6 | 21.7 | 7.9 | 255 | 10.0 | 53 | 107.0 | | |
| | | 5.5 | 14.4 | 83 | 7.5 | 22.3 | 7.9 | 262 | 6.0 | 49 | 106.4 | | |
| Jul-10 | 12:00 | Surface | 17.1 | 108 | 9.4 | 18.5 | 8.3 | 350 | 181.2 | | | 764 | 2.5 |
| | | 0.5 | 17.6 | 106 | 9.2 | 19.2 | 8.2 | 319 | 101.4 | 83 | 110.9 | | |
| | | 1.5 | 19.0 | 100 | 8.5 | 19.8 | 8.0 | 275 | 48.5 | 93 | 112.2 | | |
| | | 2.5 | 18.8 | 98 | 8.2 | 20.2 | 8.0 | 259 | 27.2 | 96 | 112.6 | | |
| | | 3.5 | 18.7 | 94 | 8.0 | 21.6 | 8.0 | 254 | 9.6 | 98 | 112.8 | | |
| | | 4.5 | 16.3 | 89 | 7.7 | 21.8 | 7.9 | 257 | 10.6 | 71 | 109.3 | | |
| | | 5.5 | 14.9 | 84 | 7.7 | 22.0 | 8.0 | 260 | 5.8 | 59 | 107.7 | | |

Table 7. Characteristics of Site 2 (70 meters east of Outfall), by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | uE$\cdot$s$^{-1}\cdot$m$^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-11 | 10:15 | Surface | 15.8 | 128 | 11.7 | 14.0 | 8.6 | 357 | 283.0 | | | 765 | 2.5 |
| | | 0.5 | 16.1 | 129 | 11.8 | 14.1 | 8.5 | 346 | 367.0 | 72 | 109.4 | | |
| | | 1.5 | 17.3 | 117 | 10.3 | 17.6 | 8.3 | 294 | 98.0 | 83 | 110.8 | | |
| | | 2.5 | 18.3 | 105 | 9.4 | 19.8 | 8.0 | 240 | 55.0 | 83 | 110.8 | | |
| | | 3.5 | 18.9 | 97 | 8.3 | 20.8 | 8.0 | 224 | 24.0 | 82 | 110.7 | | |
| | | 4.5 | 17.0 | 92 | 8.2 | 21.7 | 8.0 | 230 | 19.0 | 62 | 108.1 | | |
| | | 5.5 | 16.9 | 82 | 7.5 | 22.2 | 7.8 | 231 | 6.0 | 54 | 107.0 | | |
| Jul-14 | 13:30 | Surface | 21.9 | 134 | 10.4 | 12.9 | 8.7 | 341 | 161.0 | | | 762 | 2.5 |
| | | 0.5 | 21.2 | 133 | 10.7 | 13.0 | 8.7 | 334 | 82.3 | 97 | 112.7 | | |
| | | 1.5 | 21.2 | 120 | 9.5 | 16.6 | 8.4 | 339 | 89.6 | 108 | 114.2 | | |
| | | 2.5 | 19.6 | 99 | 7.8 | 20.5 | 7.9 | 347 | 49.2 | 113 | 114.8 | | |
| | | 3.5 | 18.7 | 92 | 7.6 | 20.8 | 7.9 | 347 | 47.1 | 100 | 113.1 | | |
| | | 4.5 | 17.1 | 88 | 7.6 | 20.8 | 7.9 | 350 | 31.6 | 73 | 109.6 | | |
| | | 5.5 | 15.8 | 83 | 7.4 | 21.1 | 7.9 | 352 | 50.8 | 59 | 107.7 | | |
| Jul-15 | 14:05 | Surface | 21.0 | 121 | 9.8 | 13.8 | 8.6 | 367 | 106.7 | | | 767 | 3.5 |
| | | 0.5 | 21.1 | 121 | 9.7 | 13.9 | 8.6 | 368 | 38.9 | 77 | 110.0 | | |
| | | 1.5 | 21.1 | 112 | 9.1 | 16.3 | 8.5 | 377 | 29.6 | 88 | 111.5 | | |
| | | 2.5 | 20.2 | 94 | 7.5 | 20.4 | 8.1 | 383 | 21.2 | 82 | 110.7 | | |
| | | 3.5 | 18.1 | 90 | 7.3 | 21.1 | 7.9 | 383 | 22.6 | 78 | 110.2 | | |
| | | 4.5 | 17.5 | 89 | 7.6 | 21.3 | 7.9 | 383 | 12.1 | 52 | 106.8 | | |
| | | 5.5 | 16.8 | 89 | 7.6 | 21.5 | 7.8 | 384 | 5.5 | 43 | 105.6 | | |
| Jul-16 | 12:00 | Surface | 20.6 | 135 | 10.6 | 16.0 | 8.5 | 321 | 439.0 | | | 765 | 3.5 |
| | | 0.5 | 20.9 | 127 | 10.4 | 17.0 | 8.4 | 326 | 238.0 | 110 | 114.3 | | |
| | | 1.5 | 20.8 | 121 | 9.9 | 17.8 | 8.3 | 334 | 230.0 | 119 | 115.5 | | |
| | | 2.5 | 20.9 | 119 | 9.6 | 18.5 | 8.2 | 338 | 153.0 | 117 | 115.2 | | |
| | | 3.5 | 21.3 | 111 | 9.2 | 18.6 | 8.2 | 343 | 91.0 | 114 | 114.8 | | |
| | | 4.5 | 19.3 | 105 | 8.5 | 19.4 | 8.0 | 348 | 59.0 | 96 | 112.5 | | |
| | | 5.5 | 17.8 | 95 | 8.4 | 20.1 | 7.9 | 349 | 47.0 | 79 | 110.3 | | |

Table 7. Characteristics of Site 2 (70 meters east of Outfall), by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE \cdot s^{-1} \cdot m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-17 | 11:25 | Surface | 21.3 | 116 | 9.2 | 17.5 | 8.3 | 376 | 1263.0 | | | 761 | 3.0 |
| | | 0.5 | 21.5 | 120 | 9.6 | 17.2 | 8.4 | 374 | 691.0 | 115 | 115.1 | | |
| | | 1.5 | 21.8 | 117 | 9.4 | 17.4 | 8.3 | 376 | 202.0 | 120 | 115.8 | | |
| | | 2.5 | 21.5 | 113 | 9.1 | 17.8 | 8.3 | 374 | 137.0 | 117 | 115.4 | | |
| | | 3.5 | 20.5 | 111 | 8.8 | 18.1 | 8.2 | 375 | 88.0 | 108 | 114.2 | | |
| | | 4.5 | 20.0 | 116 | 9.4 | 18.3 | 8.1 | 377 | 23.0 | 94 | 112.4 | | |
| | | 5.5 | 18.9 | 96 | 8.1 | 19.4 | 8.1 | 381 | 30.0 | 80 | 110.5 | | |
| Jul-18 | 9:20 | Surface | 20.8 | 111 | 9.0 | 18.0 | 8.4 | 362 | 720.0 | | | 769 | 4.5 |
| | | 0.5 | 20.3 | 114 | 9.2 | 17.7 | 8.4 | 362 | 290.0 | 96 | 112.5 | | |
| | | 1.5 | 21.0 | 110 | 8.9 | 18.2 | 8.3 | 365 | 86.0 | 104 | 113.5 | | |
| | | 2.5 | 21.2 | 107 | 8.7 | 18.1 | 8.3 | 368 | 44.0 | 100 | 113.0 | | |
| | | 3.5 | 20.6 | 107 | 8.6 | 19.2 | 8.1 | 371 | 30.0 | 83 | 110.8 | | |
| | | 4.5 | 19.6 | 98 | 8.5 | 19.8 | 8.0 | 372 | 20.0 | 71 | 109.2 | | |
| | | 5.5 | 17.8 | 96 | 8.2 | 19.8 | 8.0 | 376 | 34.0 | 51 | 106.6 | | |
| Aug-18 | 14:10 | Surface | 21.3 | 102 | 8.0 | 23.3 | 8.2 | 329 | 1346.0 | | | 769 | 2.5 |
| | | 0.5 | 20.9 | 104 | 8.2 | 23.2 | 8.2 | 330 | 909.0 | 80 | 110.4 | | |
| | | 1.5 | 19.7 | 104 | 8.4 | 23.2 | 8.2 | 332 | 298.0 | 79 | 110.3 | | |
| | | 2.5 | 19.4 | 102 | 8.5 | 23.2 | 8.2 | 335 | 108.0 | 70 | 109.1 | | |
| | | 3.5 | 18.7 | 102 | 8.4 | 23.4 | 8.2 | 338 | 64.0 | 64 | 108.3 | | |
| | | 4.5 | 17.4 | 93 | 8.0 | 23.7 | 8.2 | 340 | 44.0 | 46 | 106.0 | | |
| | | 5.5 | 16.6 | 93 | 8.1 | 23.6 | 8.2 | 343 | 36.0 | 37 | 104.8 | | |
| Aug-19 | 11:35 | Surface | 19.5 | 86 | 6.9 | 23.6 | 8.1 | 335 | 1443.0 | | | 763 | 3.8 |
| | | 0.5 | 19.0 | 86 | 7.1 | 23.7 | 8.1 | 341 | 1017.0 | 53 | 106.9 | | |
| | | 1.5 | 18.1 | 86 | 7.1 | 23.4 | 8.1 | 346 | 431.0 | 49 | 106.4 | | |
| | | 2.5 | 17.4 | 86 | 7.1 | 23.8 | 8.1 | 349 | 366.0 | 37 | 104.8 | | |
| | | 3.5 | 17.2 | 87 | 7.3 | 23.9 | 8.0 | 351 | 203.0 | 27 | 103.5 | | |
| | | 4.5 | 16.3 | 80 | 7.1 | 24.1 | 8.1 | 352 | 134.0 | 13 | 101.7 | | |
| | | 5.5 | 16.0 | 78 | 6.9 | 24.3 | 8.1 | 351 | 74.0 | 3 | 100.4 | | |

## Table 7. Characteristics of Site 2 (70 meters east of Outfall), by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE \cdot s^{-1} \cdot m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug-20 | 11:10 | Surface | 19.6 | 93 | 7.6 | 24.0 | 8.2 | 366 | 632.0 | | | 758 | 4.3 |
| | | 0.5 | 19.6 | 98 | 7.9 | 23.9 | 8.2 | 369 | 382.0 | 69 | 109.1 | | |
| | | 1.5 | 18.6 | 94 | 7.8 | 23.8 | 8.2 | 379 | 370.0 | 69 | 109.1 | | |
| | | 2.5 | 17.5 | 95 | 8.0 | 24.5 | 8.2 | 380 | 231.0 | 53 | 107.0 | | |
| | | 3.5 | 18.4 | 95 | 8.0 | 24.0 | 8.2 | 381 | 161.0 | 52 | 106.9 | | |
| | | 4.5 | 17.6 | 90 | 8.0 | 23.8 | 8.2 | 381 | 111.0 | 34 | 104.5 | | |
| | | 5.5 | 15.8 | 89 | 8.0 | 24.1 | 8.2 | 382 | 85.0 | 26 | 103.4 | | |
| Aug-21 | 11:25 | Surface | 18.8 | 90 | 7.5 | 23.9 | 8.2 | 387 | 389.0 | | | 767 | 4.3 |
| | | 0.5 | 18.6 | 91 | 7.5 | 23.8 | 8.2 | 386 | 331.0 | 54 | 107.0 | | |
| | | 1.5 | 18.5 | 91 | 7.6 | 24.0 | 8.2 | 388 | 150.0 | 48 | 106.3 | | |
| | | 2.5 | 17.8 | 91 | 7.7 | 24.0 | 8.2 | 389 | 135.0 | 37 | 104.8 | | |
| | | 3.5 | 17.6 | 94 | 7.9 | 23.8 | 8.2 | 389 | 90.0 | 30 | 103.9 | | |
| | | 4.5 | 15.7 | 93 | 8.0 | 23.9 | 8.2 | 389 | 66.0 | 24 | 103.1 | | |
| | | 5.5 | 15.6 | 89 | 7.8 | 24.0 | 8.2 | 388 | 41.0 | 10 | 101.3 | | |
| Aug-22 | 11:30 | Surface | 18.4 | 92 | 7.6 | 24.0 | 8.2 | 365 | 721.0 | | | 765 | 4.3 |
| | | 0.5 | 19.5 | 94 | 7.7 | 24.0 | 8.2 | 365 | 237.0 | 59 | 107.7 | | |
| | | 1.5 | 18.6 | 97 | 8.0 | 23.9 | 8.2 | 369 | 355.0 | 53 | 106.9 | | |
| | | 2.5 | 17.5 | 93 | 8.0 | 23.8 | 8.2 | 372 | 221.0 | 45 | 105.9 | | |
| | | 3.5 | 16.4 | 94 | 8.1 | 24.3 | 8.2 | 368 | 146.0 | 35 | 104.6 | | |
| | | 4.5 | 16.0 | 93 | 8.1 | 24.1 | 8.2 | 329 | 99.0 | 26 | 103.4 | | |
| | | 5.5 | 15.1 | 90 | 7.9 | 24.2 | 8.2 | 322 | 71.0 | 16 | 102.1 | | |

Table 8. Characteristics of Site 3 (250 meters east of outfall), by time and depth.

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE \cdot s^{-1} \cdot m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-07 | 15:25 | Surface | 17.3 | 127 | 10.8 | 20.3 | 8.4 | 391 | 133.9 | | | | 3.0 |
| | | 0.5 | 17.2 | 128 | 11.0 | 20.5 | 8.4 | 389 | 87.7 | | | | |
| | | 1.5 | 17.2 | 114 | 9.8 | 21.1 | 8.2 | 389 | 52.3 | | | | |
| | | 2.5 | 16.5 | 88 | 7.7 | 22.5 | 7.9 | 391 | 30.3 | | | | |
| | | 3.5 | 14.7 | 84 | 7.6 | 22.6 | 7.9 | 391 | 18.1 | | | | |
| | | 4.5 | 12.9 | 77 | 7.2 | 22.9 | 7.9 | 392 | 11.9 | | | | |
| | | 5.5 | 12.5 | 71 | 6.8 | 22.9 | 7.8 | 392 | 7.8 | | | | |
| Jul-08 | 13:15 | Surface | 16.0 | 117 | 10.2 | 15.5 | 8.2 | 379 | 58.7 | | | 762 | 1.5 |
| | | 0.5 | 16.1 | 112 | 9.9 | 17.2 | 8.2 | 381 | 17.5 | 36 | 104.7 | | |
| | | 1.5 | 16.8 | 102 | 8.9 | 19.9 | 8.0 | 385 | 5.5 | 51 | 106.7 | | |
| | | 2.5 | 16.8 | 93 | 8.2 | 20.9 | 8.0 | 385 | 2.3 | 56 | 107.4 | | |
| | | 3.5 | 14.6 | 81 | 7.4 | 22.6 | 7.8 | 388 | 1.5 | 32 | 104.2 | | |
| | | 4.5 | 13.7 | 75 | 7.0 | 22.9 | 7.8 | 388 | 1.2 | 13 | 101.7 | | |
| | | 5.5 | 12.7 | 73 | 6.9 | 23.1 | 7.8 | 389 | 0.8 | 0 | 100.0 | | |
| Jul-09 | 13:30 | Surface | 17.5 | 106 | 9.4 | 10.2 | 7.8 | 340 | 378.0 | | | 761 | 2.5 |
| | | 0.5 | 18.4 | 106 | 9.1 | 16.4 | 8.0 | 343 | 217.0 | 79 | 110.4 | | |
| | | 1.5 | 16.4 | 104 | 9.1 | 20.4 | 8.0 | 345 | 122.0 | 91 | 112.0 | | |
| | | 2.5 | 16.6 | 96 | 8.5 | 21.0 | 8.0 | 347 | 35.0 | 65 | 108.5 | | |
| | | 3.5 | 16.3 | 92 | 8.1 | 21.3 | 7.9 | 348 | 56.0 | 63 | 108.3 | | |
| | | 4.5 | 15.6 | 91 | 8.1 | 21.4 | 7.8 | 349 | 34.0 | 47 | 106.2 | | |
| | | 5.5 | 14.7 | 91 | 8.2 | 21.7 | 7.8 | 350 | 28.0 | 40 | 105.3 | | |
| Jul-10 | 13:50 | Surface | 16.9 | 145 | 12.9 | 16.8 | 8.6 | 340 | 204.0 | | | 764 | 1.8 |
| | | 0.5 | 17.0 | 139 | 12.4 | 17.3 | 8.6 | 339 | 140.0 | 110 | 114.4 | | |
| | | 1.5 | 17.7 | 132 | 11.7 | 18.3 | 8.4 | 341 | 31.0 | 111 | 114.5 | | |
| | | 2.5 | 18.4 | 112 | 9.4 | 19.7 | 8.2 | 344 | 27.0 | 101 | 113.2 | | |
| | | 3.5 | 17.9 | 99 | 8.5 | 21.2 | 7.9 | 348 | 15.0 | 84 | 111.0 | | |
| | | 4.5 | 16.6 | 97 | 8.5 | 21.5 | 7.8 | 349 | 6.0 | 59 | 107.7 | | |
| | | 5.5 | 15.5 | 95 | 8.4 | 21.7 | 8.1 | 350 | 3.0 | 50 | 106.5 | | |

Table 8. Characteristics of Site 3 (250 meters east of Outfall), by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE \cdot s^{-1} \cdot m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-11 | 10:45 | Surface | 16.0 | 138 | 12.7 | 13.2 | 8.6 | 287 | 162.8 | | | 765 | 2.0 |
| | | 0.5 | 16.2 | 134 | 12.3 | 14.1 | 8.6 | 290 | 83.5 | 77 | 110.1 | | |
| | | 1.5 | 17.1 | 124 | 11.1 | 18.4 | 8.3 | 297 | 105.4 | 85 | 111.1 | | |
| | | 2.5 | 16.4 | 110 | 9.9 | 19.7 | 8.2 | 305 | 25.8 | 64 | 108.3 | | |
| | | 3.5 | 16.5 | 101 | 9.1 | 20.7 | 8.1 | 305 | 17.8 | 63 | 108.2 | | |
| | | 4.5 | 15.8 | 96 | 8.7 | 21.0 | 8.1 | 299 | 11.3 | 48 | 106.2 | | |
| | | 5.5 | 16.0 | 90 | 8.1 | 21.6 | 8.0 | 269 | 10.4 | 47 | 106.1 | | |
| Jul-14 | 14:05 | Surface | 22.3 | 133 | 10.6 | 12.9 | 8.7 | 328 | 334.0 | | | 762 | 3.5 |
| | | 0.5 | 20.9 | 137 | 11.2 | 13.2 | 8.7 | 328 | 287.0 | 118 | 115.5 | | |
| | | 1.5 | 19.8 | 126 | 10.5 | 17.0 | 8.4 | 335 | 76.0 | 118 | 115.5 | | |
| | | 2.5 | 20.3 | 108 | 9.0 | 18.9 | 8.1 | 340 | 126.0 | 113 | 114.8 | | |
| | | 3.5 | 18.0 | 104 | 9.1 | 19.7 | 8.0 | 345 | 75.0 | 98 | 112.9 | | |
| | | 4.5 | 17.2 | 103 | 9.0 | 20.0 | 8.0 | 348 | 117.0 | 63 | 108.3 | | |
| | | 5.5 | 17.2 | 99 | 8.3 | 20.7 | 7.9 | 352 | 74.0 | 60 | 107.9 | | |
| Jul-15 | 14:35 | Surface | 21.0 | 124 | 9.9 | 13.6 | 8.7 | 373 | 402.0 | | | 767 | 2.8 |
| | | 0.5 | 21.1 | 124 | 9.8 | 13.6 | 8.7 | 370 | 77.0 | 91 | 111.9 | | |
| | | 1.5 | 20.2 | 125 | 10.1 | 16.5 | 8.5 | 375 | 64.0 | 101 | 113.2 | | |
| | | 2.5 | 20.3 | 109 | 8.8 | 17.0 | 8.3 | 376 | 49.0 | 96 | 112.5 | | |
| | | 3.5 | 18.6 | 100 | 8.4 | 19.3 | 8.0 | 382 | 30.0 | 83 | 110.8 | | |
| | | 4.5 | 17.7 | 101 | 8.6 | 20.2 | 8.0 | 384 | 19.0 | 63 | 108.2 | | |
| | | 5.5 | 17.6 | 98 | 8.3 | 20.5 | 8.0 | 384 | 12.0 | 65 | 108.5 | | |
| Jul-16 | 13:35 | Surface | 19.1 | 143 | 12.1 | 15.7 | 8.7 | 294 | 1603.0 | | | 765 | 2.5 |
| | | 0.5 | 19.1 | 144 | 12.3 | 15.7 | 8.7 | 296 | 928.0 | 108 | 114.0 | | |
| | | 1.5 | 19.1 | 143 | 12.1 | 15.8 | 8.6 | 302 | 401.0 | 113 | 114.7 | | |
| | | 2.5 | 19.6 | 132 | 11.1 | 17.2 | 8.4 | 308 | 74.0 | 115 | 115.0 | | |
| | | 3.5 | 19.5 | 122 | 10.2 | 18.0 | 8.3 | 312 | 61.0 | 112 | 114.6 | | |
| | | 4.5 | 18.1 | 109 | 9.4 | 18.4 | 8.2 | 318 | 54.0 | 84 | 110.9 | | |
| | | 5.5 | 18.2 | 95 | 8.3 | 19.8 | 8.0 | 321 | 32.0 | 74 | 109.6 | | |

Table 8. Characteristics of Site 3 (250 meters east of Outfall), by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE{\cdot}s^{-1}{\cdot}m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-17 | 12:05 | Surface | 20.2 | 132 | 10.6 | 15.8 | 8.7 | 364 | 1619.0 | | | 762 | 3.5 |
| | | 0.5 | 20.2 | 129 | 10.3 | 15.9 | 8.7 | 362 | 976.0 | 97 | 112.7 | | |
| | | 1.5 | 20.2 | 127 | 10.3 | 16.5 | 8.6 | 363 | 109.0 | 106 | 113.9 | | |
| | | 2.5 | 20.8 | 121 | 9.7 | 17.4 | 8.4 | 366 | 121.0 | 106 | 113.9 | | |
| | | 3.5 | 20.0 | 105 | 8.6 | 18.1 | 8.2 | 369 | 80.0 | 104 | 113.7 | | |
| | | 4.5 | 18.8 | 98 | 8.2 | 18.7 | 8.1 | 372 | 51.0 | 82 | 110.8 | | |
| | | 5.5 | 17.9 | 88 | 7.5 | 19.2 | 8.0 | 375 | 32.0 | 78 | 110.2 | | |
| Jul-18 | 9:55 | Surface | 19.8 | 127 | 10.5 | 16.3 | 8.7 | 358 | 1286.0 | | | 769 | 5.0 |
| | | 0.5 | 19.8 | 128 | 10.7 | 16.3 | 8.7 | 357 | 882.0 | 83 | 110.8 | | |
| | | 1.5 | 19.8 | 124 | 10.3 | 16.4 | 8.7 | 359 | 435.0 | 88 | 111.4 | | |
| | | 2.5 | 20.3 | 120 | 9.8 | 17.7 | 8.2 | 368 | 205.0 | 85 | 111.1 | | |
| | | 3.5 | 18.5 | 105 | 8.8 | 19.0 | 8.1 | 370 | 121.0 | 68 | 108.8 | | |
| | | 4.5 | 17.4 | 97 | 8.2 | 19.5 | 8.0 | 373 | 78.0 | 48 | 106.2 | | |
| | | 5.5 | 16.4 | 89 | 7.7 | 20.0 | 7.9 | 375 | 62.0 | 28 | 103.6 | | |
| Aug-18 | 13:10 | Surface | 20.2 | 112 | 9.0 | 22.9 | 8.4 | 361 | 149.6 | | | 769 | 3.3 |
| | | 0.5 | 20.1 | 115 | 9.2 | 22.8 | 8.4 | 358 | 129.4 | 73 | 109.5 | | |
| | | 1.5 | 20.0 | 112 | 9.0 | 23.0 | 8.3 | 356 | 112.0 | 70 | 109.1 | | |
| | | 2.5 | 20.2 | 109 | 8.8 | 23.2 | 8.3 | 348 | 61.3 | 67 | 108.7 | | |
| | | 3.5 | 19.4 | 94 | 7.9 | 23.2 | 8.2 | 326 | 9.5 | 65 | 108.5 | | |
| | | 4.5 | 17.9 | 91 | 7.8 | 23.2 | 8.1 | 320 | 3.5 | 53 | 106.9 | | |
| | | 5.5 | 17.3 | 89 | 7.5 | 23.5 | 8.1 | 353 | 4.6 | 30 | 103.9 | | |
| Aug-19 | 13:30 | Surface | 19.5 | 123 | 9.8 | 23.3 | 8.5 | 329 | 1482.0 | | | 762 | 3.5 |
| | | 0.5 | 19.5 | 121 | 9.7 | 23.4 | 8.4 | 328 | 1124.0 | 78 | 110.2 | | |
| | | 1.5 | 19.2 | 114 | 9.3 | 23.6 | 8.3 | 330 | 554.0 | 64 | 108.4 | | |
| | | 2.5 | 18.4 | 102 | 8.3 | 23.5 | 8.2 | 331 | 157.0 | 57 | 107.5 | | |
| | | 3.5 | 17.1 | 93 | 7.9 | 23.7 | 8.1 | 333 | 98.0 | 48 | 106.3 | | |
| | | 4.5 | 16.1 | 82 | 7.1 | 23.8 | 8.1 | 334 | 75.0 | 12 | 101.6 | | |
| | | 5.5 | 14.9 | 76 | 6.8 | 23.8 | 8.0 | 337 | 27.0 | 18 | 102.4 | | |

Table 8. Characteristics of Site 3 (250 meters east of Outfall), by time and depth (cont.).

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE \cdot s^{-1} \cdot m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug-20 | 13:05 | Surface | 18.8 | 127 | 10.3 | 23.4 | 8.5 | 306 | 296.0 | | | 761 | 3.5 |
| | | 0.5 | 18.9 | 124 | 10.2 | 23.4 | 8.5 | 309 | 130.0 | 84 | 111.0 | | |
| | | 1.5 | 18.8 | 118 | 9.7 | 23.6 | 8.4 | 312 | 83.0 | 86 | 111.3 | | |
| | | 2.5 | 18.7 | 116 | 9.5 | 23.6 | 8.3 | 316 | 32.0 | 76 | 110.0 | | |
| | | 3.5 | 18.6 | 102 | 8.3 | 23.8 | 8.3 | 321 | 24.0 | 54 | 107.1 | | |
| | | 4.5 | 17.6 | 88 | 7.5 | 23.9 | 8.2 | 323 | 16.0 | 40 | 105.3 | | |
| | | 5.5 | 16.3 | 88 | 7.5 | 24.1 | 8.1 | 327 | 13.0 | 21 | 102.8 | | |
| Aug-21 | 13:00 | Surface | 19.9 | 112 | 9.0 | 23.0 | 8.4 | 366 | 1418.0 | | | 767 | 3.8 |
| | | 0.5 | 18.8 | 109 | 8.9 | 23.3 | 8.4 | 364 | 150.0 | 53 | 106.9 | | |
| | | 1.5 | 18.4 | 101 | 8.4 | 23.6 | 8.3 | 365 | 116.0 | 55 | 107.2 | | |
| | | 2.5 | 16.8 | 88 | 7.4 | 23.9 | 8.2 | 366 | 87.0 | 22 | 102.9 | | |
| | | 3.5 | 16.4 | 86 | 7.4 | 23.9 | 8.1 | 366 | 49.0 | 13 | 101.7 | | |
| | | 4.5 | 15.8 | 81 | 7.2 | 24.0 | 8.1 | 366 | 27.0 | 1 | 100.1 | | |
| | | 5.5 | 15.7 | 78 | 6.8 | 23.9 | 8.1 | 366 | 18.0 | -4 | 99.5 | | |
| Aug-22 | 12:00 | Surface | 18.3 | 120 | 9.9 | 23.6 | 8.5 | 319 | 1067.0 | | | 764 | 3.5 |
| | | 0.5 | 18.2 | 110 | 9.2 | 23.8 | 8.4 | 315 | 580.0 | 73 | 109.6 | | |
| | | 1.5 | 18.0 | 105 | 8.7 | 23.9 | 8.3 | 312 | 101.0 | 62 | 108.1 | | |
| | | 2.5 | 17.9 | 97 | 8.1 | 24.0 | 8.2 | 284 | 99.0 | 45 | 105.9 | | |
| | | 3.5 | 17.1 | 92 | 7.9 | 24.1 | 8.2 | 268 | 86.0 | 30 | 103.9 | | |
| | | 4.5 | 16.3 | 92 | 7.9 | 24.2 | 8.2 | 262 | 79.0 | 25 | 103.3 | | |
| | | 5.5 | 16.7 | 91 | 7.9 | 24.1 | 8.2 | 264 | 64.0 | 11 | 101.4 | | |

Table 9. Characteristics of Site 4 (1200 meters east of outfall), by time and depth.

| Date | Time | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE \cdot s^{-1} \cdot m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jun-26 | 9:10 | Surface | 15.8 | 107.9 | 9.1 | 14.4 | 8.5 | | 432.0 | | | 764 | 2.0 |
| | | 0.5 | 16.1 | 109.5 | 9.1 | 14.6 | 8.5 | | 340.0 | 42.0 | 105.5 | | |
| | | 1.5 | 16.3 | 100.9 | 8.3 | 16.6 | 8.4 | | 205.0 | 39.0 | 105.1 | | |
| | | 2.5 | 14.8 | 85.3 | 7.1 | 20.6 | 8.2 | | 166.0 | 27.0 | 103.5 | | |
| | | 3.5 | 13.8 | 81.7 | 6.9 | 22.1 | 8.1 | | 75.0 | 17.0 | 102.2 | | |
| | | 4.5 | 12.7 | 77.1 | 6.6 | 22.6 | 8.1 | | 29.0 | 5.0 | 100.6 | | |
| | | 5.5 | 12.2 | 69.8 | 6.0 | 23.0 | 8.1 | | 21.0 | -8.0 | 99.0 | | |
| Jul-07 | 15:45 | Surface | 16.9 | 132.0 | 11.7 | 20.1 | 8.4 | 356 | 138.5 | | | 766 | 2.5 |
| | | 0.5 | 16.9 | 134.0 | 11.7 | 20.4 | 8.5 | 356 | 89.8 | 73.0 | 109.5 | | |
| | | 1.5 | 16.7 | 109.0 | 9.5 | 21.4 | 8.2 | 360 | 47.3 | 75.0 | 109.8 | | |
| | | 2.5 | 14.4 | 99.0 | 9.0 | 22.4 | 8.2 | 364 | 17.8 | 32.0 | 104.2 | | |
| | | 3.5 | 13.7 | 83.0 | 7.7 | 22.4 | 8.0 | 366 | 8.9 | 25.0 | 103.3 | | |
| | | 4.5 | 13.0 | 77.0 | 7.3 | 22.5 | 7.8 | 369 | 2.8 | -7.0 | 99.1 | | |
| | | 5.5 | 12.5 | 69.0 | 6.5 | 22.7 | 7.8 | 370 | 3.0 | -13.0 | 98.3 | | |
| Jul-08 | 13:45 | Surface | 16.0 | 112.0 | 10.2 | 16.0 | 8.3 | 403 | 62.3 | | | 761.4 | 1.5 |
| | | 0.5 | 16.1 | 117.0 | 10.6 | 17.7 | 8.3 | 403 | 34.1 | 50.0 | 106.6 | | |
| | | 1.5 | 16.2 | 113.0 | 10.1 | 20.1 | 8.2 | 403 | 16.0 | 51.0 | 106.7 | | |
| | | 2.5 | 14.7 | 91.0 | 8.3 | 22.0 | 7.8 | 407 | 6.3 | 23.0 | 103.0 | | |
| | | 3.5 | 14.1 | 82.0 | 7.7 | 22.6 | 7.8 | 407 | 4.9 | 26.0 | 103.4 | | |
| | | 4.5 | 13.2 | 77.0 | 7.3 | 22.8 | 7.9 | 407 | 3.4 | 5.0 | 100.7 | | |
| | | 5.5 | 12.6 | 68.0 | 6.5 | 22.7 | 7.9 | 407 | 1.8 | -1.0 | 99.9 | | |
| Jul-09 | 14:15 | Surface | 16.7 | 111.0 | 10.1 | 10.3 | 7.9 | 349 | 856.0 | | | 761.0 | 1.5 |
| | | 0.5 | 16.9 | 116.0 | 10.5 | 13.2 | 8.1 | 353 | 128.0 | 65.0 | 108.5 | | |
| | | 1.5 | 15.3 | 122.0 | 11.5 | 19.6 | 8.3 | 356 | 51.0 | 66.0 | 108.7 | | |
| | | 2.5 | 15.5 | 106.0 | 9.6 | 21.0 | 8.1 | 358 | 32.0 | 49.0 | 106.4 | | |
| | | 3.5 | 15.2 | 95.0 | 8.5 | 21.3 | 8.0 | 359 | 62.0 | 56.0 | 107.4 | | |
| | | 4.5 | 15.1 | 92.0 | 8.3 | 21.5 | 8.0 | 359 | 20.0 | 38.0 | 105.0 | | |
| | | 5.5 | 14.9 | 93.0 | 8.5 | 21.6 | 8.0 | 359 | 9.0 | 42.0 | 105.5 | | |

## Table 9. Characteristics of Site 4 (1200 meters east of Outfall), by time and depth (cont.).

| Date | | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE{\cdot}s^{-1}{\cdot}m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-10 | 14:30 | Surface | 16.6 | 136.0 | 12.2 | 15.3 | 8.5 | 345 | 224.0 | | | 765 | 2.0 |
| | | 0.5 | 16.9 | 143.0 | 12.6 | 16.5 | 8.7 | 348 | 117.0 | 96.0 | 112.6 | | |
| | | 1.5 | 16.4 | 110.0 | 10.0 | 19.3 | 8.2 | 357 | 58.0 | 90.0 | 111.8 | | |
| | | 2.5 | 16.1 | 106.0 | 9.4 | 20.1 | 8.2 | 360 | 30.0 | 56.0 | 107.3 | | |
| | | 3.5 | 16.0 | 104.0 | 9.2 | 20.6 | 8.2 | 360 | 10.0 | 67.0 | 108.8 | | |
| | | 4.5 | 15.9 | 102.0 | 9.2 | 21.0 | 8.1 | 362 | 6.0 | 53.0 | 106.9 | | |
| | | 5.5 | 15.2 | 98.0 | 8.9 | 21.4 | 8.0 | 363 | 4.0 | 44.0 | 105.8 | | |
| Jul-11 | 11:20 | Surface | 16.4 | 137.0 | 12.4 | 12.3 | 8.6 | 293 | 745.0 | | | 765 | 2.5 |
| | | 0.5 | 16.1 | 142.0 | 12.7 | 14.5 | 8.7 | 294 | 813.0 | 91.0 | 111.9 | | |
| | | 1.5 | 17.1 | 119.0 | 10.6 | 18.3 | 8.3 | 302 | 392.0 | 89.0 | 111.6 | | |
| | | 2.5 | 16.5 | 103.0 | 9.2 | 20.0 | 8.1 | 308 | 208.0 | 61.0 | 108.0 | | |
| | | 3.5 | 16.3 | 99.0 | 8.9 | 20.5 | 8.0 | 311 | 83.0 | 63.0 | 108.2 | | |
| | | 4.5 | 15.8 | 94.0 | 8.5 | 21.1 | 8.0 | 314 | 33.0 | 45.0 | 105.9 | | |
| | | 5.5 | 15.3 | 90.0 | 8.2 | 21.6 | 8.0 | 316 | 10.0 | 40.0 | 105.2 | | |
| Jul-14 | 14:45 | Surface | 22.5 | 132.0 | 10.4 | 13.1 | 8.7 | 335 | 933.0 | | | 762 | 2.8 |
| | | 0.5 | 22.0 | 137.0 | 11.0 | 13.2 | 8.7 | 330 | 362.0 | 131.0 | 117.2 | | |
| | | 1.5 | 19.9 | 126.0 | 10.6 | 18.1 | 8.4 | 339 | 258.0 | 146.0 | 119.2 | | |
| | | 2.5 | 18.2 | 104.0 | 9.0 | 19.0 | 8.2 | 343 | 104.0 | 116.0 | 115.2 | | |
| | | 3.5 | 17.5 | 95.0 | 8.2 | 19.9 | 8.0 | 347 | 50.0 | 95.0 | 112.5 | | |
| | | 4.5 | 15.6 | 82.0 | 7.5 | 20.9 | 7.8 | 351 | 51.0 | 77.0 | 110.1 | | |
| | | 5.5 | 15.1 | 84.0 | 7.6 | 21.0 | 7.7 | 352 | 48.0 | 50.0 | 106.6 | | |
| Jul-15 | 15:10 | Surface | 21.2 | 128.0 | 10.3 | 13.5 | 8.7 | 361 | 484.0 | | | 768 | 3.0 |
| | | 0.5 | 21.2 | 129.0 | 10.4 | 13.6 | 8.7 | 360 | 176.0 | 113.0 | 114.7 | | |
| | | 1.5 | 19.0 | 129.0 | 10.7 | 17.8 | 8.5 | 367 | 109.0 | 193.0 | 125.2 | | |
| | | 2.5 | 18.9 | 107.0 | 8.8 | 18.9 | 8.2 | 371 | 45.0 | 118.0 | 115.4 | | |
| | | 3.5 | 18.0 | 92.0 | 7.7 | 19.6 | 7.9 | 375 | 28.0 | 106.0 | 113.8 | | |
| | | 4.5 | 16.6 | 85.0 | 7.4 | 20.6 | 7.8 | 378 | 30.0 | 58.0 | 107.6 | | |
| | | 5.5 | 15.9 | 82.0 | 7.2 | 20.7 | 7.8 | 380 | 18.0 | 27.0 | 103.0 | | |

Table 9. Characteristics of Site 4 (1200 meters east of Outfall), by time and depth (cont.).

| Date | | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | $uE\cdot s^{-1}\cdot m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jul-16 | 14:10 | Surface | 20.5 | 133.0 | 11.0 | 15.7 | 8.7 | 320 | 1506.0 | | | 764 | 3.0 |
| | | 0.5 | 20.6 | 133.0 | 11.0 | 15.7 | 8.6 | 320 | 1053.0 | 112.0 | 114.6 | | |
| | | 1.5 | 20.5 | 136.0 | 11.3 | 15.7 | 8.8 | 321 | 450.0 | 142.0 | 118.5 | | |
| | | 2.5 | 19.2 | 154.0 | 12.8 | 17.1 | 8.6 | 325 | 222.0 | 150.0 | 118.8 | | |
| | | 3.5 | 18.6 | 127.0 | 10.8 | 17.6 | 8.5 | 329 | 30.0 | 102.0 | 113.3 | | |
| | | 4.5 | 17.9 | 101.0 | 8.6 | 18.8 | 8.2 | 335 | 18.0 | 71.0 | 108.9 | | |
| | | 5.5 | 17.3 | 87.0 | 7.5 | 19.7 | 7.8 | 339 | 17.0 | 45.0 | 105.9 | | |
| Jul-17 | 12:45 | Surface | 20.4 | 133.0 | 10.5 | 15.7 | 8.7 | 361 | 1618.0 | | | 762 | 3.0 |
| | | 0.5 | 20.3 | 133.0 | 10.6 | 15.6 | 8.7 | 358 | 911.0 | 88.0 | 111.6 | | |
| | | 1.5 | 20.1 | 119.0 | 9.7 | 15.8 | 8.6 | 358 | 465.0 | 95.0 | 112.5 | | |
| | | 2.5 | 18.7 | 112.0 | 9.4 | 17.4 | 8.3 | 363 | 243.0 | 76.0 | 110.0 | | |
| | | 3.5 | 18.5 | 104.0 | 8.7 | 18.2 | 8.2 | 366 | 80.0 | 74.0 | 109.7 | | |
| | | 4.5 | 17.9 | 99.0 | 8.4 | 18.6 | 8.1 | 367 | 58.0 | 61.0 | 108.0 | | |
| | | 5.5 | 17.6 | 94.0 | 8.1 | 18.8 | 8.1 | 368 | 56.0 | 60.0 | 107.9 | | |
| Jul-18 | 10:40 | Surface | 20.0 | 124.0 | 10.4 | 16.2 | 8.7 | 351 | 1682.0 | | | 769 | 2.5 |
| | | 0.5 | 20.0 | 128.0 | 10.7 | 16.1 | 8.7 | 351 | 1244.0 | 79.0 | 110.3 | | |
| | | 1.5 | 19.7 | 131.0 | 11.0 | 16.4 | 8.7 | 354 | 588.0 | 90.0 | 111.7 | | |
| | | 2.5 | 18.0 | 101.0 | 8.8 | 18.6 | 8.2 | 364 | 135.0 | 73.0 | 109.5 | | |
| | | 3.5 | 16.7 | 83.0 | 7.4 | 19.4 | 7.9 | 370 | 96.0 | 38.0 | 104.9 | | |
| | | 4.5 | 16.7 | 86.0 | 7.7 | 19.5 | 7.9 | 370 | 38.0 | 31.0 | 104.0 | | |
| | | 5.5 | 16.5 | 86.0 | 7.7 | 19.6 | 7.9 | 371 | 34.0 | 30.0 | 103.9 | | |
| Aug-18 | 12:30 | Surface | 21.1 | 109.0 | 8.6 | 22.1 | 8.2 | 401 | 1392.0 | | | 769 | 3.5 |
| | | 0.5 | 21.1 | 111.0 | 8.8 | 22.2 | 8.3 | 396 | 345.0 | 55.0 | 107.2 | | |
| | | 1.5 | 20.4 | 122.0 | 9.9 | 22.5 | 8.4 | 396 | 134.0 | 70.0 | 109.1 | | |
| | | 2.5 | 18.3 | 109.0 | 9.1 | 22.9 | 8.3 | 397 | 363.0 | 53.0 | 106.9 | | |
| | | 3.5 | 16.3 | 92.0 | 8.0 | 23.2 | 8.1 | 401 | 191.0 | 40.0 | 105.2 | | |
| | | 4.5 | 15.3 | 83.0 | 7.4 | 23.3 | 8.0 | 403 | 60.0 | 5.0 | 100.7 | | |
| | | 5.5 | 15.3 | 78.0 | 7.0 | 23.4 | 8.0 | 403 | 56.0 | 2.0 | 100.3 | | |

Table 9. Characteristics of Site 4 (1200 meters east of Outfall), by time and depth (cont.).

| Date | | Depth (m) | Temp (°C) | DO (%sat) | DO (ppm) | Salinity | pH | ORP (mV) | uE·$s^{-1}$·$m^{-2}$ | TGP (mmHg) | TGP (%) | BP (mmHg) | Secchi (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug-19 | 14:40 | Surface | 20.3 | 116.0 | 9.2 | 23.1 | 8.4 | 315 | 1313.0 | | | 761 | 3.5 |
| | | 0.5 | 20.2 | 119.0 | 9.5 | 23.1 | 8.4 | 316 | 1234.0 | 82.0 | 110.8 | | |
| | | 1.5 | 19.0 | 133.0 | 10.8 | 23.3 | 8.5 | 319 | 318.0 | 91.0 | 112.2 | | |
| | | 2.5 | 18.1 | 129.0 | 10.7 | 23.4 | 8.4 | 322 | 200.0 | 100.0 | 113.1 | | |
| | | 3.5 | 17.0 | 133.0 | 11.3 | 23.5 | 8.5 | 325 | 124.0 | 84.0 | 111.0 | | |
| | | 4.5 | 16.5 | 135.0 | 11.6 | 23.5 | 8.5 | 333 | 83.0 | 90.0 | 111.8 | | |
| | | 5.5 | 16.3 | 126.0 | 10.7 | 23.5 | 8.4 | 335 | 31.0 | 61.0 | 108.0 | | |
| Aug-20 | 13:45 | Surface | 19.2 | 117.0 | 9.5 | 23.2 | 8.4 | 325 | 221.0 | | | 760 | 3.0 |
| | | 0.5 | 19.1 | 126.0 | 10.2 | 23.3 | 8.5 | 325 | 91.0 | 83.0 | 110.9 | | |
| | | 1.5 | 18.5 | 131.0 | 10.8 | 23.4 | 8.6 | 326 | 77.0 | 99.0 | 113.0 | | |
| | | 2.5 | 17.6 | 111.0 | 9.2 | 23.6 | 8.4 | 329 | 29.0 | 75.0 | 109.9 | | |
| | | 3.5 | 17.2 | 111.0 | 9.3 | 23.6 | 8.4 | 331 | 15.0 | 76.0 | 110.0 | | |
| | | 4.5 | 16.8 | 106.0 | 9.0 | 23.7 | 8.3 | 333 | 10.0 | 49.0 | 106.4 | | |
| | | 5.5 | 16.0 | 88.0 | 7.6 | 23.8 | 8.2 | 336 | 5.0 | 37.0 | 104.9 | | |
| Aug-21 | 13:45 | Surface | 19.2 | 112.0 | 9.1 | 23.1 | 8.4 | 370 | 130.5 | | | 767 | 2.8 |
| | | 0.5 | 19.0 | 130.0 | 10.6 | 23.3 | 8.5 | 367 | 73.3 | 87.0 | 111.4 | | |
| | | 1.5 | 18.1 | 85.0 | 7.4 | 23.6 | 8.2 | 371 | 24.7 | 43.0 | 105.6 | | |
| | | 2.5 | 17.1 | 102.0 | 8.6 | 23.7 | 8.3 | 371 | 20.3 | 43.0 | 105.6 | | |
| | | 3.5 | 16.9 | 101.0 | 8.6 | 23.7 | 8.3 | 371 | 10.0 | 46.0 | 106.0 | | |
| | | 4.5 | 16.7 | 100.0 | 8.6 | 23.7 | 8.3 | 371 | 7.7 | 30.0 | 103.9 | | |
| | | 5.5 | 16.2 | 96.0 | 8.2 | 23.8 | 8.2 | 372 | 5.3 | 28.0 | 103.7 | | |
| Aug-22 | 12:35 | Surface | 18.8 | 120.0 | 9.9 | 23.3 | 8.5 | 318 | 1183.0 | | | 764 | 3.0 |
| | | 0.5 | 18.7 | 121.0 | 10.0 | 23.3 | 8.5 | 317 | 766.0 | 83.0 | 110.9 | | |
| | | 1.5 | 18.0 | 102.0 | 8.5 | 23.5 | 8.3 | 321 | 484.0 | 83.0 | 110.9 | | |
| | | 2.5 | 17.3 | 112.0 | 9.5 | 23.8 | 8.4 | 323 | 229.0 | 68.0 | 108.9 | | |
| | | 3.5 | 16.9 | 93.0 | 8.0 | 23.8 | 8.3 | 326 | 38.0 | 37.0 | 104.8 | | |
| | | 4.5 | 15.8 | 81.0 | 7.2 | 24.0 | 8.1 | 328 | 25.0 | 6.0 | 100.8 | | |
| | | 5.5 | 15.0 | 76.0 | 6.8 | 24.0 | 8.1 | 329 | 24.0 | -9.0 | 98.8 | | |

Table 10. Correlation of water quality variables and time (days) to percentage of fish at all depths, and in all experiments.

| Variable | Coefficient | Probability |
|---|---|---|
| Depth | -0.640 | 0.000 |
| Temperature | 0.282 | 0.000 |
| DO saturation | 0.473 | 0.000 |
| Salinity | -0.420 | 0.000 |
| pH | 0.529 | 0.000 |
| Light intensity | 0.373 | 0.000 |
| TGP % | 0.259 | 0.000 |
| Days | 0.000 | 0.998 |

Table 11. Correlation of water quality variables, time and depth, to percentage of fish, by site.

| | Cage Site | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | 1: Reference | | 2: 70 m east | | 3: 250 m east | | 4: 1200 m east | |
| | Coefficient | Probability | Coefficient | Probability | Coefficient | Probability | Coefficient | Probability |
| Depth | -0.624 | 0.000 | -0.628 | 0.000 | -0.687 | 0.000 | -0.655 | 0.000 |
| Temperature | 0.329 | 0.001 | 0.249 | 0.035 | 0.266 | 0.024 | 0.360 | 0.001 |
| DO saturation | 0.515 | 0.000 | 0.348 | 0.003 | 0.525 | 0.000 | 0.477 | 0.000 |
| Salinity | -0.447 | 0.000 | -0.278 | 0.018 | -0.409 | 0.000 | -0.514 | 0.000 |
| pH | 0.583 | 0.000 | 0.372 | 0.001 | 0.558 | 0.000 | 0.564 | 0.000 |
| Light intensity | 0.304 | 0.003 | 0.401 | 0.000 | 0.386 | 0.001 | 0.494 | 0.000 |
| TGP % | 0.324 | 0.001 | 0.160 | 0.181 | 0.286 | 0.015 | 0.266 | 0.014 |
| Days | 0.000 | 0.998 | 0.000 | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 |

Table 12. Correlation of water quality variables, and time, to percentage of fish at all study locations, by depth.

| | Depth (m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 0.5 | | 1.5 | | 2.5 | | 3.5 | | 4.5 | | 5.5 | |
| | Coef. | Prob. | Coef. | Prob. | Coef. | Prob. | Coef. | Prob. | Coef. | Prob. | Coef. | Prob. |
| Temperature | -0.310 | 0.023 | -0.125 | 0.369 | 0.361 | 0.007 | 0.259 | 0.058 | 0.271 | 0.048 | 0.246 | 0.730 |
| DO saturation | -0.002 | 0.986 | 0.156 | 0.260 | 0.127 | 0.361 | 0.084 | 0.548 | 0.003 | 0.983 | 0.211 | 0.125 |
| Salinity | -0.550 | 0.000 | -0.014 | 0.917 | 0.256 | 0.062 | 0.286 | 0.036 | 0.197 | 0.153 | 0.318 | 0.019 |
| pH | 0.196 | 0.156 | -0.128 | 0.356 | 0.268 | 0.050 | 0.210 | 0.128 | 0.038 | 0.785 | 0.424 | 0.001 |
| Light intensity | -0.337 | 0.013 | 0.095 | 0.496 | 0.230 | 0.094 | 0.259 | 0.059 | 0.159 | 0.251 | 0.227 | 0.099 |
| TGP % | -0.149 | 0.282 | 0.032 | 0.821 | 0.120 | 0.388 | -0.043 | 0.758 | 0.038 | 0.784 | -0.075 | 0.591 |
| Days | -0.629 | 0.000 | -0.004 | 0.997 | 0.472 | 0.000 | 0.494 | 0.000 | 0.397 | 0.003 | 0.584 | 0.000 |

Table 13. Significant variables related to the distribution of chum salmon at 4 sites in Port Moody Arm.

| | Cage Site | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | 1: Reference | | 2: 70 m east | | 3: 250 m east | | 4: 1200 m east | |
| | Coefficient | T-Stat | Coefficient | T-Stat | Coefficient | T-Stat | Coefficient | T-Stat |
| Log temperature | | | | | | | 2.610 | 2.2 |
| Log DO saturation | 7.176 | 5.7 | | | | | | |
| Log salinity | | | | | | | | |
| Log pH | 10.857 | 2.6 | | | | | 14.455 | 3.5 |
| Log TGP | -31.927 | -5.3 | | | | | -11.645 | 3.4 |
| Log Light intensity | | | | | 0.177 | 1.9 | | |
| Depth | -0.372 | -4.5 | -0.331 | -6.3 | | | -0.316 | -4.7 |
| Constant | 95.995 | 3.9 | 3.447 | 19.0 | 32.209 | 2.1 | 19.932 | 1.4 |
| Adjusted Multiple $R^2$ | 0.63 | | 0.35 | | 0.54 | | 0.55 | |
| n | 96 | | 72 | | 72 | | 84 | |

* - determined by stepwise regression analysis (n = 12)

Table 14. Significant variables related to the horizontal distribution of chum salmon over all sites in Port Moody Arm*.

| | Depth (m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 0.5 | | 1.5 | | 2.5 | | 3.5 | | 4.5 | | 5.5 | |
| | Coef. | T-Stat | Coef. | T-Stat | Coef. | T-Stat | Coef. | T-Stat | Coef. | T-Stat | Coef. | T-Stat |
| Log temperature | | | | | 4.488 | 4.9 | | | | | | |
| Log DO saturation | | | 2.839 | 2.7 | | | | | | | | |
| Log salinity | | | | | 2.895 | 3.3 | | | | | | |
| Log pH | | | -20.48 | -3.4 | | | | | -12.79 | -1.9 | | |
| Log Light intensity | | | 0.261 | 2.6 | | | | | | | | |
| Log TGP | | | | | | | | | | | | |
| Log Days | -1.169 | -4.9 | | | | | 1.746 | 4.7 | 1.694 | 3.8 | 2.632 | 5.7 |
| Constant | 8.815 | 8.8 | 31.53 | 3.2 | -20.61 | -4.6 | -5.778 | -3.7 | 20.91 | 1.5 | -9.630 | -5.0 |
| Adjusted Multiple $R^2$ | 0.30 | | 0.18 | | 0.33 | | 0.29 | | 0.19 | | 0.38 | |
| n | 54 | | 54 | | 54 | | 54 | | 54 | | 54 | |

* - determined by forward stepwise regression analysis (n = 12).

Table 15. Results of forward stepwise regression analyses relating water quality variables and depth, to percentage of fish using all data.

| Variable | Coefficient | T-stat |
|---|---|---|
| Log Temperature | 2.98 | 4.7 |
| Log DO saturation | 1.21 | 1.7 |
| Log Salinity | | |
| Log pH | 4.42 | 1.6 |
| Log Light intensity | | |
| Log TGP % | -11.59 | -4.3 |
| Depth | -0.879 | -9.3 |
| Constant | 34.20 | 2.7 |
| Adjusted Multiple $R^2$ | 0.48 | |
| n | 324 | |

Table 16. Selected BGS Operational Record: Summer 1997.

| Date | Number of Units Operating | Daily Plant Generation (MW-Hr) | Calculated Water Flow* (1000 m$^3$Day-1 | Discharge Temperature (°C) |
|---|---|---|---|---|
| 16-Jun | 1 | 2,320 | 479 | 19.8 |
| 17-Jun | 2 | 4,450 | 543 | 24.6 |
| 18-Jun | 2 | 4,168 | 571 | 23.5 |
| 19-Jun | 2 | 6,251 | 755 | 24.6 |
| 20-Jun | 1 | 2,807 | 338 | 24.9 |
| 21-Jun | 2 | 4,469 | 530 | 23.9 |
| 22-Jun | 2 | 4,610 | 522 | 24.4 |
| 23-Jun | 2 | 4,376 | 553 | 22.8 |
| 24-Jun | 2 | 4,171 | 396 | 26.5 |
| 25-Jun | 2 | 4,752 | 497 | 24.8 |
| 26-Jun | 3 | 8,288 | 945 | 23.0 |
| 27-Jun | 3 | 8,133 | 876 | 23.6 |
| **Mean** | **2** | **4900** | **584** | **23.9** |
| **S. D.** | **0.6** | **1825** | **183** | **1.6** |
| 1-Jul | 2 | 7,205 | 791 | 23.1 |
| 2-Jul | 2 | 6,449 | 784 | 22.0 |
| 3-Jul | 2 | 7,540 | 906 | 22.0 |
| 4-Jul | 3 | 8,218 | 861 | 24.0 |
| 5-Jul | 3 | 8,690 | 828 | 25.2 |
| 6-Jul | 3 | 8,312 | 912 | 23.5 |
| 7-Jul | 2 | 6,944 | 747 | 23.5 |
| 8-Jul | 3 | 7,927 | 869 | 23.5 |
| 9-Jul | 3 | 9,475 | 970 | 24.7 |
| 10-Jul | 3 | 9,799 | 1,012 | 25.6 |
| 11-Jul | 3 | 8,381 | 999 | 24.8 |
| 12-Jul | 3 | 8,280 | 940 | 25.4 |
| 13-Jul | 3 | 8,715 | 1,005 | 25.1 |
| 14-Jul | 2 | 5,564 | 609 | 26.2 |
| 15-Jul | 2 | 5,591 | 642 | 25.9 |
| 16-Jul | 2 | 5,809 | 653 | 26.7 |
| 17-Jul | 2 | 5,793 | 874 | 24.1 |
| 18-Jul | 2 | 6,151 | 853 | 24.5 |
| **Mean** | **2.5** | **7491** | **848** | **24.4** |
| **S. D.** | **0.5** | **1357** | **124** | **1.3** |
| 11-Aug | 1 | 1,479 | 538 | 18.7 |
| 12-Aug | 2 | 4,666 | 738 | 22.6 |
| 13-Aug | 3 | 8,391 | 928 | 26.2 |
| 14-Aug | 3 | 8,204 | 1,128 | 24.2 |
| 15-Aug | 2 | 7,210 | 898 | 24.8 |
| 16-Aug | 3 | 8,436 | 1,159 | 24.3 |
| 17-Aug | 3 | 8,119 | 1,098 | 24.5 |
| 18-Aug | 3 | 8,361 | 1,088 | 24.6 |
| 19-Aug | 3 | 8,403 | 1,084 | 24.6 |
| 20-Aug | 3 | 8,343 | 1,042 | 24.8 |
| 21-Aug | 3 | 10,793 | 1,195 | 25.9 |
| 22-Aug | 3 | 11,013 | 1,194 | 26.1 |
| **Mean** | **2.7** | **7785** | **1008** | **24.3** |
| **S. D.** | **0.7** | **2548** | **200** | **2.0** |

*Flow Rates Accurate to plus 10.5%, minus 6.5%

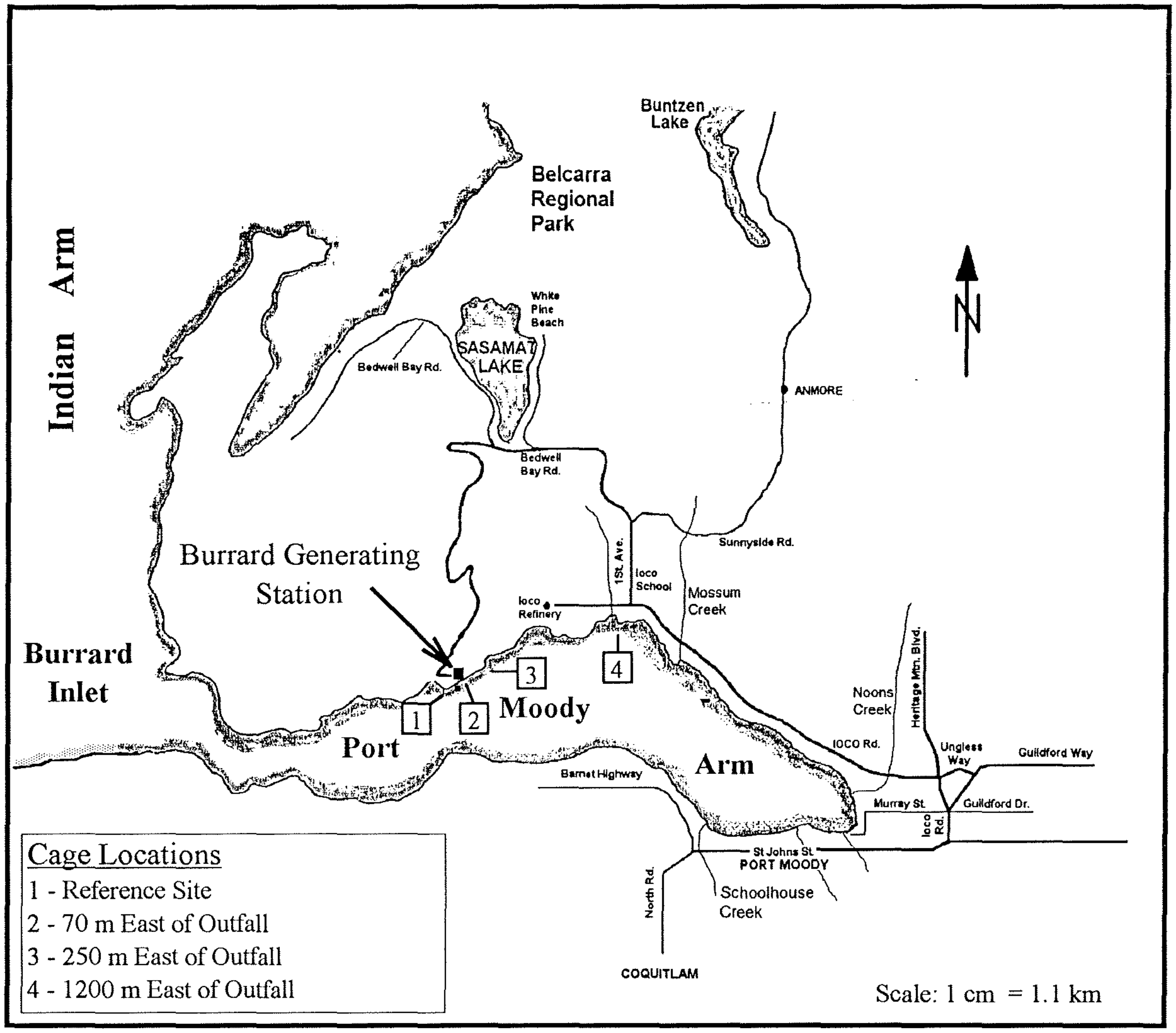


Figure 1. Location of Burrard Generating Station and study sites, Port Moody, B.C.

Figure 2. Side view of 6 m long vertical cage.

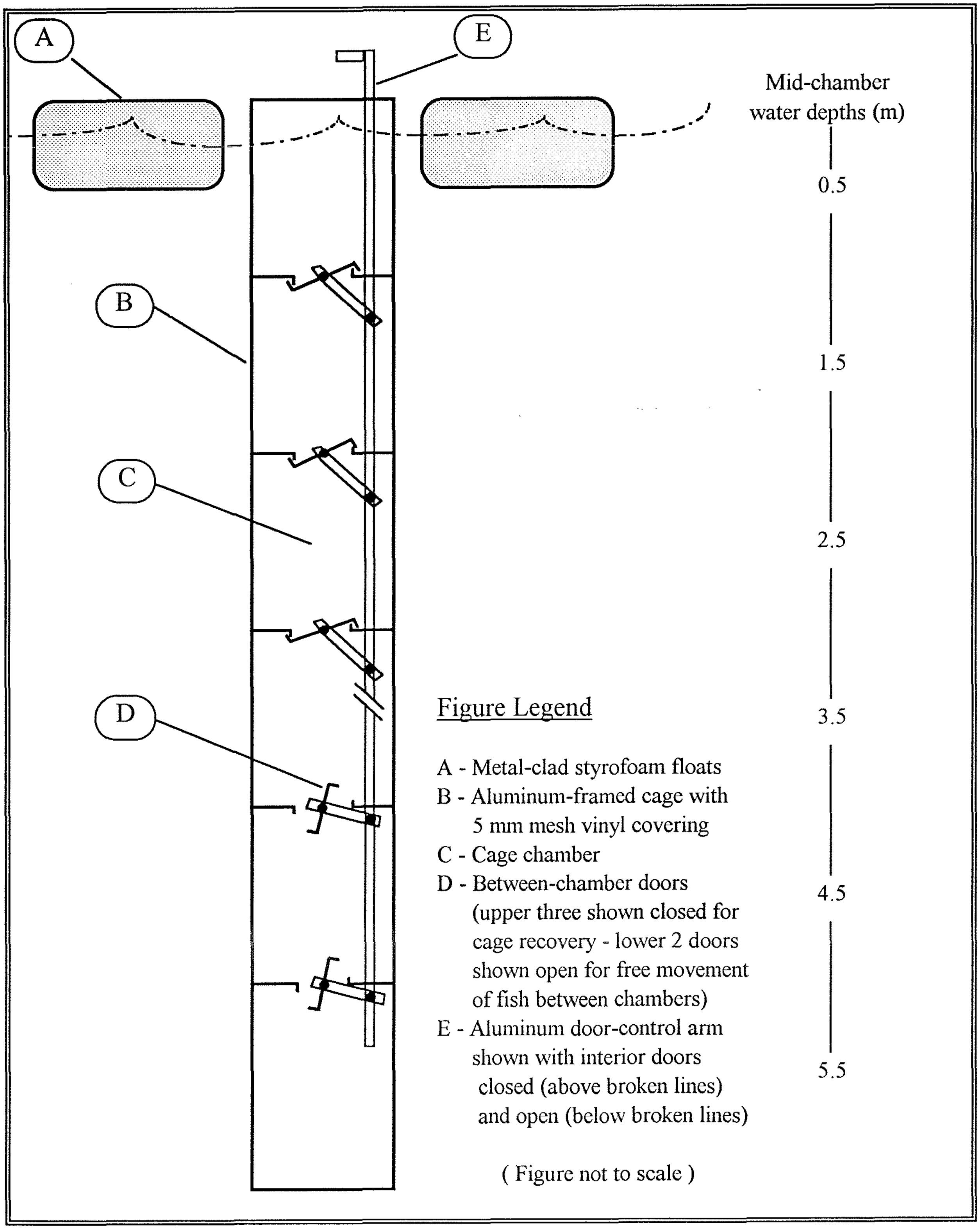


Figure Legend

A - Metal-clad styrofoam floats
B - Aluminum-framed cage with 5 mm mesh vinyl covering
C - Cage chamber
D - Between-chamber doors (upper three shown closed for cage recovery - lower 2 doors shown open for free movement of fish between chambers)
E - Aluminum door-control arm shown with interior doors closed (above broken lines) and open (below broken lines)

( Figure not to scale )

Figure 3. Vertical distribution of fish - Reference Site (1).

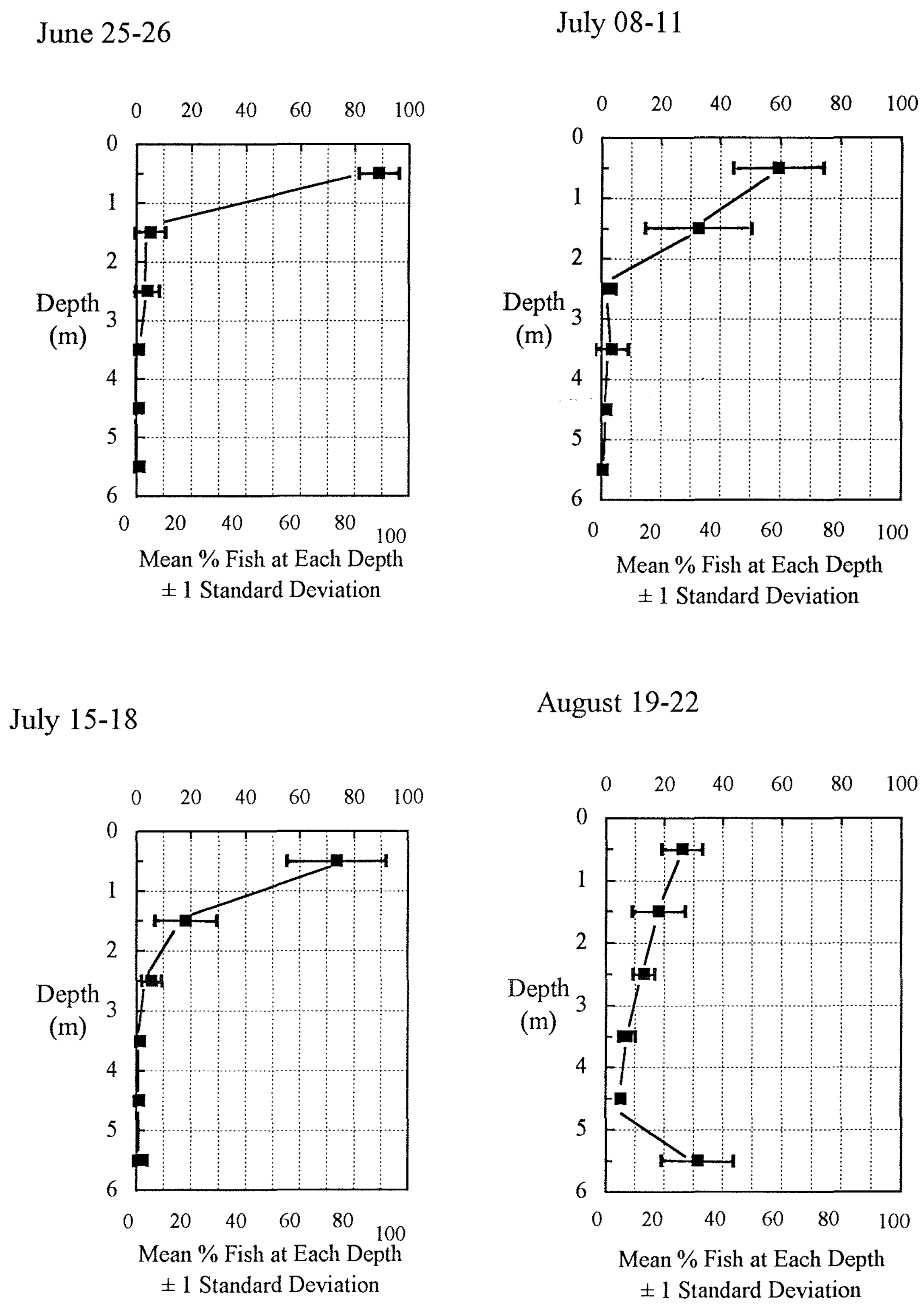
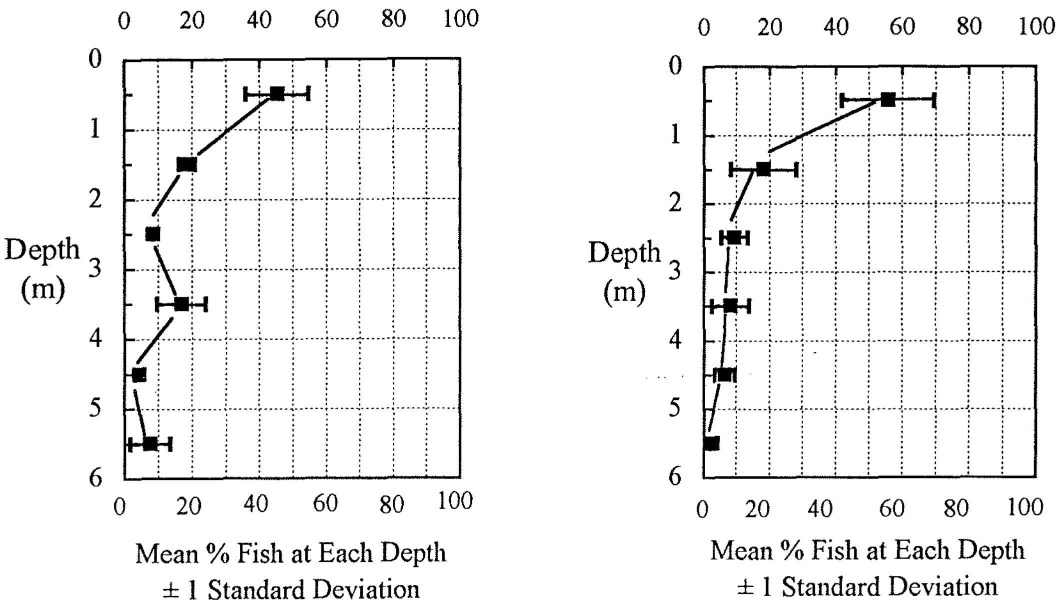
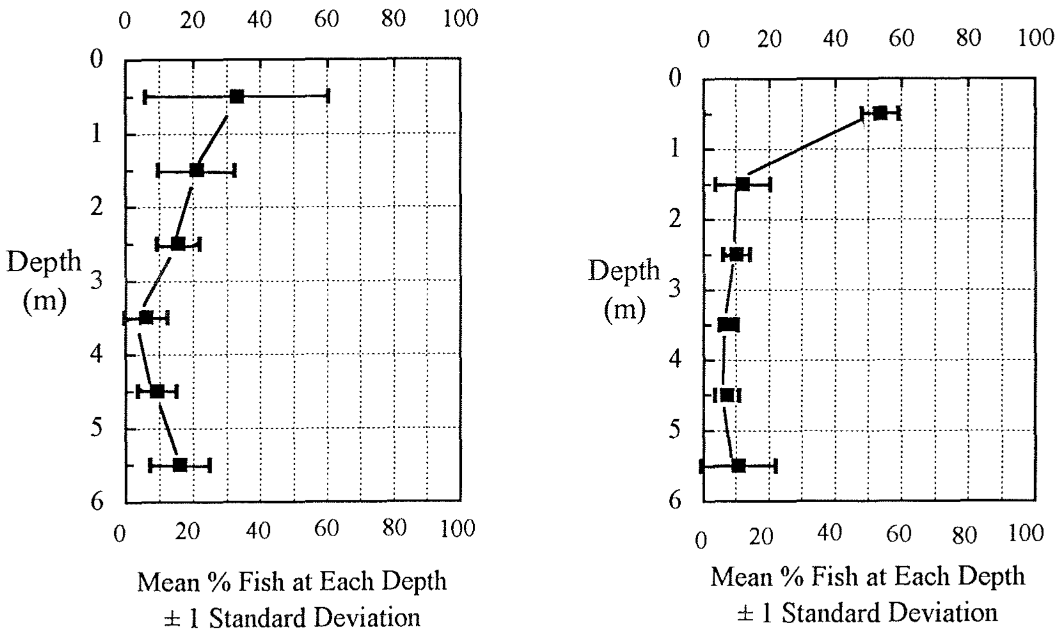


Figure 4. Vertical distribution of fish - 70 m east of Outfall (Site 2).

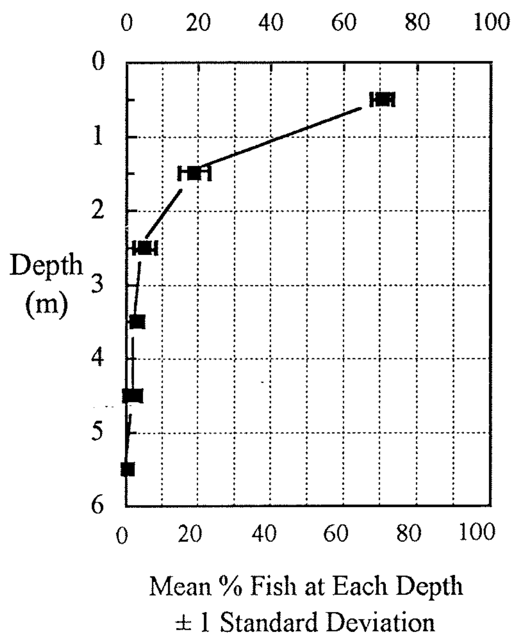

June 25-26

July 08-11

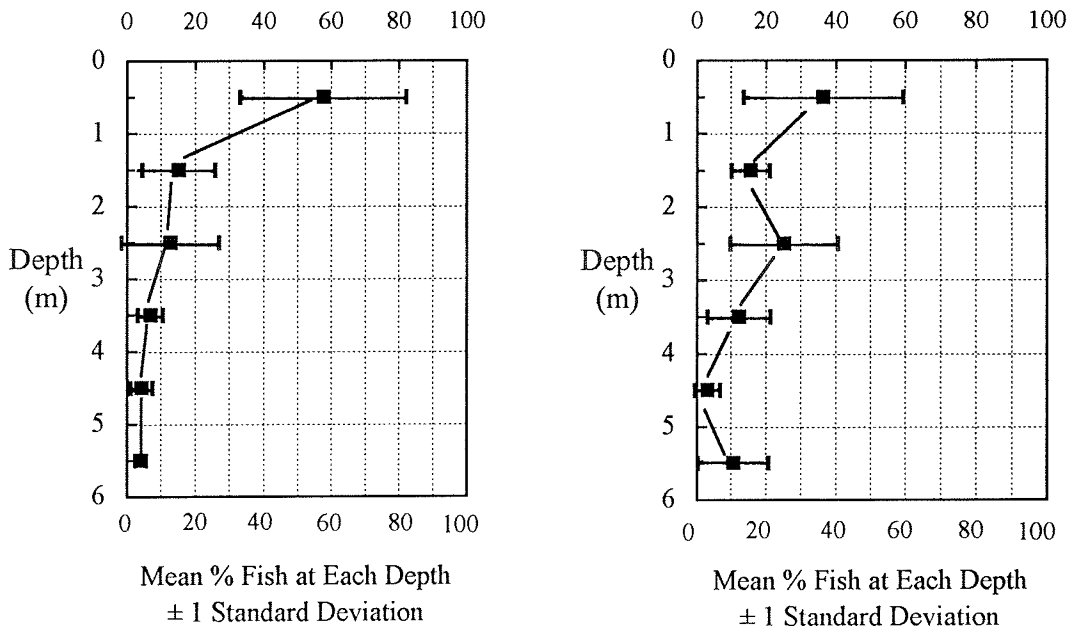

July 15-18

August 19-22

Figure 5. Vertical distribution of fish - 250 m east of Outfall (Site 3).



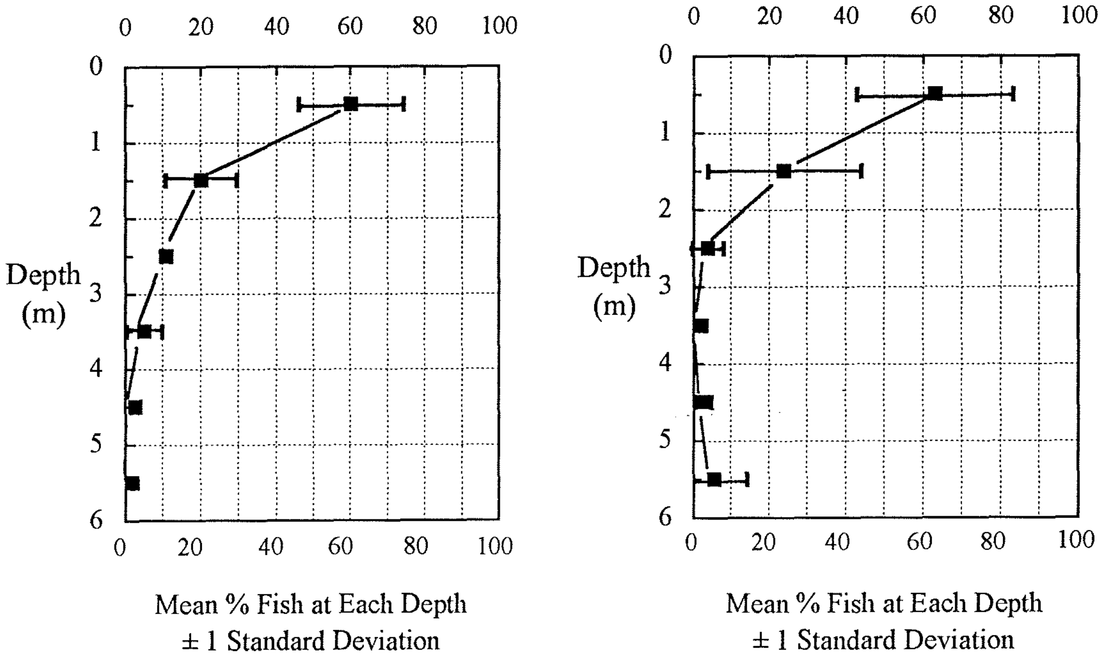
July 08-11



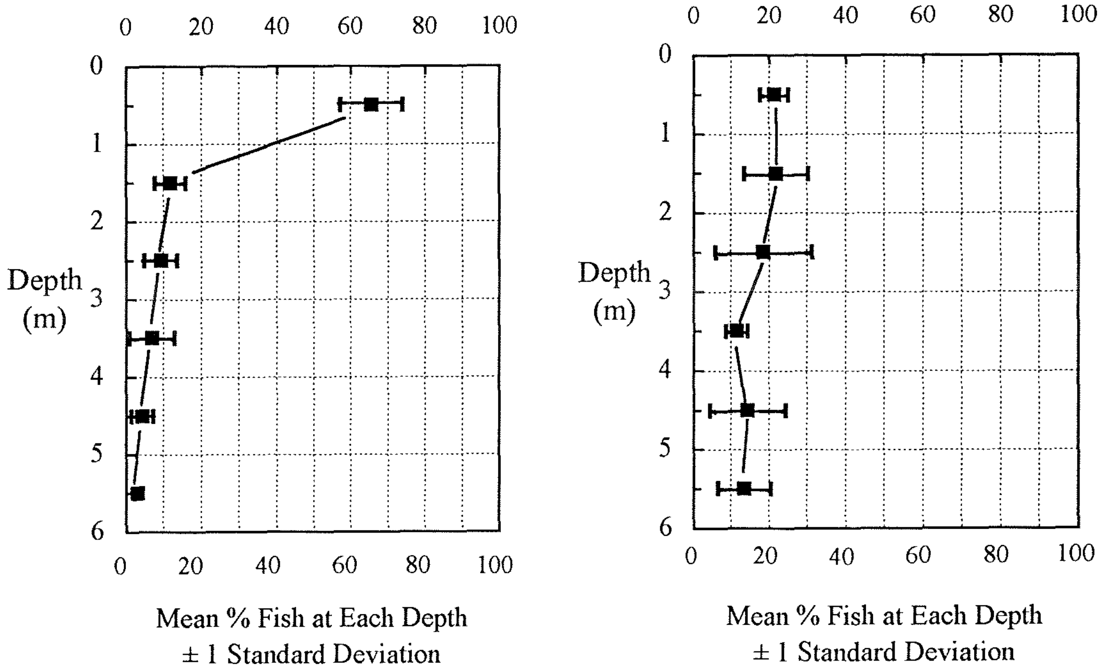
July 15-18

August 19-22

Figure 6. Vertical distribution of fish - 1200 m east of Outfall (Site 4).


June 25-26

July 08-11


July 15-18

Aug. 19-22

Figure 7. Fork length (mm) of fish used in the cage experiment.

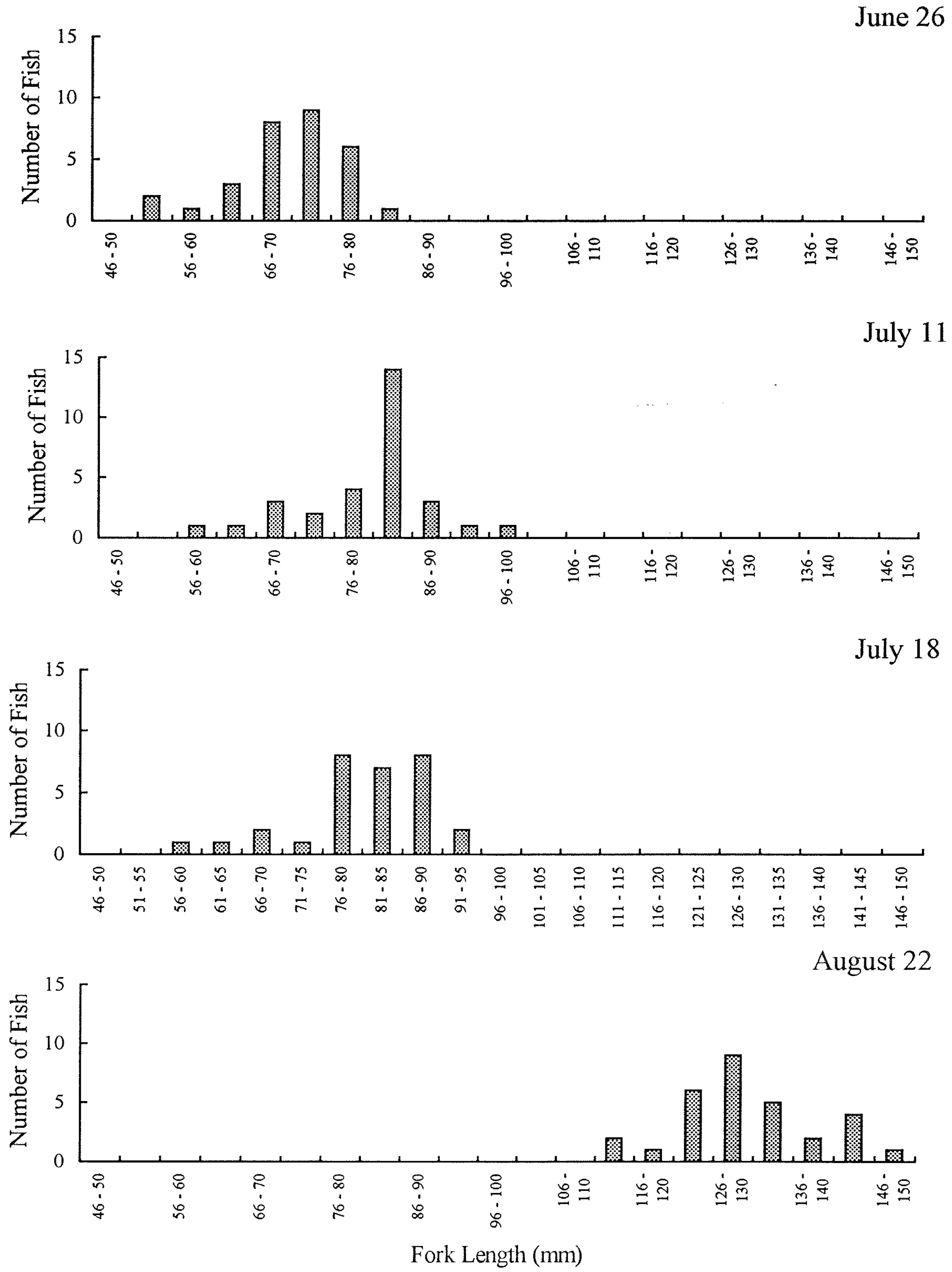
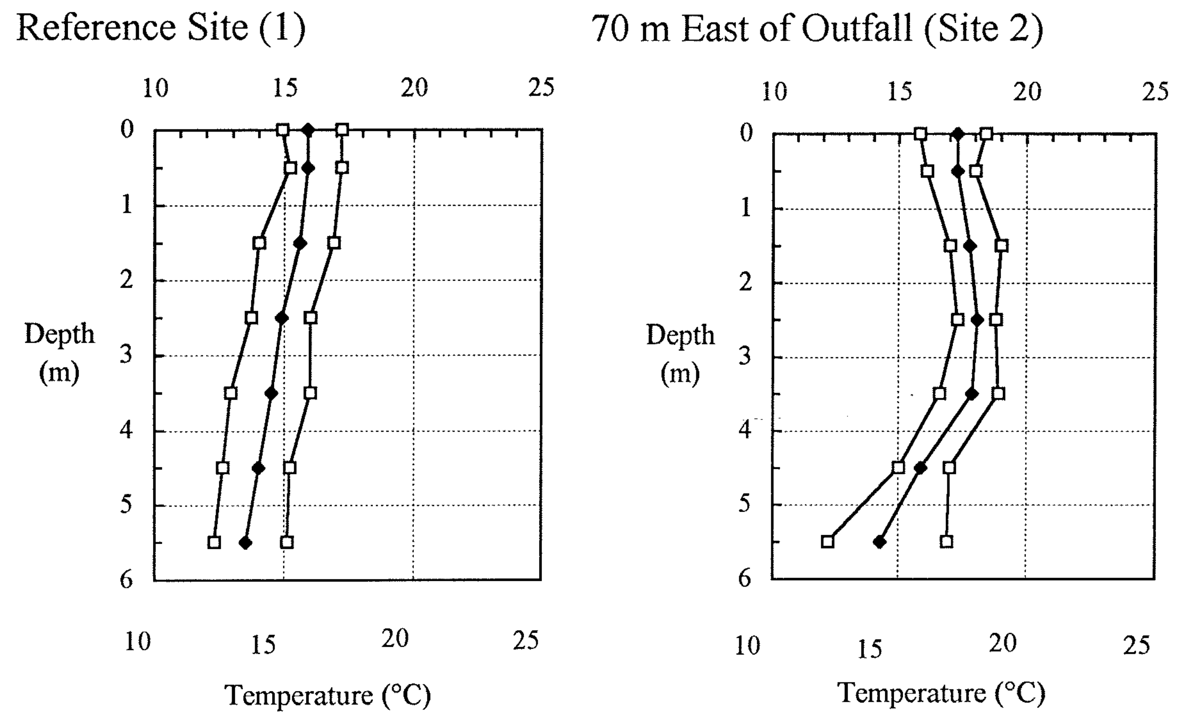


Figure 8. Maximum, mean, and minimum temperatures - July 07-11



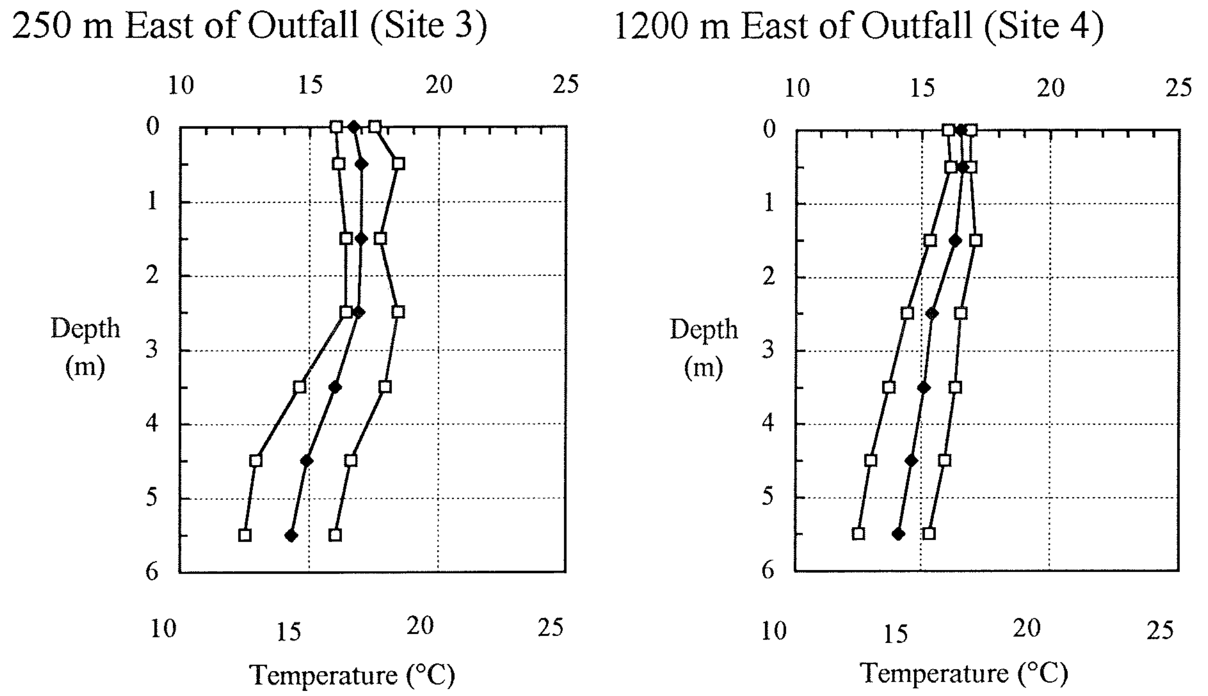
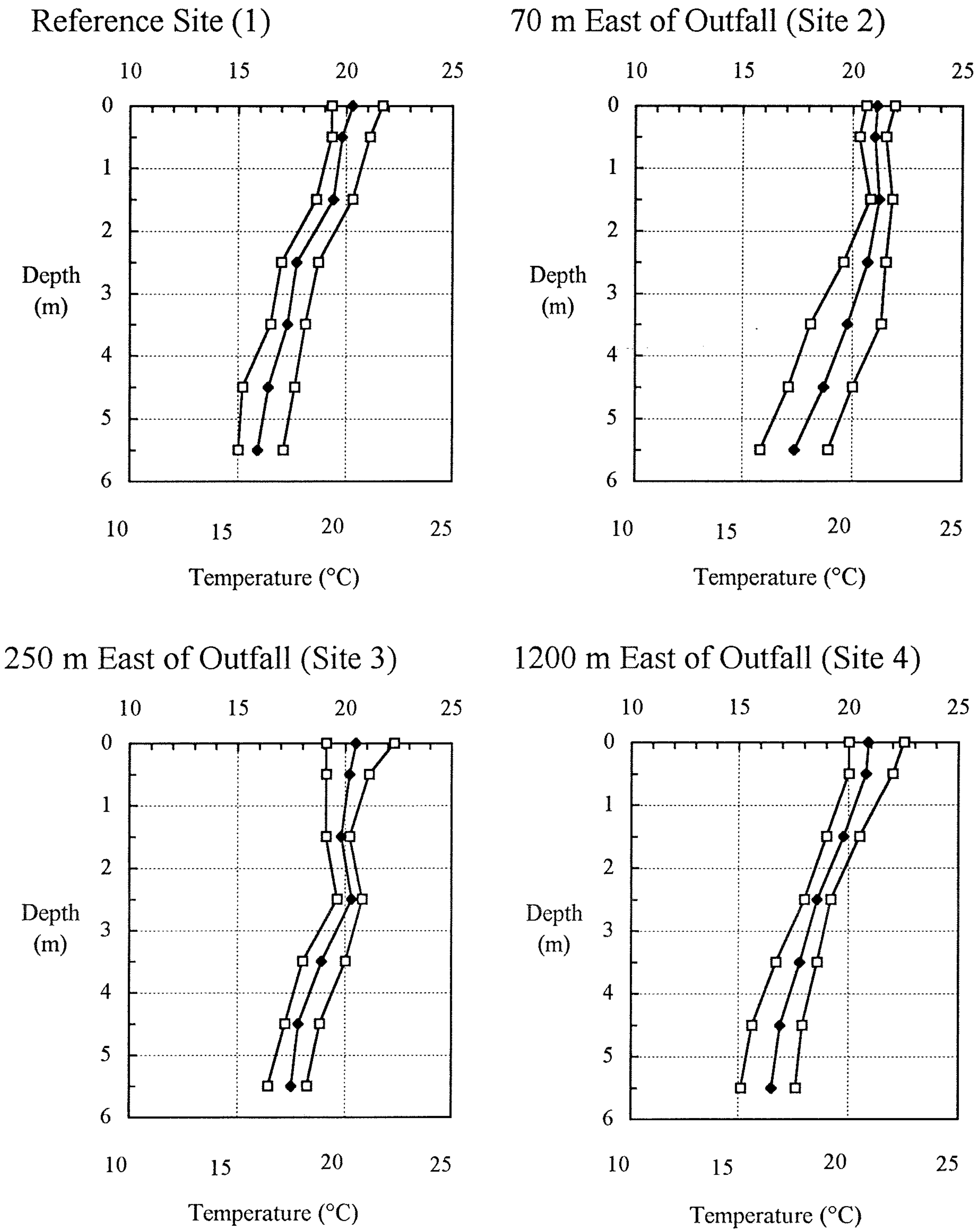


Figure 9. Maximum, mean, and minimum temperatures - July 14-18



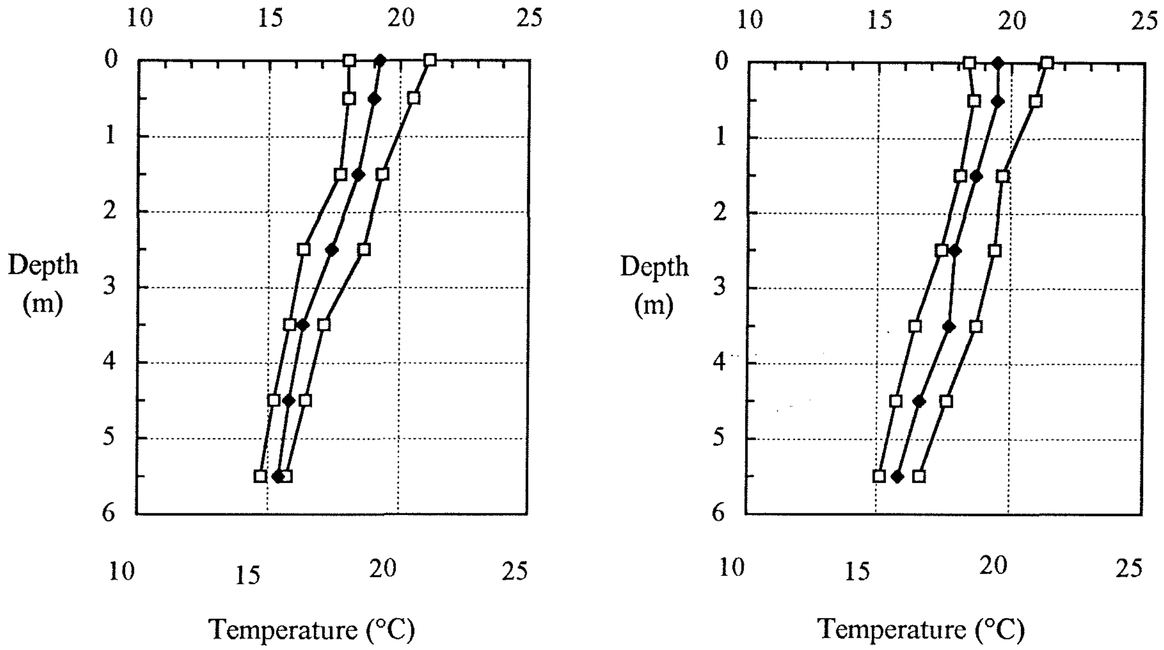
Reference Site (1)

70 m East of Outfall (Site 2)

250 m East of Outfall (Site 3)

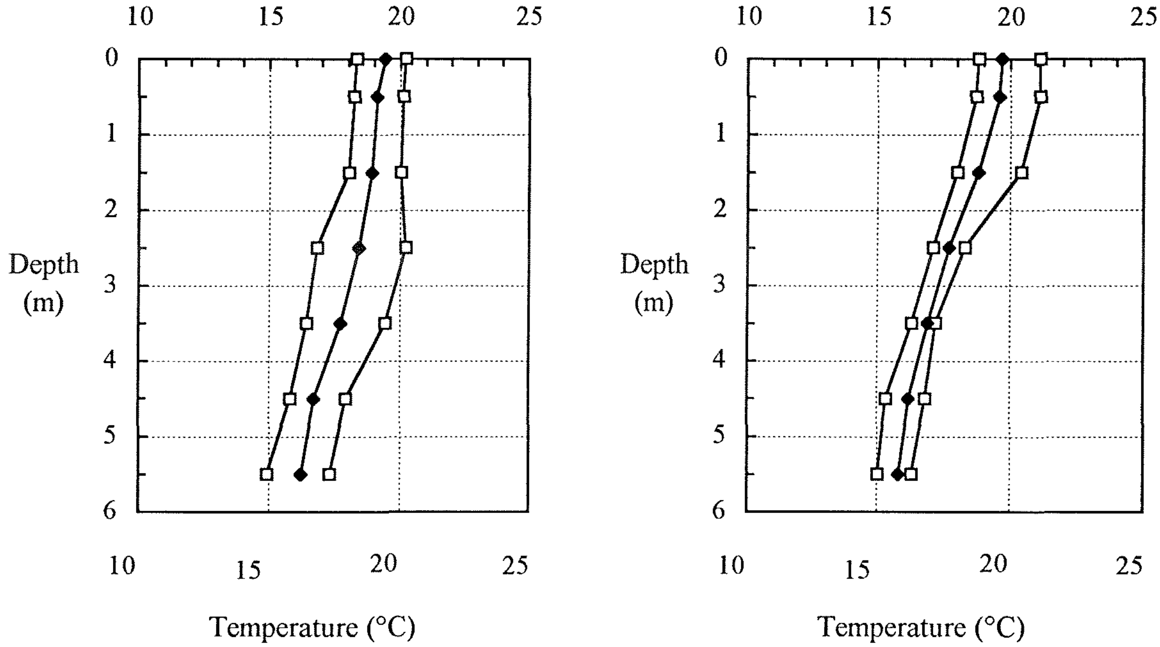
1200 m East of Outfall (Site 4)

Figure 10. Maximum, mean, and minimum temperatures - August 18-22.



Reference Site (1)

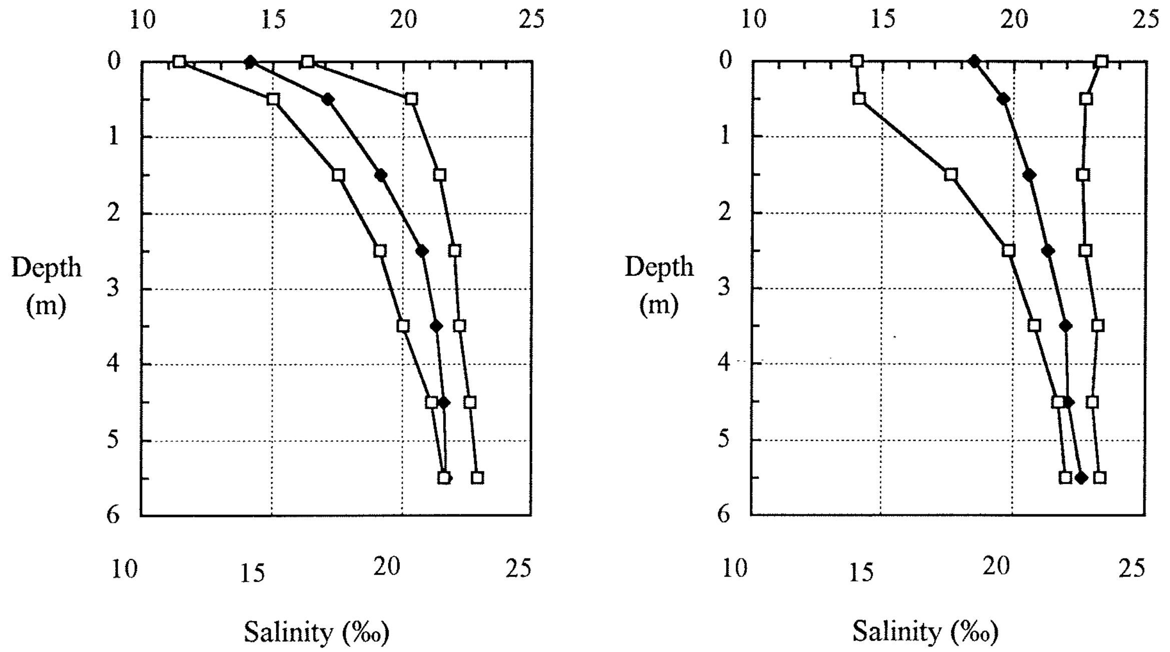
70 m East of Outfall (Site 2)



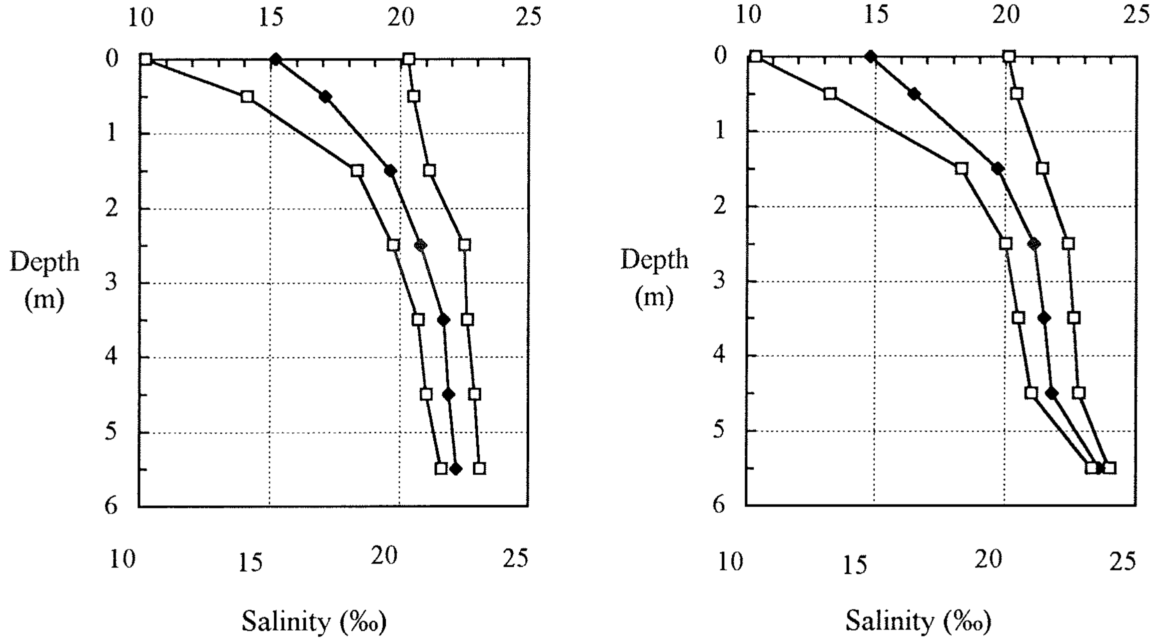
250 m East of Outfall (Site 3)

1200 m East of Outfall (Site 4)

Figure 11. Maximum, mean, and minimum salinity - July 07-11.


Reference Site (1)

70 m East of Outfall (Site 2)


250 m East of Outfall (Site 3)

1200 m East of Outfall (Site 4)

Figure 12. Maximum, mean, and minimum salinity - July 14-18.

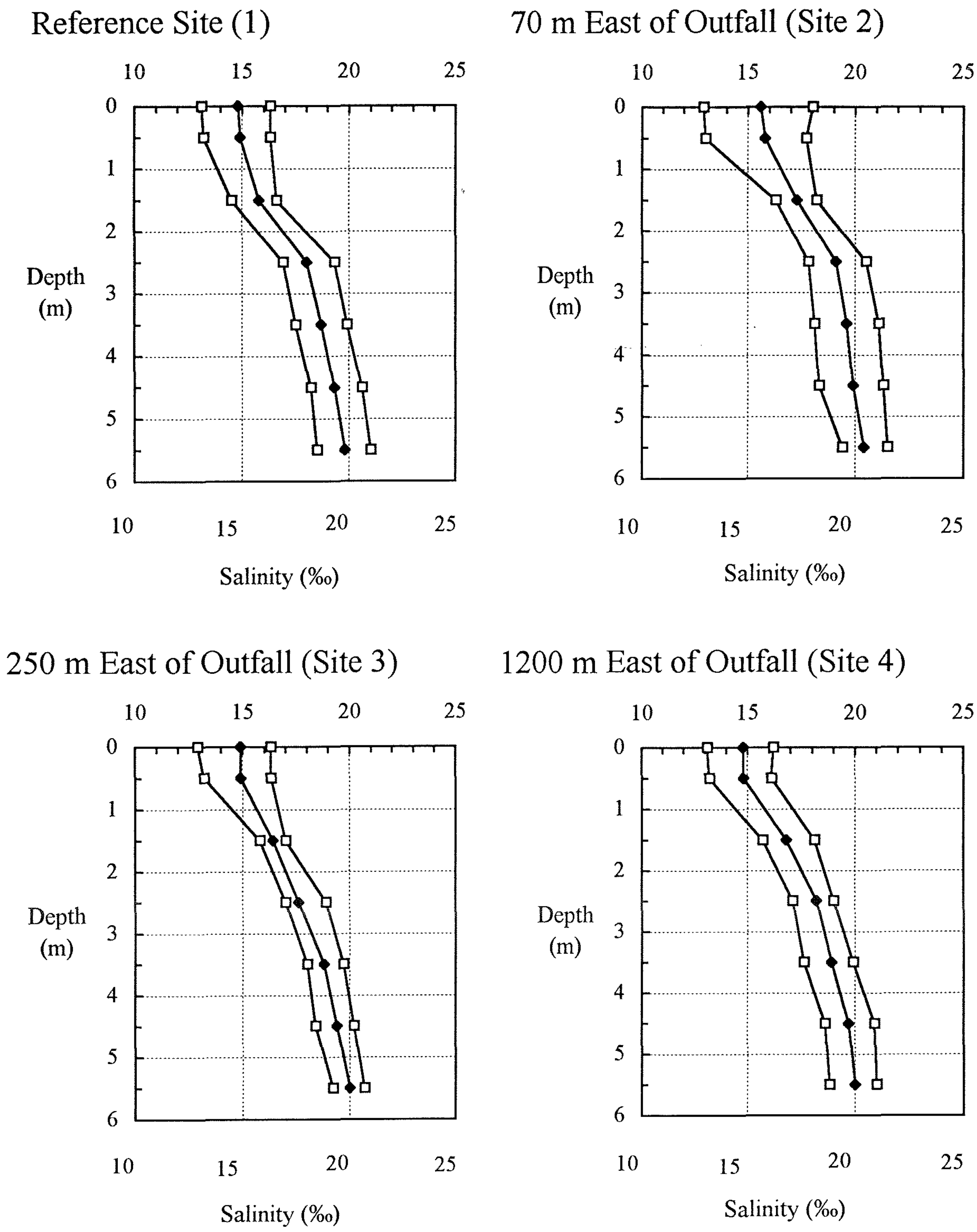
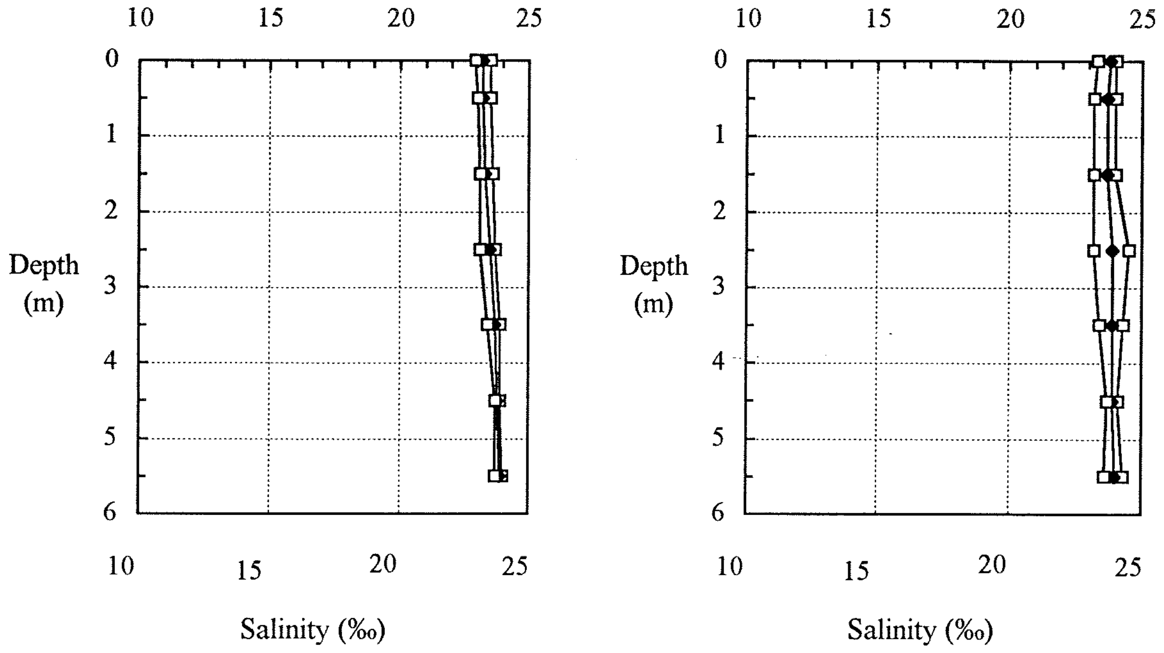
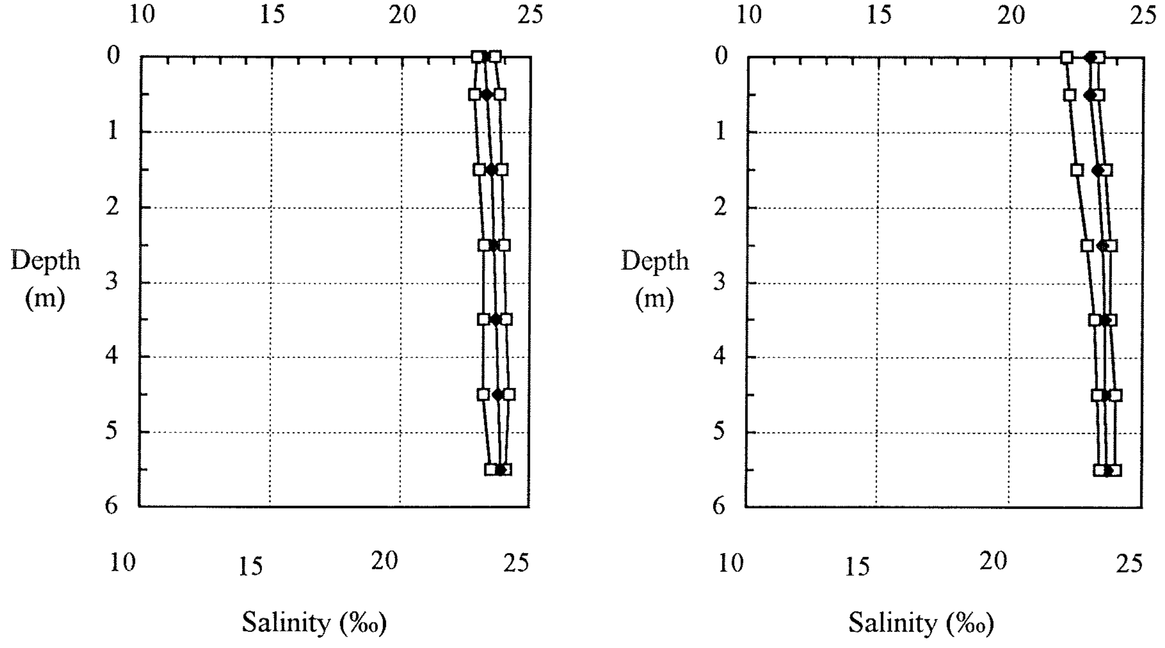


Figure 13. Maximum, mean, and minimum salinity - August 18-22.



Reference Site (1)

70 m East of Outfall (Site 2)



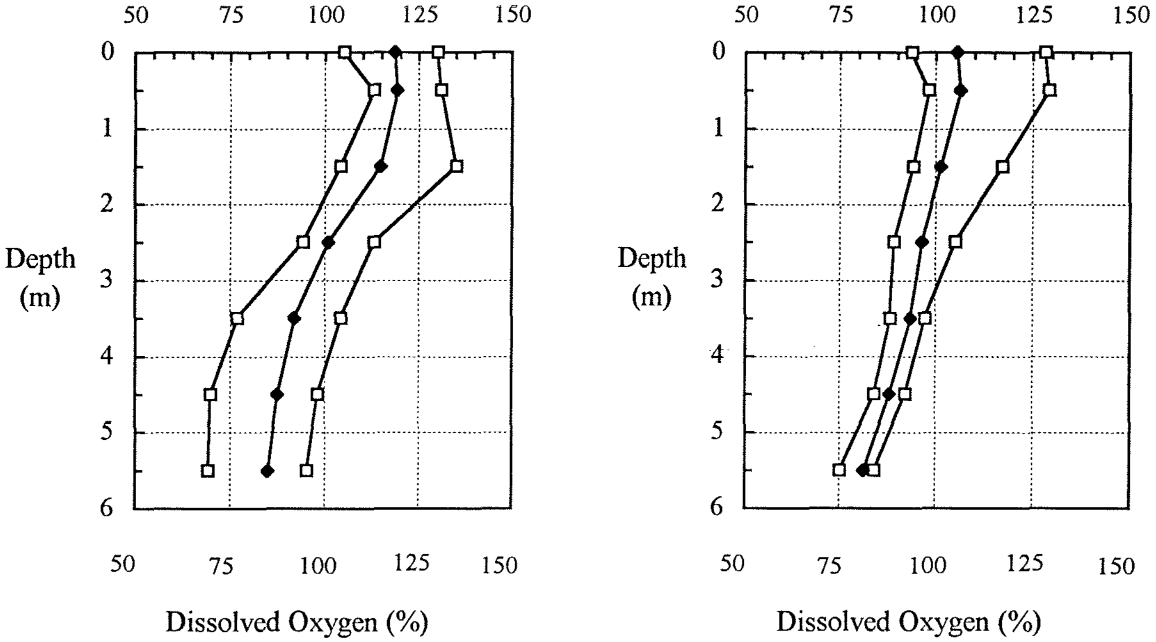
250 m East of Outfall (Site 3)

1200 m East of Outfall (Site 4)

Figure 14. Maximum, mean, and minimum $DO_2$ (% Sat.) - July 07-11

Reference Site (1)

70 m East of Outfall (Site 2)



250 m East of Outfall (Site 3)

1200 m East of Outfall Site (4)

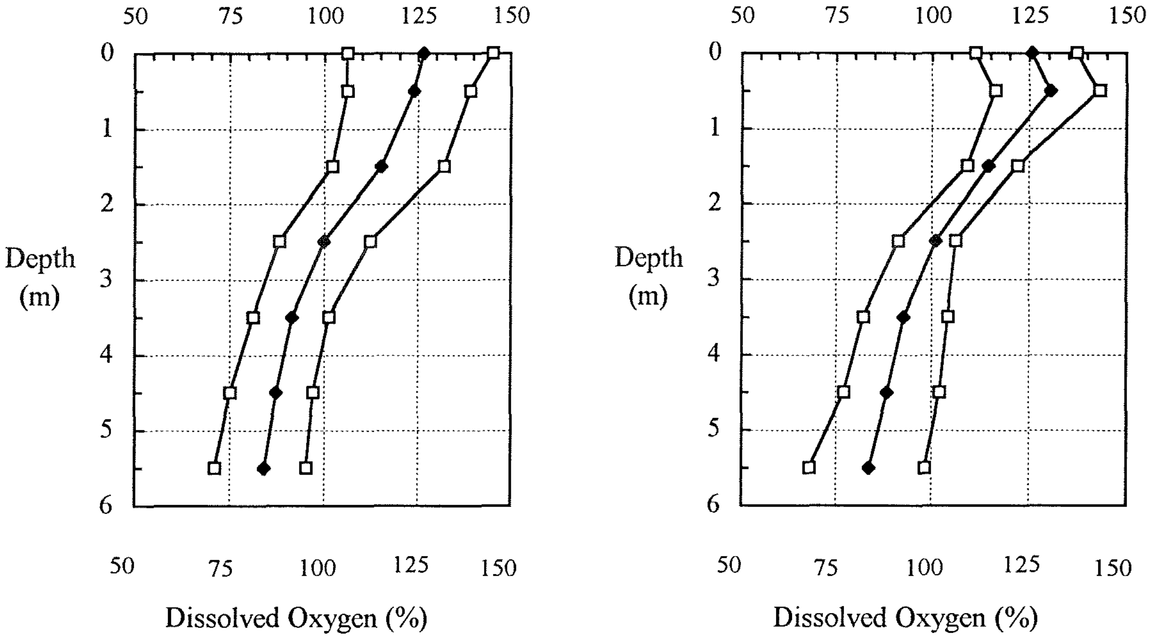
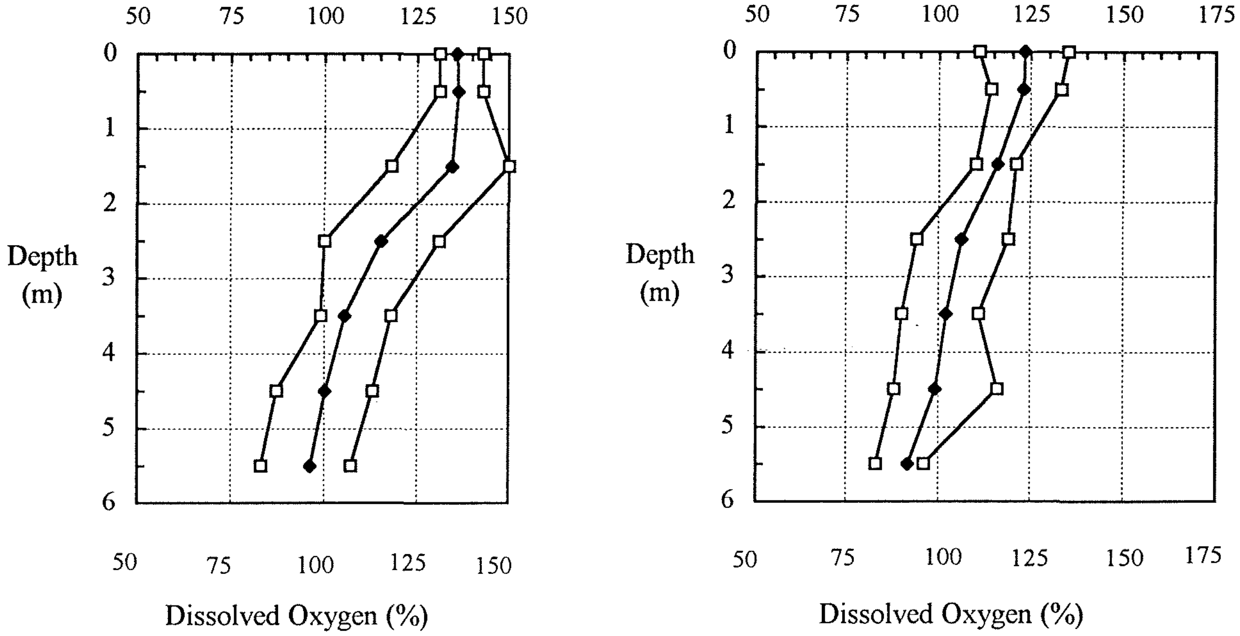


Figure 15. Maximum, mean, and minimum $DO_2$ (% Sat.) - July 14-18.

Reference Site (1)

70 m East of Outfall (Site 2)



50 m East of Outfall (Site 3)

1200 m East of Outfall (Site 4)

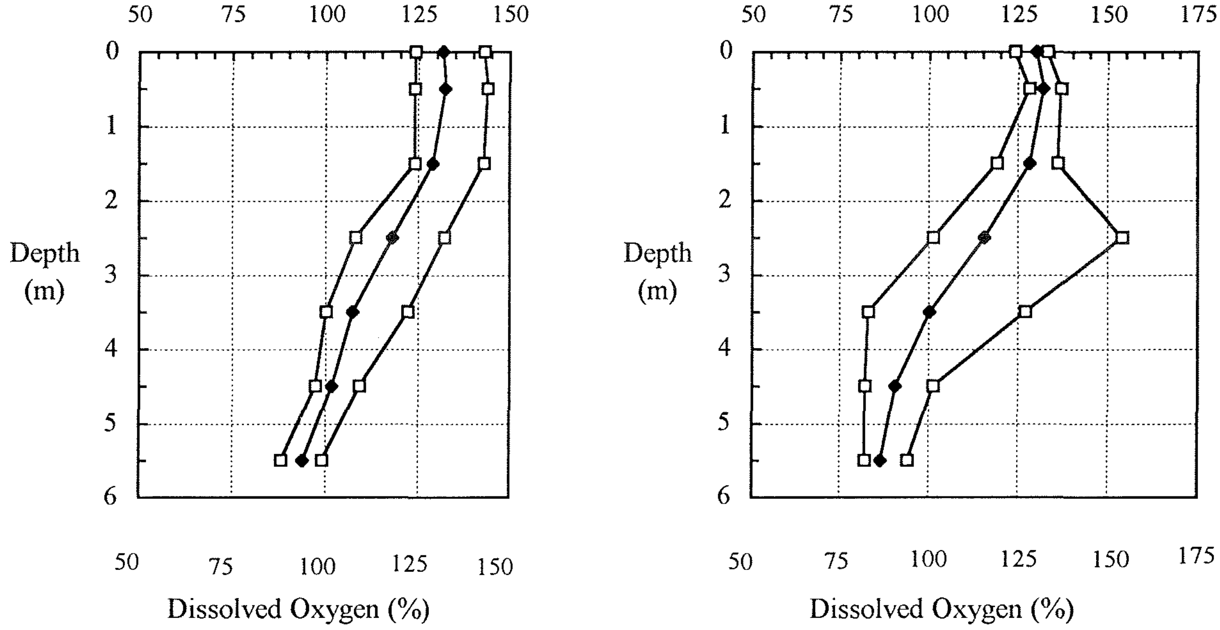
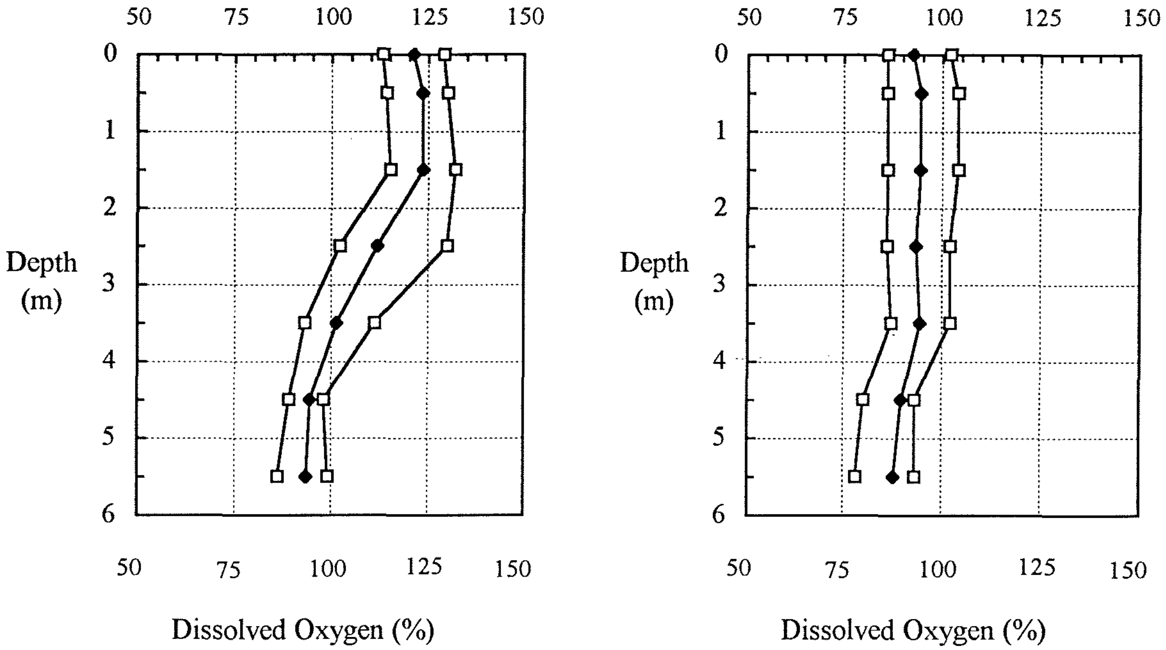


Figure 16. Maximum, mean, and minimum $DO_2$ (% Sat.) - Aug. 18-22.

Reference Site (1)

70 m East of Outfall (Site 2)



250 m East of Outfall (Site 3)

1200 m East of Outfall (Site 4)

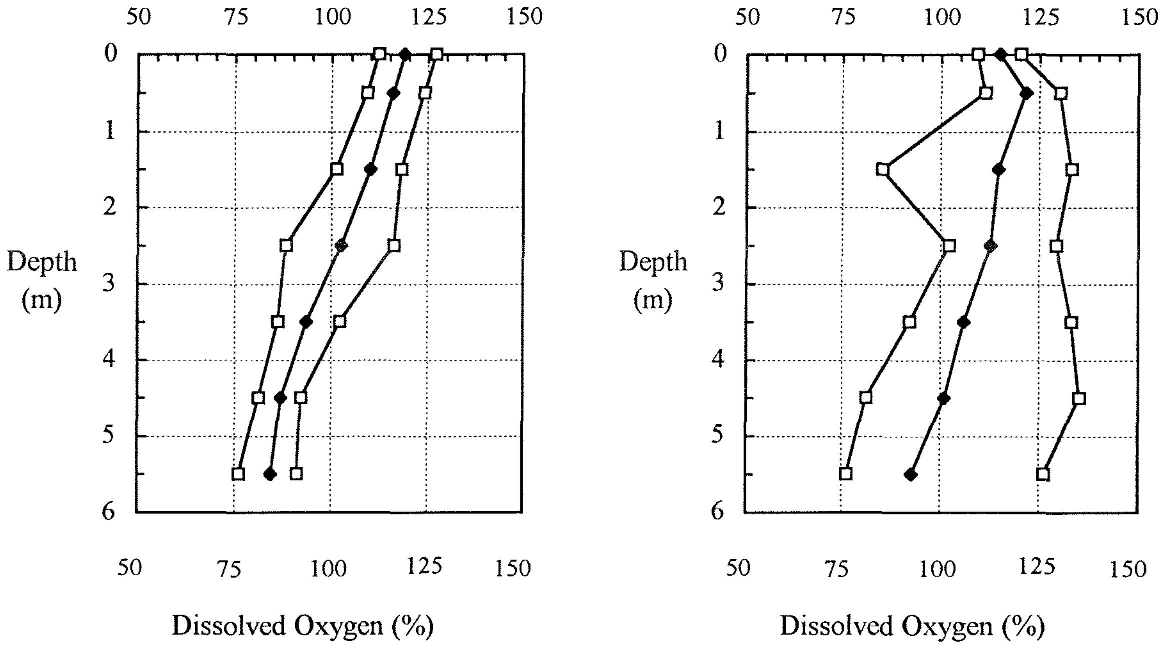
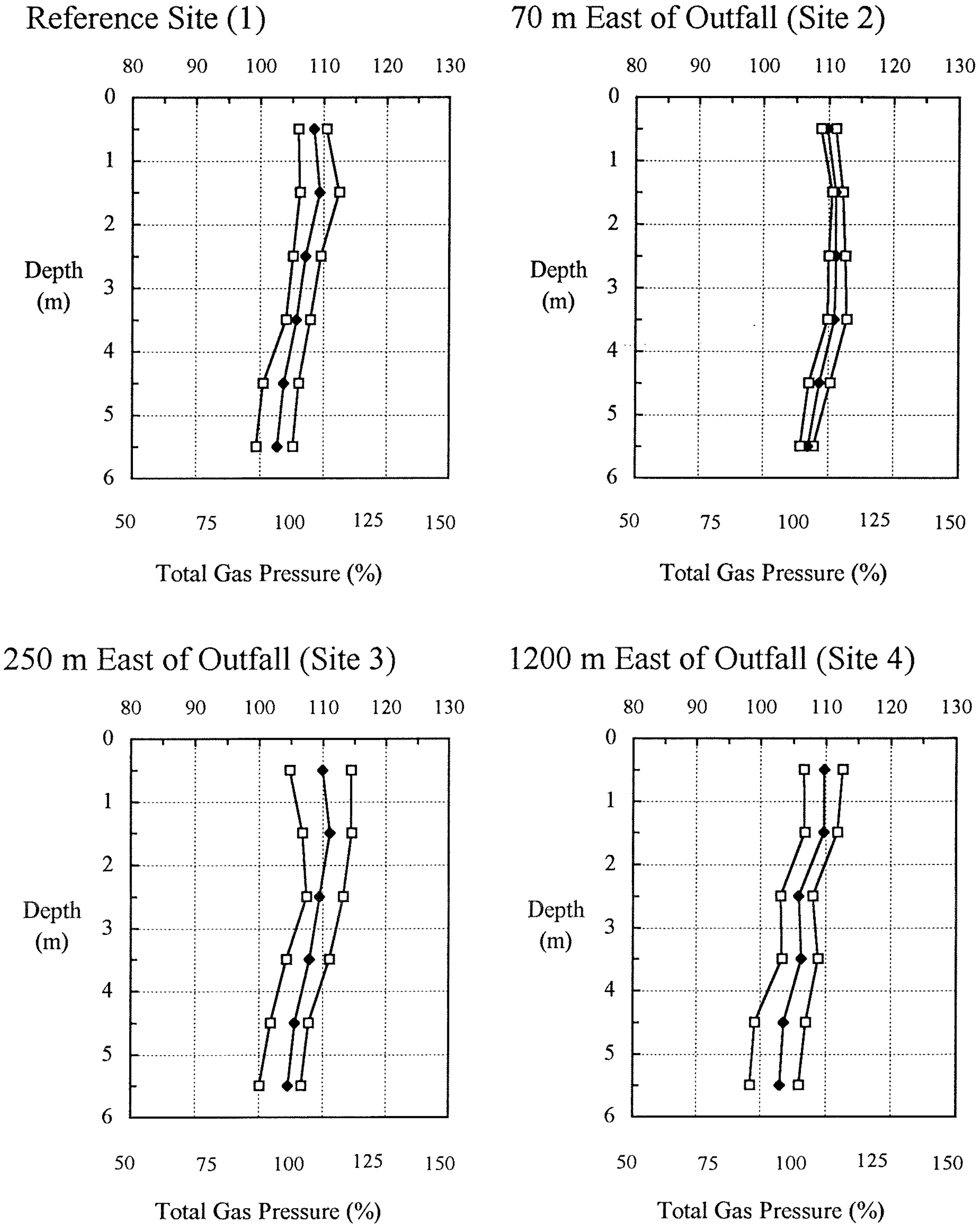


Figure 17. Maximum, mean, and minimum TGP (% Sat.) - July 07-11.



Reference Site (1)

70 m East of Outfall (Site 2)

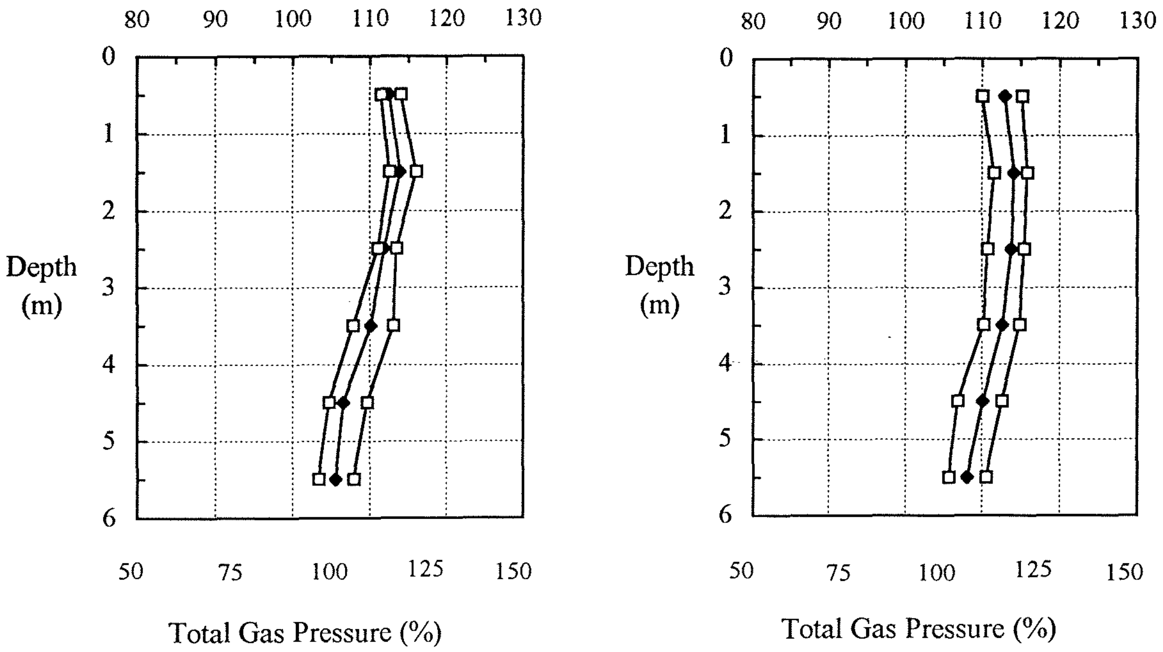
250 m East of Outfall (Site 3)

1200 m East of Outfall (Site 4)

Figure 18. Maximum, mean, and minimum TGP (% Sat.) - July 14-18.

Reference Site (1)

70 m East of Outfall (Site 1)



250 m East of Outfall (Site 3)

1200 m East of Outfall (Site 4)

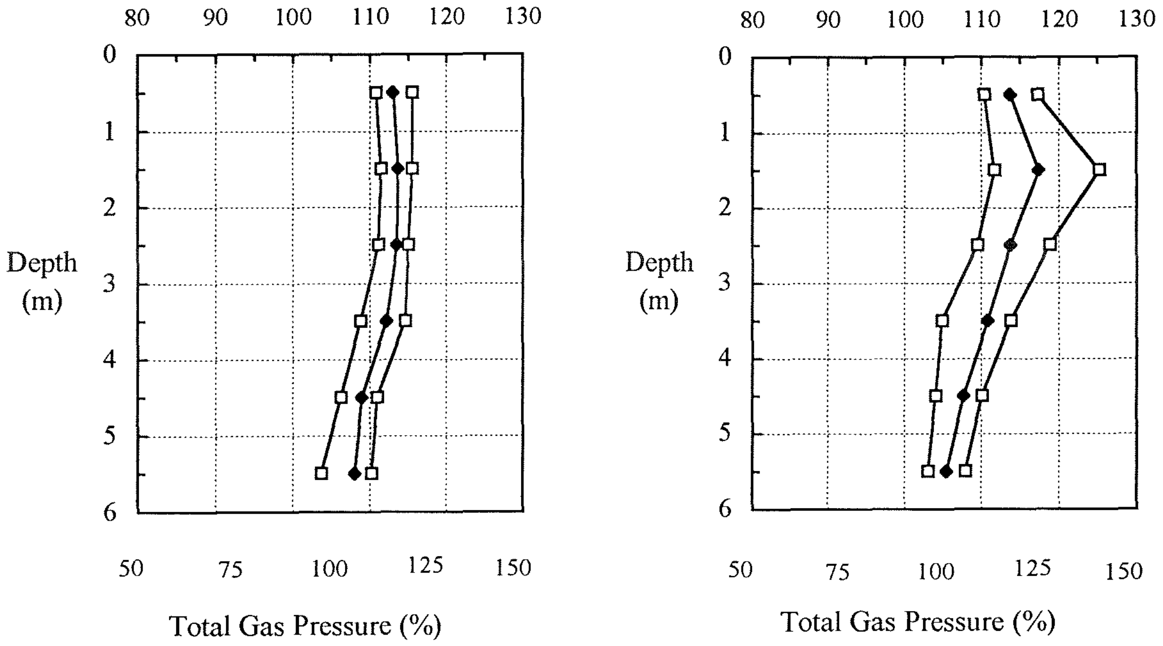
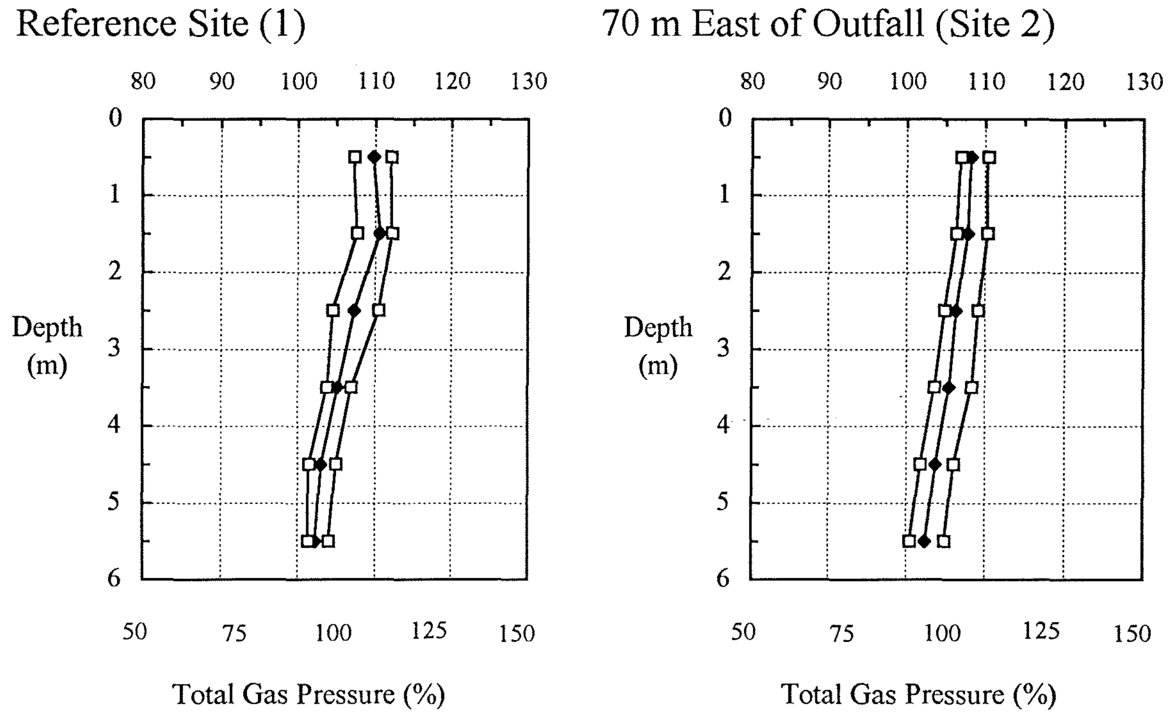
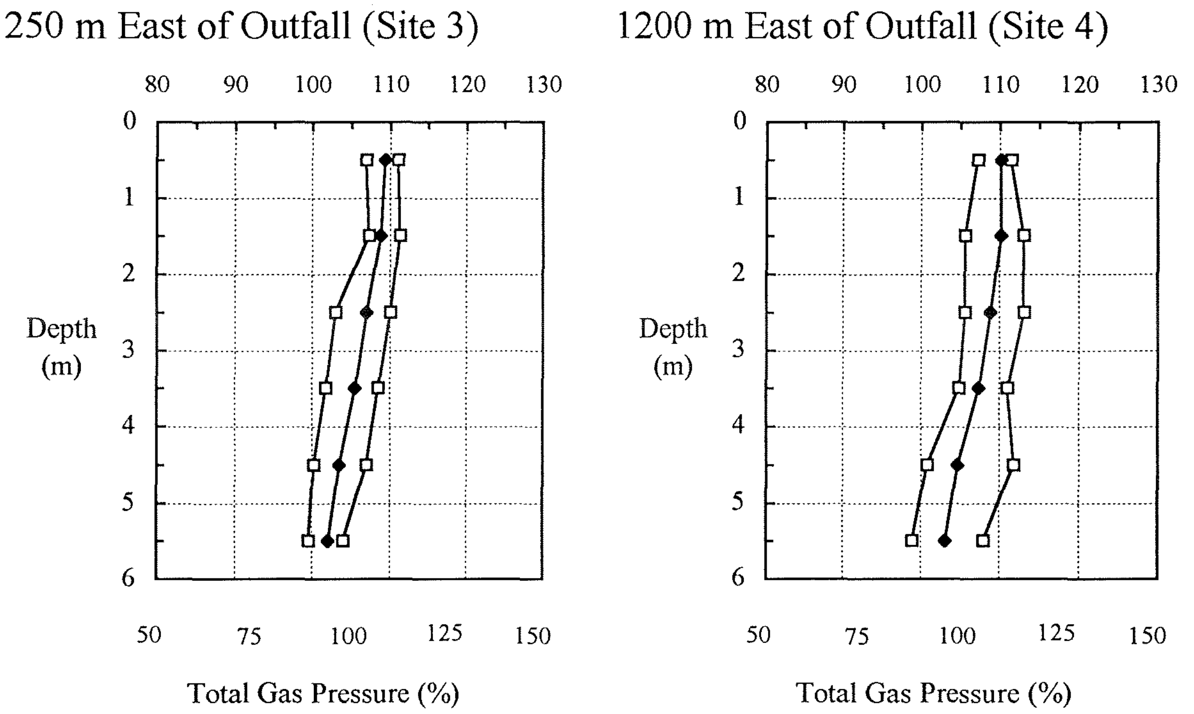


Figure 19. Maximum, mean, and minimum TGP (% Sat.) - August 18-22.

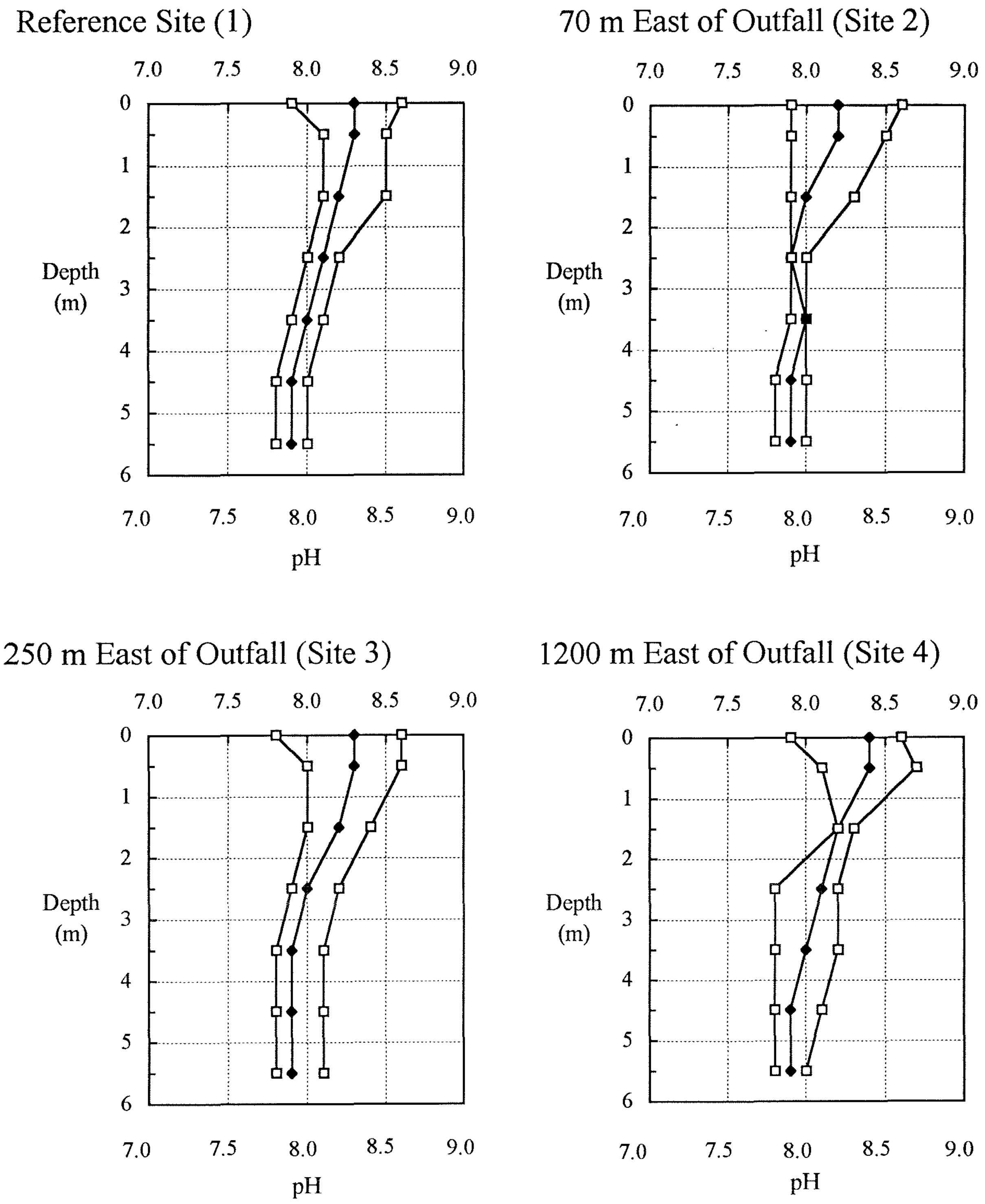

Reference Site (1)

70 m East of Outfall (Site 2)


250 m East of Outfall (Site 3)

1200 m East of Outfall (Site 4)

Figure 20. Maximum, mean, and minimum pH - July 07-11.



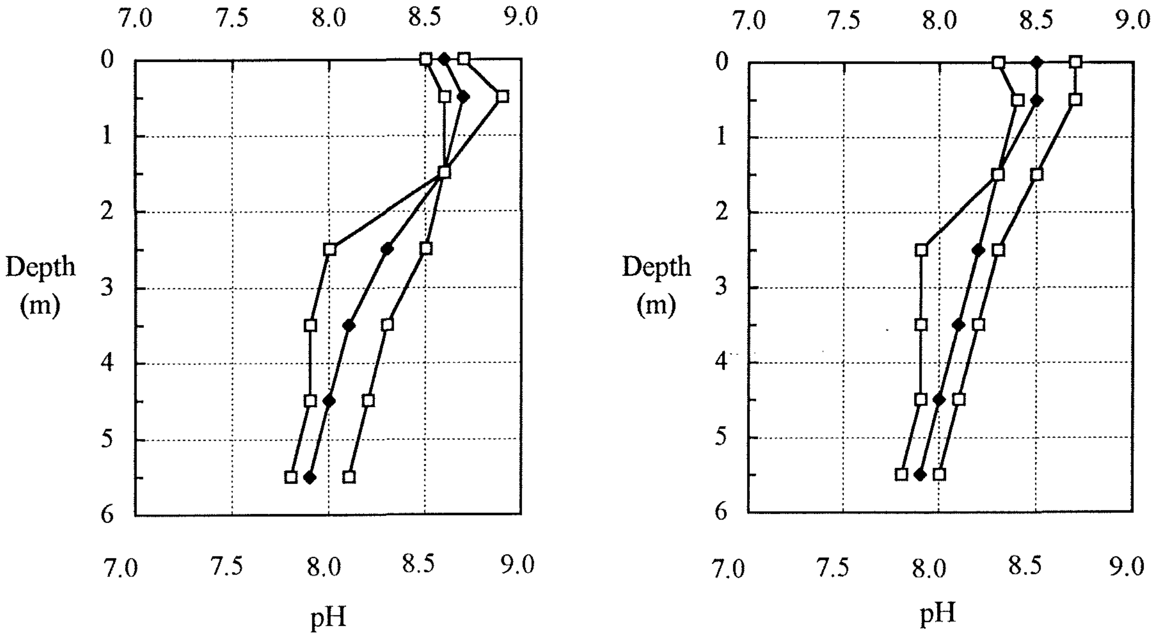
Reference Site (1)

70 m East of Outfall (Site 2)

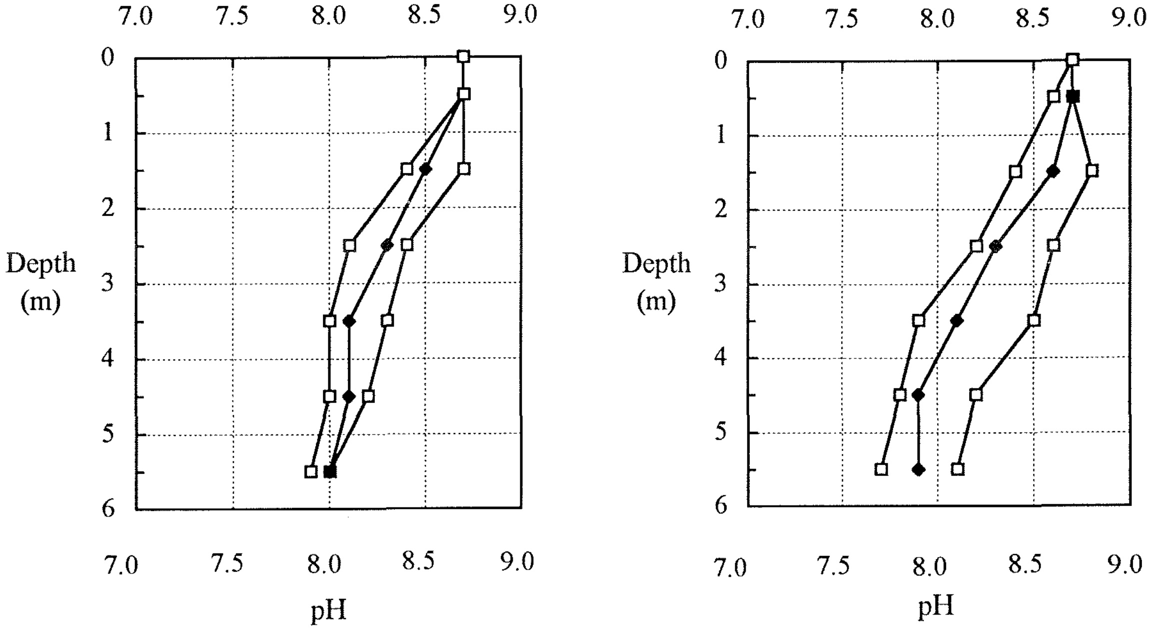
250 m East of Outfall (Site 3)

1200 m East of Outfall (Site 4)

Figure 21. Maximum, mean, and minimum pH - July 14-18.


Reference (1)

70 m East of Outfall (Site 2)


250 m East of Outfall (Site 3)

1200 m East of Outfall (Site 4)

Figure 22. Maximum, mean, and minimum pH - August 18-22.

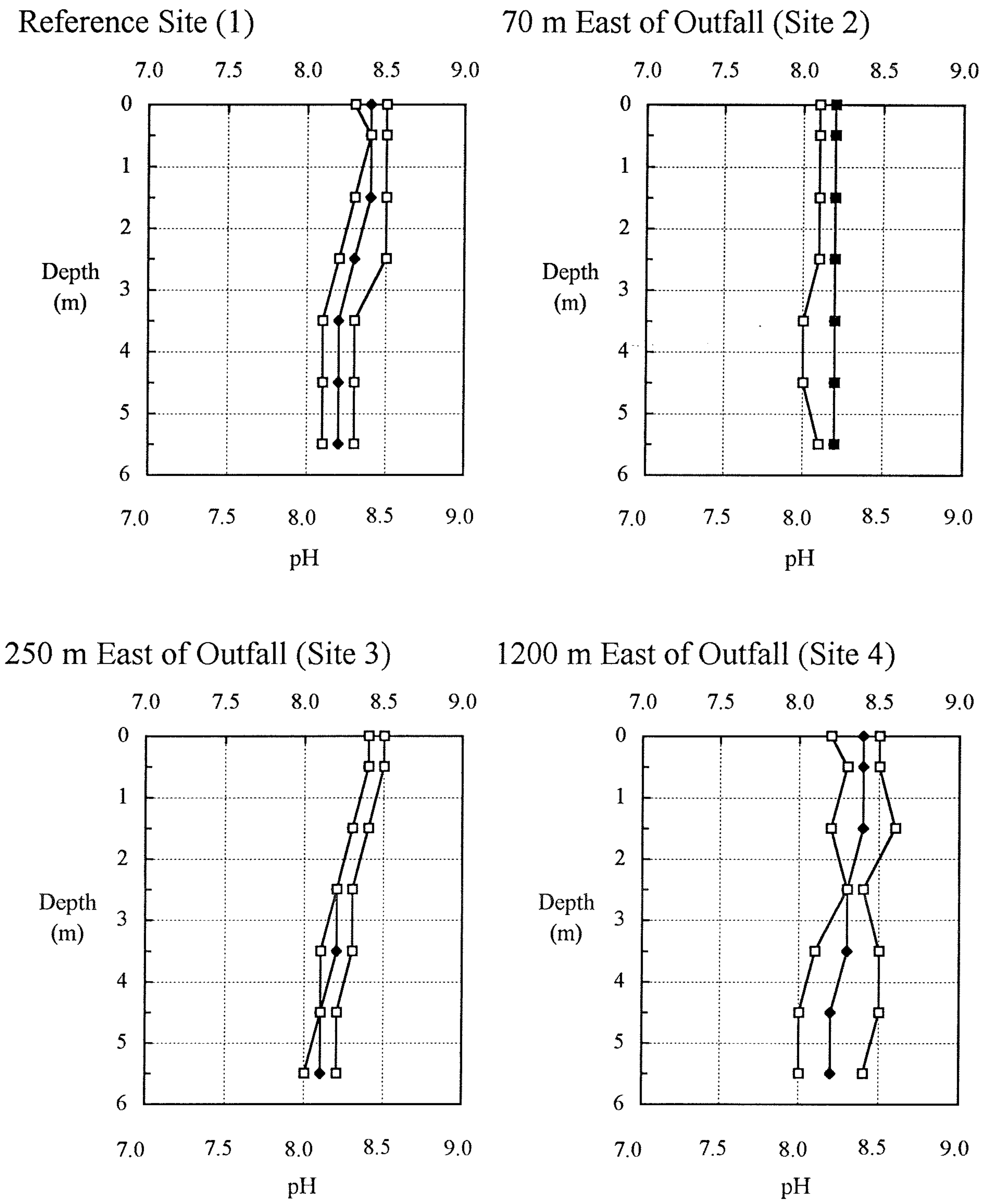
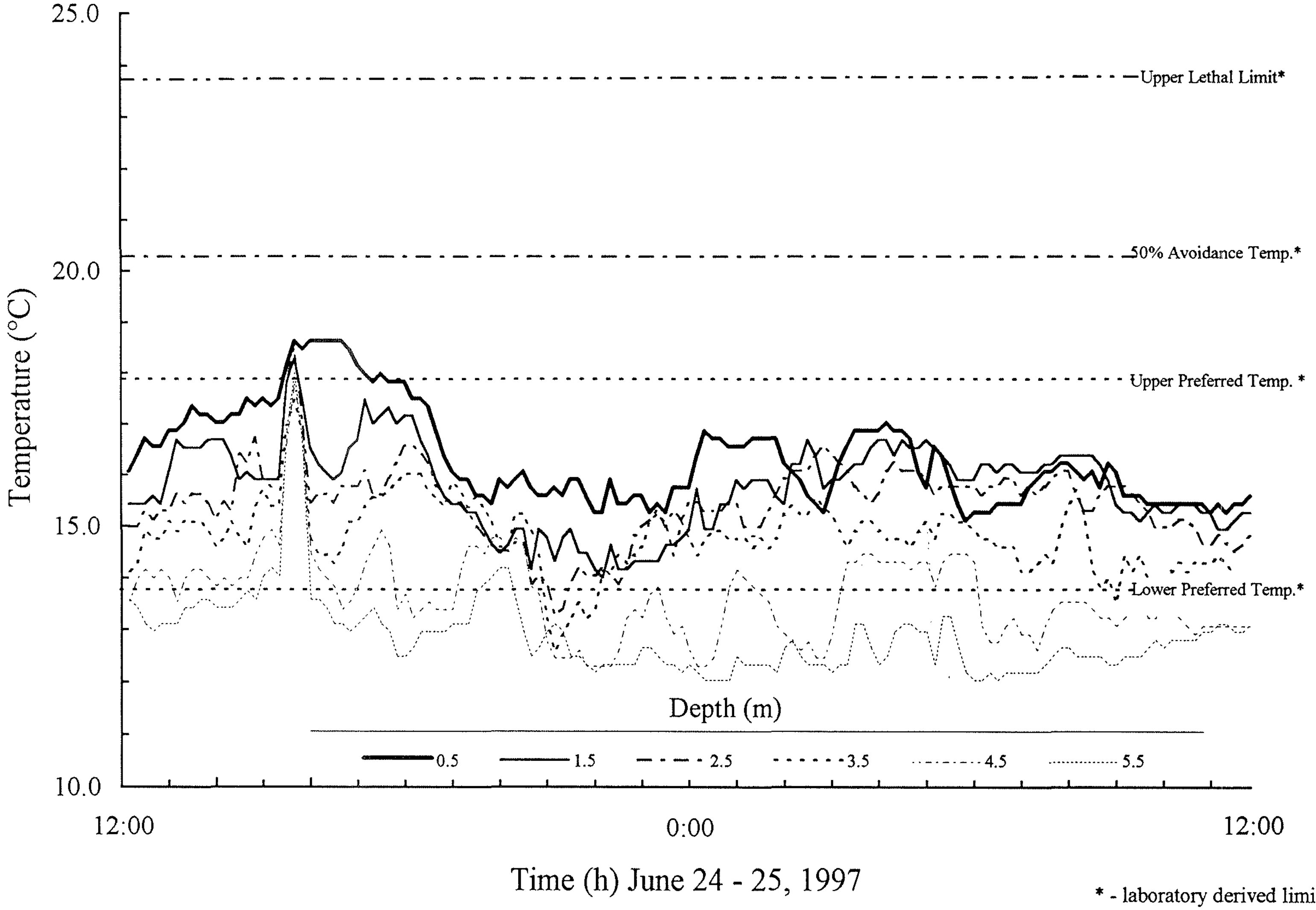


Figure 23. Water temperature:
Reference Site (1) - June 24-25



* - laboratory derived limit

Figure 24. Water temperature:
100, 200 and 1200 meters east of Outfall - June 24-26

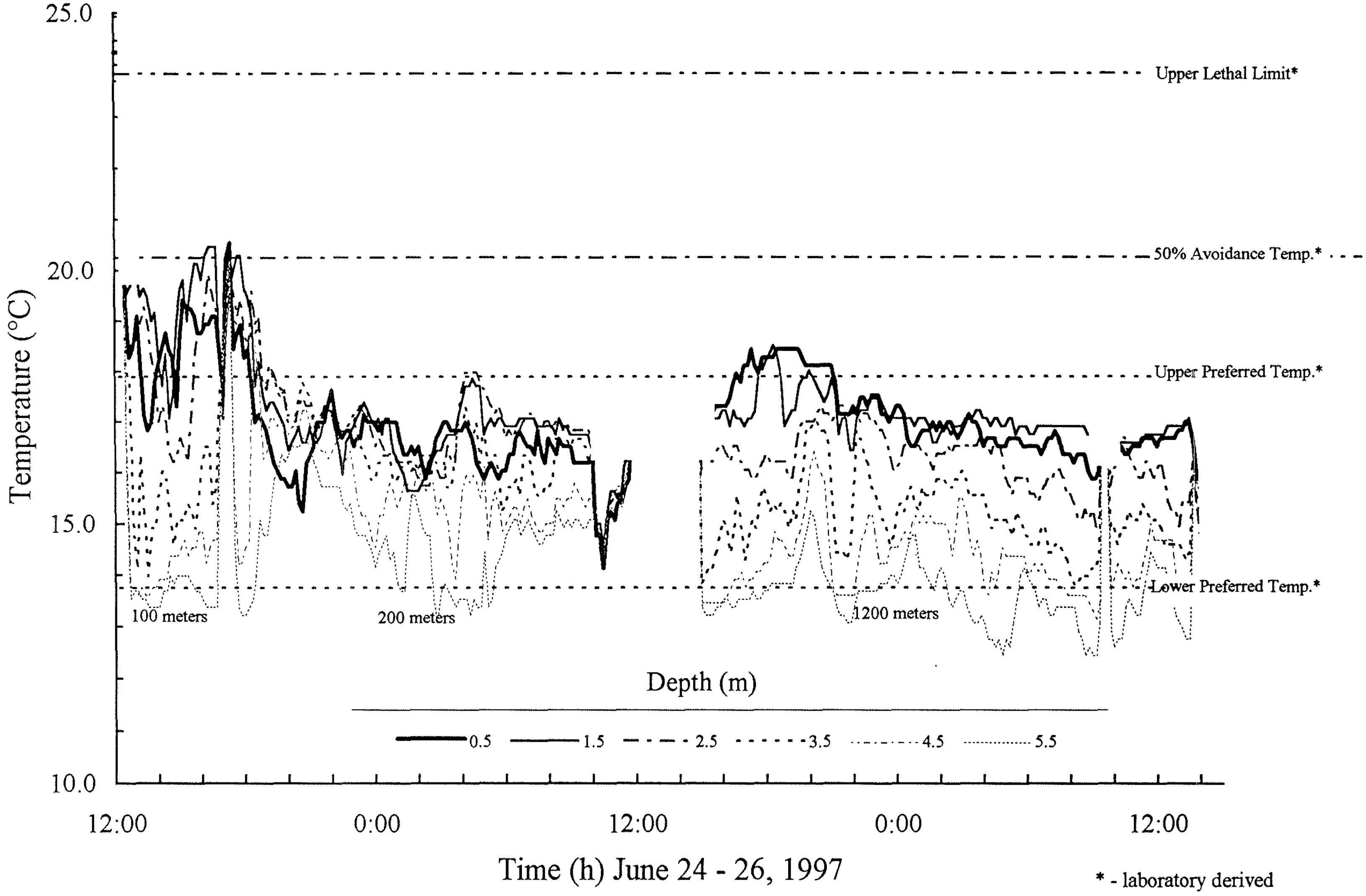
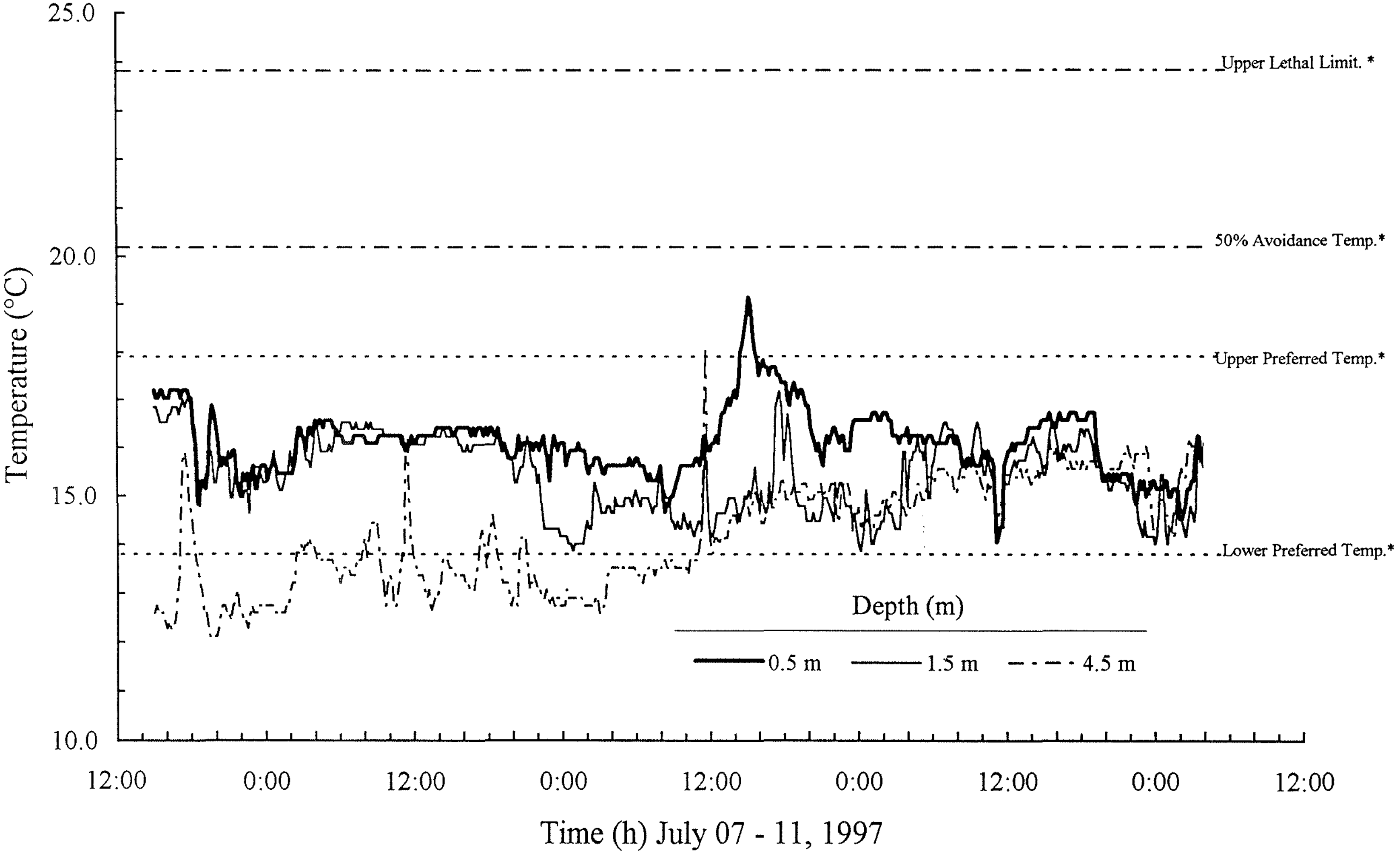
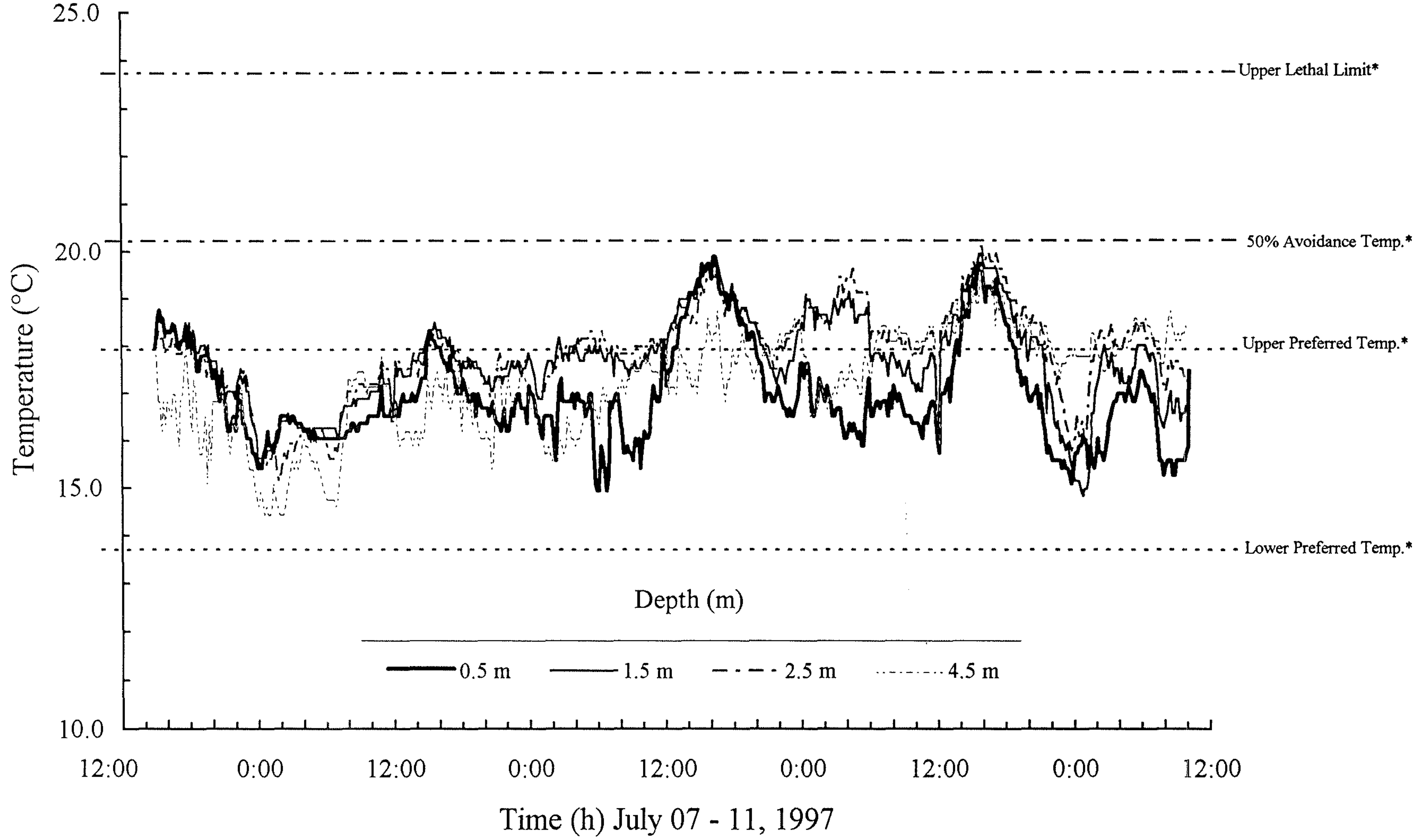


Figure 25. Water temperature:
Reference Site (1) - July 07-11.



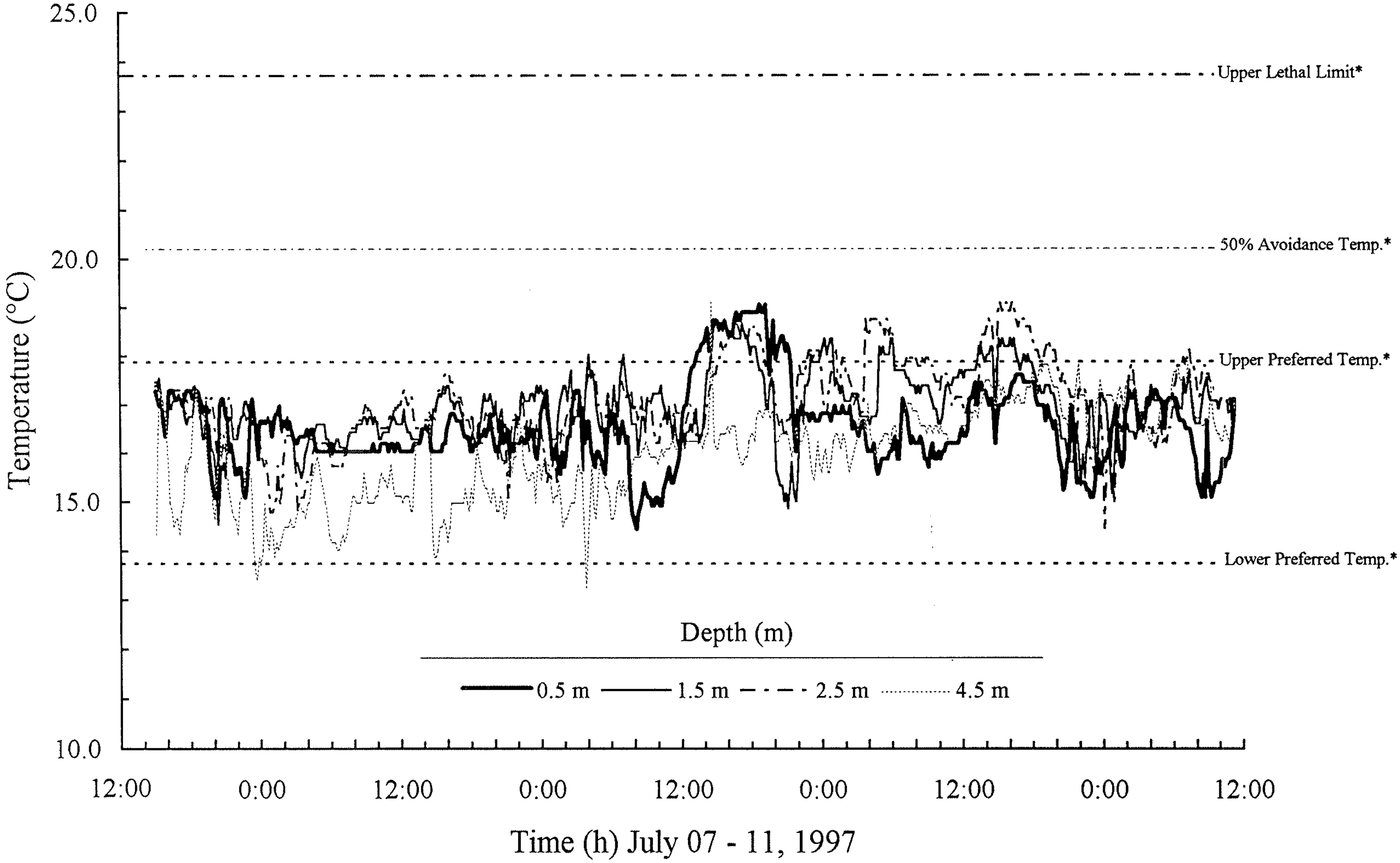
* - laboratory derived

Figure 26. Water temperature:
Site 2 (70 m east of outfall) - July 07-11.



* - laboratory derived

Figure 27. Water temperature:
Site 3 (250 m east of outfall) - July 07-11.



* - laboratory derived

Figure 28. Water temperature:
Site 4 (1200 m east of outfall) - July 07-11.

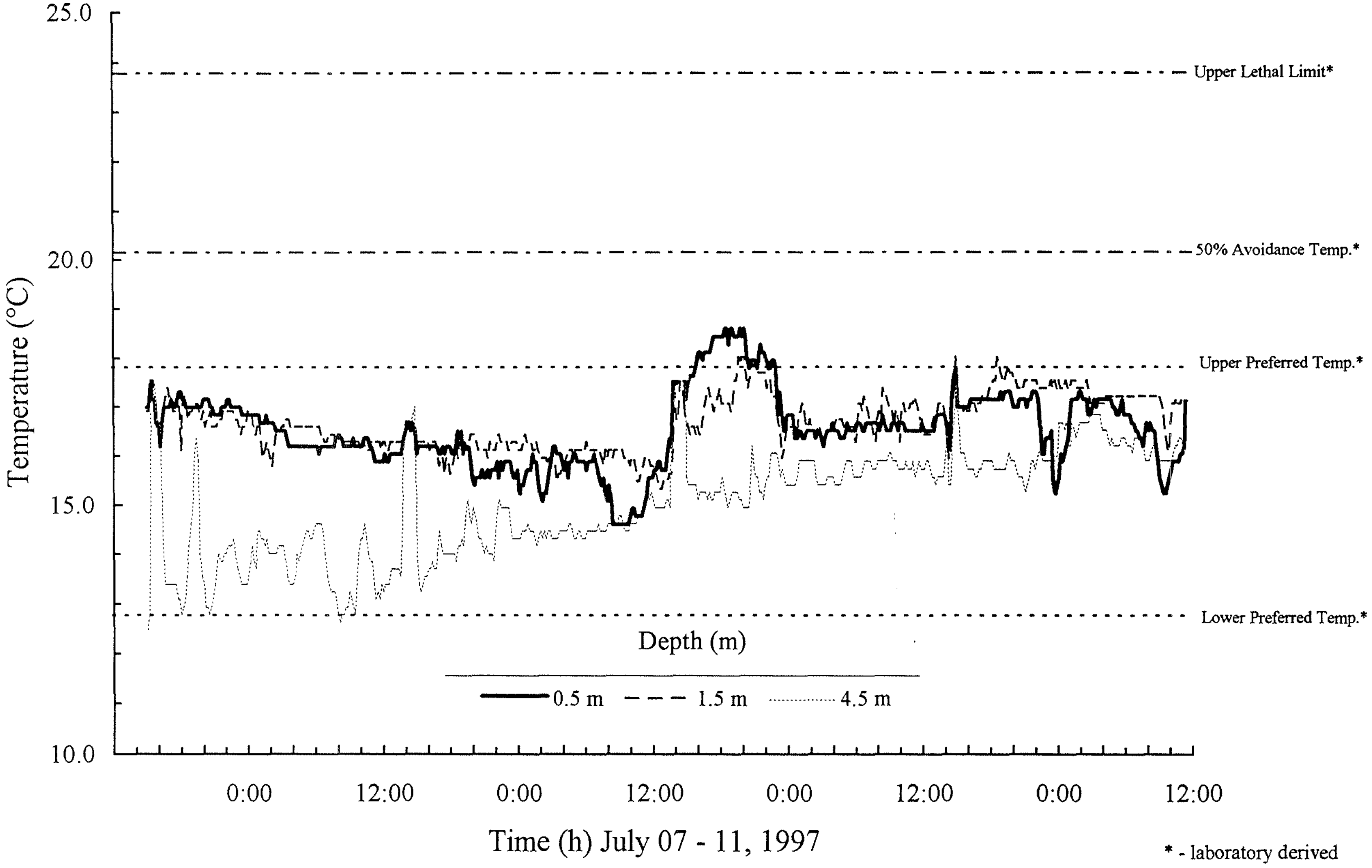
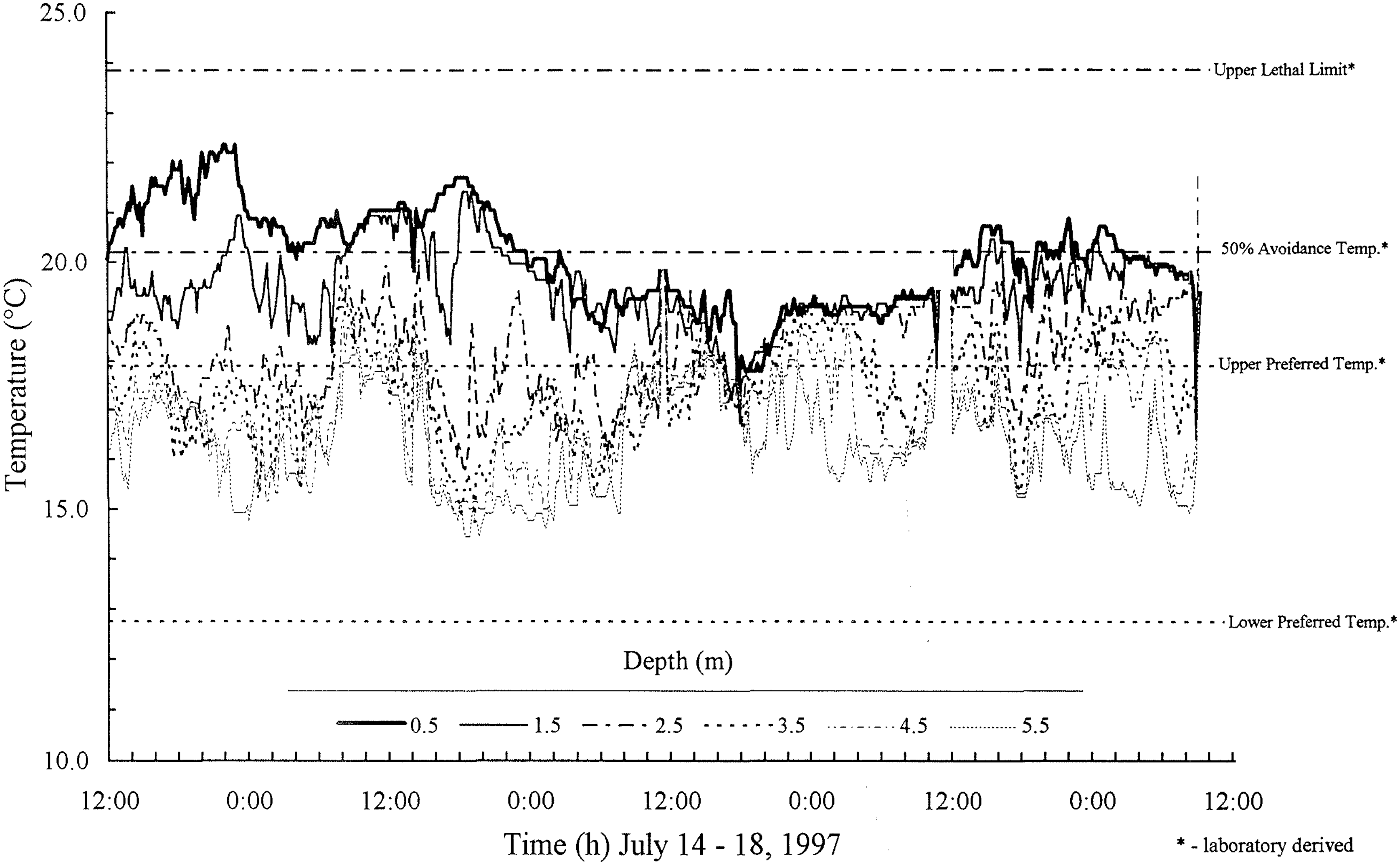
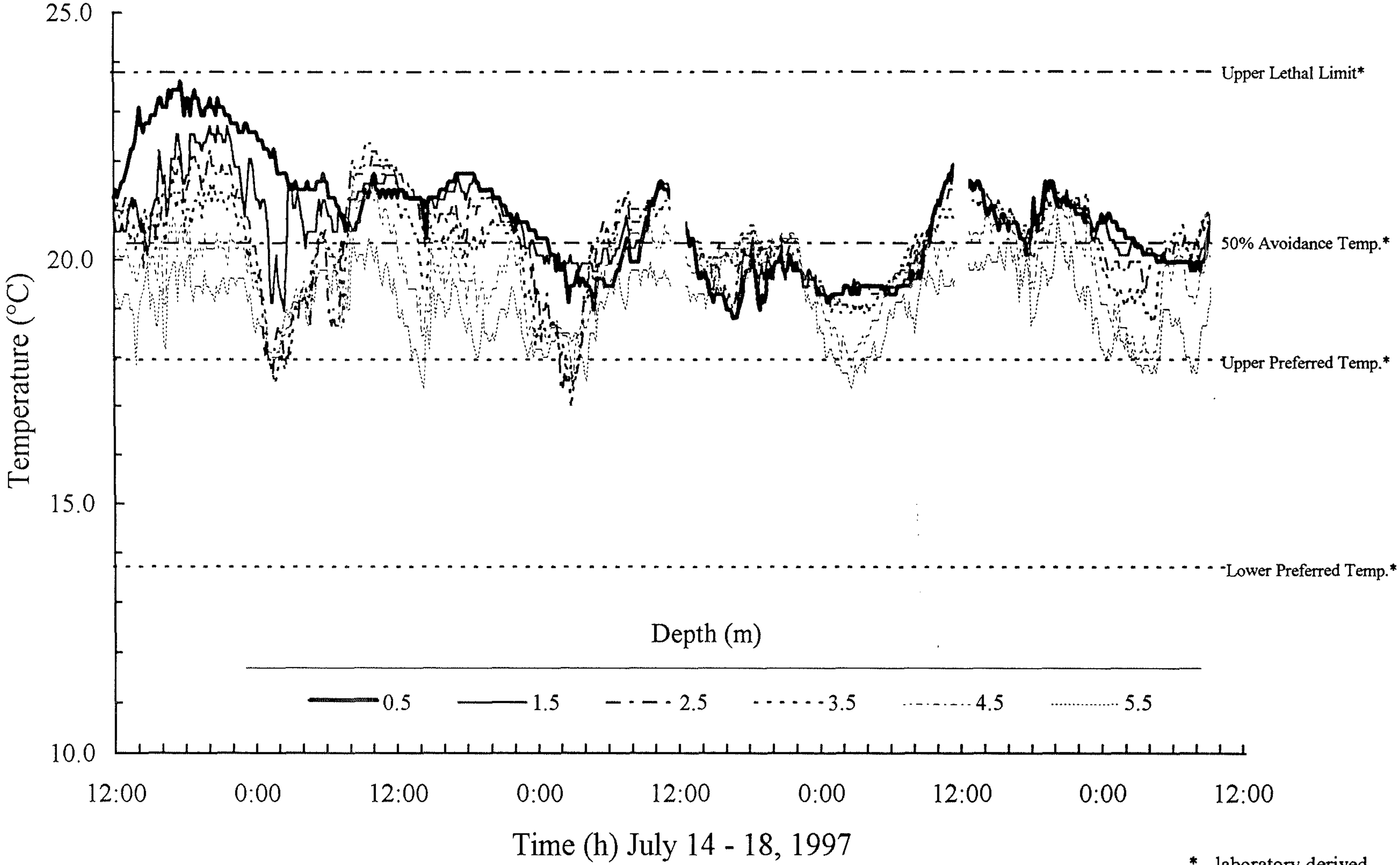


Figure 29. Water temperature:
Reference Site (1) - July14-18.



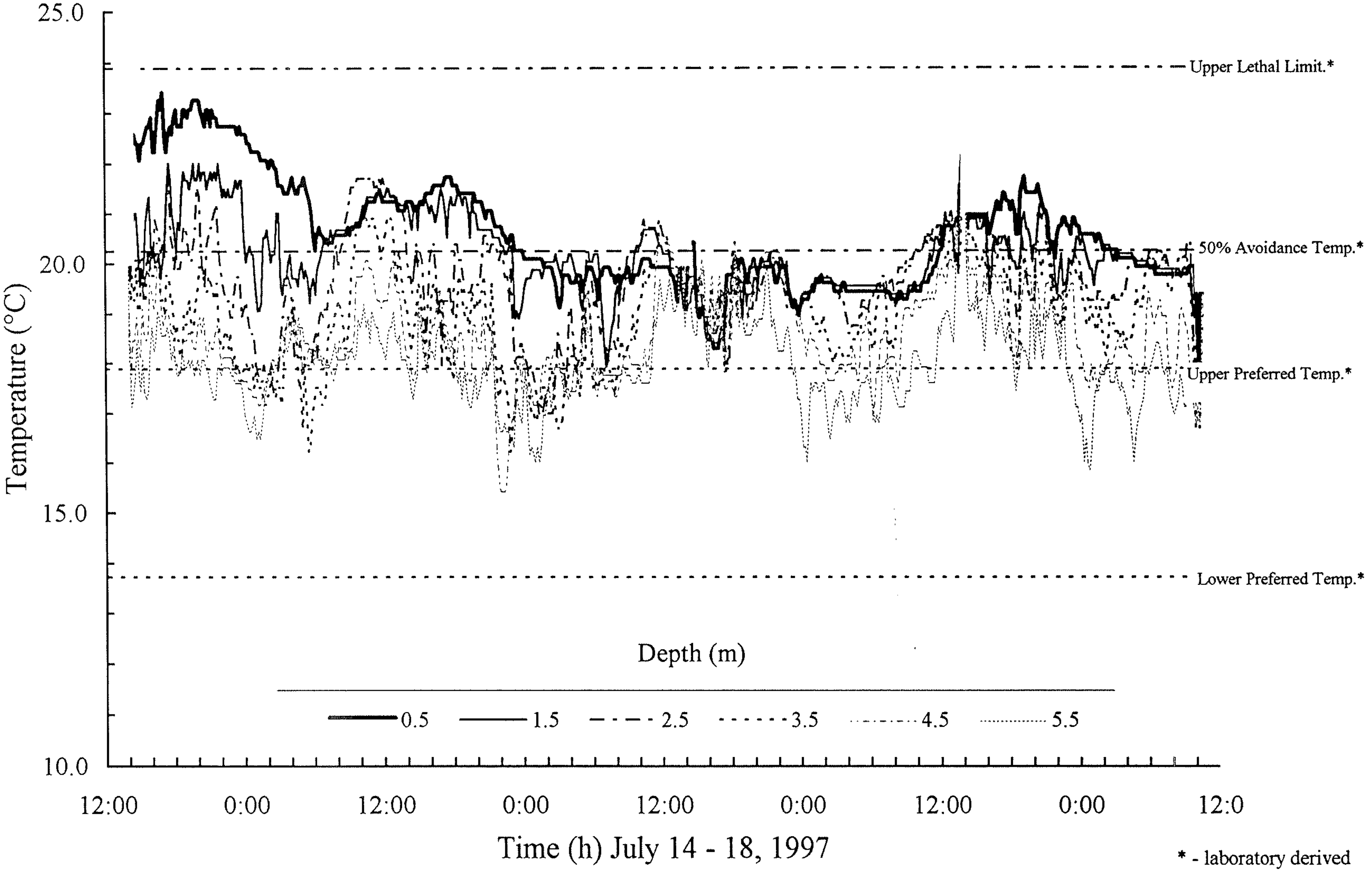
* - laboratory derived

Figure 30. Water temperature:
Site 2 (70 m east of outfall) - July14-18.



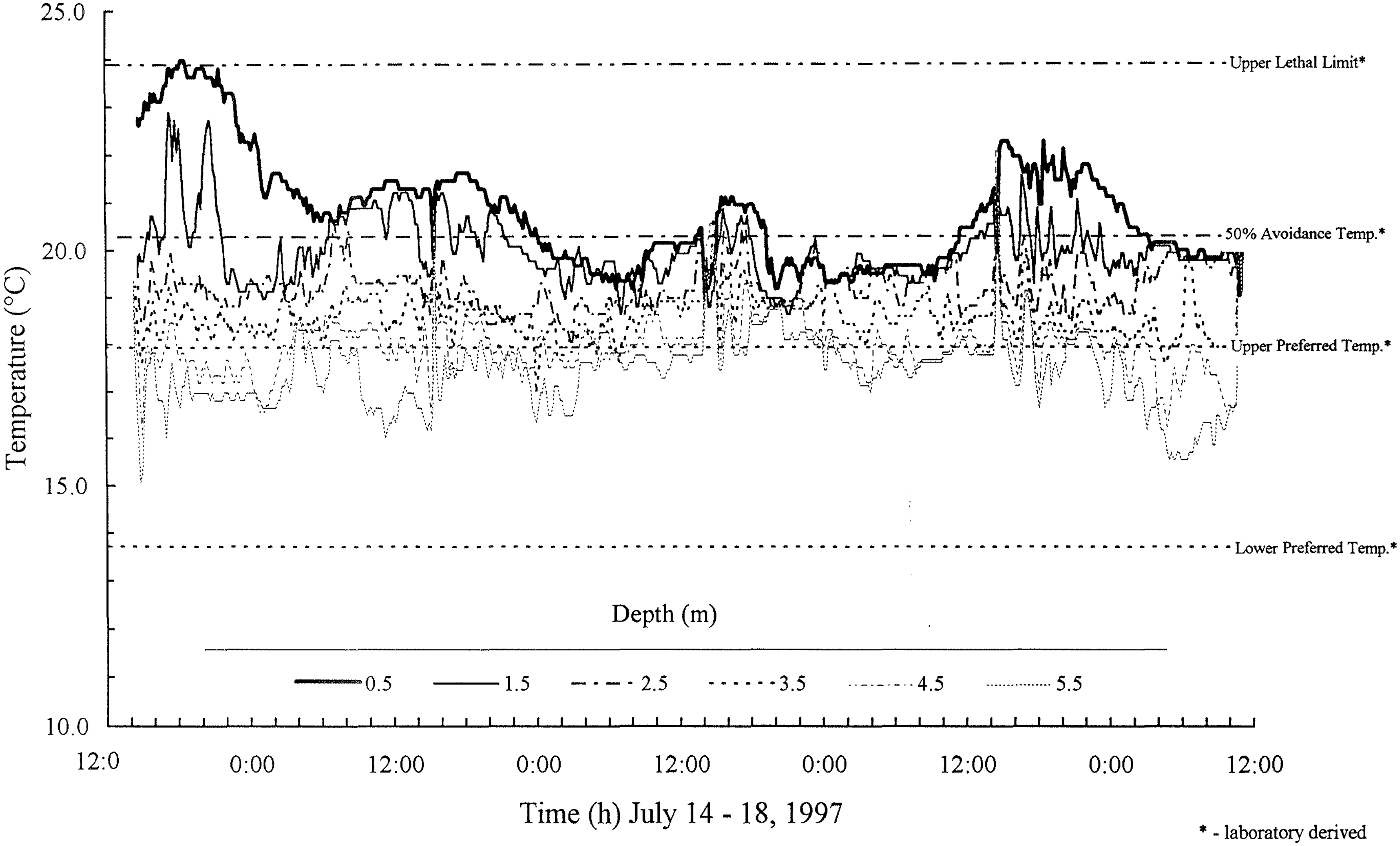
* - laboratory derived

Figure 31. Water temperature:
Site 3 (250 m east of outfall) - July 14-18.



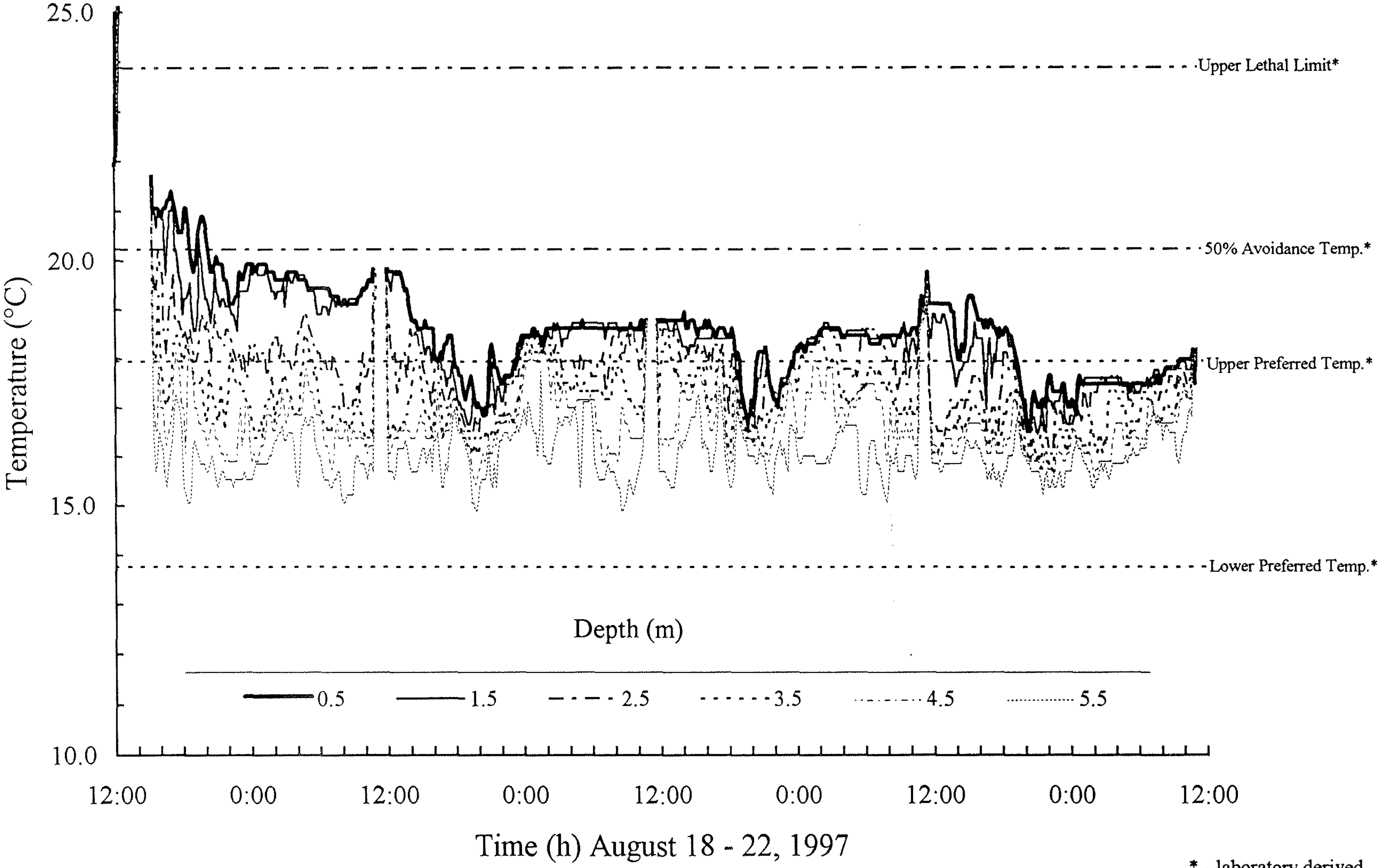
* - laboratory derived

Figure 32. Water temperature:
Site 4 (1200 m east of outfall) - July 14-18.



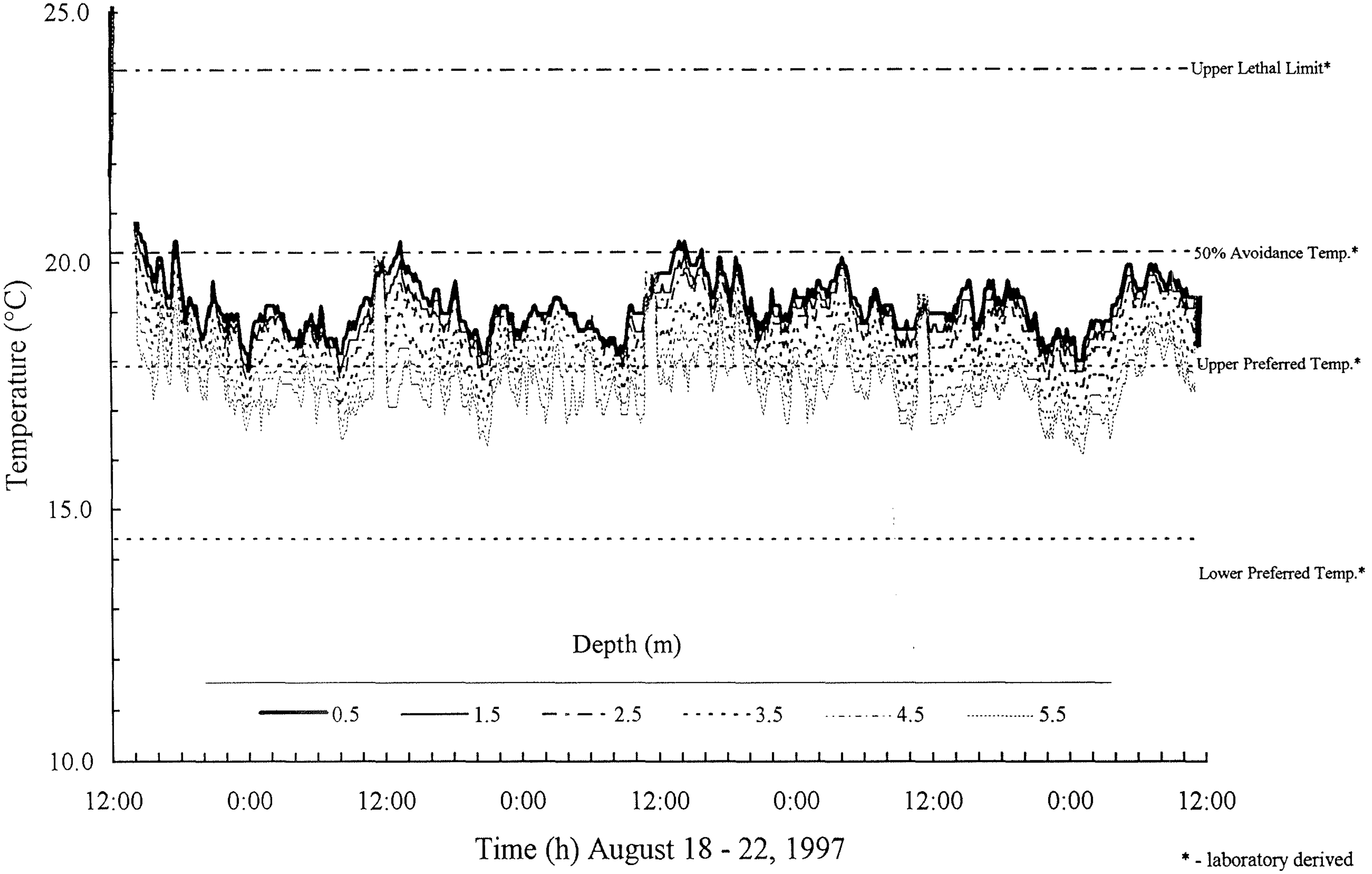
* - laboratory derived

# Figure 33. Water temperature: Reference Site (1) - August 18-22.



* - laboratory derived

Figure 34. Water temperature:
Site 2 (70 m east of outfall) - August 18-22.



* - laboratory derived

# Figure 35. Water temperature:
# Site 3 (250 m east of outfall) - August 18-22.

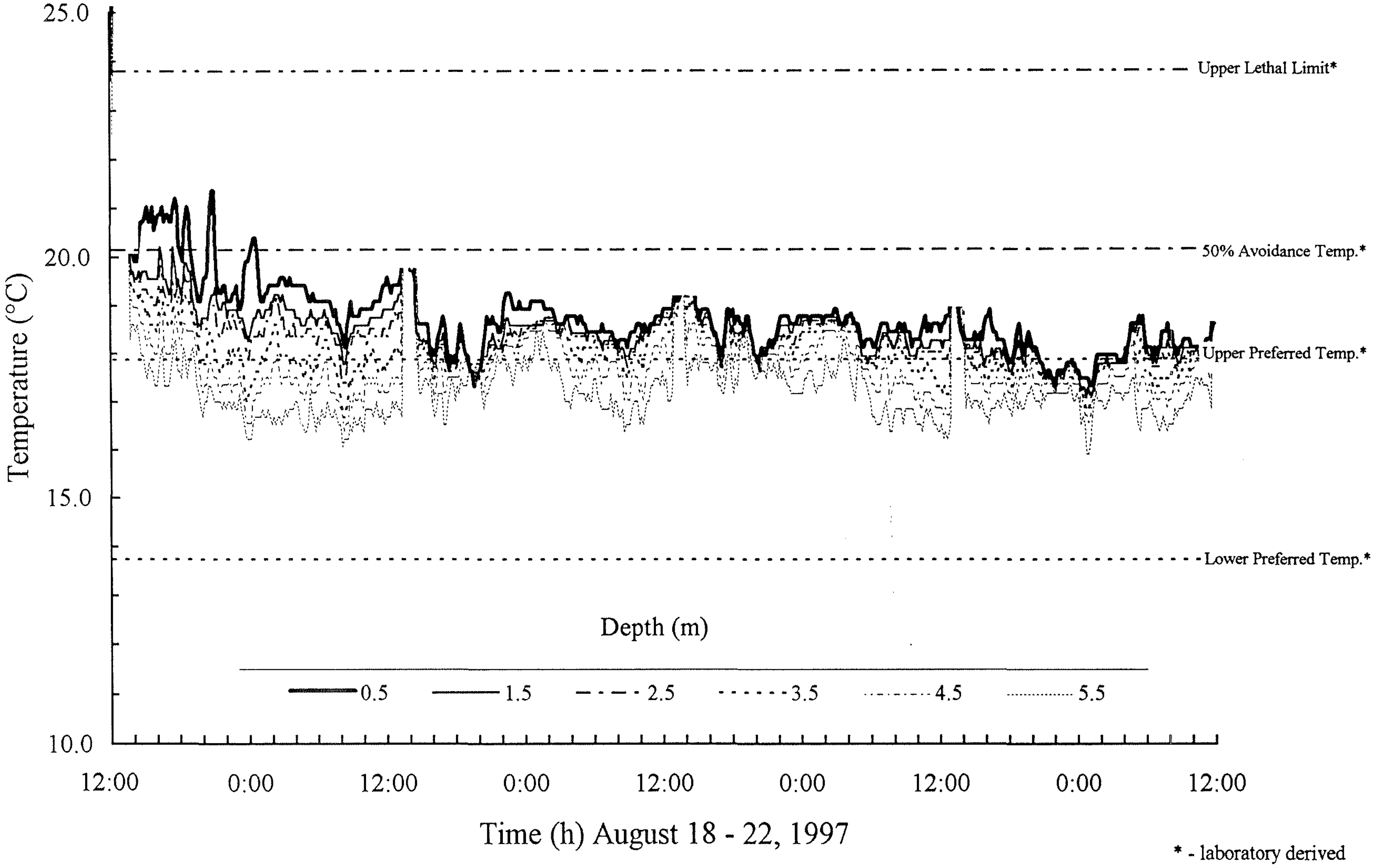


Figure 36. Water temperature:
Site 4 (1200 m east of outfall) - August 18-22.