Effect of Thermal Effluent on the Survival, Growth, and Condition of Juvenile Chum Salmon (*Oncorhynchus keta*)

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EFFECT OF THERMAL EFFLUENT ON THE SURVIVAL, GROWTH AND CONDITION OF JUVENILE CHUM SALMON (*ONCORHYNCHUS KETA*)

by

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PREFACE

This report summarizes the results of studies on the effect of thermal effluent on the survival, growth, and condition of juvenile chum salmon (*Oncorhynchus keta).*

This study complements others that were also were initiated in response to potential increases in the thermal discharge from British Columbia Hydro and Power Authority's (BC Hydro) Burrard Generating Station, into the marine waters of Port Moody Arm. This gas-fired steam electric generating station operates under a permit from the provincial government, and utilizes a once-through seawater cooling system. The permit allows for the discharge of up to 1.7 million m^3 daily of 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. A study plan was submitted by BC Hydro to federal and provincial regulatory authorities in 1996, and it was approved in 1997. Studies were undertaken over the following 3 years and they included surveys of migrating adult and juvenile salmonids in the main tributaries to Port Moody Arm, an examination of the potential effects of the thermal effluent on salmon behavior and survival and on planktonic organisms, and the heat budget of the arm. Other reports document the results of these investigations.

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ABSTRACT

Greenbank, J.D., R.P. Fink, M.Z. Lu, S.L. Rendek, and I.K. Birtwell. 2001. Effect of thermal effluent on the survival, growth, and condition of juvenile chum salmon, (*Oncorhynchus keta*). Can. Tech. Rep. Fish. Aquat. Sci. 2341: 90 p.

The effects of BC Hydro's Burrard Generating Station's (BGS's) (≤ 27 °C) cooling water effluent on the survival, growth, and condition of juvenile chum salmon (*Oncorhynchus keta*) was examined in four experiments (16 to 20 days in duration) in the spring and summer of 1998. The duration of exposure approached maximum residence times for these fish in near shore coastal waters. In each experiment, fish were exposed to cooling water (CW) in an indoor test facility located at the BGS. Groups of 30-50 fish in the first three studies were exposed to 0% (control), 6%, 12%, 25%, 35%, and 50% CW mixed with seawater pumped continuously from 5-m depth at a site removed from the influence of the BGS CW discharge. In the fourth experiment in August, the 6% and 12% CW treatments were replaced with 65% and 75% CW treatments to examine fish survival and growth at temperatures proximal to the upper lethal limit for juvenile chum salmon in fresh water (23.8 °C). In addition, fish were also studied in 50% cooling water at low total gas pressure (TGP) and in shallow water pumped continuously from 1-m depth within Port Moody Arm (outside the influence of the CW discharge). The latter two treatments enabled a separation of the effects of dissolved gas supersaturation within the BGS effluent from those of elevated temperature, and an assessment of seasonal changes in the shallow surface water on juvenile chum salmon during the late spring and summer, when water temperatures within Port Moody Arm peak naturally.

The first three experiments conducted in May through July (at the time of year when juvenile salmon are expected to reside in Port Moody Arm), identified a positive relationship between fish growth rates and their exposure to BGS cooling water at concentrations as high as 50%. The fourth experiment, conducted in August, demonstrated that exposure to ≤35% CW concentrations did not affect fish growth significantly, but in higher concentrations (50% and 65%) growth rates tended to be reduced. In the fourth experiment, reducing the TGP in the 50% CW treatment, to eliminate dissolved gas supersaturation, did not prevent the reduction of growth rate. In general the growth of chum salmon decreased above 20 °C; a temperature that approximated the laboratory-derived 50% avoidance level for these fish in response to rising temperature.

Overall mortality of juvenile chum salmon among the 0% - 50% CW treatments was less than 1%. However, mortality was 9.1% in the shallow water that was pumped from Port Moody Arm, and it was 2.9% in the 50% CW treatment. High fish mortality (28% and 30%) occurred in the two shallow-water treatments during one of the four experiments which coincided with turbid waters of high TGP (up to 119%), high dissolved oxygen levels, and elevated pH; conditions indicative of seasonal algal blooms. Mortality in the 65% CW (22.6 °C) was 13.3% over 16 days while that in the 75% CW (23.4 °C) was100% in 5 days.

The condition of fish deteriorated during the course of the first three experiments, as evidenced by increasing incidences and severities of external signs of ill health in almost all fish including

controls. No health assessment was conducted during the fourth study. The signs of ill health included cataracts, split corneas, scale loss, petechial hemorrhages in the lateral line, and torn fins, as well as characteristic signs of Gas Bubble Trauma (GBT) such as exopthalmia, bubbles in the eyes, lateral lines and unpaired fins. There was a significant increase in external signs of ill health that correlated positively with increasing cooling water concentrations in the second study. In the third study the 6% - 35% CW treatment groups showed approximately half the signs of ill health as the other treatment groups including the controls, conditions indicative of disease. However, the only experimental treatment in which a statistically significant increase in the signs of GBT occurred, relative to control fish, was for two groups of fish in shallow water from Port Moody Arm during the first experiment.

During late spring and early summer, it is expected that the growth rate of juvenile chum salmon residing within the warmer waters of the cooling water discharge plume from the BGS would be enhanced (provided food was not limiting), relative to individuals in adjacent waters at lower ambient temperatures. However, in summer, the growth of any juvenile chum salmon remaining within the plume could be retarded relative to fish residing outside the plume. But, it is probable that most juvenile chum salmon would have entered the oceanic phase of their life cycle before the time when adverse effects on growth might occur in the near-shore habitat of Port Moody Arm due to the presence of BGS's CW and/or other (natural) variables.

It is concluded that the effects of the BGS discharge of CW will not have a significant negative impact on the growth of juvenile chum salmon populations that utilize Port Moody Arm.

RÉSUMÉ

Greenbank, J.D., R.P. Fink, M.Z. Lu, S.L. Rendek, and I.K. Birtwell. 2001. Effect of thermal effluent on the survival, growth, and condition of juvenile chum salmon, (*Oncorhynchus keta*). Can. Tech. Rep. Fish. Aquat. Sci. 2341: 90 p.

Les effets des déversements d'eaux de refroidissement réchauffées (≤ 27 °C) par la centrale thermique Burrard de BC sur la survie, la croissance et la condition de jeunes saumons kétas (*Oncorhynchus keta*) ont été examinés lors de quatre expériences qui ont duré entre 16 et 20 jours au cours du printemps et de l'été 1998. La durée d'exposition des saumons approchait le temps de résidence maximum de ces poissons dans les eaux du littoral situées proches de la côte. Dans chaque expérience, les poissons étaient exposés à des eaux de refroidissement réchauffées dans un bassin situé dans des installations couvertes, à l'intérieur de la centrale. Des groupes de 30 à 50 poissons ont été exposés à des mélanges contenant 0% (témoin), 6%, 12%, 25%, 35% et 50% d'eaux de refroidissement diluées dans de l'eau de mer pompée en continue à 5 m de profondeur, loin du déversoir des eaux de refroidissement de la centrale. En août, on a exposé les saumons à des mélanges de 65% et de 75% en eaux de refroidissement pour examiner la survie et la croissance des poissons à des températures proches du seuil létal connu pour les jeunes saumons kétas en eau douce (23.8 °C). Les poissons ont également été étudiés alors qu'ils évoluaient dans un mélange à 50% d'eaux de refroidissement avec une faible PGT et en eau peu profonde pompée en continue à 1 m de fond dans le bras Port Moody (loin de l'influence du déversoir de la centrale). Ces deux dernières expériences ont permis d'une part de séparer les effets de la sursaturation en gaz (PGT élevée) de ceux de la température et d'autre part d'évaluer l'effet des changements saisonniers dans les eaux de surface sur les jeunes saumons kétas entre la fin du printemps et la fin de l'été, période au cours de laquelle la température des eaux du bras Port Moody atteint son maximum annuel.

Les trois expériences réalisées entre mai et juillet (période de l'année où les jeunes saumoneaux résident dans le bras Port Moody) ont permis de mettre en évidence une corrélation positive entre le taux de croissance des poissons et la concentration en eaux de refroidissement réchauffées de la centrale Burrard jusqu'à des concentrations de 50%. En août, l'exposition à des concentrations moindres (≤ 35%) n'a eu aucun effet notable sur la croissance des poissons mais la croissance avait tendance à être retardée pour des concentrations de 50% et de 65% (la réduction de la PGT, c'est à dire l'élimination de la sursaturation des gaz dissous, dans les expériences utilisant une concentration en eaux de refroidissement de 50% n'a pas empêché le retard de croissance). En général, la croissance des saumons kétas diminuait lorsque la température dépassait 20 °C, température proche du seuil de répulsion (50%) observé en laboratoire pour ces poissons.

La mortalité des jeunes saumons kétas est restée inférieure à 1% dans les six mélanges, mais a atteint une moyenne de 9.1% pour les saumons évoluant dans l'eau peu profonde pompée dans le bras Port Moody. La mortalité a par contre atteint 28% et 30% pour une des quatre expériences en eau peu profonde alors que la turbidité de l'eau, la PGT (jusqu'à 119%), la concentration en oxygène dissous et le pH étaient élevées, conditions typiques d'un épisode de fleur d'eau. Sur cinq jours, on a observé une mortalité de 13.3% dans le mélange à 65% (22.6 C) et de 100% dans le

jours, on a observé une mortalité de 13.3% dans le mélange à 65% (22.6 C) et de 100% dans le mélange à 75% (23.4 °C).

La détérioration de la condition des poissons s'est accompagné d'une incidence croissante de signes extérieurs de mauvaise santé de plus en plus sévères au cours des expériences, habituellement en réponse à l'augmentation de la concentration en eaux de refroidissement. Ces signes (cataractes, fissures de la cornée, perte d'écailles, hémorragies ponctuelles sur la ligne latérale et nageoires abîmées, ainsi que des symptômes typiques d'une embolie gazeuse tels que l'exophtalmie, des bulles dans les yeux et sur la ligne latérale ainsi que des nageoires abîmées) ont augmenté entre la première et la troisième étude au cours de laquelle la santé de presque tous les poissons s'est détériorée de façon évidente. On a observé une corrélation positive entre l'incidence des symptômes et la concentration en eaux de refroidissement dans la seconde étude. Lors de la troisième étude, tous les groupes présentaient cependant des symptômes similaires. De plus, seules les conditions expérimentales appliquées à deux groupes de poissons évoluant dans de l'eau peu profonde du bras Port Moody au cours de la première expérience se sont accompagnées d'une augmentation statistiquement significative de l'incidence des symptômes typique de l'embolie gazeuse par rapport aux témoins.

Entre la fin du printemps et le début de l'été, on peut donc prévoir que le taux de croissance des jeunes saumons kétas qui fréquentent le panache formé par les eaux réchauffées par les déversements de la centrale thermique Burrard sera plus élevé que celui des saumons qui fréquentent des eaux voisines où la température est moindre. L'été, la croissance des jeunes saumons kétas qui restent dans le panache pourrait cependant être plus lente que celle des poissons restant à l'extérieur du panache. Il est néanmoins probable que la plupart des jeunes saumons kétas ont depuis longtemps migré vers l'océan lorsque les conditions néfastes pouvant nuire à leur croissance apparaissent dans les habitats proche des berges du bras Port Moody, conditions dues aux déversements de la centrale Burrard ou à des processus naturels.

Nous en concluons que les effets des déversements d'eaux de refroidissement réchauffées par la centrale thermique Burrard ont un impact insignifiant sur la croissance des jeunes saumons kétas qui fréquentent le bras Port Moody.

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INTRODUCTION

British Columbia Hydro and Power Authority (BC Hydro) operates the natural gas-fired Burrard Generating Station (BGS) at Port Moody, BC. The station, located at the eastern end of Burrard Inlet (Figure 1), draws from Port Moody Arm up to 1.7 million cubic meters of seawater daily to cool its steam condensers, and subsequently discharges it back to the arm at a temperature $\leq 27\ ^{o}C$. The station currently operates under a Permit (No. PE-07178) issued by the BC Ministry of Environment, Lands and Parks (BCMELP 1995). In December 1995, and as part of an amendment to that Permit, BCMELP required BC Hydro to submit an environmental study plan designed to assess the potential effects of the operation of BGS on the water quality and biological communities of Port Moody Arm. BCMELP and the Burrard Inlet Environmental Review Committee (BERC) accepted the study plan (BC Hydro 1996). The plan, which encompassed at least two years of research, comprised several components that were designed to further an understanding of the effects of the BGS cooling water (CW) discharge on the aquatic communities in Port Moody Arm. A critical component was an examination of the influence of CW on the survival, growth, and condition of juvenile chum salmon (*Oncorhynchus keta*), a fish species having both local and regional importance. With the cooperation of BC Hydro, an existing experimental facility at the BGS was employed to examine several aspects of the interaction between chum salmon and BGS CW during a two-year investigation. These included the influence of CW on the survival, growth, and condition of juvenile chum salmon; the relationship between excess total gas pressure (TGP) and fish growth, survival and condition; the influence of the surface waters (i.e., that drawn from 1-m depth) of Port Moody Arm on the survival, growth, and condition of juvenile chum salmon, irrespective of BGS operation; and the spatial and temporal effects of the BGS effluent on juvenile chum salmon and other fish species.

Results of the first year of this experimental program have been discussed previously (Greenbank et al. 1998), and are briefly summarized below.

PRINCIPAL FINDINGS OF THE 1997 STUDY

During 1997, three consecutive experiments of 20 - 28 days in duration, performed between June and September, examined the survival and growth of juvenile chum salmon exposed to concentrations (0%, 6%, 12%, 25% and 50%) of BGS CW mixed with seawater drawn from 3 m in depth from PMA. Problems associated with stress and subsequent fish mortality limited interpretation of results from the first experiment and no significant relationships between CW concentration and growth rate were identified. In the two subsequent experiments, however, daily mean growth rates in the CW treatment regimes ranged from 2.38% to 6.38% wet weight. Significant decreases in growth rate, relative to the controls (0%), were evident in the 25% and 50% CW treatments but not in the 6% and 12% CW treatments. During the latter two experiments in 1997, survival of fish in BGS CW was greater than 95% in all treatments, even at temperatures approaching lethal thresholds for this species. Overall growth rates of fish in treatments and controls in the third experiment were substantially lower than those in the first two studies.

For the CW regimes we examined in 1997, the decrease in growth of chum salmon was linear with respect to the number of degree·hours of exposure, a mathematical construct relating exposure temperature, total hours of exposure, and an experimentally derived thermal avoidance threshold temperature of 18.7 °C. This linear relationship was found to be valid for studies 2 and 3 ($R^2 = 0.90$), but not for study 1.

The decrease in growth of fish in response to increases in total gas pressure (TGP) above the level of 100% saturation was also a linear relationship. However, multiple regression with both variables (TGP and degree·hours) determined that all of the differences in growth could be explained in terms of the number of degree·hours of exposure. Further, it was found that TGP and the number of degree·hours of exposure were linearly related ($R^2 = 0.9$) and these two variables were not independent of each other.

Based on a relatively inconsistent examination of experimental fish in 1997, a relationship between the incidence of signs of Gas Bubble Trauma (GBT), and exposure of fish to BGS CW, could not be made. This situation could be explained in part by the etiology of GBT in that its expression in fish following their exposure to dissolved gas supersaturated (>100% TGP) water is not necessarily uniform (Fidler and Miller 1997), and the manner in which GBT signs were assessed in the laboratory.

In summary, we found that fish survived and grew well in all CW treatments. A decrease in growth occurred at CW concentrations ≥ 25%, and although we measured pH, dissolved oxygen, TGP, salinity, and temperature, we determined that the differences in fish growth between treatments could be explained by the temperature variable. TGP and temperature were both highly correlated with fish growth in our experiments, however, TGP and temperature were also highly correlated with each other and, therefore, we were unable to separate any TGP effects from those of temperature.

1998 RESEARCH DESIGN

A joint industry/government workshop to evaluate the 1997 study results was held in January 1998. Representatives from BC Hydro, Fisheries and Oceans Canada, BCMELP, and BERC, as well as senior investigators from the 1997 research programs attended the meeting. From this review, improvements in experimental design were recommended for inclusion in a second year of experiments. These included the separation of TGP effects from temperature effects by incorporating gas equilibration columns on two exposure tanks receiving 50% CW; a more rigorous assessment of GBT in treated and control fish; an assessment of the growth of groups of juvenile chum salmon held in shallow water drawn continuously from Port Moody Arm at a location nearby but considered to be outside the influence of the BGS discharge plume; and determination of any potential benefits to salmonid growth early in the season, when juveniles first enter Port Moody Arm.

During the 1997 studies, the daily operation of the BGS changed in response to varying regional electric power demands, and this produced changes in the volume and temperature of the BGS CW. In addition to elevated temperature, the effluent on occasion probably contained trace amounts of volatile chlorine-produced oxidants (CPOs) and/or dechlorination agents (SO_2), and was also supersaturated with dissolved gases. In combination with changes in plant operation, the naturally occurring changes in ambient seawater conditions at the CW intake and the location where control/dilution water was drawn to the experimental chambers from Port Moody Arm, produced a dynamic range of physical and chemical characteristics within the controlled fish exposure tanks. In addition, periodic failure of the temporary seawater system that was used to bring seawater to the apparatus resulted in variation in conditions within some experiments.

The paramount advantage of conducting environmental research under semi-industrial conditions, is that the results obtained are more easily related to the actual conditions which fish might occupy within the receiving waters. In comparison with off-site laboratory studies, for example, the number of assumptions required to apply experimental results to the receiving environment are significantly reduced. The on-site, controlled-exposure studies with juvenile chum salmon performed at the BGS during 1997 and 1998 enabled the ongoing evaluation of the quality of the receiving water (in terms of its effects on exposed fish) drawn continuously to the test apparatus from the receiving waters of Port Moody Arm, and that of a range of concentrations of CW mixed with this seawater.

A series of four consecutive controlled-exposure studies was undertaken at the BGS research facility, each using a standardized set of CW concentrations diluted with seawater drawn from outside the zone of influence of the thermal plume. To account for the day-to-day variation in plant operating conditions and daily changes in ambient seawater characteristics during each of these four experiments, we integrated fish growth at a weight-specific food ration over a 20-day period of CW exposure, and related that growth to both the average water quality conditions as well as to specific, shorter term, water quality changes. Seasonal changes in water quality (as well as changes in the heat tolerance of the fish over time due to progressive acclimation) were accounted for by conducting experiments from May through August. To separate the effects of TGP from those of temperature alone, we fitted air equilibration columns on two of the four tanks that received a 50% concentration of CW. Two "shallow-water" tanks, which received a continuous supply of Port Moody Arm water drawn from a location outside of the influence of the CW discharge plume, were incorporated in the design to determine whether the surface waters of Port Moody Arm were suitable for salmonid growth throughout the spring and summer months.

The overall intent of the 1998 investigation was to: (i) characterize the effect of different concentrations of the once-through CW effluent on the survival, growth and condition of underyearling, saltwater-adapted, chum salmon; (ii) confirm, if possible, the results obtained during the 1997 program; (iii) distinguish the effects on growth of juvenile chum salmon due to high temperature alone, from those related to possible interactive effects with high TGP; and (iv) relate any observed effects to potential interactions between the operation of the BGS and chum salmon juveniles occupying Port Moody Arm.

MATERIALS AND METHODS

FISH TRANSPORT

On April 23 1998, 4000 chum salmon fry (0.75g average weight) were obtained from the Mossom Creek Hatchery (Port Moody, BC). These fish were transported in 10 °C fresh water within a 200-L covered polyethylene tank to the outdoor fish-holding facility at BGS. During transport, compressed oxygen at a flow rate of approximately 1 $L \cdot min^{-1}$ was supplied using a custom designed fine bubble diffuser bar, and dissolved oxygen was maintained between 75% and 100% air saturation. Seawater was introduced to the transfer tank to gradually increase the salinity to 16‰, afterwhich the fish were vaccinated against *Vibrio* sp. using a 20 second exposure to a 1:10 dilution of Biovax 1300 (Syndel Laboratories Ltd., Vancouver, BC). Using a dip net, the fish were then transferred to each of two outdoor holding tanks (~2000 fish per tank). The total time for the transport, vaccination, seawater transfer, and movement of the fish to the holding tanks at BGS was approximately 90 minutes. The temperature of the stock tanks at the time of transfer was 9.4 °C, dissolved oxygen was 8.1 mg/L (86% saturation) and salinity was 26.0‰.

STOCK TANK FISH HUSBANDRY

The fish were maintained outdoors in two 5550 L circular fiberglass holding tanks which were 3.1 m in diameter and 1.2 m in height. Loose-fitting fiberglass lids provided approximately 80% overhead cover. Seawater for both the holding tanks and the test apparatus (control/dilution water) was drawn continuously from Port Moody Arm at a station removed from the influence of the CW plume. This water was drawn from a depth of 5 m using one of two 7 HP 125 psi-rated centrifugal pumps located upstream from the BGS (Photograph 1), and delivered through 100 m of 75 mm rigid PVC pipe. Each of the two holding tanks received a continuous flow of unfiltered seawater at 30 - 40 $L \cdot min^{-1}$, while the balance (~200 $L \cdot min^{-1}$) was delivered to the main experimental header tank. The 90% replacement time for water in the holding tanks was < 3 hours, using the calculations provided by Sprague (1969). To ensure that dissolved gas levels were approximately at equilibrium, each holding tank was fitted with a 1.2 m long by 15 cm diameter PVC gas equilibration packed column. Holding tank temperature (± 0.1 °C), dissolved oxygen (± 2% air saturation), and salinity (± 0.1‰) were measured with a Yellow Springs Instruments (Yellow Springs, OH) Model 85 SCT meter; total gas pressure (TGP; ± 1 mm Hg) was measured using Alpha Designs' (Victoria, BC) Tensionometer 300c; and pH was measured with a Hanna Instruments (Bedfordshire, England) HI Model 9023 portable pH meter (± 0.01 pH unit). Seawater quality in the holding tanks and the on-site test facility (i.e. the control/dilution water) was monitored daily.

Fish in the holding tanks were fed an artificial pelleted diet (Moore-Clarke Ltd., Vancouver, BC, Nutra-plus™ starter feed No. 0; followed by No. 2) at a rate of 4 - 5% of total fish biomass daily. Twenty-four hour belt feeders (Zeigler Brothers Inc., Gardners, PA) delivered food primarily at dawn and dusk, with smaller amounts fed throughout the day. Ration was adjusted on a weekly basis using an estimated growth rate of 5% per day, with adjustments made following sampling. Any dead or moribund fish were removed from the holding tanks daily, and the tanks were periodically siphoned to remove excess food and waste.

A low daily mortality rate (0.5% - 1.0%) began in one holding tank on May 21, 1998. This tank of fish was treated for 14 days with the antibiotic oxytetracycline (100 $mg \cdot kg^{-1} d^{-1}$) starting on May 26, which reduced daily fish mortality to < 5%. During treatment, the feed ration was reduced to compensate for a loss of appetite and to ensure that all medication would be delivered. Following treatment, daily mortality fell to less than 0.5%. Fish to be used in the second experiment were drawn from the untreated stock tank on June 8. After the start of the second study, the few fish remaining in the untreated tank were destroyed, the tank was cleaned and sterilized, and the treated tank population was subsequently split between the two tanks to reduce loading density. Mortality again increased in one stock tank through June 25, at which time a second 14 day treatment of oxytetracycline (100 $mg \cdot kg^{-1} d^{-1}$) was administered. Fish samples sent to the BC Ministry of Agriculture and Fisheries Foods (BCMAFF) for histological analyses on June 29 indicated that septicemia, which is a systemic bacterial infection of the blood was the probable underlying cause of the mortalities. Mortality levels dropped to < 0.5% per day prior to the completion of the antibiotic treatment on July 9. The third experiment was started on July 13, and there was no mortality in either of the stock tanks from this date through August 24 at which time all remaining fish were released to Port Moody Arm (as would have occurred upon release from the hatchery).

TEST APPARATUS

BC Hydro's indoor mussel larvae settlement study apparatus was modified in 1997 for the growth studies with juvenile chum salmon (Greenbank et al. 1998). In 1997 BGS CW and natural seawater was delivered to each of twelve 123-L polyethylene rectangular tanks, through two separate constant-head delivery systems. In 1998, an additional shallow water delivery system (drawing water from Port Moody Arm at a depth of 1 m) was installed. Two of the four test tanks receiving 50% CW were equipped with 75 mm diameter x 80 cm long PVC gas equilibration columns to reduce dissolved gas supersaturation in the CW to air saturated levels. Modifications completed in 1998 are shown in Photograph 2, and in Figure 2. A 2000-L polyethylene head tank, which was supported above the experimental tanks (3-m total head pressure), supplied the test facility with seawater from outside the BGS effluent zone of influence (the screened seawater intake was located 50 m SW of the offshore structures at a depth of 5 m). Cooling water was delivered from a stainless steel submersible well pump (Grundfoss 1 h.p.) located directly in the mouth of the underwater discharge (Photograph 3) to a covered 300-L polyethylene head tank located 2 m above the experimental tanks. With the possible exception of minor changes in temperature and gas pressure occurring in the 100-m supply pipe, which were beyond our control, CW delivered to the test apparatus was thought to be representative of that entering Port Moody Arm from the BGS thermal discharge. Residence time for CW within the delivery system was estimated to be about 1 minute.

Seawater for the two shallow water tanks was delivered at a rate of 60 $L \cdot min^{-1}$ from an offshore location in Port Moody Arm, using a submersible well pump (Grundfoss 0.5 h.p.) at 1 m depth, and 80 m of flexible 5-cm diameter PVC pipe. The pump was protected by a 150-mm diameter perforated PVC housing, screened with plastic agricultural shade cloth (estimated pore size of ~1mm). Water for each of the two experimental shallow-water tanks was metered from a covered 60-litre polyethylene head tank, located 2 m above these tanks.

Two changes were made to the seawater supply used for control treatment groups and for diluting BGS CW in 1998. The main seawater intake was relocated from the immediate proximity of the BGS offshore structures to a location 50 m west in order to reduce the potential influence of cleaning operations at the station's intake screens. At the same time the depth of the seawater intake was increased from 3 to 5 meters in order to better reflect the water quality of seawater initially entrained at the BGS CW discharge.

Seawater delivery rates to each 130-L experimental tank were regulated by 3.8 cm PVC ball valves and were monitored using one of three sizes of in-line flow meters (Fabco Plastics, Maple, ON; F400N Series; 0.1 to 1.0 $L \cdot min^{-1}$, 0.4 to 4.0 $L \cdot min^{-1}$, and 1.8 to 18.0 $L \cdot min^{-1}$) depending on the flow requirements of the tank. Each experimental tank had an independent seawater supply line, regulating ball valve and in-line flow meters for delivering seawater, CW, or shallow seawater at a fixed and controlled rate of 15 $L \cdot min^{-1}$ (Photograph 2). The seawater and CW flows were combined 40 cm upstream from each tank, and were discharged through submerged, vertical 3.8 cm diameter PVC pipes each having twelve 0.6 cm holes drilled in a line along the length of the pipe to baffle the flows. The time for 90% replacement of seawater in the tank was approximately 20 minutes (Sprague 1969). To provide clockwise circulation patterns within each tank, the discharge holes were set approximately 45° off the center line of the length of the tank. The resulting flow pattern was circular in nature, but included a low-flow zone close to the baffled discharge pipe where the majority of the excess food and waste accumulated. Water exited each tank from the surface through a screened overflow.

Natural photoperiod was simulated with a three-phase lighting system. A 15-watt incandescent bulb (pre-dawn), a 75-watt incandescent bulb (dawn) and two 40-watt, daylight spectrum fluorescent bulbs (full daylight) were suspended 1.2 m above the tanks. This basic lighting was duplicated for each set of six experimental tanks. All of the lights were controlled with electronic timers (Noma, Southfield, Michigan; 125 V, 15 Amp). A 30-minute pre-dawn period was followed by a 30-minute dawn period, and a variable daylight period. The lights were turned off in 0.5 h intervals in the reverse order to represent dusk and sunset. The length of the daylight period was adjusted periodically during the study to reflect a seasonal change in daylight hours.

Each experimental tank was equipped with a 24-hr belt feeder (Zeigler Brothers Inc., Gardners, PA) set daily to deliver food primarily through the dawn and dusk hours. The outside walls of all the tanks were covered with 4-ml black plastic to prevent shadows being cast through the semi-opaque tank walls (see Photograph 2). Black 0.6-cm vinyl mesh was installed around the feeders, to provide overhead cover and prevent fish from escaping. Each tank was provided with underwater cover to provide additional refuge, and consisted of a rectangular sheet of 0.6-cm thick black acrylic (46 cm x 20.5 cm) with rectangular holes at each end. The acrylic sheets rested diagonally across the width of each tank at an angle of 45°, and were positioned at the end opposite to the tank drain.

TEST PROCEDURE

At the beginning of each experiment, fish from one of the two holding tanks were netted and transferred to a clean, covered, seawater-filled 75-L bucket equipped with a submerged air stone. Small groups of ten to twenty fish were anaesthetized in covered 10-L containers using a 4% (by weight) solution of tricaine-methane-sulphonate (MS-222); and individually measured for fork length (± 1 mm) and weight (Mettler Model PL-200 balance; ± 0.02 g). Fifty fish per experimental tank were used during the first two studies, while 40 and 30 fish were used in the last two studies respectively to maintain an appropriate loading density of 10 kg·m^3 in the test tanks. Fish were selected from a pre-determined size range to ensure that initial mean lengths and weights were equivalent in all tanks. A sub-sample of 30 fish per experiment from the stock tank provided an estimate of the mean weight of fish for the selection process (Table 1). To distribute the effect of capture bias equally among all treatments, subgroups of 10 fish at a time were allowed to recover from the anesthetic prior to being placed in the tanks by slowly submerging the transfer tubs and allowing the fish to swim free.

Fish were then acclimated for two days to 100% control/dilution water (i.e., seawater drawn continuously from Port Moody Arm), before exposure to a designated CW concentration. During this time, the seawater flow rate to each tank was maintained at 15 L·min^{-1}. The only exception was the two groups of fish exposed in each study to 100% shallow water drawn from Port Moody Arm at a depth of 1 meter. Fish introduced to the two tanks receiving shallow water at a flow rate of 15 L·min^{-1} were transferred in 50% seawater and 50% Port Moody Arm shallow water, and then allowed to swim into the test tanks containing 100% Port Moody Arm shallow water.

Following the two day acclimation period, CW was introduced to each tank (Table 2). Control tanks received 0% CW and in studies 1 to 3 a range of 6% - 50% CW was used whereas in study 4 concentrations of 25% - 75% CW were achieved by metering the appropriate flow of dilution water and CW. Experimental CW concentrations were established using proportional flow and the combined flow of CW plus dilution water to each tank was 15 L·min^{-1}.. Two tanks received 100% shallow water pumped from Port Moody Arm at a rate of 15 L·min^{-1}. Duplicate tanks were run in all studies for the controls, 50% CW, 50% CW with low TGP, and the shallow water treatments. All flow rates were checked and recorded twice daily.

The feed ration for each test tank was calculated based on the estimated total biomass in each tank. The objective was to feed a ration equivalent to 6% of total biomass (wet weight) daily. The ration was corrected daily using an estimated growth rate of 5% per day (Salo 1991) and was adjusted for any mortalities that occurred.

Temperature, total gas pressure (TGP), salinity, dissolved oxygen, and pH were measured daily in each of the tanks. The temperature in each tank was also automatically determined at 30-minute intervals using wireless data loggers (Onset Computer Corporation, Pocasset, MA, Optic Stowaway 8k loggers; ± 0.2 °C). The experimental tanks were siphoned daily, to remove feces and excess food.

At the end of each study, fish were removed from the test tanks with a small dipnet and given a lethal dose of anesthetic (MS-222) before being measured for fork length (±1 mm) and their wet weight (± 0.02 g) determined. The fish were then placed in a drying oven heated to 60 ± 2 °C, for a period of 2 to 5 days (depending on the size of the fish) until a constant dry weight was obtained (measurements were within 0.05%).

FISH CONDITION

In the 1998 studies an assessment of fish condition was undertaken that was based, in part, on the procedure described by Mesa and Warren (1997). Due to time constraints associated with processing large numbers of fish at the completion of each study, 25% of each experimental population (5 – 10 fish per tank) received a detailed external assessment for visible signs of ill health.

The left side of each fish was externally examined for gross GBT signs such as popeye (exopthalmia), large bubbles under the skin and hemorrhages. The left lateral line was then examined under a dissecting microscope for the presence gas bubbles. A severity ranking of the percentage of the lateral line occluded with gas bubbles was assigned (0 = no bubbles present, 1 = 1% - 5% occluded, 2 = 6% - 25% occluded, 3 = 26% - 50% occluded and 4 = > 50% occluded). If gas bubbles were apparent in the lateral line, the paired fins on the left side of the fish were examined and the same severity rating was used to estimate percent of the fin covered with gas bubbles.

DATA ANALYSIS

Means and standard deviations were calculated for all water quality parameters in each study. In general, the measured values for water quality parameters in the experimental tanks including dissolved oxygen, salinity, and pH, fell within acceptable ranges for fish growth. Temperature and TGP, however, were often outside the range normally considered to be optimal for salmon growth (Brett et al. 1969; Colt et al. 1991). All of the water quality parameters were analyzed to assess their relationship to fish growth through linear and multiple regression.

Initial and final fish weight data were analyzed in several ways. Histograms of average weight (by treatment) were plotted to determine the size distribution of the test populations prior to treatment. The average weights and standard deviations of each pre-treatment group were then compared for significant differences using pairwise comparison probabilities generated from one-way Analyses of Variance (ANOVAs) at a p-value ≤ 0.05 (Microsoft Excel Vers. 5. CTI Statistical Add-Ins). To determine if significant differences in fish growth resulted from the CW treatment regime, post-treatment average wet weights and dry weights were also analyzed using one-way ANOVAs. However, with the wet weights, the average initial weight (i.e. pre-treatment) for each test group was subtracted from each individual post-treatment fish weight of the same treatment to account for pre-treatment variability in fish size. Average weights were used for all analyses as individual fish were not identified.

Length data were not compared for significant differences between CW treatments as was done with the fish weight data. However, length data were used to calculate condition factors for all fish (pre and post-treatment) using the Fulton-type (k) condition factor (Murphy and Willis 1996):

Condition Factor (k) = $(W / l^3) \times 100{,}000$ [W = wet weight (g); L = fork length (mm)]

The mean condition factor for each test group was plotted against the mean water temperature for that group to reveal if the treatment affected the condition factor of the fish.
Since individual growth rates for each fish were not available, a specific growth rate (% weight$\cdot d^{-1}$) was calculated for each treatment group using the following formula from Shelbourne et al. (1973):

$$\text{Specific Growth Rate (\% weight}\cdot d^{-1}) = \frac{[\ln W_1 - \ln W_o]}{t} \times 100$$

[W_1 = end mean weight (g); W_o = initial mean weight (g); t = time (days)]

Growth rates were plotted against mean exposure temperature to assess the nature and strength of the temperature-growth correlation. To ensure these relationships were not created by stressful conditions resulting in a change of osmotic balance, which would result in water loss or retention, we plotted mean dry weights against mean exposure temperature.

Each water quality parameter was independently tested (linear regression, $p \leq 0.05$) for a significant relationship with fish growth. Parameters which showed little or no correlation with fish growth in any of the studies (i.e., pH and salinity) were not included in further analysis. Parameters which had a significant correlation with fish growth, such as temperature, TGP, and dissolved oxygen, were further examined using multiple regression. All two-way combinations of these three variables were tested independently against growth rates using multiple regression ($p \leq 0.05$). Further, to determine if these variables were intercorrelated we plotted them against each other and examined the regression lines and coefficients of determination.

The importance of increasing temperature on growth rate in salmonids has been well established (Weatherly and Gill 1995; Brett 1995). Provided food is not limiting, growth rate in many salmon species increases to a maximum between 15 °C and 20 °C, and then rapidly decreases as the incipient lethal limit is approached (Weatherly and Gill 1995). Therefore, in this investigation, effort was directed toward both collecting and analyzing water temperature data. Daily mean, maximum, and minimum temperatures were calculated from the data set (48 readings per day) and plotted to indicate general trends in the temperature regime over time. The relationships between mean temperature (over the whole study) and the specific growth rate was also determined for each treatment. Both linear and 2nd order polynomials were fitted to the comparative data for growth rate versus mean temperature. To determine if the polynomial function was a better descriptor of the growth-temperature relationship we used multiple regression analysis. The x variable (temperature) and the x^2 variable (temperature)^2 were tested (multiple regression, $p \leq 0.05$) to determine if the x^2 variable was significant. Where the relationship between mean temperature and fish growth was poor, further analysis was conducted. Firstly, the individual records for temperature were analyzed for specific events (e.g. short-term high temperature episodes or fluctuating temperatures) which may have affected fish growth. Secondly, other water quality variables (e.g. TGP, dissolved oxygen, water clarity) were analyzed to determine if these factors contributed significantly to the temperature-growth relationship.

Data on fish condition were pooled for each CW treatment and compared to the number of related external signs of ill health observed in control fish. All observed signs were grouped into 2 overlapping categories, one being known or suspected signs of GBT (i.e. bubbles in the eyes, lateral line or unpaired fins), and two, all signs of ill health (including those related to GBT or disease). Each recorded sign was given an arbitrary value of 1. The results were compiled for individual fish, summed for groups of fish of like treatment and expressed as the mean number of signs per fish. A two-sided T-test ($p < 0.05$) was used to compare the mean number of signs in control groups with the mean number of signs in each treatment group, pooling the variance to account for unequal numbers of fish in each test group (Norman and Streiner 1994).

RESULTS

It should be noted that the CW concentrations discussed below represent nominal concentrations. Some variation in flow conditions occurred during each experiment. Interpretation of our growth-water quality relationships is based on actual water quality measurements rather than on the nominal CW concentrations. Studies 1 – 3 were of 20 days in duration. Study 4 was of 16 days duration as this study ended abruptly when the main sea water supply system failed. Therefore, only lengths and weights were obtained from these fish and no health assessment was included in the data analysis.

WATER QUALITY

Water quality results are summarized in Tables 3 through 6. Throughout each of the four studies, trends in water quality between treatments were similar. Temperature and TGP increased as CW concentrations increased. Daily minimum, maximum, and mean temperatures are shown in Appendix 1. For the CW treatments, dissolved oxygen generally decreased slightly with higher concentrations of CW while the salinity and pH did not.

For each of the two 50% CW/low TGP treatments, water quality was similar to the 50% CW treatment except that TGP was typically 4% - 5% lower. Except in Study 1 where differences of about 1 °C or more were recorded, these differences in temperature between the 50% CW treatments and the 50% CW/low TGP treatments were usually < 0.5 °C.

Water quality in each of the two shallow-water treatments was consistently different from all other treatment groups. The pH was often higher as was dissolved oxygen. The salinity was lower, when compared to each of the other treatments (including the control/dilution water drawn from 5-m depth) in the same study (Tables 3 - 6). The shallow water temperatures were similar to the 25% BGS CW treatment in Studies 1, 2, and 4 and to the 50% treatments in Study 3.

FISH SURVIVAL

With few exceptions, the survival of fish throughout each of the 16 to 20 day growth studies was high. In each of the four studies, all fish survived in the control tanks. For the four treatments where groups of fish were held throughout the study period in 50% CW (two groups with high TGP and two with low TGP), only eight fish died over the first three studies and these mortalities were restricted to one of the 50% CW tanks in Study 1 (see Table 7). In Study 2, there was 30% and 28% mortality in the two shallow-water treatments over a one day period which coincided with a phytoplankton bloom in the inlet, and no fish deaths in any of the other tanks. In Study 3, one fish died in each of the shallow-water treatments as did one in the 25% CW treatment. In studies 2 and 3, the water in each of the two shallow-water tanks was turbid, and the dissolved gas levels (dissolved oxygen and TGP) fluctuated widely although mean values were consistently and appreciably higher than in any other treatments (Tables 4 and 5).

In study 4, mortality ranged from 0% (for each of the controls, shallow-water treatments, 25% CW, and 35% CW), to 100% (75% CW) (see Table 7). The 75% CW treatment produced lethal temperatures (23.4 ± 1 °C; Table 6) which induced 100% mortality within 5 days. There were four deaths (13.3% of exposed fish) in the 65% CW treatment (22.6 ± 0.8 °C; Table 6) over the 16 day duration of the experiment. The mortality in the four 50% CW tanks (high and low TGP) ranged from 3.3% to 16.7% (Table 7).

FISH CONDITION

Signs of ill health that were observed during this investigation included cataracts, split cornea, scale loss, petechial hemorrhages in the lateral line, and torn fins, as well as signs of GBT such as popeye (exopthalmia), bubbles in the eye, lateral line and unpaired fins. The condition of fish exposed to BGS CW or Port Moody Arm surface water was determined following the first three studies. Results from studies 1-3 are presented in Tables 8 and 9 and the data are shown in Appendices 2 and 3 with a mean of 0.1 representing one ill health sign for every 10 fish examined. The number of signs of ill health observed in fish after each study was relatively low but increased, over time, from a mean of less than 1.0 after Study 1, to between 2.0 and 3.0 following Study 3 (Table 8). The mean number of signs specifically related to GBT however, did not increase over time, and they remained between 0.0 and 0.6 (Table 9). With the exception of a general increase in the mean number of signs of ill health with increasing CW exposure in Study 2, there were few significant differences in the condition of treated fish from these studies. The pattern of observed disease signs (i.e. discoloration, popeye, subcutaneous lesions and swelling near the caudal peduncle) and two subsequent antibiotic treatments of stock tank fish suggests that fish used in the second experiment may have had a low level bacterial infection which could have contributed to the overall reduction of growth rates observed in that study.

Study 1

When all health-related signs were combined there was no apparent effect of BGS CW on the external condition of fish relative to the control groups (Table 8). However, fish exposed to Port

Moody Arm shallow water had a significantly higher number of signs of ill health (mean 0.7 ± 0.9) than the controls (0.1 ± 0.3; $p \leq 0.05$) (Table 9).

Study 2

At the conclusion of Study 2, the mean number of visible signs of ill health ranged from 0.2 to 1.1 per fish. Those fish with the fewest signs were from the control group, and those with the most were from higher concentration CW groups and the shallow water treatment group. All treatment groups had at least twice the number of signs of ill health as the controls, but only the 35% CW (mean 0.8 ± 0.7), 50% CW/low TGP (mean 1.1 ± 1.0), and the Port Moody Arm shallow water treatment (mean 0.8 ± 0.8) groups were significantly higher than the controls (mean 0.2 ± 0.4: $p \leq 0.05$, Table 8). Fish used in the second experiment may have had a low level bacterial infection which could have contributed to the increased number of signs of ill health as compared with the results from Study 1.

With respect to signs of GBT (Table 9), none of the fish treated with BGS CW or Port Moody Arm shallow water were found to be significantly different from the controls.

Study 3

At the conclusion of Study 3 (Table 8) the mean number of signs of ill health per fish ranged from 1.0 to 2.6. Low to medium concentrations of BGS CW (6% - 35%) appeared to confer a benefit on the fish in comparison with controls, and the higher 50% CW and 50% CW/low TGP treatments, and shallow water treatment groups. The 12% CW group (mean 1.0 ± 0.6) showed significantly fewer signs of ill health than did the controls (mean 2.3 ± 0.9: $p \leq 0.05$). Overall, the 6% - 35% CW treatment groups showed approximately half the signs of other treatment groups including the controls. None of the treatment groups were significantly different from the controls in respect to signs of GBT.

CONDITION FACTOR

Condition factors of individual fish were calculated pre- and post-treatment (Appendix 4). There was a general trend of increasing condition factor from Study 1 to Study 4 (see Figure 3). Pre-treatment condition factors increased from approximately 0.84 in Study 1 to 1.00 in Study 4. However, pre-treatment condition factors in Study 2 (0.95) were slightly higher than those in Study 3 (0.90) probably reflecting the influence of a disease episode in the latter group and subsequent antibiotic treatment of the stock tank fish at a reduced ration. The mean post-treatment condition factors increased over time from 0.95 in Study 1 to 1.20 in Study 4 (Figure 3).

The highest correlation between condition factor and exposure to BGS CW was found in Studies 2 and 3 (Figure 3). In Study 2, there was a near-linear increase in condition factor as CW exposure increased. In Study 3, there was an initial increase in condition factor from 1.04 in the controls to as high as 1.13 in 35% CW, followed by a decrease back to near control levels of 1.05 in 50% CW (~ 20 °C).

FISH GROWTH

Despite selecting fish from within a relatively narrow size range for inclusion in each study, the initial wet weights of several of the groups of fish introduced to each test chamber were found to differ significantly from each other. In studies 1, 2 and 3 there were 2, 6, and 8 groups of fish respectively whose mean initial wet weights were significantly different than those for other groups in the same study, according to pairwise comparisons (Appendix 4). Although these differences were statistically significant, they were small (max. 6%), as shown in Figure 4 and Table 10. There were no significant differences in the mean initial wet weights of fish in Study 4. Length data are shown in Appendices 6 and 7 although no statistical comparisons were made between CW treatments and controls.

GROWTH IN STUDY 1

In Study 1, the growth rates of those groups of fish held for 20 days in CW at concentrations of 25%, 35%, and 50% (with or without gas equilibration to reduce dissolved gas supersaturation) were consistently and significantly higher than growth rates of each of the two control groups (Tables 11 and 12). Growth rates for each of the two groups of fish held in shallow water from Port Moody Arm were also significantly higher than those for each of the two control groups. The 6% and 12% CW treatment fish did not grow appreciably better than the control groups.

The relationship between fish growth rates and mean test temperature for each treatment is illustrated in Figure 5. In Study 1, a trend showing increasing growth rates with increasing mean temperatures was evident within the range of CW concentrations (0% to 50%) investigated. Additionally, the growth rates determined for the shallow water and 50% CW/low TGP treatments were comparable to those obtained at similar temperatures for the series of concentrations of CW mixed with control/dilution water (Figure 3). There were differences in water quality variables other than temperature for these two treatments. Total gas pressure in the shallow water treatment tanks, for example, averaged 110% (compared with a mean value of 105% in the 25% CW treatment, which was otherwise similar in mean temperature), suggesting that elevated TGP did not adversely affect growth under these conditions.

GROWTH IN STUDY 2

In Study 2, fish held for 20 days in CW concentrations of 6% - 50% grew better with increasing CW concentration. All CW treatments except the 6% CW produced significantly faster growth when compared to the controls (Tables 11 and 12). The 50% CW/low TGP treatment, was similar to the 50% CW treatment, in terms of mean temperature and mean fish growth. However, the TGP-equilibrated 50% CW/low TGP treatments had a mean TGP value of 103%, compared to a mean TGP level of 108% in the non-equilibrated 50% CW treatments (Table 4). As in Study 1, this reduction in total gas pressure did not appear to have a significant effect on fish growth relative to the non-equilibrated 50% CW treatments.

In this experiment, the growth rate for the shallow water treatments was below that of fish exposed to 6% - 50% CW concentrations (Figure 5). This slower growth in the shallow water treatments (mean temperature 16.5 °C, mean dissolved oxygen 119% air saturation), relative to that in CW treatments with a similar mean temperature (25% CW, mean temperature 16.0 °C; mean dissolved oxygen 99.2% air saturation and 35% CW, mean temperature 17.2 °C, mean dissolved oxygen 98.8% air saturation) was associated with a significant supersaturation of dissolved oxygen. During Study 2, the water in each of the two shallow-water tanks was often turbid, to the extent that the fish in these tanks were not visible. The fish mortalities in each of the two shallow-water tanks occurred over a short period of time and was high (28% and 30%). Fish growth in the shallow water treatment groups in Study 2 was considerably lower than that Study 1. If, as suspected, the high dissolved oxygen values recorded in these tanks during daytime reflected a eutrophic condition, at night, dissolved oxygen depression to levels below air saturated values would be expected and such variation, if severe enough, would have an adverse effect on fish metabolism.

GROWTH IN STUDY 3

In Study 3, there were significant increases in the growth of fish held for 20 days, in all CW treatments, (6% to 50% CW) when compared with the control groups. Unlike Studies 1 and 2, however, the mean growth rates continued to increase with each higher CW concentration, and each of the 50% CW treatments produced growth rates which were higher than all other treatments including the controls.

Each of the two 50% CW/low TGP treatments had much lower growth rates than those for other groups held at a similar mean temperature, including the two groups of fish held in 50% CW with high TGP (Figure 5). Based on Studies 1, 2 and 4, we would have predicted equal or better growth than that in the 50% CW/high TGP treatments.

Growth rates for each of the two groups of fish in the shallow water treatments were well below that of fish from the 6% - 50% concentration series (Figure 5). While the mean temperature (20.0 °C) to which these fish were exposed was equivalent to that of the 50% CW treatment, levels of TGP (mean 111%) and dissolved oxygen (mean 122.1%) in the shallow-water treatments were both significantly higher than for any other treatment in this study (Table 5) and might (together with a possible dissolved oxygen depression at night), have contributed to this negative effect.

GROWTH IN STUDY 4

In the first three studies fish that were exposed to the 50% concentration of CW grew faster than their corresponding control groups (Tables 11 and 12). To broaden the scope of the investigation, the 6% and 12% treatments were replaced with 65% and 75% CW concentrations in the fourth study.

Growth rates in this 16-day study were generally lower than those for corresponding treatments in Studies 1, and 3 but not Study 2. Growth rates in 25% CW, 35% CW, and one of the two 50% CW concentrations did not differ significantly from those of the control groups (Table 12). The 65% CW and one of the 50% CW concentrations, however, produced growth rates significantly lower than the control groups. Both the 50% CW treatments produced the same mean growth rate of 2.6% per day (Table 8); however the high variability in fish growth in one of the 50% CW tanks resulted in an insignificant result compared to the control groups.

Apart from the 25% - 50% concentration series, there was a substantial difference in growth rate between the two 50% CW/low TGP treatments. This difference resulted from a mechanical failure to the water delivery system to one of these two treatments, which resulted in a temperature increase of 1 °C - 4 °C over the first 5 days followed by a further increase of up to 5.1 °C to a temperature of 26.6 °C for a period of 2 hours. The mean temperature over the duration of the study was 22.1 °C. Fish exposed to this regime had a growth rate of 1.2% per day which was substantially lower than the "replicate" treatment's growth rate of 2.8% per day. The mortality rate of 10% for this tank was also higher than the 3.3% in the replicate treatment. A similarly poor growth rate of 1.6% per day occurred in the group exposed to 65% CW, where the mean water temperature throughout the 16-day period of exposure was 22.6 °C and mortality 13.3% (Table 6). All fish in 75% CW died within 5 days and therefore growth rates were not calculated.

The shallow-water tanks in Study 4 produced slightly lower growth when compared to the 25% CW treatment which had a similar mean temperature. The only major difference identified in the water quality data for these treatments (Table 6) is that the standard deviations for the mean dissolved oxygen and TGP levels were high, indicating considerable fluctuation in these parameters in comparison with those in the other treatments.

TEMPERATURE AND GROWTH

The results of the four growth studies in 1998 demonstrated a relationship between mean exposure temperature and the growth of fish. That relationship changed over time with thermal exposure, fish size and time of year. To characterize the interaction between temperature and growth we examined both linear and polynomial regression data from all treatment groups (Table 13). R^2 values are shown for regression analyses restricted to data for the main concentration series tested (i.e., 0% and 6% to 50% CW in Studies 1 to 3; 0% and 25% to 65% CW in Study 4), and regression analyses including the 50% CW/low TGP and shallow-water treatments. As shown in Table 13, the correlations of growth versus mean temperature for the main dilution series were high in each study, and were consistently better for the polynomial regressions (R^2 = 0.71 to 0.93) than for the respective linear regressions ($R^2 = 0.62$ to 0.86). A worse fit ($R^2 = 0.43$ to 0.68) for polynomial regressions of the temperature and growth-rate data was found when all data, including that for the 50% CW/low TGP and shallow-water treatments, were used in the regression analysis. This suggests that factors other than temperature may have been related to any reduced growth rates observed.

Table 14 shows the R^2 values and probability (p) values resulting from linear regression analysis of all water quality variables versus growth rates. The majority of the significant relationships were found with temperature, dissolved oxygen ($mg \cdot L^{-1}$), and TGP, and, accordingly, we limited multiple regression analysis to those factors. Since sample sizes were low ($n = 12$), the three variables were run two at a time in all three possible combinations. All of the treatments were used in the multiple regression analysis to determine which water quality parameters were most important in determining the growth of fish in the 50% CW/low TGP and shallow-water treatments.

Temperature and TGP vs growth

The combination of temperature and TGP had a significant relationship (multiple regression - temperature and TGP vs growth: $F < 0.05$) with fish growth rates in Studies 1, 2 and 4 (Table 15). The temperature variable showed a significant independent p-value in Studies 1 and 2. TGP was not significant in all studies and we determined that TGP provided no additional information beyond the temperature relationship in terms of fish growth. TGP and temperature were, however, highly correlated ($R^2 = 0.99$ for the main CW concentration series in each of the four studies; see Appendix 8).

Temperature and dissolved oxygen vs growth

As shown by the F-values for the multiple regression analyses (Table 15), temperature and dissolved oxygen were correlated significantly with fish growth rates in Studies 1, 2, and 4. However, as with TGP, the independent p-values were only significant for temperature (Table 15). Again, all of the variability in growth could be explained by mean temperature. These two variables were also highly correlated ($R^2 = 0.92$ to 0.99 for each of the four studies; see Appendix 8).

TGP and dissolved oxygen vs growth

The multiple regression statistics showed significant results with dissolved oxygen and TGP in Studies 1 and 2 only (see F-values, Table 15). In both of these two studies, the independent p-values for both dissolved oxygen and TGP were significant. It should be noted that the slope of the dissolved oxygen versus growth curve was negative; that is, an increase in dissolved oxygen was correlated with a decrease in growth. Rather, the decrease in fish growth was associated with very high (above 100% saturation) mean levels of dissolved oxygen with large fluctuations. These significant relationships indicate that, from the perspective of the 50% CW/low TGP and shallow-water treatment groups, supersaturated levels of both TGP and dissolved oxygen were significantly and negatively correlated with fish growth. No determinations of dissolved gases were made at night and it is expected that dissolved oxygen depression would have occurred due to the demands of algal respiration. Accordingly, levels of dissolved oxygen would most likely have fluctuated above and below the 100% saturation level and thereby been a negative influence on the growth of the chum salmon in these waters.

Summary of fish growth

When the data for all treatments are considered together (50% CW/low TGP and shallow-water treatments included) the temperature-growth relationship identified in the 0% - 50% CW dilution series weakens, which suggests that dissolved oxygen and TGP have a significant effect on fish growth in some conditions. We found that both TGP and dissolved oxygen were significantly and negatively correlated with fish growth rates when temperature was excluded from the analyses (Table 15).

The 50% CW/low TGP treatments were generally lower in total dissolved gases by about 5% saturation compared with the 50% CW treatments. The 50% CW tanks ranged from 106% to 109% TGP, while the 50% CW/low TGP tanks ranged from 102% to 104% TGP (Tables 3 - 6). With the exception of Study 3, in which growth rates in the 50% CW/low TGP treatments were lower than those in the respective 50% CW treatments, this reduction of TGP had no effect on growth at the temperatures we examined.

In Studies 2, and 3, fish exposed to Port Moody Arm shallow water grew less than fish exposed to BGS CW at equivalent temperature regimes, but greater than that achieved in the control groups held in water drawn from a 5 m depth within Port Moody Arm. These results indicate that the relatively slower growth rates in the shallow water treatments, for Study 2 and 3, relative to other treatments, were associated with fluctuating levels of dissolved oxygen and turbidity in the shallow-water tanks which was likely a consequence of high productivity in surface waters of Port Moody Arm. In Studies 1, 2 and 3 both of the shallow water groups grew faster than the control groups; however, the differences were significant only in Study 1. In Study 4 both of the shallow water groups grew significantly less than did the fish comprising the control groups.

DRY WEIGHTS

Dry weights were determined for all fish at the end of the study (Figure 6). The total range of percent moisture was from 73% to 78% (Appendix 9). A comparison of the plots of polynomial regressions and individual values for the data from all four studies representing growth rates (based on wet weight) and mean temperatures (Figure 5), alongside the equivalent data representing dry weights and mean temperatures (Figure 6), indicates that the plots based on wet or dry weights are insignificantly different. Thus the differences in growth rates between treatment groups reflect increases in biomass rather than changes in tissue water content due to osmotic stress or other factors.

DISCUSSION

In general, we found increasing growth with increasing CW concentration (6% - 50%) in Studies 1 to 3, and a decrease in growth with increasing CW concentrations (25% - 65%) in Study 4.

FISH SURVIVAL

In each of the four studies, most fish survived in all concentrations up to 65% BGS CW. In Study 4 overall temperatures increased as did the mortality rates in the higher concentrations of CW. Temperatures in the outdoor stock fish holding tanks were approaching 20 °C in the week prior to commencing Study 4 in August. However, the average temperature for the month of July in the stock tank was 16.0 °C. Other than temperature, there may have been some cumulative adverse effects on stock fish due to the stress of holding conditions for the three months prior to Study 4 and the recuperation from two antibiotic treatments for septicemic infections. Although water quality and loading densities were within acceptable limits for the maintenance of healthy fish, weekly fish sampling, daily water quality monitoring and fish being removed from the tanks for the other three studies may have contributed to a possible infection and the resultant increased mortality seen in the higher concentrations of CW in the fourth study. This added stress may have also reduced fish tolerance in all of the treatments during Study 4. In general, the signs of ill health increased over time (Table 8) suggesting that the health of the fish in the holding tanks decreased slightly. However, there was no mortality in treatments with less than 50% CW during Study 4.

For the most part, mortality in all four studies was limited to either the shallow water from Port Moody Arm or the ≥ 50% CW treatments. In Study 3, 30% and 28% of the fish in the shallow water treatment groups died over a two-day period mid-way through the study. These mortalities coincided with an algal bloom in the surface water of the Port Moody Arm. *Heterosigma* sp. have been identified in Port Moody Arm as the causative agent of at least one fish kill in the two years preceding 1998 (L. Nikl, Fisheries and Oceans Canada, New Westminster, BC; pers. comm.). Since these mortalities were short-lived and confined to the shallow water groups, it is possible that *Heterosigma* sp. may have been involved in the death of these fish.

FISH GROWTH

The range of growth rates observed in the 1998 program (2.8% - 5.0% wet weight·day^{-1}) compare well with reported growth rates for this species during its nearshore residence period under natural conditions [3.5% - 6.7% wet weight·day^{-1} (Weatherly and Gill 1995); 3.5 - 5.7% wet weight·day^{-1}, (cited in Groot et al. 1995)]. Exposure of juvenile chum salmon to BGS CW at concentrations up to and including 50% resulted in a concentration-dependent increase in chum salmon growth rates for the first three studies (May through July), and a decrease in the fourth study in August (Figure 5). For the temperature regimes examined in these studies we found that growth was best described with a 2nd order polynomial function with respect to the mean temperature exposure ($R^2 = 0.90$). This relationship was positive for Studies 1, 2 and 3 and negative for Study 4.

A number of other water quality variables may have affected growth. Water clarity was intermittently poor in the shallow water tanks during the first three studies. There were times the fish in the tanks were not visible from above due to the turbidity created presumably by primary production. The growth rates in the shallow water tanks were consistently lower than the treatment group with the equivalent temperature regime. It is possible that increased turbidity may have decreased the fish's ability to see and obtain food. It is speculated that gill irritation caused by the high densities of plankton may also have effected the behavior and/or energy consumption of these fish. Both of these two phenomena could have affected fish growth within these groups.

The overall lower growth rates observed in Study 2 and Study 4 may have been the result of a low level septicemic infection for which the outdoor holding tanks were treated with antibiotics one week after the start of Study 2 and again just prior to Study 3. Compared to Study 1 and 3, fish growth in Study 2 and Study 4 was much lower in all treatment groups and controls.

One of the objectives of these studies was to separate the effects of high temperature plus high TGP from those of high temperature alone. However, the growth rates produced in the 50% CW/low TGP treatments were similar to those produced in the 50% CW treatments in Studies 1, 2 and 4. In Study 3, the growth rates of each group of fish held in the air-equilibrated 50% CW/low TGP treatments were significantly lower than the observed growth rates found in the two 50% CW treatments with no air equilibration. An examination of the water quality data for these treatments (Table 5) did not provide a satisfactory explanation for the reduction in growth. The temperature in the 50% CW/low TGP treatments was 0.4 °C higher than the 50% CW. The dissolved oxygen levels were slightly higher (but below 100% air saturation) in the 50% CW/low TGP tanks, and the TGP levels were considerably lower (but still slightly above 100% air saturation). The low TGP treatment was expected to produce better growth than the other 50% CW treatments assuming a negative effect of exposure to low levels of TGP. Our expectation of the 50% CW/low TGP treatments was an increase in growth rates relative to the 50% CW treatments with unregulated TGP. We anticipated that the combined effect of high temperature and high TGP would reduce growth in juvenile chum more than high temperature alone. We did not see this effect in any of the studies and, in Study 3, the opposite effect of lower growth in low TGP treatments was found. The objective of separating the effects of TGP and temperature arose during the 1997 investigation in which the recorded TGP levels were much higher. However, in 1997 the seawater for the experimental tanks was also drawn from 3 m depth in PMA instead of the 5 m depth used in 1998. The bearing this may have had on TGP levels is unknown. In the 1998 studies, the mean TGP levels were lower and did not surpass 109% in any of the four studies which included 50% CW (Tables 3 - 6). The 50% CW/low TGP treatments generally had mean TGP values which were only 4 to 5 % TGP lower than the respective values for the 50% CW treatments. At the temperature of the 50% CW treatments in the 1998 studies (Tables 3 - 6) minor differences in dissolved gas supersaturation from 109% to 104% TGP had no demonstrable effect on fish growth.

As stated previously, all of the fish were fed a daily ration of 6% of total biomass. Feeding rates have been shown to increase with increasing water temperature to meet metabolic demands, thus giving rise to the potential for food as a growth limiting factor. The continual presence of excess food on the bottoms of the tanks in these studies revealed that the ration was not limiting in any of the treatments. Thomas et al. (1986) found no difference in growth rates of juvenile coho salmon (*Oncorhynchus kisutch*) fed rations of 4% and 8% wet weight per day and daily fluctuations in temperature ranging from 6.5 to 20 °C. These authors assumed that the fish were fed to satiation at 4% of their wet weight per day. Brett et al. (1969) found that, for juvenile sockeye salmon (*Oncorhynchus nerka*) in fresh water, the maximum food intake per day was approximately 8% of the dry body weight at 20 °C. In the present experiments, where food was not limiting, we demonstrated an increase in growth with increasing CW concentrations (corresponding to increasing temperatures) in each of Studies 1, 2, and 3.

FISH CONDITION

The issue of general health in fish exposed to BGS CW is an important aspect in qualifying the results of the growth component of this investigation. For example, both 1997 and 1998 experimental programs demonstrated that juvenile chum salmon can survive and grow well in BGS CW concentrations up to 50%, at temperatures approaching, and for short periods of time exceeding, the reported upper incipient lethal threshold of 23.8 °C for this species (Brett 1952). Some fish exposed to BGS CW in 1997, however, developed signs of GBT. Therefore in 1998, we determined whether the general health of fish exposed to BGS CW was significantly different from that of control fish exposed to 5.0 meter deep Port Moody Arm seawater, and also whether exposure to BGS CW resulted in an increase in the development of signs of GBT. In two of the three studies in which a health assessment was conducted we found no significant increase in the signs of ill health in fish exposed to BGS CW.

One of the chief difficulties associated with assessing GBT in fish is the lack of consistency in the expression of typical signs of high TGP exposure. Small fish (20-40 mm in fork length) for example, are known to die from elevated TGP exposures without developing any of the classical external signs associated with GBT which develop in larger fish (Bonnie Antcliffe, Fisheries and Oceans, Canada,Vancouver, BC; pers. comm.). When signs of GBT are present, they are not usually expressed uniformly between fish of similar size. In addition, mortality of fish exposed to waters of elevated TGP is partly size dependent, so that salmonid fish below 50 mm fork length have a significantly lower mortality rate than fish of greater length when exposed to the same conditions(Fidler and Miller 1997).

Of those external signs typically associated with GBT in salmonids including exophthalamus (pop eye), as well as bubbles in the eye, lateral line and unpaired fins, only fish exposed to Port Moody Arm shallow water in Study 1 demonstrated a significant increase in signs of GBT relative to control fish. While the overall incidence of GBT signs did not increase over the first three studies, the level of signs of ill health increased significantly, possibly indicating a disease problem. Given the low incidence of signs of GBT in this investigation, no conclusions in respect to the benefit of reducing TGP (i.e. 50% CW/low TGP) can be made. Growth of fish in the 50% CW/low TGP tanks was the same or less than that achieved in the 50% CW.

Development of signs of GBT in juvenile chum salmon exposed to Port Moody Arm surface waters for 20 days in Study 1 confirms the findings of other freshwater studies in which exposure to oxygen supersaturated water produced obvious signs of GBT in cutthroat trout (*Oncorhynchus clarki clarki*) (Edsall and Smith 1991). These authors also demonstrated that development of signs of GBT in rainbow trout exposed to oxygen supersaturation could be prevented by reducing the overall TGP to less than 110%. In Study 1, the significant increase in GBT signs at 110% TGP was associated with dissolved oxygen levels of 130% in the shallow water treatment group. In the 50% CW treatment in Study 1, where the levels of TGP were also 110%, the dissolved oxygen levels were 101% and there was no significant increase in GBT signs, compared with controls, in the fish we examined.

The relative sensitivity of different marine fish species to high TGP exposure has not been adequately explored although the few species which have been examined indicate the development of similar signs of GBT to those found in freshwater species (Fidler and Miller 1997). In consequence, water quality guidelines for the protection of aquatic biota from the effects of dissolved gas supersaturation have been set at the same level as for freshwater environments (i.e. a Δp of < 76mm Hg or 110% TGP at sea level). The measured TGP in the 50% CW treatments ranged from 106% to 109%. However, Port Moody Arm surface waters, as a direct consequence of naturally occurring plankton blooms often had TGP levels that exceeded 110%, in the daytime, during periods of high productivity (Birtwell et al. 1998). Direct mortality of 28% - 30% over a one day period, was evident in fish exposed to PMA shallow water in Study 2 while a significant increase in signs of GBT was observed in shallow water treated fish in Study 1, suggesting that prolonged exposure to these waters can be lethal to juvenile salmon during plankton blooms in the summer period. Since chum salmon juveniles successfully occupy these waters during the same times of year in which these investigations were conducted (Hwang et al. 1994), it may be that they are able to compensate for elevated gas pressure in surface waters, possibly through avoidance by either temporarily occupying deeper waters, through lateral displacement or through some other means.

With the exception of Study 2, exposure to BGS CW did not result in a decrease in the health of experimental fish relative to that observed in control fish. The concentration dependent increase in signs of ill health observed in Study 2 may have been the result of the faster development of fish exposed to higher temperatures since the difference was not observed following Study 3. That is, it may be that all fish used in this investigation had the equivalent potential for developing specific signs (i.e. cataracts), but that the development of those signs was accelerated in fish exposed to higher temperatures. By Study 3, almost all fish, including the controls, had developed some signs of ill health and there was no concentration dependent increase. This indicates that the experimental fish may have had a low level bacterial infection, as stock tank fish were treated with antibiotics during this time.

The higher incidence of signs of GBT observed in fish in both control and BGS CW during the 1997 investigation may have been caused in part by excess gas pressure in the seawater used to dilute the CW; a situation that was not observed in 1998. Only fish exposed to Port Moody Arm surface water showed a significantly higher incidence of GBT than control fish. The depth change of the seawater intake from 3 m to 5m in 1998, significantly reduced the total gas pressure in both dilution seawater and therefore CW treatments, relative to 1997. During the 1997 study, control fish were periodically exposed to TGP in excess of 110% and it seems likely that excess dissolved gas (primarily oxygen) in the near surface waters of Port Moody Arm contributed to the total gas pressure of the BGS CW in that investigation.

IMPLICATIONS OF TEST RESULTS IN RELATION TO PORT MOODY ARM

There is very little information on the temporal and spatial distribution of fish in the Port Moody Arm of Burrard Inlet. However, when considering the potential effect of the BGS thermal discharge on the growth and condition of chum salmon, these topics are important considerations. The 1997 studies, conducted from June through August, did not span the entire utilization period for juvenile chum salmon in Port Moody Arm. The 1998 studies which started May 13 and were completed on August 31covered more of this period, thereby enhancing the seasonal relevance and applicability of these investigations. It has been determined that chum salmon fry may reside in the waters of Port Moody Arm as early as March or April (Hwang et al. 1994; Greenbank et al. 2001). However, our study design (including the need to acclimate hatchery-reared chum fry to Port Moody Arm seawater before the start of the first study) did not permit experimentation before mid-May. The 1998 studies extended beyond the seasonal near-shore utilization period for juvenile chum salmon. Salo (1991) stated that downstream migration occurs from February through May in southern BC. Juvenile chum salmon have been recorded as early as January in the estuary of the Fraser River (Birtwell, I. K., Fisheries and Oceans Canada, West Vancouver, BC, unpublished data), but the majority of chum salmon typically enter estuarine waters in March (Healy 1982; Macdonald and Chang 1993), and peak in April and May thereafter decreasing as they slowly (3 to 5 $km \cdot d^{-1}$) migrate to the Pacific Ocean (Simenstad and Salo 1987). However, some researchers have recorded their presence in Georgia Strait in the fall (refer to Healey 1982). Thus it may be expected that this salmonid species will utilize Port Moody Arm for a period of about 5 months and that within this period, individuals may be resident there for days to weeks (Levy et al. 1979).

Although there was a trend of increasing growth with increasing CW concentrations in the first three studies in 1998, in the fourth study there was an inverse relationship. However, it is very likely that most juvenile chum salmon would have moved offshore during the time spanned by the fourth study. It is also possible that few fish would be present during late July when the third study was conducted, at which time there was an increase in growth in fish exposed to the higher CW concentrations.

Fish presence within the BGS discharge plume has not been determined. Further, a number of questions regarding the actual behavior of chum salmon in and around the heated-water discharge remain unanswered. In controlled laboratory studies on the responses of juvenile chum salmon to thermal change, Birtwell et al. (2001a) determined a "preferred" temperature range of 13.7 °C - 17.9 °C and a 50% avoidance threshold at 20.2 °C. In addition, Birtwell et al. (2001a) determined that juvenile chum salmon would quickly enter and then exit water of potentially lethal temperatures in order to feed. Chum salmon are opportunistic and selective predatory sight feeders, which consume a variety of items that reflect abundance in fresh and salt waters (Higgs et al. 1995). Langford (1990) reviewed a number of thermal discharge studies in which both foraging and predatory fish species fed and survived in close proximity to, as well as directly in, high temperature plumes. Our studies showed an increase in fish growth up to 20 °C and a decrease in growth at temperatures beyond that. Thus the decrease in growth rate occurred around a temperature that approximated the juvenile chum salmon laboratory determined 50% avoidance response to increasing temperature.

At present, there is no information as to the availability of food in the BGS discharge plume. Salo (1991) showed that the migration rate of juvenile chum salmon in Hood Canal was partly regulated by the density of suitable food organisms. Therefore, it seems unlikely that juvenile chum salmon would continue to reside in a sub-optimal thermal environment if food supplies were inadequate, and alternative sources available. Port Moody Arm is, however, eutrophic and accordingly one may expect that food organisms may be abundant because of this feature.

SUITABILITY OF THE SHALLOW WATERS OF PORT MOODY ARM FOR GROWTH OF JUVENILE CHUM SALMON

Chum salmon juveniles are known to occupy shallow water environments for the first few weeks of their saltwater residency (Salo 1991). In order to characterize the suitability of Port Moody Arm surface waters for juvenile salmonids, we compared growth rates of chum salmon in shallow water against those obtained in deeper water (5 m) with or without the presence of BGS CW. The shallow-water treatment groups generally experienced temperature regimes similar to those in the 25% CW treatment groups. During a warm weather period coinciding with Study 3, the temperature in the shallow-water tanks more closely resembled that in the 50% CW treatments.

In Study 1, growth of fish in the shallow-water tanks was slightly less than that in the 25% CW treatment but still significantly higher than that in the controls. The only measured difference in water quality was elevated dissolved gas levels, especially dissolved oxygen which was elevated to a mean value of 130% air saturation in the shallow-water treatments but only 98% - 103% air saturation in all other treatments (Table 3). Additionally, the mean TGP level in these shallow-water treatments was 110%, which was higher than all other treatments (102.5% – 109.3% TGP) including the control groups (mean 101.6% TGP). Individual TGP values in the surface water from Port Moody Arm during Study 1 were also much more variable than those for the control or other groups (Table 3).

The slightly lower growth rates for equivalent temperatures and the increased mortality during Study 2 in the shallow-water treatments were associated with plankton blooms, high daytime dissolved oxygen and TGP levels approaching 110%. The expected, and corresponding decrease in dissolved oxygen as a consequence of phytoplankton respiratory processes that occurred at night was not examined. It is plausible that such depressions, if large, would increase the variation in dissolved oxygen (and TGP) that was recorded during daytime and further stress the experimental fish. There were significant plankton blooms during the investigation that occasionally produced turbid conditions in the shallow-water experimental tanks. Chum salmon are visual predators and impairment of their vision by highly turbid water could, in turn, affect their growth. Benfield and Minello (1995) found a significant decrease in predation rates by Gulf killifish with increased turbidity of the water; this species is also a visual predator feeding primarily on shrimp in estuarine environments.

Blooms of *Heterosigma* sp. have been implicated in the past as the likely cause of fish kills in the shallow waters near Rocky Point in the south-eastern portion of Port Moody Arm. Since the atypically high (28% and 30%) mortality in the two groups of fish held in shallow water from Port Moody Arm during Study 2 occurred over a one-day period, it is conceivable that exposure to *Heterosigma* sp. may have occurred.

It is evident that, at certain times, the water quality of shallow water from Port Moody Arm aside from the seasonally-elevated temperatures, may adversely affect the growth and survival of chum salmon. However, it is difficult to extrapolate these findings to the natural environment of Port Moody Arm wherein fish have the choice to move to different waters which may be more favorable to their survival and the maintenance of their health and fitness. From field observations the distribution of plankton, for example, in Port Moody Arm is often seen to be extremely patchy in nature. Juvenile chum salmon may avoid areas of high turbidity (due to episodic plankton blooms) and supersaturated levels of TGP in Port Moody Arm, while otherwise benefiting from the near-optimal temperatures until July and, presumably, an abundance of food. However, if upper surface waters exceed preferred temperature levels due to the discharge of BGS CW, reduced abundance in these waters may occur as the fish move to optimize metabolic function. Nevertheless, motivation to feed, in addition to responding to other cues will, seemingly, not prohibit occupancy of surface waters for brief periods (Birtwell et al. 2001a). The field experiments of McGreer and Vigers (1983) and Birtwell and Kruzynski (1989) exemplify this point.

TEMPERATURE EFFECTS ON JUVENILE CHUM SALMON AND APPLICABILITY TO OTHER SALMONIDS

Juvenile chum salmon were selected for this study due to their relative abundance and importance in Port Moody Arm. Pink salmon (*Oncorhynchus gorbuscha*) and chum salmon are both abundant species in Port Moody Arm. Although the pink salmon likely originate in the Indian River at the head of Indian Arm, several of the small streams feeding Port Moody Arm support runs of chum salmon (Greenbank et al. 2001). Coho salmon (*O. kisutch*) and cutthroat (*O. clarki clarki*) are also present in Port Moody Arm (Hwang et al. 1994) at very low numbers. Relative to other salmonid species, chum and pink salmon are the most sensitive to high temperatures based on their Ultimate and Upper Incipient Lethal Temperatures (UILT) (Brett 1952). Brett (1952) reported an UILT of 23.1 °C for juvenile chum salmon acclimated at 15 °C and an Ultimate Upper Lethal Temperature of 23.8 °C (the level that was lethal to the fish irrespective of higher acclimation temperature). Juvenile pink salmon had the same UILT following 15 °C acclimation, while juvenile coho, sockeye (Brett 1952), and chinook (Blahm and

McConnel 1970) had UILT's of 24.3 °C, 24.4 °C, and 25.0 °C respectively following their acclimation to this same temperature. At higher acclimation temperatures (20 °C and 24 °C), juvenile pink salmon had a slightly higher UILT tolerance (i.e., 23.9 °C, for both acclimation temperatures) compared to juvenile chum which had an UILT of 23.7 °C at 20 °C acclimation and 23.8 °C at 23 °C acclimation. Temperatures in this range were only recorded during August in Study 4 in the 75% CW treatment in which all fish died.

Considering their relative abundance compared to the other salmonid species which frequent the waters of Port Moody Arm, and their demonstrated sensitivity to high temperatures, we consider that our examination of the effects of the BGS CW discharge on chum salmon represents an assessment that is also probably applicable for other juvenile salmonids that utilize these waters.

SPATIAL EXTENT OF 'ZONE OF EFFECT'

Table 16 illustrates the possible relationship between the BGS CW, time of year, and growth of juvenile chum salmon. Exposure to BGS CW resulted in both positive and negative effects on growth depending on the time of year. In the 1997 report we undertook a preliminary assessment of the impact of CW based on a residual chlorine dilution model (Webb, 1992). More recent investigations describing the thermal environment of Port Moody Arm suggests that the area within Port Moody Arm affected by the BGS heated-water discharge (as measured by the increase in water temperature over background) could be smaller than that previously estimated (Taylor et al. 2001). Furthermore, it may not be realistic to extrapolate the results of these studies to delineated habitat areas. Although Taylor et al. (2001) found maximum short term (i.e. 0.5 hrs) temperature increases of 1 to 3 °C which are attributable to BGS operation, monthly means indicated temperature increases on the order of 0.5 °C above background. Based on our 16 - 20-day experimental growth measurements, the latter differences in temperature if applied to our data would not be expected to result in measurable differences in fish growth among treatments. Although fish growth correlated well with 16 - 20-day mean temperatures, fish in the experiments were routinely exposed to short-term fluctuations in water temperature of 5 °C and occasionally up to 10 °C.

Birtwell et al. (1998, 2001a, 2001b) explored the behavior of juvenile chum salmon in Port Moody Arm and under simulated marine conditions at the West Vancouver Laboratory. In laboratory studies, some chum salmon avoided temperatures which were lower than those found in the 50% CW treatments. However, the fish would also briefly venture into water which surpassed the UILTs for this species in order to feed. We deduce, therefore, that juvenile chum salmon will likely feed in areas of the BGS CW mixing zone in which CW concentrations are ≥ 50%, unless food is absent. Whether the fish would reside in the initial mixing zone long enough to realize a positive or negative effect on growth is unknown. However, juvenile chum salmon will grow well (and possibly better) during the majority of their expected near-shore residency period in concentrations of CW up to, and including 50%, providing food is not limited, and temperature not stressful.

SUMMARY AND CONCLUSIONS

Over the two year study, this investigation examined the effect of BGS CW on the survival, condition, and growth of juvenile saltwater-adapted chum salmon. The overall effect of this heated-water discharge on wild juvenile chum salmon would appear to be small. Reduced growth rates were determined, in the laboratory, for those experimental fish in ≥ 50% concentrations of CW and at elevated temperatures that tend to occur, during the portion of the year, outside of the expected chum salmon utilization period in Port Moody Arm. However, a benefit to the growth of juvenile chum salmon could accrue during spring and early summer due to an elevation in temperature more favorable to metabolic function relative to temperature in waters not influenced by the BGS CW discharge plume.

It is our conclusion that the combination of the thermal avoidance behavior determined by Birtwell et al. (1998, 2001a), the documented expected utilization period of juvenile chum salmon in Port Moody Arm (MacDonald and Chang 1993; Hwang et al. 1994; Greenbank et al. 2001) as well as the results of this investigation, provide sufficient evidence to indicate that the discharge of CW from the BGS will have a minimal effect on populations of juvenile chum salmon.

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Table 1. Time of year, exposure duration and number and size range[1] of fish for each study in 1998.

	Study 1	Study 2	Study 3	Study 4
Dates	May 11 - June 2	June 8 - June 31	July 13 - Aug 4	Aug 7 - Aug 31
Exposure Duration (d)	20	20	20	16
No. Fish / Tank	50	50	40	30
Weight Range (g)	1.0 - 2.5	5.0 - 7.0	7.0 - 10.0	14.0 - 21.0

1. Size range of fish at the start of each study.

Table 2. Test concentrations, flow rates and treatment assignments in 1998.

	Flow Rates (L·min^{-1})		Treatment Assignments (Tank No.)			
Treatment (% CW)	SW	CW	Study 1	Study 2	Study 3	Study 4
0%	15	0	8	8	8	8
0%	15	0	12	12	12	12
6%	14.1	0.9	10	10	10	-
12%	13.2	1.8	1	1	1	-
25%	11.25	3.75	2	2	2	2
35%	9.75	5.25	11	11	11	11
50%	7.5	7.5	3	3	3	3
50%	7.5	7.5	4	4	4	4
50% CW: Low TGP	7.5	7.5	5	5	5	5
50% CW: Low TGP	7.5	7.5	6	6	6	6
65%	5.25	9.75	-	-	-	1
75%	3.75	11.25	-	-	-	10
Shallow	15	15	7	7	7	7
Shallow	15	15	9	9	9	9

\- Not Tested

Table 3. Study 1 (May 11 - June 2, 1998) - water quality parameter mean values with standard deviations.

Treatment	Temp.(°C)		pH		Salinity (‰)		DO ($mg \cdot L^{-1}$)		DO (% Sat.)		TGP (delta p)		TGP (% Sat.)	
% Cooling Water	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
0%	12.5	0.5	7.5	0.1	24.8	0.2	9.3	1.7	102.6	17.6	13	5	101.7	0.7
0%	12.5	0.5	7.5	0.1	24.9	0.2	9.2	1.5	101.5	16.4	11	5	101.5	0.6
6%	13.0	0.5	7.5	0.1	24.9	0.2	9.2	1.4	101.8	15.8	19	6	102.5	0.7
12%	13.5	0.5	7.5	0.1	24.8	0.2	9.0	1.2	101.6	13.6	26	7	103.3	0.9
25%	14.8	0.6	7.5	0.1	24.9	0.2	8.8	1.5	101.8	16.1	39	10	105.1	1.2
35%	16.1	0.8	7.5	0.1	24.9	0.1	8.6	1.3	100.2	13.6	53	13	106.9	1.8
50%	17.6	1.2	7.5	0.1	24.9	0.1	8.3	1.2	101.3	15.0	71	22	109.2	2.9
50%	18.0	1.0	7.5	0.1	24.9	0.2	8.2	1.2	101.0	14.4	71	21	109.3	2.7
50% CW: Low TGP	17.7	1.6	7.5	0.1	24.9	0.2	8.2	1.2	99.6	12.7	30	13	103.8	1.7
50% CW: Low TGP	17.8	1.9	7.5	0.1	24.9	0.1	8.0	0.9	98.0	10.2	32	18	104.1	2.3
Shallow	14.6	1.0	7.8	0.2	22.5	0.7	11.5	2.6	130.1	30.1	74	32	109.7	4.2
Shallow	14.6	1.0	7.9	0.2	22.5	0.7	11.5	2.4	128.4	27.1	76	36	110.0	4.7

Table 4. Study 2 (June 8 - June 31, 1998) - water quality parameter mean values with standard deviations.

Treatment	Temp.(°C)		pH		Salinity (‰)		DO ($mg \cdot L^{-1}$)		DO (% Sat.)		TGP (delta p)		TGP (% Sat.)	
% Cooling Water	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
0%	14.2	0.7	7.5	0.1	24.6	0.4	8.8	1.4	99.9	16.4	2	3	100.3	0.4
0%	14.1	0.7	7.5	0.2	24.5	0.4	8.8	1.4	100.0	13.9	3	3	100.4	0.4
6%	14.5	0.7	7.5	0.1	24.5	0.4	8.9	1.7	101.1	18.1	10	5	101.3	0.6
12%	15.0	0.7	7.5	0.1	24.4	0.4	8.4	0.8	96.8	8.6	15	5	102.0	0.7
25%	16.0	0.8	7.5	0.1	24.5	0.5	8.4	1.4	99.2	16.7	28	9	103.8	1.2
35%	17.2	1.0	7.5	0.1	24.5	0.3	8.2	1.4	98.8	14.0	44	12	105.8	1.7
50%	18.5	1.3	7.4	0.1	24.5	0.4	7.7	1.0	94.7	11.2	61	19	108.0	2.5
50%	18.4	1.4	7.4	0.1	24.5	0.4	7.8	0.9	95.5	12.2	61	19	108.0	2.4
50% CW: Low TGP	18.5	1.4	7.5	0.1	24.5	0.4	7.7	0.9	94.5	10.8	21	7	102.8	1.0
50% CW: Low TGP	18.6	1.5	7.4	0.1	24.5	0.4	7.8	1.0	96.0	11.5	26	8	103.3	1.0
Shallow	16.5	1.2	7.8	0.2	23.1	1.0	10.1	1.9	119.4	24.1	60	20	107.8	2.6
Shallow	16.5	1.2	7.8	0.2	23.2	1.0	10.0	1.9	119.3	23.1	62	21	108.1	2.8

Table 5. Study 3 (July 13 - August 4, 1998) - water quality parameter mean values with standard deviations.

Treatment	Temp.(°C)		pH		Salinity (‰)		DO (mg·L^{-1})		DO (% Sat.)		TGP (delta p)		TGP (% Sat.)	
% Cooling Water	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
0%	16.1	1.5	7.4	0.1	25.1	0.3	7.8	0.5	91.7	5.4	-2	3	99.7	0.4
0%	16.1	1.5	7.5	0.2	25.0	0.3	7.8	0.5	92.6	5.0	-2	3	99.7	0.4
6%	16.5	1.4	7.4	0.2	25.0	0.3	7.7	0.4	91.9	4.9	3	4	100.4	0.5
12%	17.0	1.5	7.4	0.1	25.0	0.3	7.6	0.4	91.0	4.8	8	3	101.1	0.4
25%	18.0	1.4	7.4	0.1	25.0	0.3	7.3	0.4	89.4	4.8	21	6	102.8	0.8
35%	19.0	1.5	7.4	0.1	25.0	0.3	7.1	0.4	89.2	5.2	34	8	104.5	1.1
50%	20.3	1.5	7.4	0.1	25.0	0.3	6.7	0.4	85.5	4.8	51	13	106.7	1.7
50%	20.2	1.4	7.4	0.1	25.0	0.3	6.7	0.4	85.8	5.2	48	13	106.2	1.6
50% CW: Low TGP	20.3	1.5	7.4	0.1	25.0	0.3	7.0	0.4	90.4	5.4	15	5	102.0	0.6
50% CW: Low TGP	20.6	1.5	7.4	0.1	25.0	0.3	7.0	0.4	90.3	5.4	17	5	102.2	0.6
Shallow	20.0	1.5	7.8	0.2	23.4	0.8	9.7	1.6	122.0	18.5	82	28	110.7	3.7
Shallow	20.0	1.5	7.8	0.2	23.4	0.8	9.7	1.6	122.2	18.3	83	27	110.8	3.5

Table 6. Study 4 (August 7 - August 31, 1998) - water quality parameter mean values with standard deviations.

Treatment	Temp.(°C)		pH		Salinity (‰)		DO (mg·L-1)		DO (% Sat.)		TGP (delta p)		TGP (% Sat.)	
% Cooling Water	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
0%	16.6	0.8	7.1	0.1	25.5	0.3	7.0	0.4	83.4	5.2	-3.2	4.0	99.6	0.5
0%	16.6	0.8	7.1	0.1	25.5	0.4	7.0	0.4	84.1	5.0	-5.1	4.6	99.3	0.6
25%	18.6	0.7	7.2	0.2	25.5	0.3	6.6	0.4	82.3	4.9	18.4	6.7	102.4	0.9
35%	19.8	0.8	7.2	0.2	25.5	0.3	6.3	0.4	80.3	4.7	32.2	8.0	104.2	1.0
50%	21.2	0.7	7.2	0.2	25.5	0.3	6.0	0.3	79.0	4.6	51.2	9.2	106.7	1.2
50%	21.2	0.8	7.2	0.2	25.5	0.3	6.1	0.3	79.3	4.7	52.2	11.4	106.8	1.5
65%	22.6	0.8	7.2	0.1	25.5	0.3	5.9	0.3	78.7	5.4	73.7	14.3	109.6	1.9
75%	23.4	1.0	7.2	0.1	25.5	0.4	6.0	0.4	81.6	5.4	87.6	16.8	111.5	2.2
50% CW:Low TGP	21.2	0.7	7.2	0.2	25.5	0.3	6.4	0.2	83.4	3.7	16.4	4.1	102.1	0.5
50% CW:Low TGP	22.1	1.6	7.2	0.1	25.5	0.3	6.4	0.3	84.5	3.8	27.5	15.4	103.6	2.0
Shallow	18.7	1.7	7.4	0.2	25.0	0.3	7.5	1.5	93.7	20.7	43.7	36.7	105.7	4.8
Shallow	18.7	1.7	7.4	0.2	25.0	0.3	7.6	1.5	95.2	21.8	45.6	36.3	106.0	4.7

Table 7. Fish mortality by treatment for each study in 1998.

Treatment	Study 1		Study 2		Study 3		Study 4	
% Cooling Water	No. Dead	% Mortality	No. Dead	% Mortality	No. Dead	% Mortality	No. Dead	% Mortality
0%	0	0	0	0	0	0	0	0.0
0%	0	0	0	0	0	0	0	0.0
6%	0	0	0	0	0	0	-	-
12%	0	0	0	0	0	0	-	-
25%	0	0	0	0	1	2.5	0	0.0
35%	0	0	0	0	0	0	0	0.0
50%	8	16	0	0	0	0	2	6.7
50%	0	0	0	0	0	0	5	16.7
65%	-	-	-	-	-	-	4	13.3
75%	-	-	-	-	-	-	30	100.0
50% CW: Low TGP	0	0	0	0	0	0	1	3.3
50% CW: Low TGP	0	0	0	0	0	0	3	10.0
Shallow	0	0	15	30	1	2.5	0	0.0
Shallow	0	0	14	28	1	2.5	0	0.0

- Not Tested

Table 8. The mean number of signs of ill health in control and treated groups of juvenile chum salmon in 1998.

STUDY 1

TREATMENT	TOTAL NUMBER OF FISH	NUMBER OF SIGNS OF ILL HEALTH PER FISH	SD
CONTROL	20	0.100	0.308
6% COOLING WATER	20	0.200	0.422
12% COOLING WATER	10	0.100	0.316
25% COOLING WATER	10	0.100	0.316
35% COOLING WATER	10	0.100	0.316
50% COOLING WATER	14	0.357	0.633
50% COOLING WATER:LOW TGP	18	0.111	0.323
SHALLOW WATER	18	0.722	0.878

STUDY 2

TREATMENT	TOTAL NUMBER OF FISH	NUMBER OF SIGNS OF ILL HEALTH PER FISH	SD
CONTROL	15	0.200	0.414
6% COOLING WATER	9	0.444	0.527
12% COOLING WATER	9	0.556	0.527
25% COOLING WATER	9	0.556	0.726
35% COOLING WATER	9	0.778	0.667
50% COOLING WATER	16	0.563	0.629
50% COOLING WATER:LOW TGP	14	1.143	0.966
SHALLOW WATER	12	0.750	0.754

STUDY 3

TREATMENT	TOTAL NUMBER OF FISH	NUMBER OF SIGNS OF ILL HEALTH PER FISH	SD
CONTROL	13	2.308	0.855
6% COOLING WATER	7	1.714	1.380
12% COOLING WATER	7	1.000	0.577
25% COOLING WATER	7	1.714	1.113
35% COOLING WATER	7	1.857	0.690
50% COOLING WATER	12	2.583	0.900
50% COOLING WATER:LOW TGP	14	2.643	0.633
SHALLOW WATER	13	2.538	1.127

(dark shaded box) indicates significantly higher number of signs of ill health per fish than in controls ($p<0.05$)

(light dotted box) indicates significantly lower number of signs of ill health per fish than in controls ($p<0.05$)

Table 9. The mean number of signs of GBT in control and treated groups of juvenile chum salmon in 1998.

STUDY 1

TREATMENT	TOTAL NUMBER OF FISH	NUMBER OF SIGNS OF GBT PER FISH	SD
CONTROL	20	0.100	0.308
6% COOLING WATER	10	0.000	0.000
12% COOLING WATER	10	0.100	0.316
25% COOLING WATER	10	0.000	0.000
35% COOLING WATER	10	0.100	0.316
50% COOLING WATER	14	0.286	0.611
50% COOLING WATER:LOW TGP	18	0.000	0.000
SHALLOW WATER	18	0.722	0.895

STUDY 2

TREATMENT	TOTAL NUMBER OF FISH	NUMBER OF SIGNS OF GBT PER FISH	SD
CONTROL	15	0.067	0.258
6% COOLING WATER	9	0.333	0.500
12% COOLING WATER	9	0.222	0.441
25% COOLING WATER	9	0.111	0.333
35% COOLING WATER	9	0.222	0.441
50% COOLING WATER	16	0.125	0.342
50% COOLING WATER:LOW TGP	14	0.071	0.243
SHALLOW WATER	12	0.083	0.289

STUDY 3

TREATMENT	TOTAL NUMBER OF FISH	NUMBER OF SIGNS OF GBT PER FISH	SD
CONTROL	13	0.001	0.001
6% COOLING WATER	7	0.286	0.756
12% COOLING WATER	7	0.001	0.001
25% COOLING WATER	7	0.143	0.378
35% COOLING WATER	7	0.001	0.001
50% COOLING WATER	12	0.083	0.289
50% COOLING WATER:LOW TGP	14	0.001	0.001
SHALLOW WATER	13	0.154	0.376

[shaded box] indicates significantly higher number of signs of GBT per fish than in controls ($p<0.05$)

Table 10. Initial and final mean weights, and growth of control and treated groups of juvenile chum salmon in 1998.

TREATMENT	STUDY 1			STUDY 2			STUDY 3			STUDY 4		
	Initial Weight (g)	Final Weight (g)	Growth (g)	Initial Weight (g)	Final Weight (g)	Growth (g)	Initial Weight (g)	Final Weight (g)	Growth (g)	Initial Weight (g)	Final Weight (g)	Growth (g)
CONTROL	1.82	4.24	2.42	6.20	11.29	5.09	8.47	19.70	11.23	17.70	29.60	11.90
CONTROL	1.81	4.11	2.31	6.26	11.21	4.95	8.69	18.82	10.13	17.20	29.30	12.10
6% COOLING WATER	1.76	4.02	2.26	6.21	11.24	5.03	8.45	21.38	12.93	-	-	-
12% COOLING WATER	1.82	4.29	2.47	6.14	11.90	5.76	8.53	21.70	13.17	-	-	-
25% COOLING WATER	1.81	5.21	3.40	6.14	12.78	6.64	8.49	22.08	13.59	17.30	28.00	10.70
35% COOLING WATER	1.75	4.91	3.16	6.13	12.98	6.85	8.65	21.83	13.18	17.60	29.90	12.30
50% COOLING WATER	1.80	4.91	3.11	6.14	13.14	7.00	8.42	22.50	14.08	18.00	26.60	8.60
50% COOLING WATER	1.72	4.91	3.19	6.14	13.64	7.50	8.55	23.27	14.72	17.60	28.00	10.40
65% COOLING WATER	-	-	-	-	-	-	-	-	-	17.20	22.20	5.00
75% COOLING WATER	-	-	-	-	-	-	-	-	-	18.00	-	-
50% CW:LOW TGP	1.80	4.67	2.87	6.30	13.68	7.38	8.21	18.09	9.88	18.00	28.20	10.20
50% CW:LOW TGP	1.79	5.04	3.25	6.07	12.38	6.31	8.65	18.74	10.09	17.40	21.10	3.70
SHALLOW WATER	1.78	4.52	2.75	6.26	11.77	5.51	8.60	20.78	12.18	17.80	27.20	9.40
SHALLOW WATER	1.79	4.70	2.91	5.98	11.65	5.67	8.23	19.77	11.54	17.50	26.40	8.90

- Not Tested

Table 11. Specific growth rate (%W per day) as a function of treatment in 1998.

Treatment	Study 1	Study 2	Study 3	Study 4
Contol	4.0	2.9	4.2	3.2
Contol	3.9	2.8	3.9	3.3
6% CW	3.9	2.8	4.6	
12% CW	4.1	3.2	4.7	
25% CW	5.0	3.5	4.8	3.0
35% CW	4.9	3.6	4.6	3.3
50% CW	4.8	3.6	4.9	2.6
50% CW	5.0	3.8	5.0	2.6
65% CW				1.6
75% CW				fish died
50% CW: Low TGP	4.5	3.7	4.0	2.8
50% CW: Low TGP	4.9	3.4	3.9	1.2*
Shallow Water	4.5	3.0	4.4	2.4
Shallow Water	4.6	3.2	4.4	2.9

* Mechanical failure in water delivery system

1. Specific Growth Rate: $\%\text{wet weight/day} = \frac{\ln W_1 - \ln W_0}{t} \times 100$

where: W_1 = mean end weight (g)
W_0 = mean initial weight (g)
t = time (days)

Table 12. P-Values generated in 1998 from ANOVA (≤0.05) for all growth rates compared to control groups 1 and 2.

	Study 1 Controls		Study 2 Controls		Study 3 Controls		Study 4 Controls	
Treatments	1	2	1	2	1	2	1	2
6% CW	ns	ns	ns	ns	0.001	0.000		
12% CW	ns	ns	0.036	0.014	0.000	0.000		
25% CW	0.000	0.000	0.000	0.000	0.000	0.000	ns	ns
35% CW	0.000	0.000	0.000	0.000	0.000	0.000	ns	ns
50% CW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50% CW	0.000	0.000	0.000	0.000	0.000	0.000	ns	ns
65% CW							0.000	0.000
75% CW							fish died	
50% CW: Low TGP	0.000	0.000	0.000	0.000	0.008	ns	ns	0.036
50% CW: Low TGP	0.000	0.000	0.000	0.000	0.026	ns	0.000	0.000
Shallow Water	0.019	0.001	ns	ns	ns	0.000	0.004	0.002
Shallow Water	0.000	0.000	ns	0.042	ns	0.006	0.001	0.000

ns — Not significantly different from the control group
Treatment group significantly larger than control
Treatment group significantly smaller than control
Treatment group not included in this experiment

Table 13. R^2 values for linear and polynmial functions describing growth versus mean temperature in 1998.

	Main Dilution Series[1]		All Treatments[2]	
	Linear	Polynomial	Linear	Polynomial
Study 1	0.75	0.87	0.66	0.80
Study 2	0.86	0.91	0.68	0.69
Study 3	0.62	0.71	0.01	0.43
Study 4	0.69	0.93	0.53	0.63

1. Main dilution series did not include the shallow water and 50 % CW: Low TGP treatments.
2. All treatments included the shallow water and 50 % CW: Low TGP treatments.

Table 14. R^2 values for linear regression of growth rates by study vs all water quality variables in 1998.

	n	Water Quality Variables: Temp (°C)		TGP (delta p)		DO (mg·L^{-1})		DO (% Sat)		pH		Salinity (‰)	
		R^2 Value	P-Value	R^2 Value	P-Value	R^2 Value	P-Value	R^2 Value	P-Value	R^2 Value	P-Value	R^2 Value	P-Value
Study No. 1 - All[1]	12	0.660	0.001	0.379	0.030	0.084	0.360	0.003	0.860	0.004	0.850	0.001	0.930
Study No. 1 - main[2]	8	0.725	0.007	0.737	0.006	0.712	0.008	0.346	0.130	0.150	0.340	0.364	0.110
Study No. 2 - All	12	0.732	0.000	0.295	0.067	0.458	0.016	0.184	0.160	0.103	0.310	0.048	0.490
Study No. 2 - main	8	0.893	0.000	0.897	0.000	0.871	0.000	0.566	0.030	0.649	0.016	0.164	0.320
Study No. 3 - All	12	0.003	0.860	0.106	0.302	0.037	0.550	0.030	0.590	0.020	0.660	0.005	0.830
Study No. 3 - main	8	0.621	0.020	0.610	0.020	0.635	0.020	0.630	0.020	0.687	0.010	0.068	0.530
Study No. 4 - All	11	0.530	0.010	0.291	0.090	0.126	0.280	0.004	0.850	0.002	0.890	0.002	0.890
Study No. 4 - main	7	0.692	0.020	0.736	0.010	0.596	0.040	0.537	0.060	0.149	0.390	0.314	0.190
Study No. 2-97	10	0.553	0.010	0.496	0.020	0.372	0.060	0.043	0.570	0.236	0.150	0.787	0.000
Study No. 3-97	10	0.871	0.000	0.720	0.001	0.058	0.500	0.761	0.000	0.681	0.003	0.598	0.008

1. All treatments included.
2. Main series only, 50 % CW: Low TGP and Shallow water treatments excluded.

Shaded areas indicate significant relationships ($p < 0.05$) between growth rates and the associated water quality variable.

Table 15. Linear and multiple regression statistics for mean values of temperature, TGP and dissolved oxygen vs growth rates for each study in 1998.

	Variables	Linear Regression R^2 Value	Linear Regression P-Value	Multiple Regression R^2 Value	Multiple Regression Significance F	Multiple Regression Independent P-Values
Study 1	Temperature	0.660	0.001	0.706	0.004	0.011
	TGP	0.379	0.030			0.267
Study 2	Temperature	0.732	0.000	0.732	0.003	0.004
	TGP	0.295	0.067			0.967
Study 3	Temperature	0.003	0.860	0.154	0.470	0.490
	TGP	0.106	0.302			0.236
Study 4	Temperature	0.530	0.010	0.532	0.048	0.077
	TGP	0.291	0.090			0.847

	Variables	Linear Regression R^2 Value	Linear Regression P-Value	Multiple Regression R^2 Value	Multiple Regression Significance F	Multiple Regression Independent P-Values
Study 1	Temperature	0.660	0.001	0.375	0.006	0.002
	Dissolved Oxygen	0.084	0.360			0.542
Study 2	Temperature	0.732	0.000	0.813	0.001	0.003
	Dissolved Oxygen	0.458	0.016			0.080
Study 3	Temperature	0.003	0.860	0.039	0.835	0.887
	Dissolved Oxygen	0.037	0.550			0.575
Study 4	Temperature	0.530	0.010	0.629	0.019	0.011
	Dissolved Oxygen	0.126	0.280			0.183

	Variables	Linear Regression R^2 Value	Linear Regression P-Value	Multiple Regression R^2 Value	Multiple Regression Significance F	Multiple Regression Independent P-Values
Study 1	Dissolved Oxygen	0.084	0.360	0.691	0.005	0.015
	TGP	0.379	0.030			0.002
Study 2	Dissolved Oxygen	0.458	0.016	0.863	0.000	0.000
	TGP	0.295	0.067			0.001
Study 3	Dissolved Oxygen	0.037	0.550	0.301	0.198	0.146
	TGP	0.106	0.302			0.098
Study 4	Dissolved Oxygen	0.596	0.040	0.321	0.212	0.568
	TGP	0.291	0.090			0.168

Table 16. Interaction matrix for BGS cooling water and juvenile chum salmon in Port Moody Arm.*

1998 Experimental Timing			Study 1	Study 2	Study 3	Study 4
Calendar Month	March	April	May	June	July	August
Juvenile Chum Salmon in Port Moody Arm	Yes	Yes	Yes	Decreasing[1]	Unlikely[1]	No[1]
Influence of Cooling Water on Fish Growth	Unknown	Potentially Beneficial	Beneficial (1998 Results)	Beneficial (1998 Results)	1998 Results 1997 Results	Detrimental (97-98 Results)
BGS - Chum Salmon Growth Interaction	Unknown Interaction[2]	May be Positive[2]	Positive Interaction	Positive Interaction	Interaction Unlikely[3]	No Interaction[4]
PMA - Surface Waters: Effect on Fish Growth[5]	No Information	No Information	Equal or better than Controls[5]	Better than Controls[5]	Slightly better than Controls[5]	Worse than Controls[5]
Effect on Fish Health[5]	Presumed Acceptable	Presumed Acceptable	Marginal (GBT Signs)[6]	Direct Mortality[6]	Mortality Threshold[6]	No Mortality Observed[6]

1 - Unpublished DFO data report - Hwang, Clark, and Naito 1994
2 - Important factors include food availability and heat tolerance of fry
3 - Fish most likely in deeper water, unlikely to be in Port Moody Arm
4 - Most unlikely juvenile chum still in Port Moody Arm at >150mm FL
5 - 1998 Growth data shallow water treatments vs controls
6 - 1998 Observed signs of ill health and/or direct mortality

* assumption that rather than avoid heated sea water, fish will hold in the plume for extended periods, and that food within the discharge plume is not limiting to fish growth.

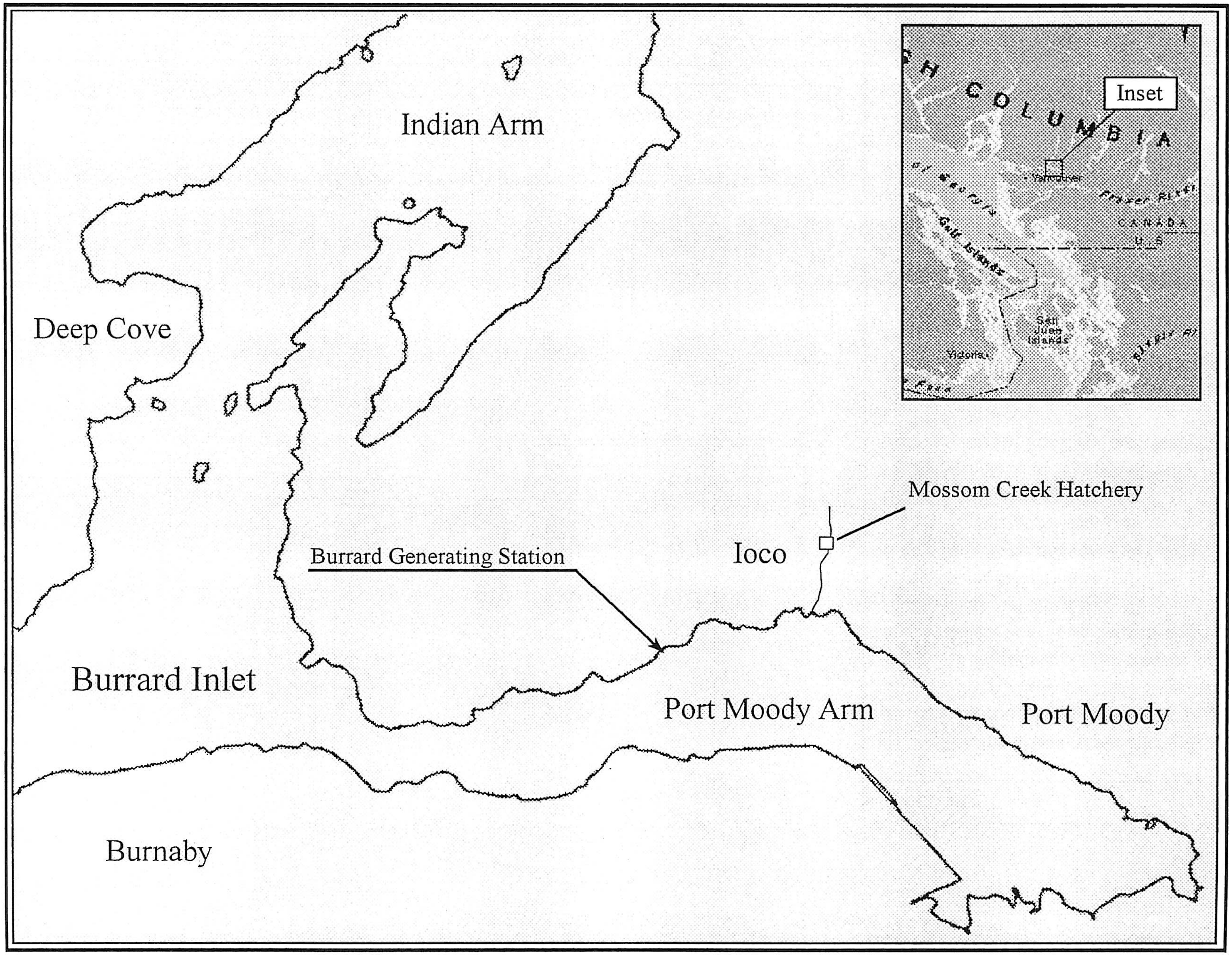


Figure 1. Location of Burrard Generating Station on Port Moody Arm, British Columbia.

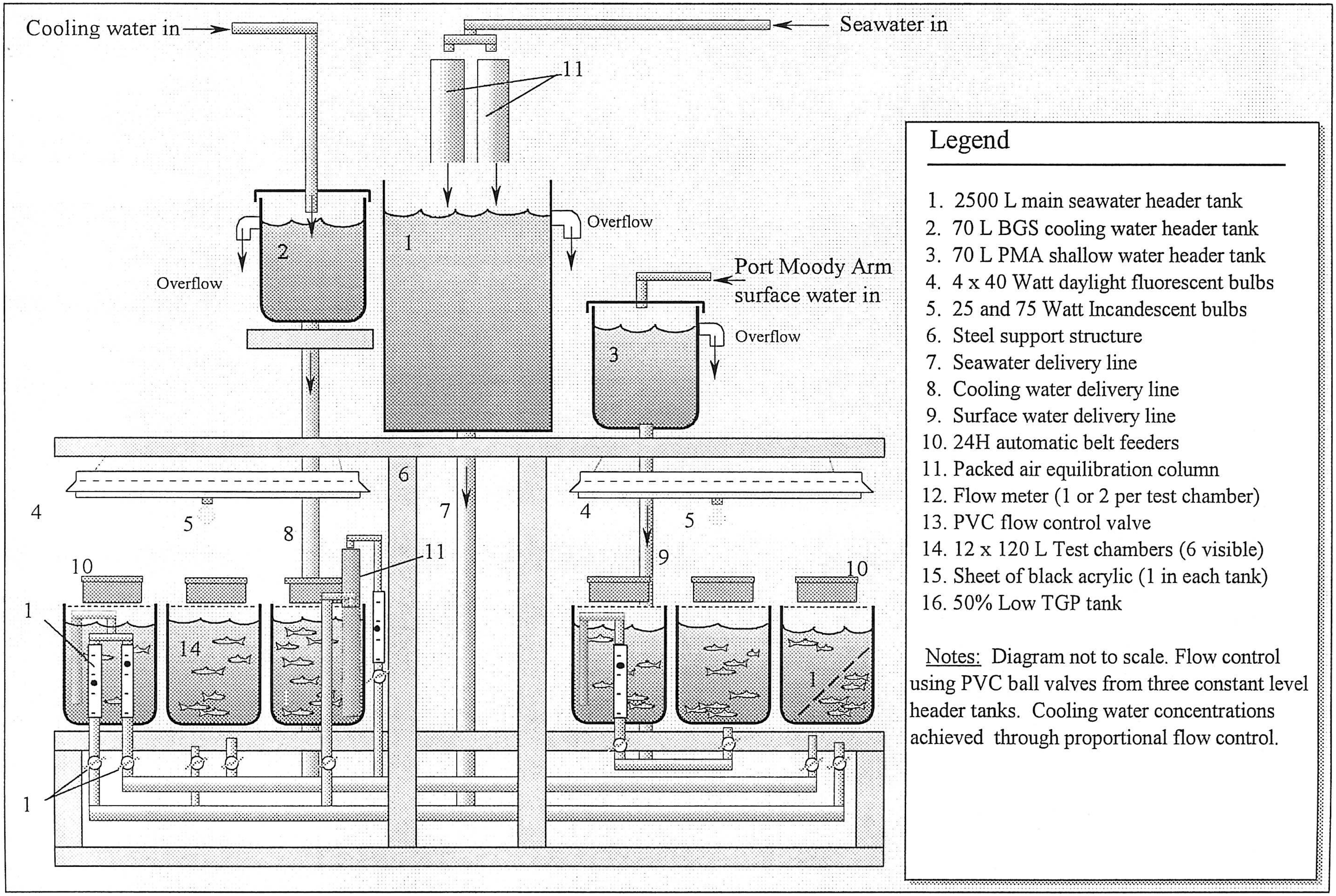


Figure 2. Schematic representation of test apparatus (1998 version).

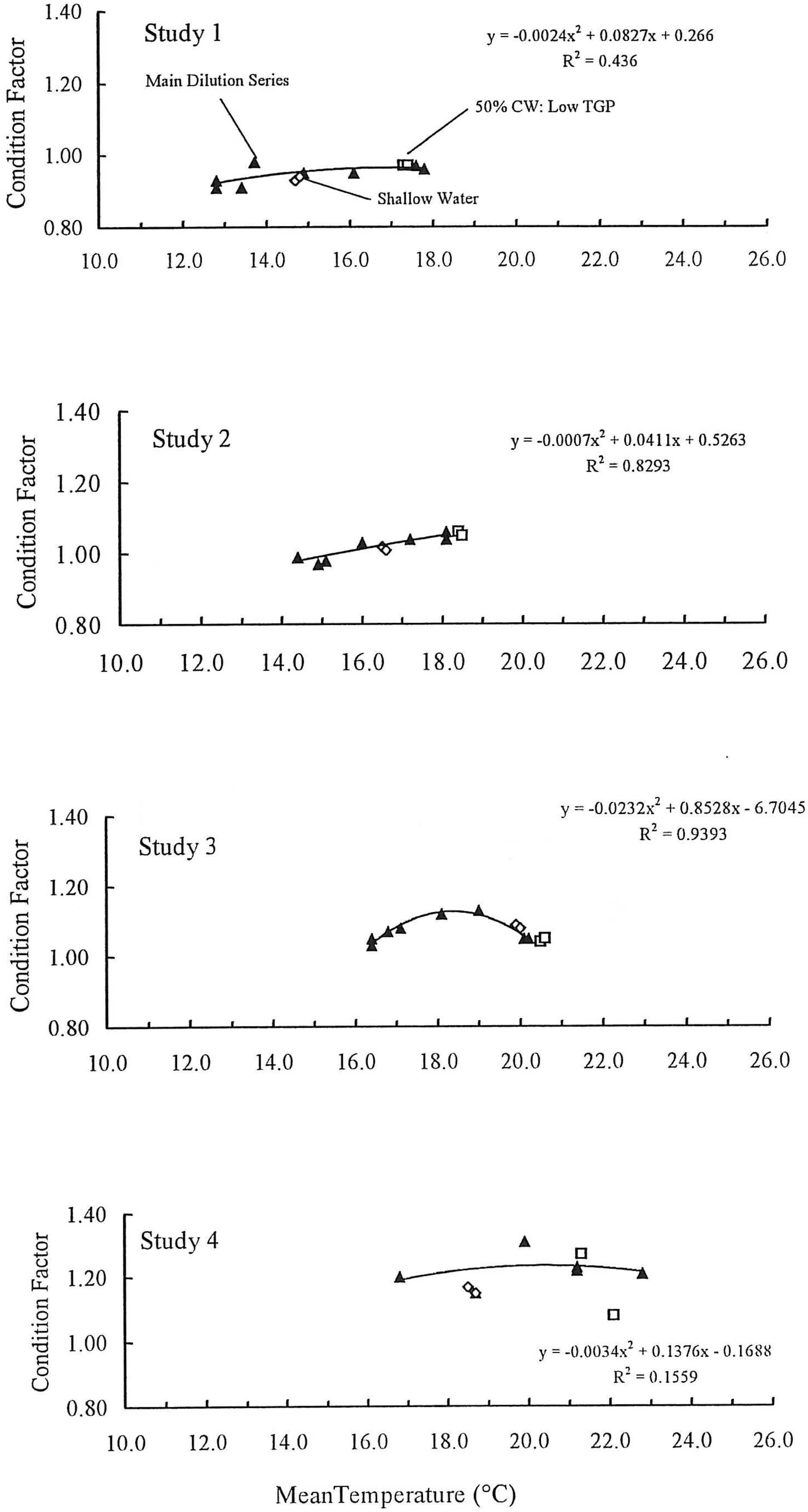


Figure 3. The effect of mean exposure temperature on condition factor in 1998.

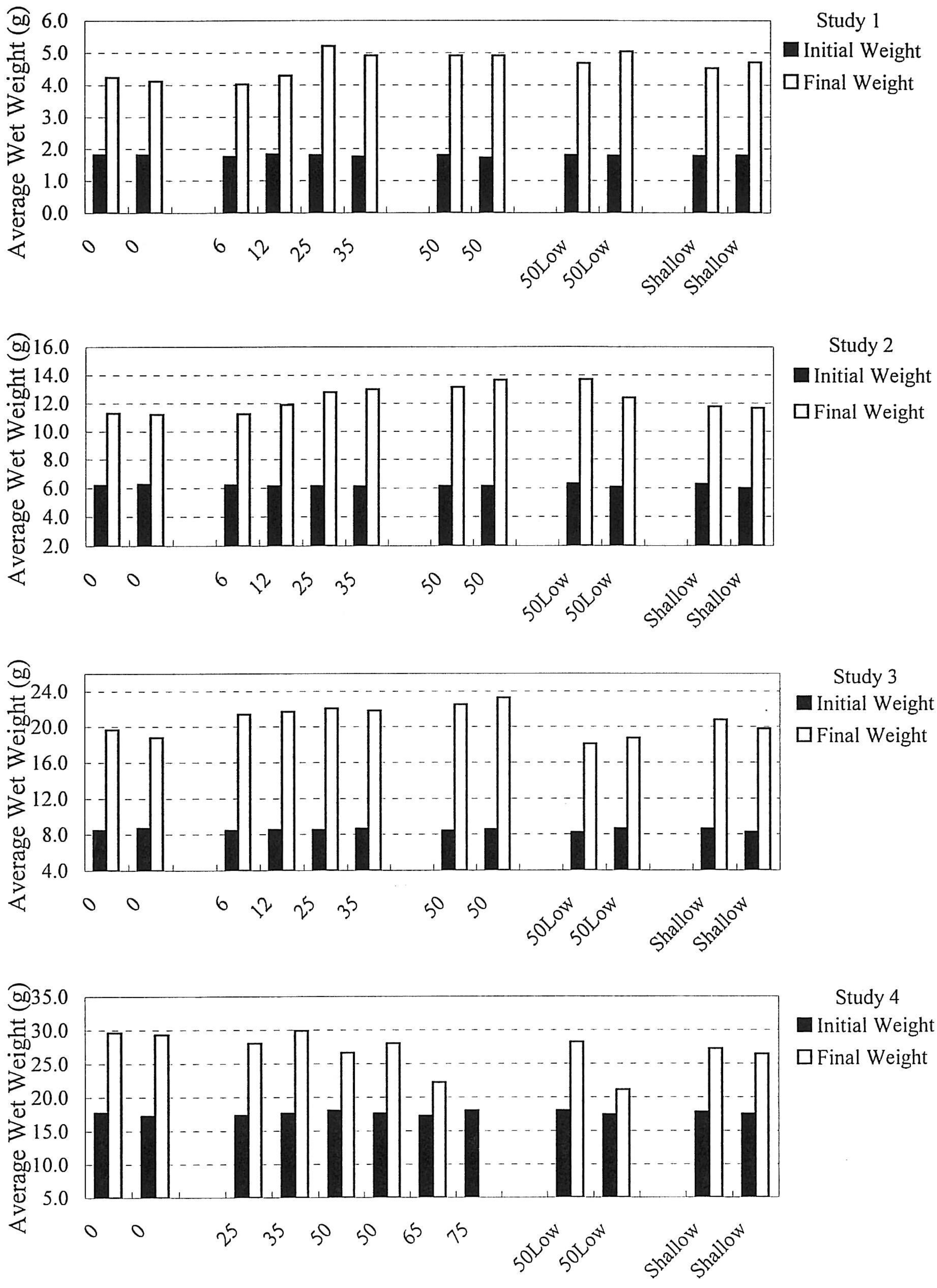


Figure 4. Initial and final weights of fish for each study in 1998.

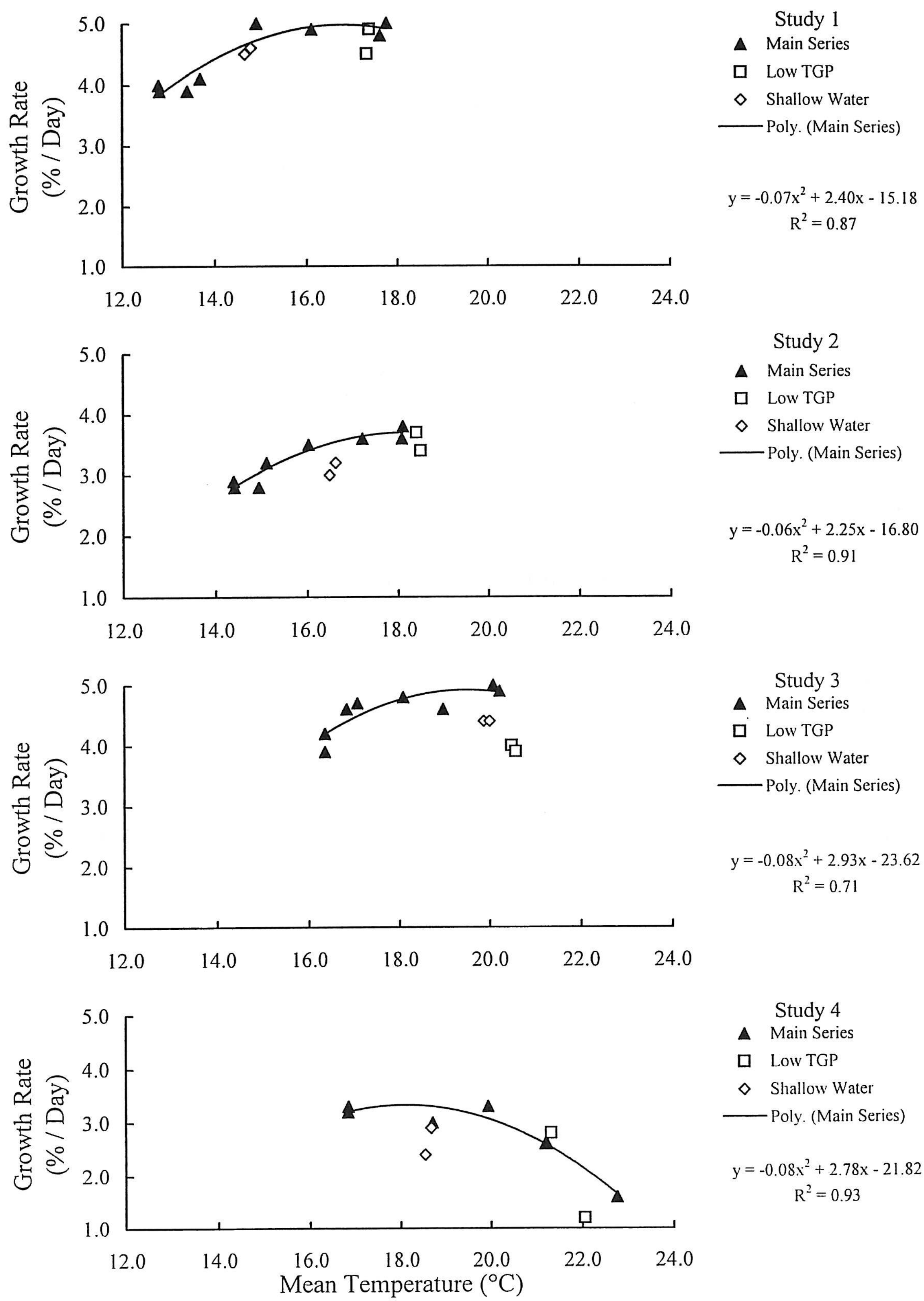


Figure 5. Growth rate (% per day) vs mean temperature in 1998.

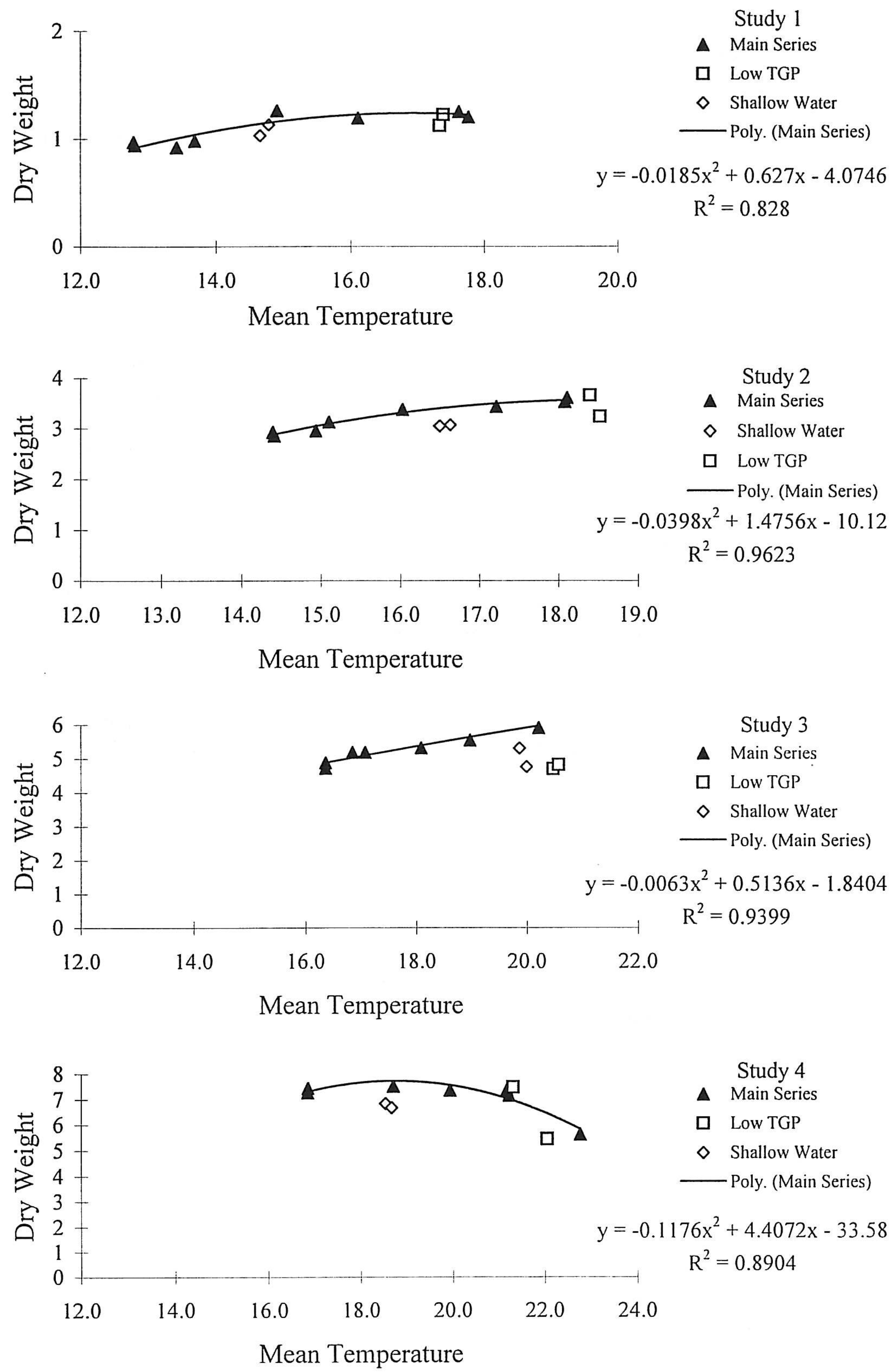
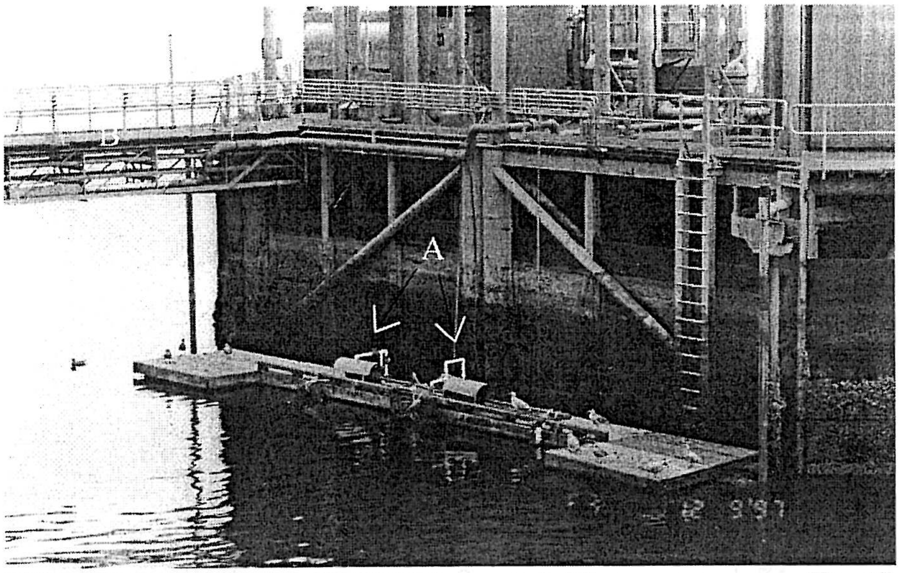


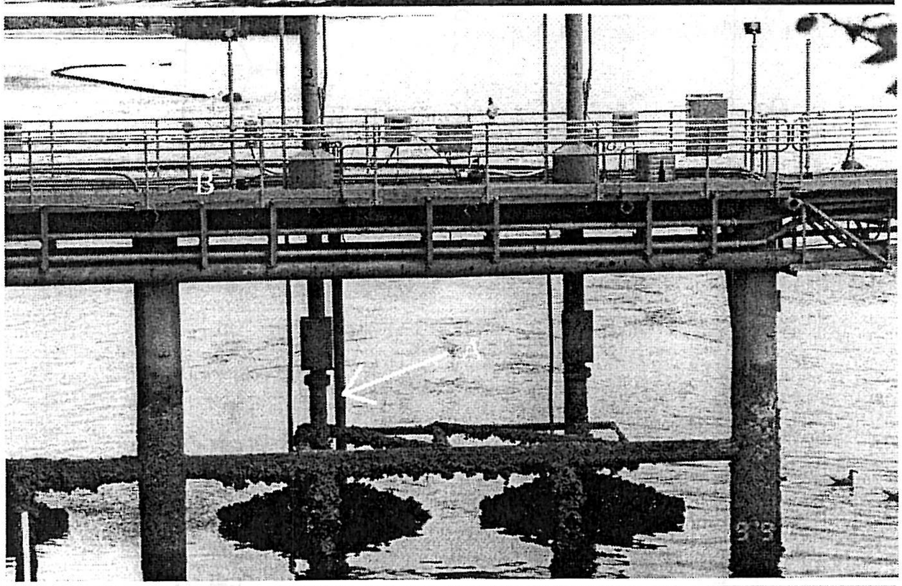
Figure 6. Dry weights (g) vs mean temperature (°C) in 1998.



Photograph 1. Seawater pumps located on offshore works

A. Seawater supply pumps located on a floating dock at the offshore works.

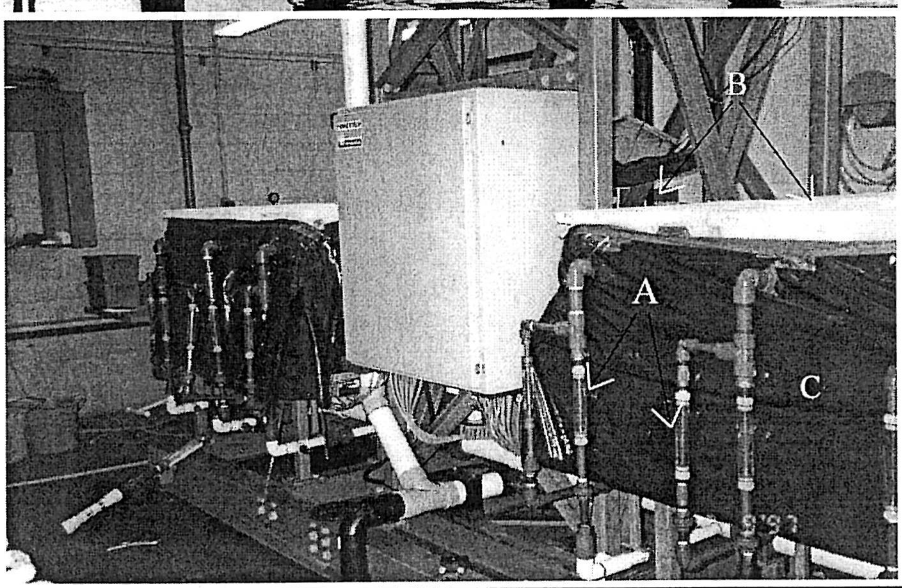
B. Offshore catwalk.



Photograph 2. Still well location

A. Cooling water delivery pump still well location. The cooling water delivery pump is located at mid-pipe depth directly downstream of cooling water discharge.

B. Offshore catwalk.



Photograph 3. Test apparatus.

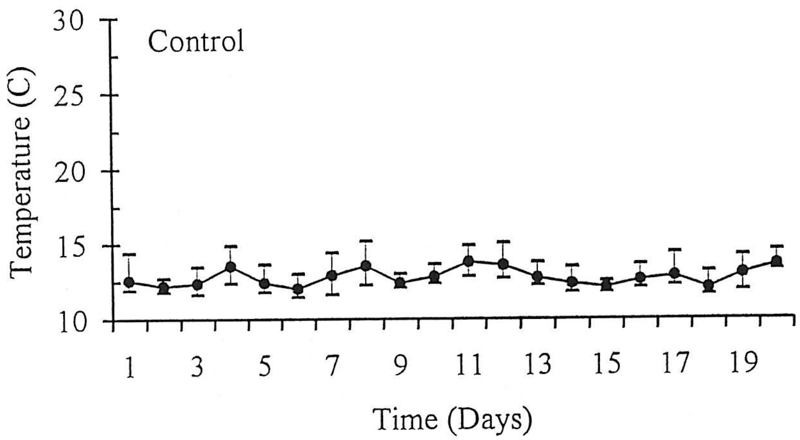
A. Cooling water and seawater delivery line flow meters.

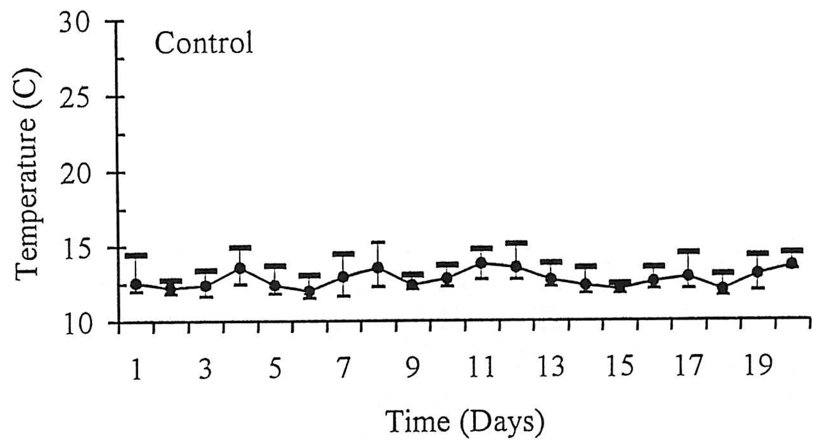
B. 130 L. experimental fish tanks.

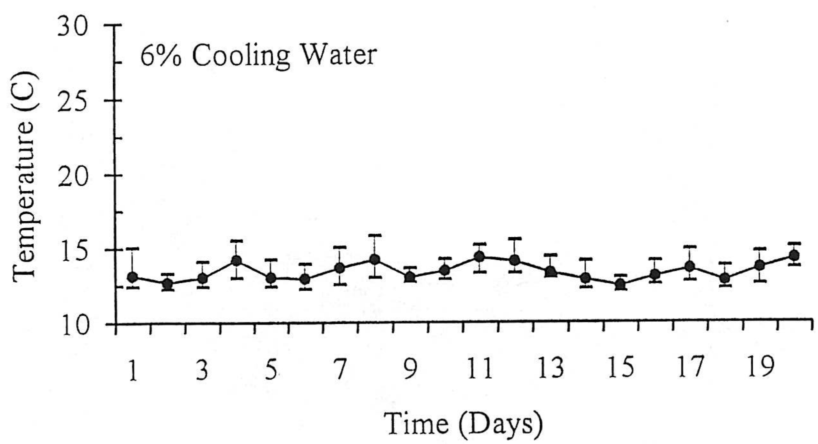
C. Side covering (balck poly.) to reduce fish stress caused by shadows cast across tank sidewalls.

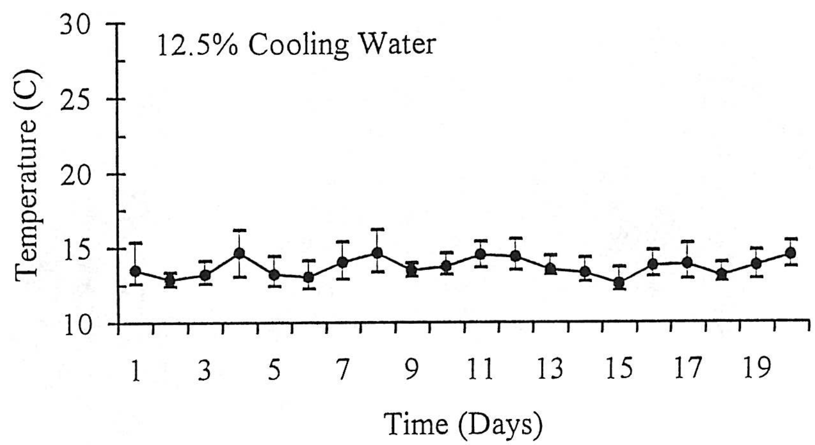
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment.

Study 1 - May 11-June 2, 1998



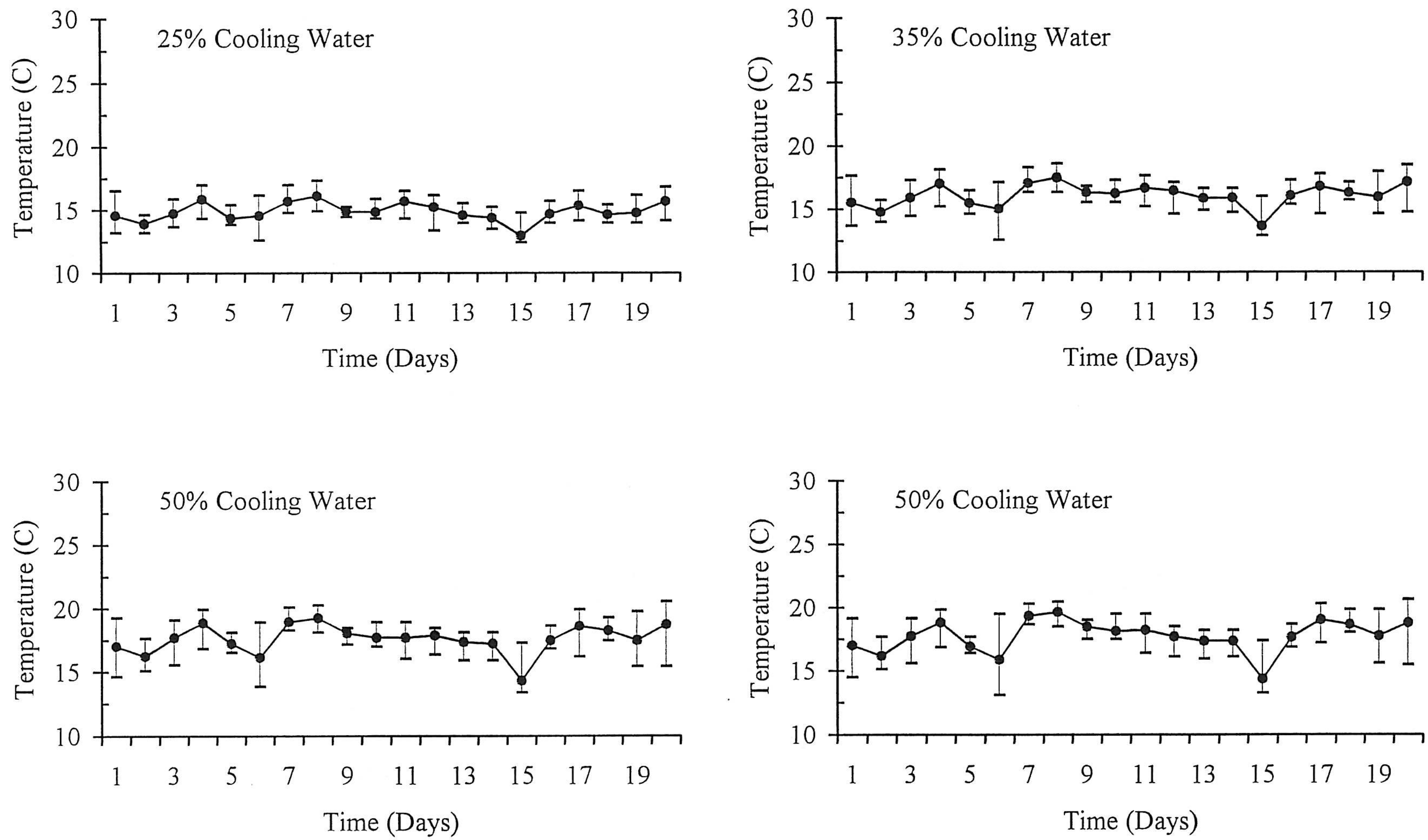






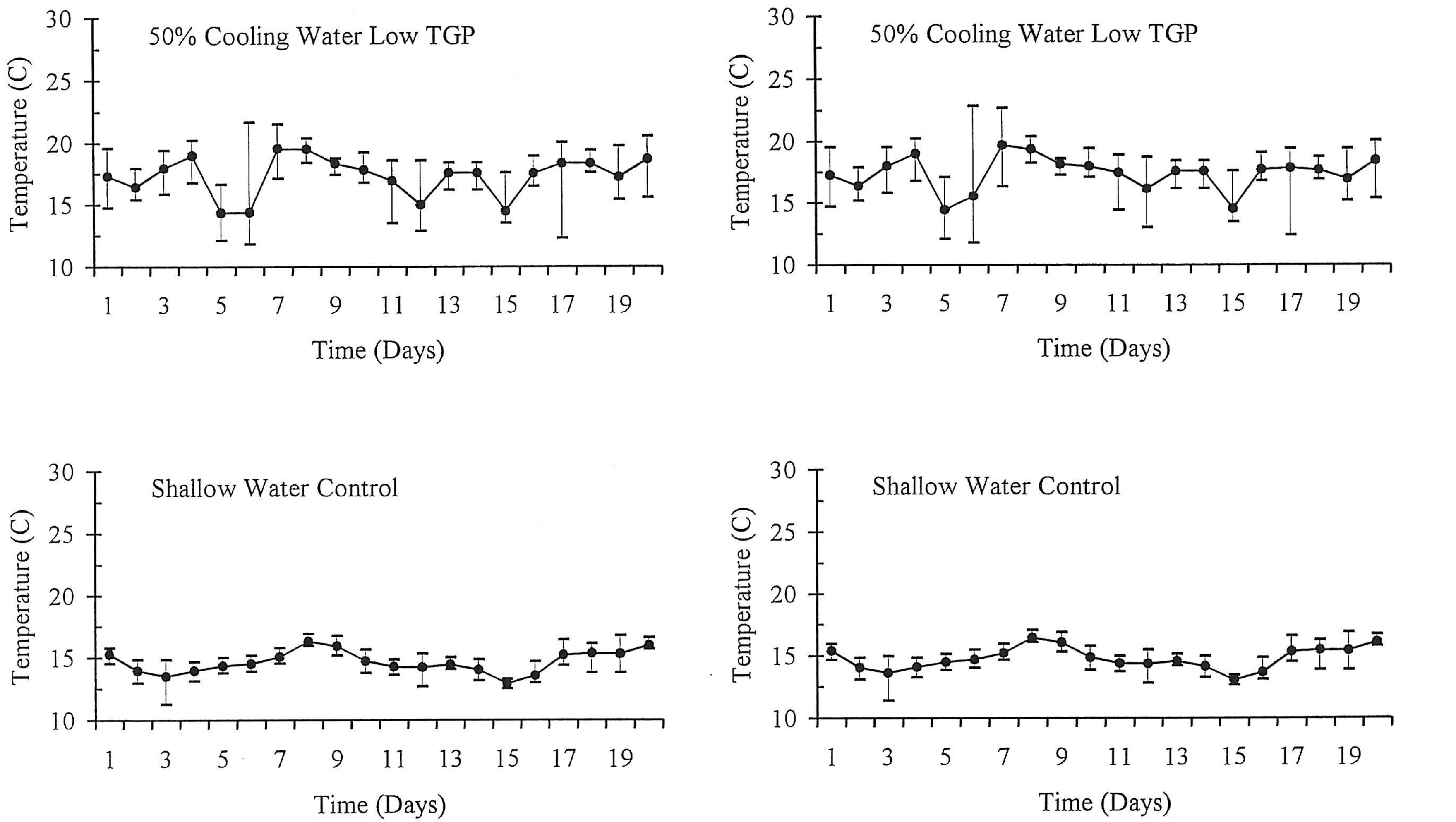
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment (cont.).

Study 1 - May 11-June 2, 1998



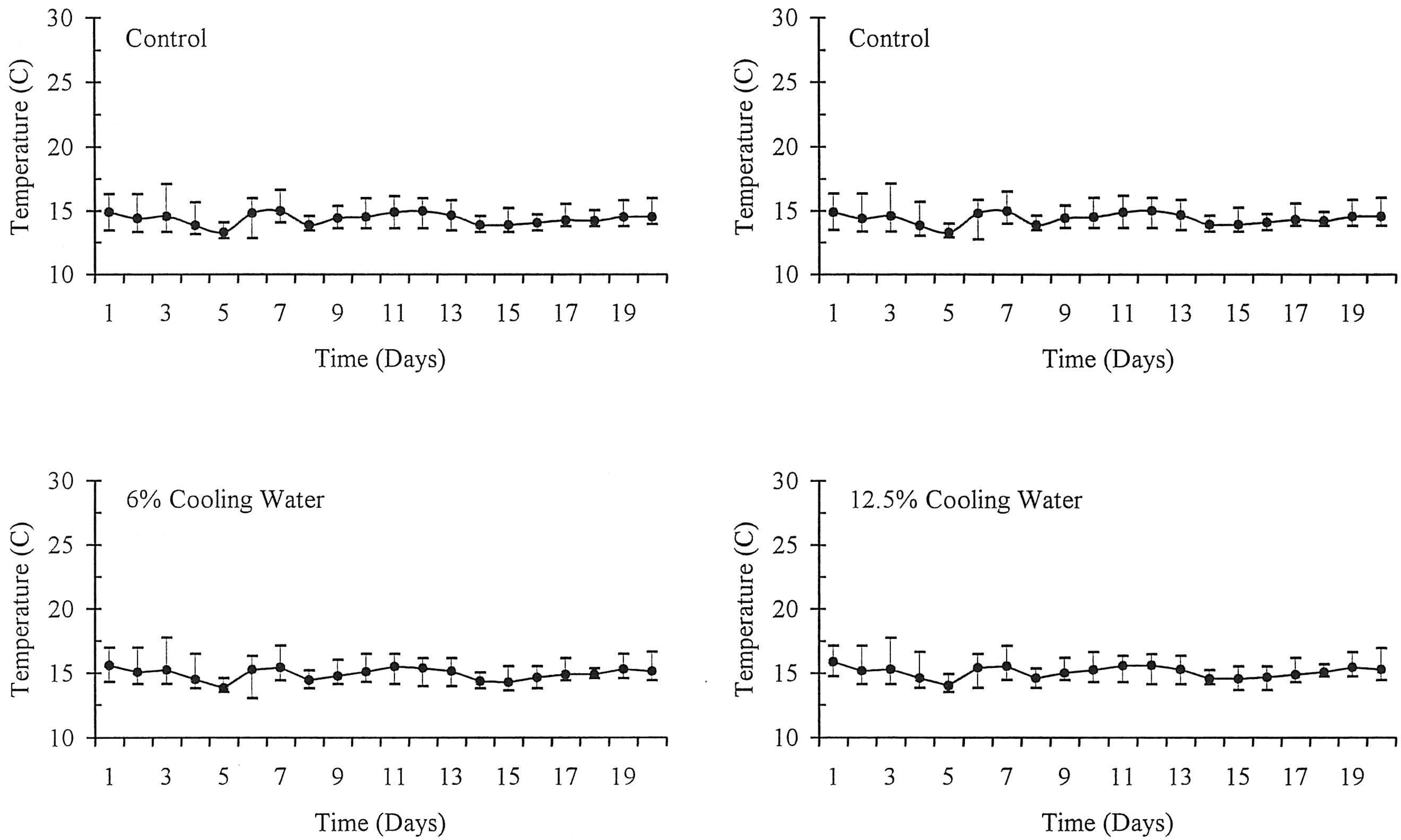
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment (cont.).

Study 1 - May 11-June 2, 1998



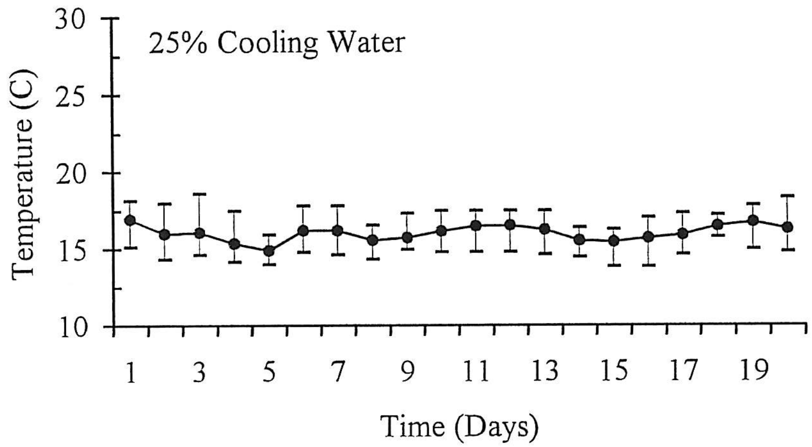
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment (cont.).

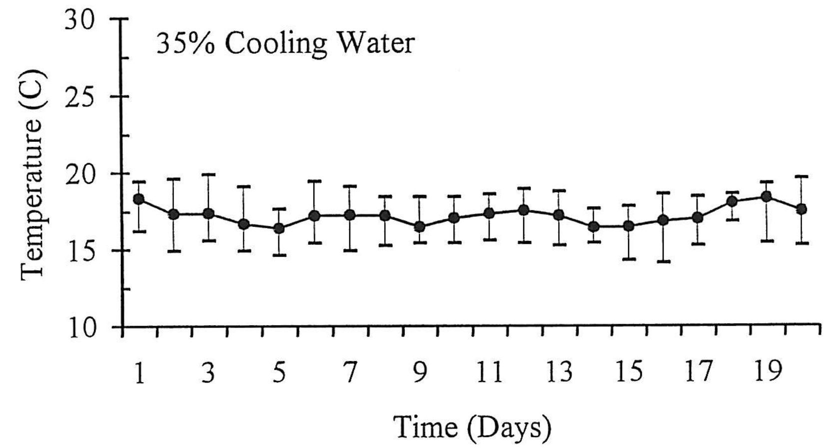
Study 2 - June 8-June 31, 1998

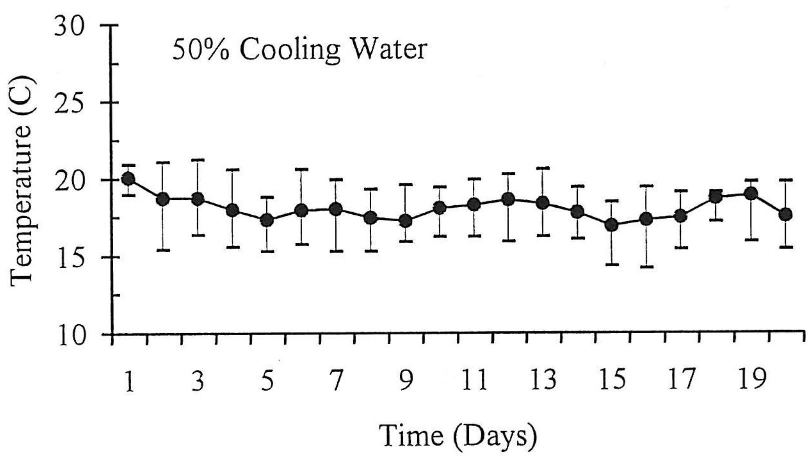


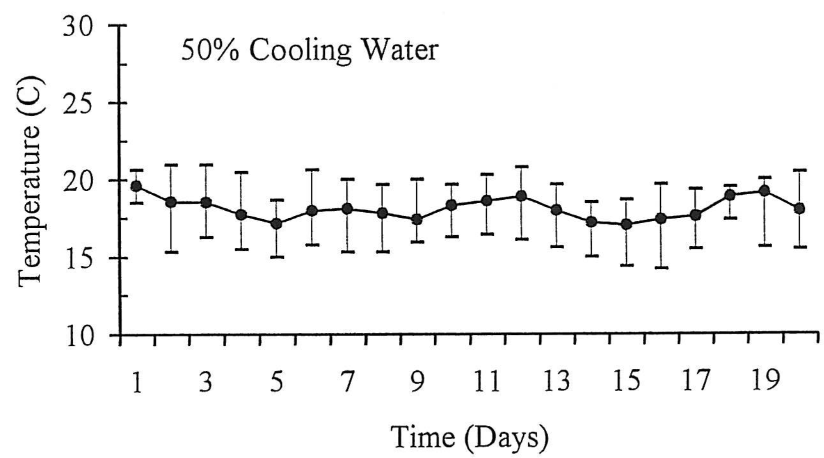
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment (cont.).

Study 2 - June 8-June 31, 1998



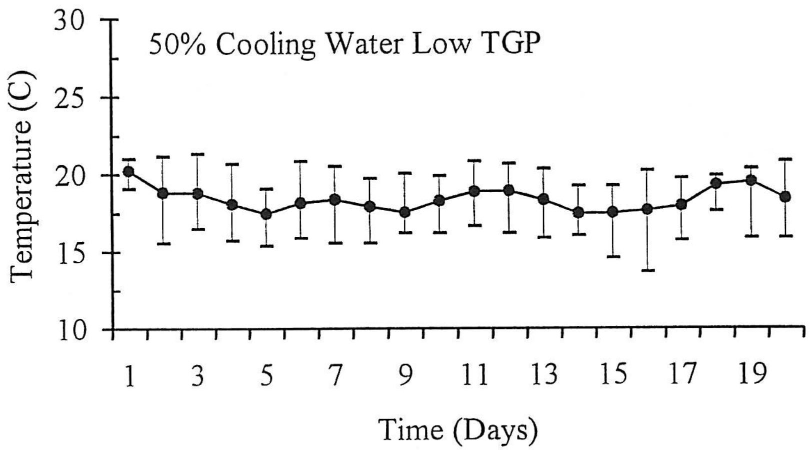


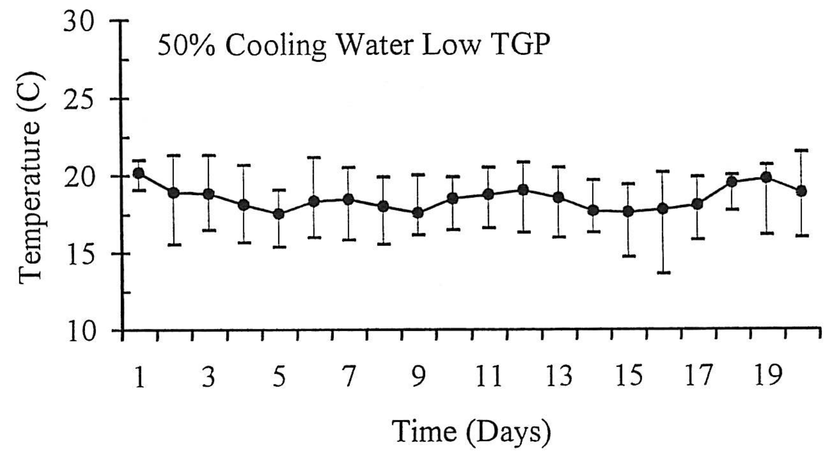


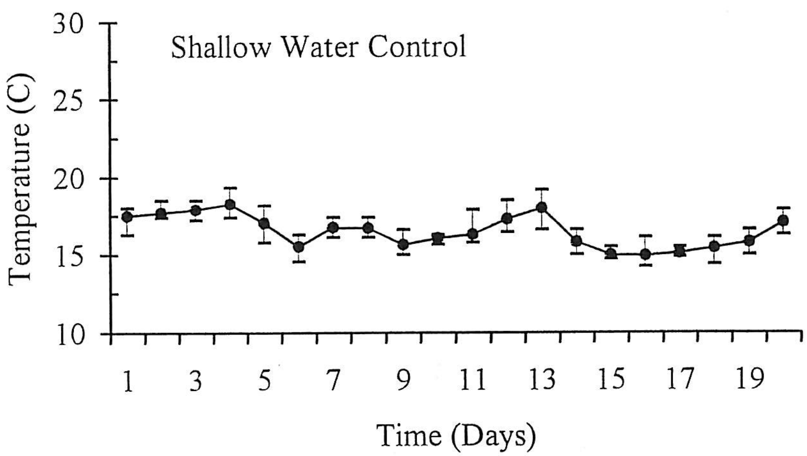


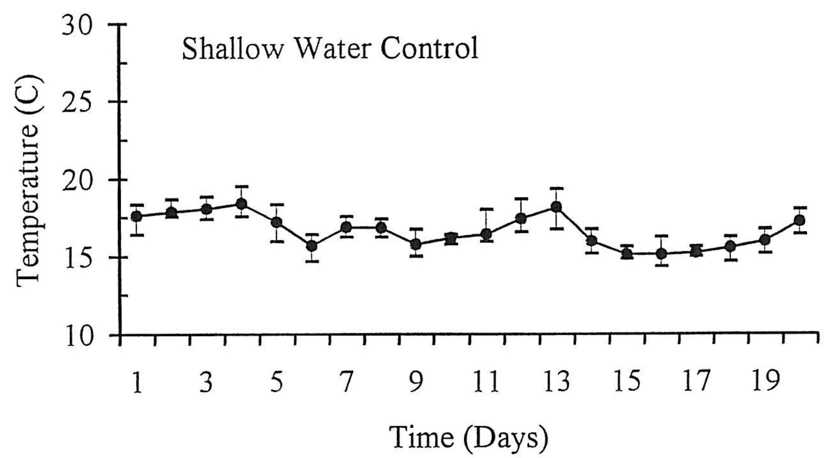
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment (cont.).

Study 2 - June 8-June 31, 1998



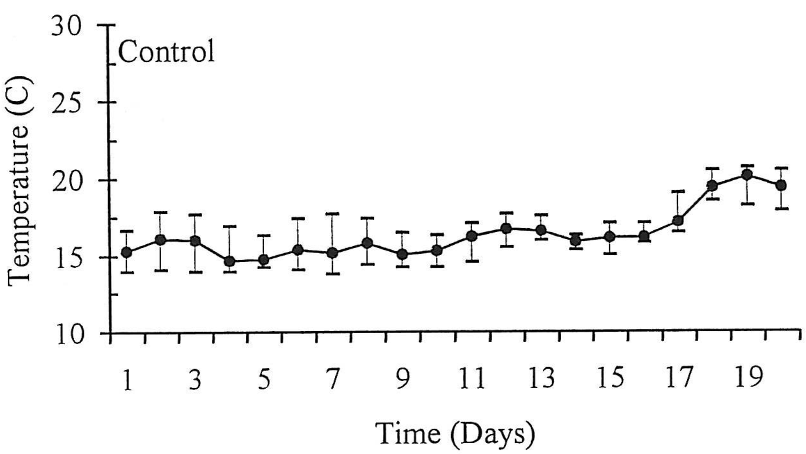


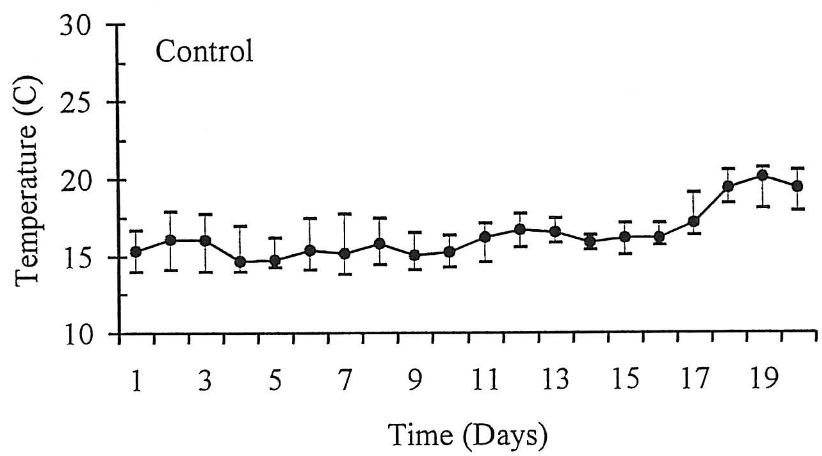


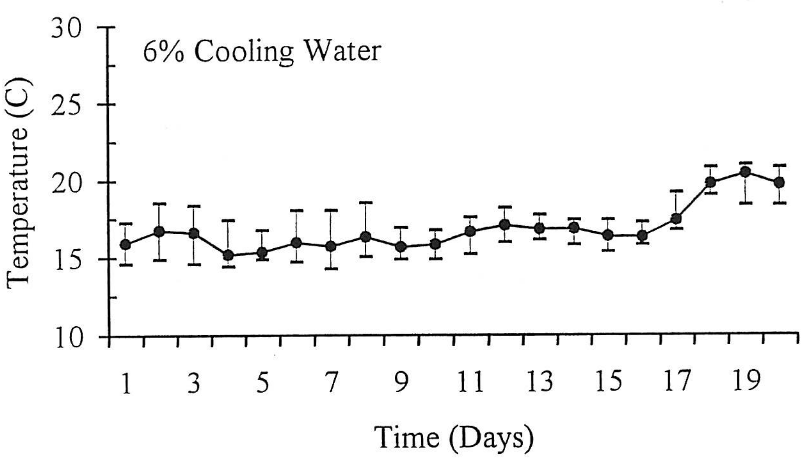


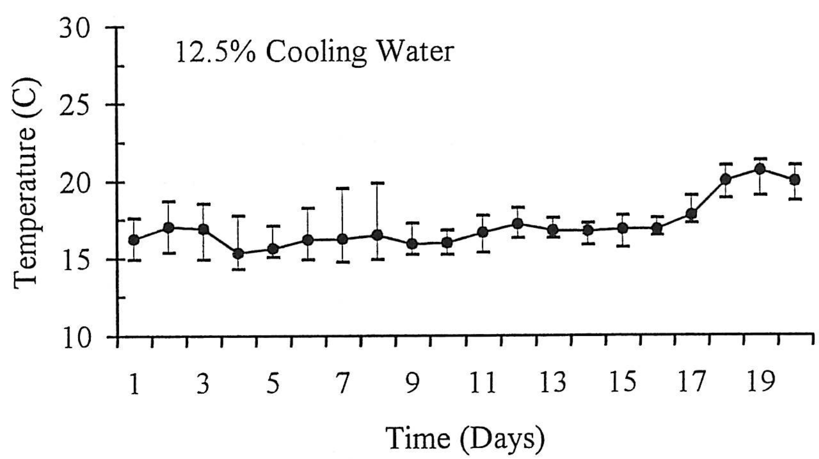
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment (cont.).

Study 3 - July 13-August 4, 1998



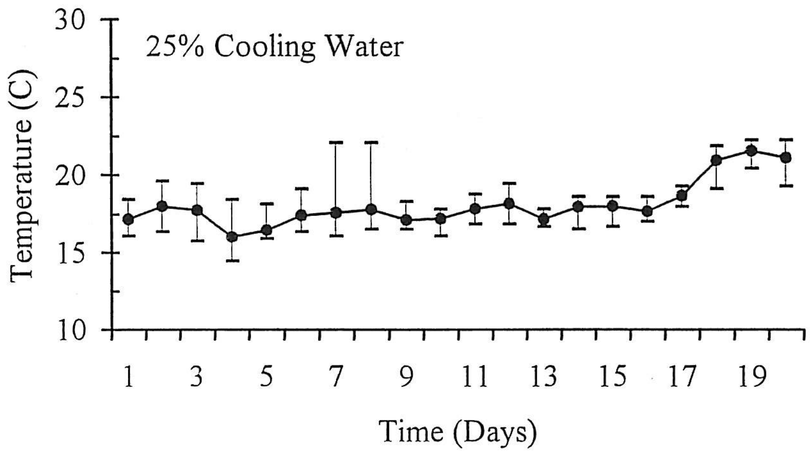


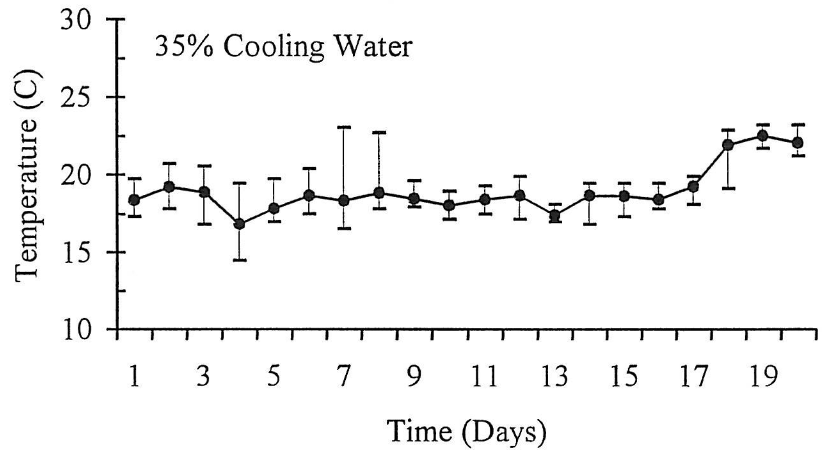


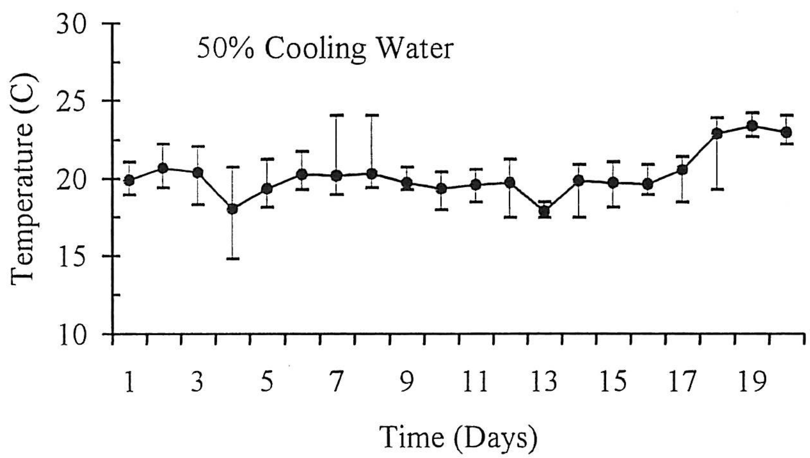


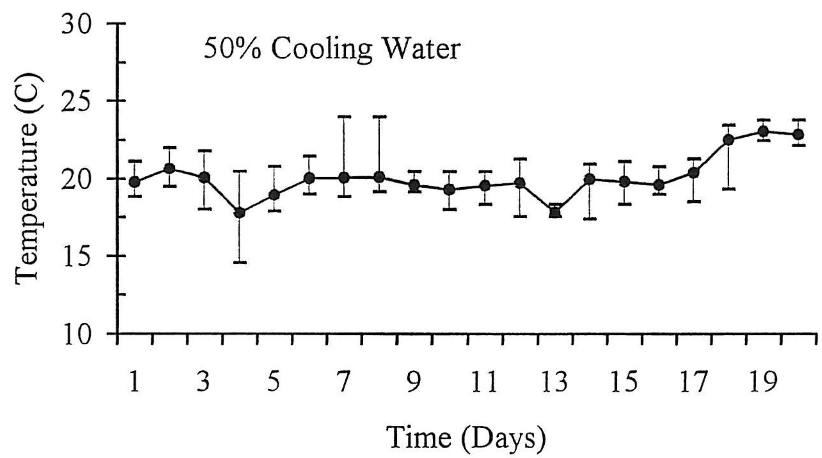
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment (cont.).

Study 3 - July 13-August 4, 1998



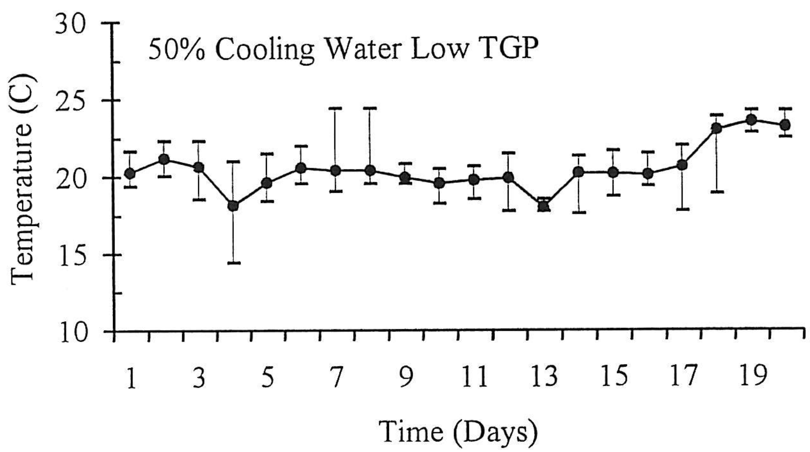


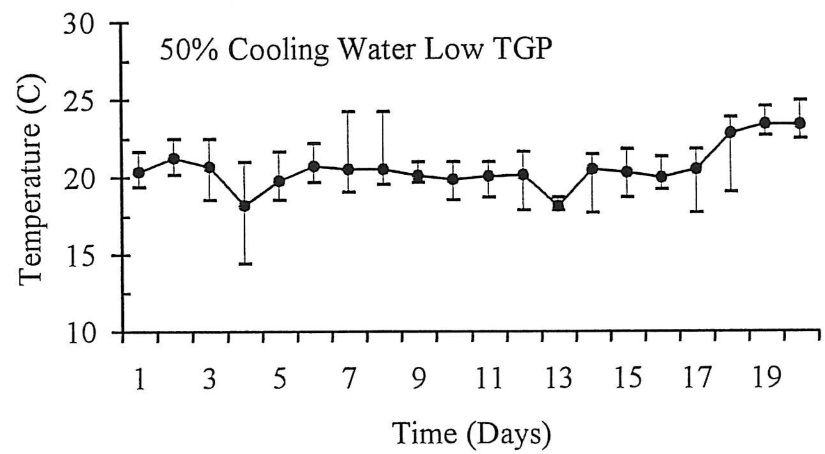


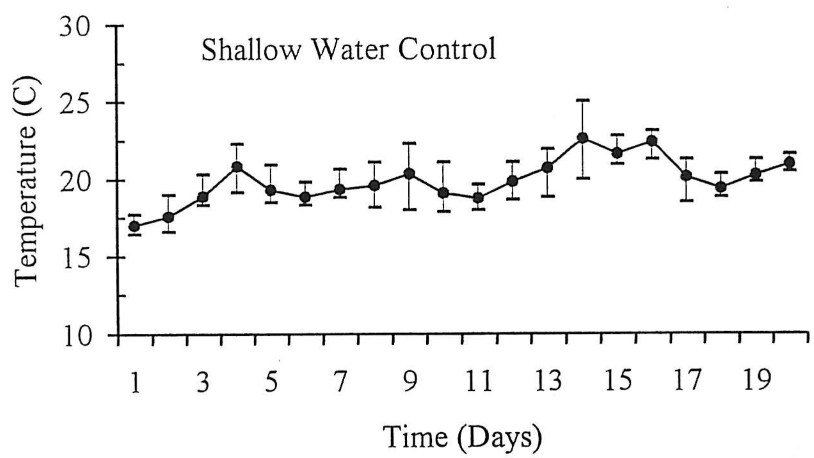


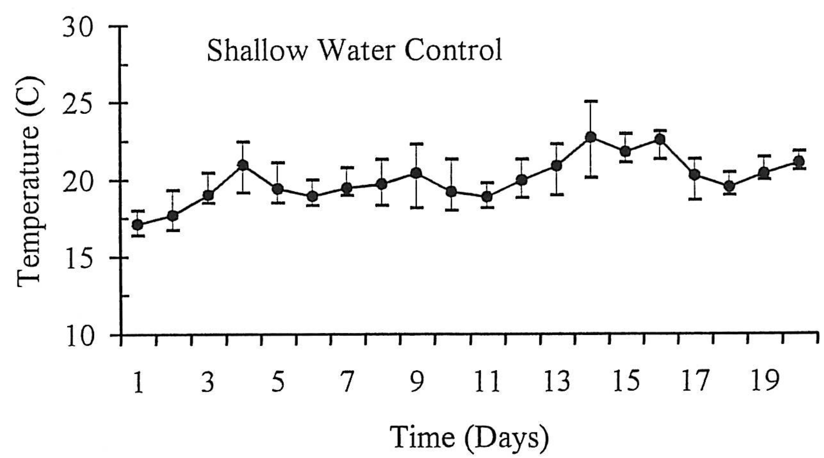
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment (cont.).

Study 3 - July 13-August 4, 1998



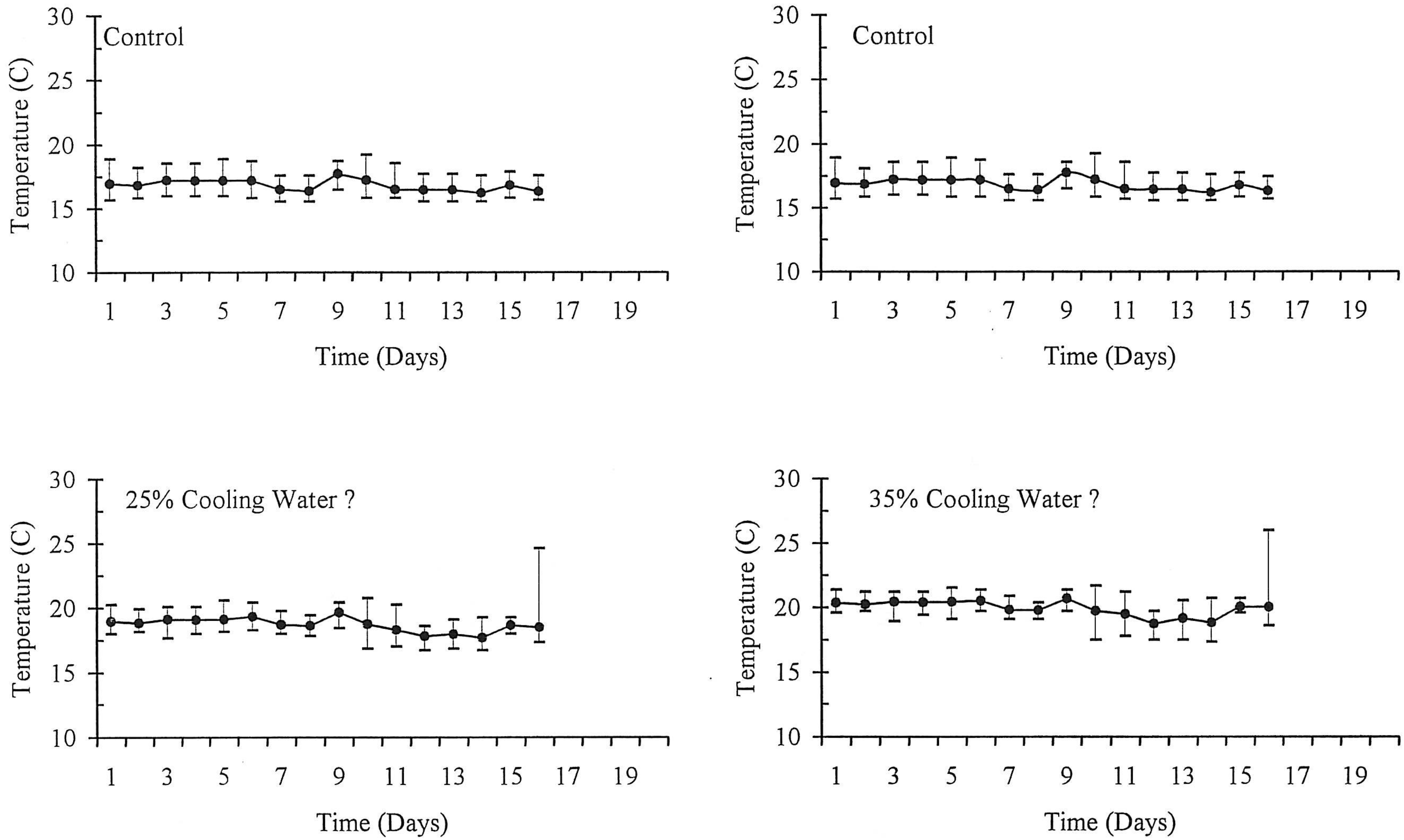






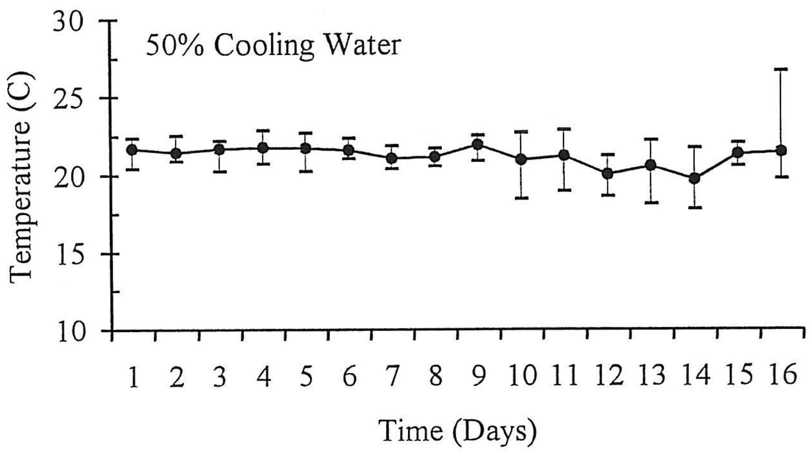
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment (cont.).

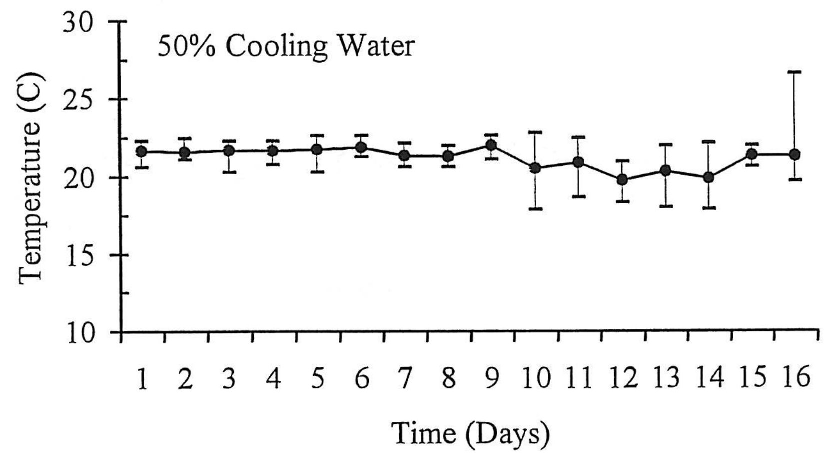
Study 4 - August 7-August 31, 1998

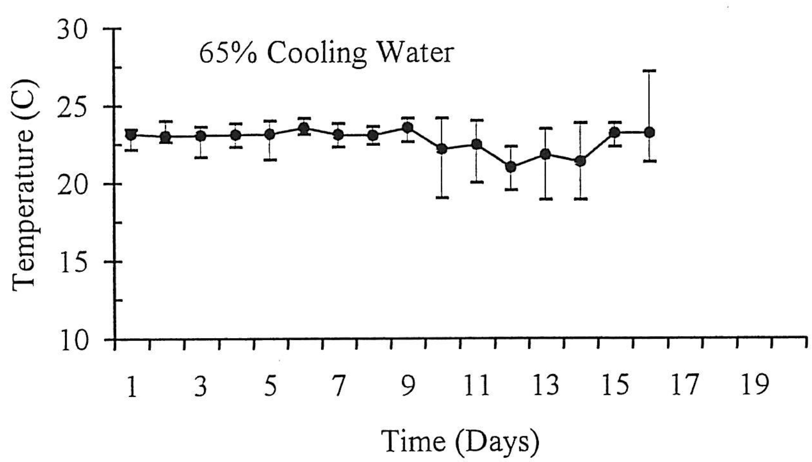


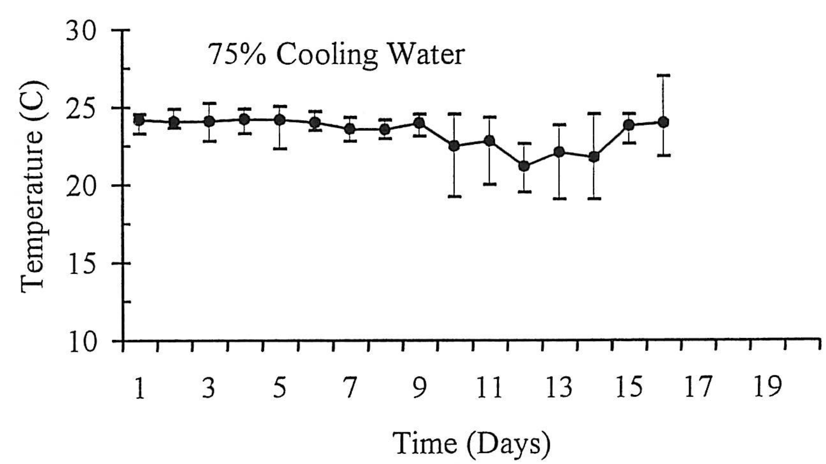
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment (cont.).

Study 4 - August 7-August 31, 1998



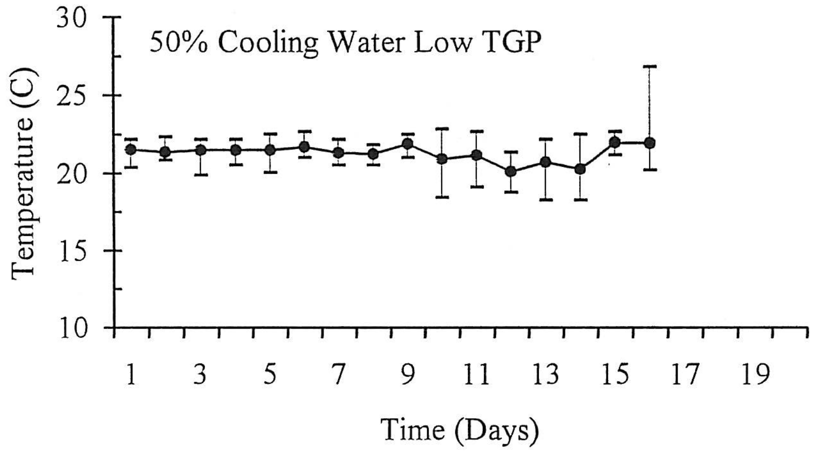


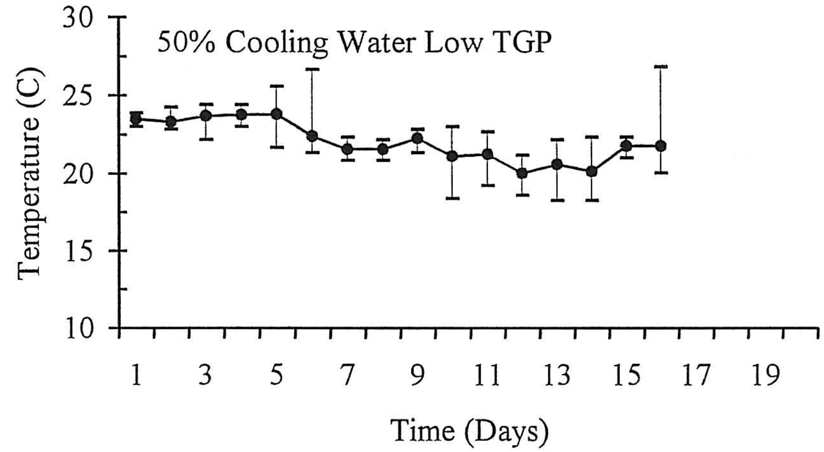


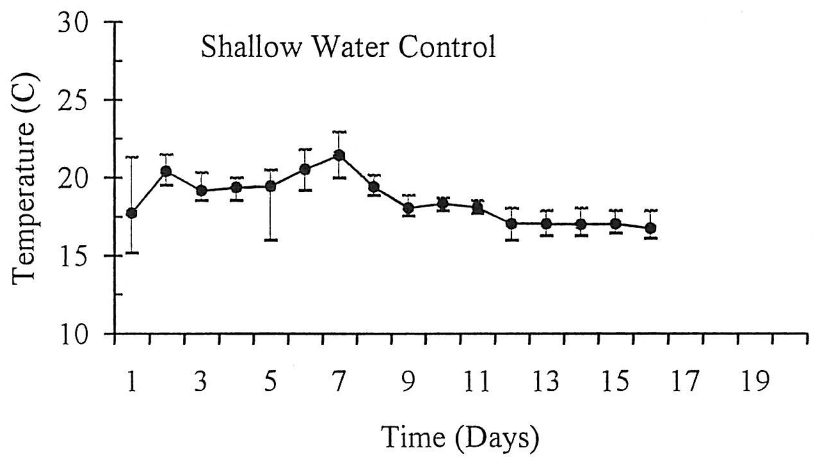


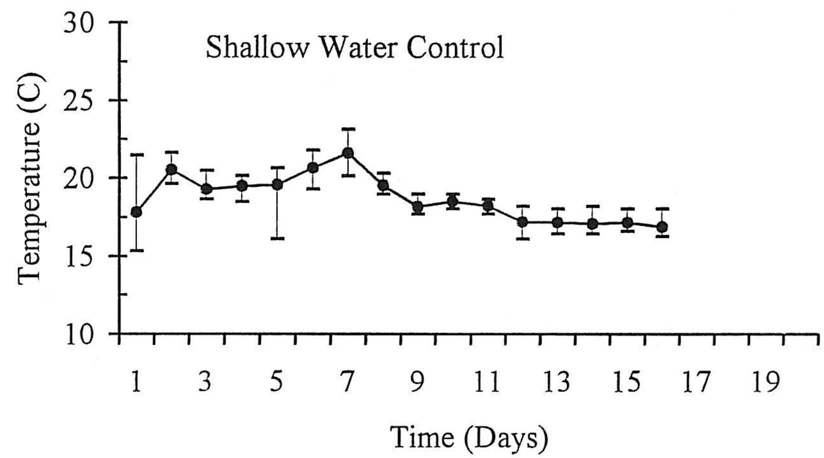
Appendix 1. Plots of daily mean, and range of water temperatures for each treatment (cont.).

Study 4 - August 7-August 31, 1998









Appendix 2. The incidence and percentage of fish showing signs of Gas Bubble Trauma in control and treated groups of juvenile chum salmon.

STUDY 1: MAY 11 - JUNE 02, 1998

	EYE			LATERAL LINE AND UNPAIRED FINS				
TREATMENT	EXOPTHALMIA	BUBBLES	MISC. SIGNS	LATERAL LINE	CAUDAL	DORSAL	ANAL	ADIPOSE
CONTROL	0% 0/10	0% 0/10	0% 0/10	10% 1/10	0% 0/10	0% 0/10	0% 0/10	0% 0/10
CONTROL	0% 0/9	0% 0/9	0% 0/9	22% 2/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9
6% COOLING WATER	0% 0/10	0% 0/10	0% 0/10	30% 3/10	0% 0/10	0% 0/10	0% 0/10	0% 0/10
12% COOLING WATER	0% 0/10	0% 0/10	0% 0/10	10% 1/10	0% 0/10	0% 0/10	0% 0/10	0% 0/10
25% COOLING WATER	0% 0/10	0% 0/10	0% 0/10	10% 1/10	0% 0/10	0% 0/10	0% 0/10	0% 0/10
35% COOLING WATER	0% 0/10	0% 0/10	0% 0/10	10% 1/10	0% 0/10	0% 0/10	0% 0/10	0% 0/10
50% COOLING WATER	20% 1/5	0% 0/5	mouth hemmorhage	40% 2/5	0% 0/5	0% 0/5	0% 0/5	0% 0/5
50% COOLING WATER	0% 0/9	0% 0/9	0% 0/9	11.1% 1/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9
50% CW:LOW TGP	0% 0/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9
50% CW:LOW TGP	0% 0/9	0% 0/9	0% 0/9	11.1% 1/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9
SHALLOW WATER	0% 0/8	0% 0/8	0% 0/8	25% 2/8	25% 2/8	0% 0/8	0% 0/8	0% 0/8
SHALLOW WATER	0% 0/10	0% 0/10	anal hemmorhage	50% 5/10	0% 0/10	0% 0/10	0% 0/10	0% 0/10

Appendix 2. The incidence and percentage of fish showing signs of Gas Bubble Trauma in control and treated groups of juvenile chum salmon (cont.).

STUDY 2: JUNE 8 - JUNE 31, 1998

	EYE			LATERAL LINE AND UNPAIRED FINS				
TREATMENT	EXOPTHALMIA	BUBBLES	MISC. SIGNS	LATERAL LINE	CAUDAL	DORSAL	ANAL	ADIPOSE
CONTROL	0% 0/8	0% 0/8	0% 0/8	0% 0/8	0% 0/8	0% 0/8	0% 0/8	0% 0/8
CONTROL	0% 0/7	0% 0/7	0% 0/7	0% 0/7	torn caudal	0% 0/7	0% 0/7	0% 0/7
6% COOLING WATER	0% 0/9	0% 0/9	0% 0/9	33% 3/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9
12% COOLING WATER	0% 0/9	0% 0/9	0% 0/9	56% 5/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9
25% COOLING WATER	0% 0/9	0% 0/9	0% 0/9	44% 4/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9
35% COOLING WATER	0% 0/9	0% 0/9	0% 0/9	56% 5/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9
50% COOLING WATER	0% 0/8	13% 1/8	0% 0/8	25% 2/8	small rip	0% 0/8	0% 0/8	0% 0/8
50% COOLING WATER	0% 0/8	0% 0/8	Cataracts	25% 2/8	0% 0/8	0% 0/8	0% 0/8	0% 0/8
50% CW:LOW TGP	0% 0/9	0% 0/9	0% 0/9	56% 5/9	0% 0/9	0% 0/9	0% 0/9	0% 0/9
50% CW:LOW TGP	0% 0/8	0% 0/8	Cataracts	50% 4/8	25% 2/8	13% 1/8	0% 0/8	0% 0/8
SHALLOW WATER	0% 0/6	0% 0/6	Cataracts	17% 1/6	0% 0/6	0% 0/6	0% 0/6	0% 0/6
SHALLOW WATER	0% 0/6	0% 0/6	Cataracts	50% 3/6	0% 0/6	0% 0/6	0% 0/6	0% 0/6

Appendix 2. The incidence and percentage of fish showing signs of Gas Bubble Trauma in control and treated groups of juvenile chum salmon (cont.).

STUDY 3: JULY 13 - AUGUST 04, 1998

	EYE			LATERAL LINE AND UNPAIRED FINS				
TREATMENT	EXOPTHALMIA	BUBBLES	MISC. SIGNS	LATERAL LINE	CAUDAL	DORSAL	ANAL	ADIPOSE
CONTROL	0% 0/6	0% 0/6	Cataract Split L/R	83% 5/6	33% 2/6	0% 0/6	0% 0/6	0% 0/6
CONTROL	0% 0/7	0% 0/7	Cataract Split L/R	86% 6/7	29% 2/7	0% 0/7	0% 0/7	0% 0/7
6% COOLING WATER	14% 1/7	14% 1/7	Split L/R	29% 2/7	43% 3/7	0% 0/7	0% 0/7	0% 0/7
12% COOLING WATER	0% 0/7	0% 0/7	Cataract Split L/R	43% 3/7	0% 0/7	0% 0/7	0% 0/7	0% 0/7
25% COOLING WATER	0% 0/7	14% 1/7	1 Split L Split L/R	43% 3/7	0% 0/7	0% 0/7	29% 2/7	0% 0/7
35% COOLING WATER	0% 0/7	0% 0/7	Split L/R	29% 2/7	86% 5/7	0% 0/7	0% 0/7	0% 0/7
50% COOLING WATER	0% 0/6	33% 2/6	Cataract Split L/R	83% 5/6	50% 3/6	50% 3/6	0% 0/6	0% 0/6
50% COOLING WATER	0% 0/6	0% 0/6	Cataract Split L/R Collapsed R Pupil	83% 5/6	67% 4/6	17% 1/6	0% 0/6	0% 0/6
50% CW:LOW TGP	0% 0/7	0% 0/7	Split L/R L Cataract	100% 7/7	71% 5/7	0% 0/7	0% 0/7	0% 0/7
50% CW:LOW TGP	0% 0/7	0% 0/7	Cataract Split L/R	100% 7/7	71% 5/7	0% 0/7	0% 0/7	0% 0/7
SHALLOW WATER	0% 0/6	0% 0/6	Cataract Split L/R Collapsed R Pupil	50% 3/6	33% 2/6	0% 0/6	0% 0/6	0% 0/6
SHALLOW WATER	0% 0/6	0% 0/6	Cataract Split L/R Collapsed L Pupil	83% 5/6	0% 0/6	0% 0/6	0% 0/6	0% 0/6

Appendix 3. Severity and prevalence of signs of Gas Bubble Trauma in control and treated groups of juvenile chum salmon (studies 1, 2 and 3 in 1998).

TREATMENT	FISH EXAMINED	OCCLUSION 0%	1 - 5%	6 - 25%	26 - 50%	> 50%
		INDIVIDUALS WITH GAS EMBOLI IN LATERAL LINE				
CONTROL	47	34	10	3	0	0
6% COOLING WATER	26	18	7	1	0	0
12% COOLING WATER	26	17	7	2	0	0
25% COOLING WATER	26	22	8	0	0	0
35% COOLING WATER	26	22	6	2	0	0
50% COOLING WATER	42	25	10	7	0	0
50% CW:LOW TGP	49	25	12	11	1	0
SHALLOW WATER	42	23	9	10	0	0

TREATMENT	FISH EXAMINED	OCCLUSION 0%	1 - 5%	6 - 25%	26 - 50%	> 50%
		INDIVIDUALS WITH GAS EMBOLI IN CAUDAL FIN				
CONTROL	47	43	4	0	0	0
6% COOLING WATER	26	23	3	0	0	0
12% COOLING WATER	26	26	0	0	0	0
25% COOLING WATER	26	26	0	0	0	0
35% COOLING WATER	26	20	6	0	0	0
50% COOLING WATER	42	35	7	0	0	0
50% CW:LOW TGP	49	37	12	0	0	0
SHALLOW WATER	42	38	4	0	0	0

Appendix 4. Mean Condition Factors (CFs) for each treatment, at the start and end of each study in 1998.

Treatment	Study 1 (May 11-June 2, 1998) Initial CF Mean	Initial CF Std. Dev.	Final CF Mean	Final CF Std. Dev.	Study 2 (June 8-June 31, 1998) Initial CF Mean	Initial CF Std. Dev.	Final CF Mean	Final CF Std. Dev.
0% CW	0.84	0.06	0.93	0.06	0.95	0.06	0.99	0.08
0% CW	0.83	0.06	0.91	0.05	0.94	0.05	0.99	0.05
6% CW	0.84	0.06	0.91	0.06	0.94	0.04	0.97	0.04
12% CW	0.85	0.07	0.98	0.14	0.97	0.05	0.98	0.16
25% CW	0.85	0.07	0.95	0.05	0.95	0.05	1.03	0.05
35% CW	0.83	0.07	0.95	0.05	0.96	0.05	1.04	0.05
50% CW	0.85	0.07	0.97	0.14	0.95	0.05	1.04	0.05
50% CW	0.84	0.06	0.96	0.05	0.96	0.06	1.06	0.06
50% Low TGP	0.84	0.06	0.97	0.04	0.97	0.05	1.06	0.05
50% Low TGP	0.83	0.05	0.97	0.04	0.94	0.05	1.05	0.08
Shallow	0.82	0.05	0.93	0.05	0.96	0.06	1.02	0.05
Shallow	0.84	0.05	0.94	0.06	0.95	0.05	1.01	0.06

Treatment	Study 3 (July 13-August 4, 1998) Initial CF Mean	Initial CF Std. Dev.	Final CF Mean	Final CF Std. Dev.	Study 4 (August 7-August 31, 1998) Initial CF Mean	Initial CF Std. Dev.	Final CF Mean	Final CF Std. Dev.
0% CW	0.90	0.04	1.05	0.06	1.00	0.04	1.20	0.08
0% CW	0.89	0.03	1.03	0.05	0.99	0.05.	1.20	0.07
6% CW	0.88	0.04	1.07	0.05	-	-	-	-
12% CW	0.88	0.03	1.08	0.06	-	-	-	-
25% CW	0.89	0.03	1.12	0.07	0.98	0.05	1.15	0.07
35% CW	0.88	0.03	1.13	0.07	0.99	0.04	1.31	0.08
50% CW	0.89	0.03	1.05	0.06	1.01	0.04	1.22	0.09
50% CW	0.90	0.05	1.05	0.04	0.99	0.04	1.23	0.10
65% CW	-	-	-	-	0.99	0.05	1.21	0.09
75% CW	-	-	-	-	1.01	0.10	-	-
50% Low TGP	0.88	0.04	1.04	0.06	1.01	0.05	1.27	0.11
50% Low TGP	0.89	0.05	1.05	0.06	0.99	0.04	1.08	0.13
Shallow	0.89	0.04	1.09	0.04	1.00	0.05	1.17	0.08
Shallow	0.88	0.03	1.08	0.05	0.99	0.05	1.15	0.05

- Not Tested

Appendix 5. Pairwise comparison probabilities (ANOVA) for initial weights and growth rates, study 1[1,2]

Growth Study No. 1 (May 11 - June 2, 1998) - Initial Weights

	0% CW	0% CW	6% CW	12% CW	25% CW	35% CW	50% CW	50% CW	50% Low	50% Low	Shallow	Shallow
0% CW		0.779	0.175	0.947	0.759	0.147	0.595	0.028	0.739	0.464	0.336	0.559
0% CW			0.282	0.729	0.979	0.241	0.802	0.055	0.958	0.651	0.496	0.762
6% CW				0.155	0.294	0.923	0.409	0.399	0.307	0.533	0.693	0.440
12% CW					0.709	0.129	0.550	0.024	0.690	0.424	0.304	0.516
25% CW						0.252	0.823	0.059	0.979	0.670	0.513	0.782
35% CW							0.357	0.456	0.263	0.472	0.623	0.385
50% CW								0.096	0.843	0.840	0.667	0.958
50% CW									0.062	0.143	0.216	0.107
50% Low										0.690	0.530	0.802
50% Low											0.819	0.881
Shallow												0.706
Shallow												

Growth Study No. 1 (May 11 - June 2, 1998) - Fish Growth (End Wt. - Average Initial Wt.)

	0% CW	0% CW	6% CW	12% CW	25% CW	35% CW	50% CW	50% CW	50% Low	50% Low	Shallow	Shallow
0% CW		0.355	0.227	0.690	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.000**	0.019	**0.000**
0% CW			0.776	0.186	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.001**	**0.000**
6% CW				0.108	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
12% CW					**0.000**	**0.000**	**0.000**	**0.000**	**0.002**	**0.000**	0.052	**0.001**
25% CW						0.073	0.067	0.111	**0.000**	0.253	**0.000**	**0.000**
35% CW							0.725	0.844	0.028	0.522	**0.001**	0.053
50% CW								0.606	0.142	0.378	0.016	0.210
50% CW									0.017	0.657	**0.000**	0.033
50% Low										**0.005**	0.253	0.795
50% Low											**0.000**	0.011
Shallow												0.161
Shallow												

1. Highlighted values indicate a significant difference (p-value < 0.05) between the two matrixed treatment groups.
2. Bold values indicate a p-value < 0.01.

Appendix 5. Pairwise comparison probabilities (ANOVA) for initial weights and growth rates, study 2[1,2] (cont.).

Growth Study No. 2 (June 8 - June 31, 1998) - Initial Weights

	0% CW	0% CW	6% CW	12% CW	25% CW	35% CW	50% CW	50% CW	50% Low	50% Low	Shallow	Shallow
0% CW		0.567	0.898	0.563	0.574	0.479	0.540	0.536	0.314	0.212	0.540	0.036
0% CW			0.656	0.250	0.256	0.201	0.236	0.234	0.663	0.069	0.968	**0.008**
6% CW				0.480	0.490	0.404	0.459	0.455	0.379	0.169	0.627	0.026
12% CW					0.988	0.897	0.972	0.968	0.113	0.503	0.234	0.127
25% CW						0.885	0.960	0.955	0.117	0.494	0.240	0.124
35% CW							0.924	0.929	0.087	0.589	0.187	0.163
50% CW								0.995	0.105	0.526	0.220	0.136
50% CW									0.104	0.530	0.218	0.138
50% Low										0.024	0.693	**0.002**
50% Low											0.063	0.392
Shallow												**0.007**
Shallow												

Study No. 2 (June 8 - June 31, 1998) - Fish Growth (End Wt. - Average Initial Wt.)

	0% CW	0% CW	6% CW	12% CW	25% CW	35% CW	50% CW	50% CW	50% Low	50% Low	Shallow	Shallow
0% CW		0.681	0.862	0.036	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.225	0.092
0% CW			0.809	0.014	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.117	0.042
6% CW				0.023	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.170	0.066
12% CW					**0.006**	**0.001**	**0.000**	**0.000**	**0.000**	0.089	0.478	0.799
25% CW						0.525	0.268	**0.007**	0.020	0.292	**0.001**	**0.005**
35% CW							0.639	0.041	0.092	0.092	**0.000**	**0.001**
50% CW								0.112	0.221	0.031	**0.000**	**0.000**
50% CW									0.714	**0.000**	**0.000**	**0.000**
50% Low										**0.001**	**0.000**	**0.000**
50% Low											0.024	0.069
Shallow												0.670
Shallow												

1. Highlighted values indicate a significant difference (p-value < 0.05) between the two matrixed teratment groups.
2. Bold values indicate a p-value < 0.01.

Appendix 5. Pairwise comparison probablities (ANOVA) for initial weights and growth rates, study 3[1,2] (cont.).

Growth Study No. 3 (July 13 - August 4, 1998) - Initial Weights

	0% CW	0% CW	6% CW	12% CW	25% CW	35% CW	50% CW	50% CW	50% Low	50% Low	Shallow	Shallow
0% CW		0.217	0.937	0.694	0.925	0.321	0.788	0.801	0.155	0.321	0.485	0.198
0% CW			0.189	0.400	0.254	0.808	0.133	0.326	**0.008**	0.809	0.592	0.012
6% CW				0.636	0.862	0.284	0.850	0.740	0.180	0.283	0.436	0.227
12% CW					0.765	0.549	0.508	0.888	0.070	0.548	0.760	0.093
25% CW						0.369	0.716	0.875	0.130	0.369	0.546	0.167
35% CW							0.208	0.459	0.016	0.999	0.769	0.023
50% CW								0.602	0.249	0.207	0.333	0.308
50% CW									0.094	0.458	0.655	0.124
50% Low										0.016	0.034	0.893
50% Low											0.768	0.023
Shallow												0.047
Shallow												

Study No. 3 (July 13 - August 4, 1998) - Fish Growth (End Wt. - Average Initial Wt.)

	0% CW	0% CW	6% CW	12% CW	25% CW	35% CW	50% CW	50% CW	50% Low	50% Low	Shallow	Shallow
0% CW		0.032	**0.001**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.008**	0.026	0.061	0.533
0% CW			**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	0.630	0.950	**0.000**	**0.006**
6% CW				0.652	0.192	0.614	0.023	**0.000**	**0.000**	**0.000**	0.146	**0.007**
12% CW					0.390	0.955	0.067	**0.002**	**0.000**	**0.000**	0.058	**0.002**
25% CW						0.424	0.342	0.026	**0.000**	**0.000**	**0.007**	**0.000**
35% CW							0.078	**0.002**	**0.000**	**0.000**	0.052	**0.001**
50% CW								0.196	**0.000**	**0.000**	**0.000**	**0.000**
50% CW									**0.000**	**0.000**	**0.000**	**0.000**
50% Low										0.674	**0.000**	**0.001**
50% Low											**0.000**	**0.005**
Shallow												0.212
Shallow												

1. Highlighted values indicate a significant difference (p-value < 0.05) between the two matrixed treatment groups.
2. Bold values indicate a p-value < 0.01.

Appendix 5. Pairwise comparison probabilities (ANOVA) for initial weights and growth rates, study 4[1,2] (cont.).

Growth Study No. 4 (August 7 - August 31, 1998) - Initial Weights

	0% CW	0% CW	25% CW	35% CW	50% CW	50% CW	65% CW	75% CW	50% Low	50% Low	Shallow	Shallow
0% CW		0.279	0.425	0.910	0.493	0.845	0.285	0.395	0.425	0.489	0.679	0.746
0% CW			0.775	0.332	0.078	0.375	0.988	0.054	0.060	0.695	0.135	0.447
25% CW				0.493	0.139	0.547	0.786	0.100	0.111	0.916	0.226	0.635
35% CW					0.425	0.934	0.339	0.336	0.363	0.562	0.598	0.833
50% CW						0.379	0.080	0.868	0.910	0.169	0.786	0.313
50% CW							0.383	0.296	0.321	0.619	0.542	0.898
65% CW								0.056	0.063	0.707	0.139	0.456
75% CW									0.958	0.123	0.662	0.241
50% Low										0.137	0.701	0.262
50% Low											0.269	0.712
Shallow												0.461
Shallow												

Study No. 4 - (August 7 - August 31, 1998) Pairwise Comparison Probabilities of Fish Growth (End Wt. - Average Initial Wt.)

	0% CW	0% CW	25% CW	35% CW	50% CW	50% CW	65% CW	50% Low	50% Low	Shallow	Shallow
0% CW	0.000	0.843	0.175	0.683	**0.000**	0.110	**0.000**	0.057	**0.000**	**0.004**	**0.001**
0% CW		0.000	0.120	0.834	**0.000**	0.074	**0.000**	0.036	**0.000**	**0.002**	**0.000**
25% CW			0.000	0.078	0.017	0.758	**0.000**	0.574	**0.000**	0.130	0.038
35% CW				0.000	**0.000**	0.047	**0.000**	0.021	**0.000**	**0.001**	**0.000**
50% CW					0.000	0.048	**0.000**	0.069	**0.000**	0.362	0.718
50% CW						0.000	**0.000**	0.817	**0.000**	0.255	0.094
65% CW							0.000	**0.000**	0.139	**0.000**	**0.000**
50% Low								0.000	**0.000**	0.346	0.134
50% Low									0.000	**0.000**	**0.000**
Shallow										0.000	0.572
Shallow											0.000

1. Highlighted values indicate a significant difference (p-value < 0.05) between the two matrixed treatment groups.
2. Bold values indicate a p-value < 0.01.

Appendix 6. Mean initial and final lengths for control and treated groups of juvenile chum salmon in 1998.

STUDY 1 (May 11 - June 2, 1998)

	INITIAL LENGTH (mm)		FINAL LENGTH (mm)		Δ IN LENGTH (mm)
TREATMENT	MEAN	SD	MEAN	SD	MEAN
CONTROL	60	3	77	3	17
CONTROL	60	2	76	3	16
6% COOLING WATER	59	3	76	3	17
12% COOLING WATER	60	2	77	3	17
25% COOLING WATER	60	2	82	3	22
35% COOLING WATER	60	2	80	3	20
50% COOLING WATER	60	3	79	4	19
50% COOLING WATER	59	2	80	3	21
50% CW:LOW TGP	60	2	78	3	18
50% CW:LOW TGP	60	2	80	3	20
SHALLOW WATER	60	3	78	4	18
SHALLOW WATER	60	3	79	4	19

STUDY 2 (June 8 - June 31, 1998)

	INITIAL LENGTH (mm)		FINAL LENGTH (mm)		Δ IN LENGTH (mm)
TREATMENT	MEAN	SD	MEAN	SD	MEAN
CONTROL	87	3	104	4	17
CONTROL	87	2	104	4	17
6% COOLING WATER	87	2	105	3	18
12% COOLING WATER	86	3	106	5	20
25% COOLING WATER	86	3	107	4	21
35% COOLING WATER	86	3	108	5	22
50% COOLING WATER	86	2	108	4	22
50% COOLING WATER	86	2	109	4	23
50% CW:LOW TGP	87	3	109	4	22
50% CW:LOW TGP	86	3	106	4	20
SHALLOW WATER	87	2	105	4	18
SHALLOW WATER	86	3	105	5	19

Appendix 6. Mean initial and final lengths for control and treated groups of juvenile chum salmon in 1998 (cont.).

STUDY 3 (July 13 - August 4, 1998)

	INITIAL LENGTH (mm)		FINAL LENGTH (mm)		Δ IN LENGTH (mm)
TREATMENT	MEAN	SD	MEAN	SD	MEAN
CONTROL	98	3	123	5	25
CONTROL	99	3	122	4	23
6% COOLING WATER	98	3	127	4	29
12% COOLING WATER	98	3	127	4	29
25% COOLING WATER	99	3	127	6	28
35% COOLING WATER	99	3	127	4	28
50% COOLING WATER	98	3	126	4	28
50% COOLING WATER	99	3	127	4	28
50% CW:LOW TGP	98	3	120	4	22
50% CW:LOW TGP	99	3	121	5	22
SHALLOW WATER	99	2	124	3	25
SHALLOW WATER	98	3	122	4	24

STUDY 4 (August 7 - August 31, 1998)

	INITIAL LENGTH (mm)		FINAL LENGTH (mm)		Δ IN LENGTH (mm)
TREATMENT	MEAN	SD	MEAN	SD	MEAN
CONTROL	121	4	135	5	14
CONTROL	120	4	134	6	14
25% COOLING WATER	121	3	134	6	13
35% COOLING WATER	121	4	132	5	11
50% COOLING WATER	121	2	130	4	9
50% COOLING WATER	121	4	131	5	10
65% COOLING WATER	120	3	122	3	2
75% COOLING WATER	121	6	-	-	-
50% CW:LOW TGP	121	4	130	4	9
50% CW:LOW TGP	121	3	125	5	4
SHALLOW WATER	121	4	132	4	11
SHALLOW WATER	121	4	132	5	11

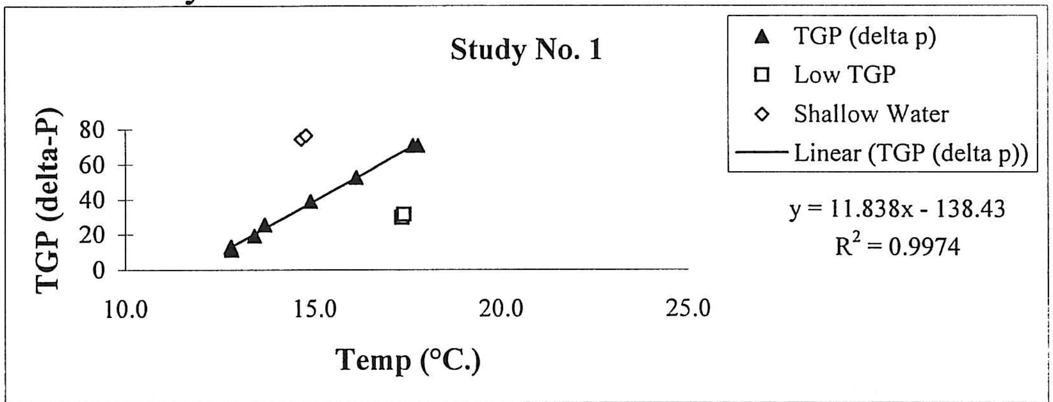
- Not Tested

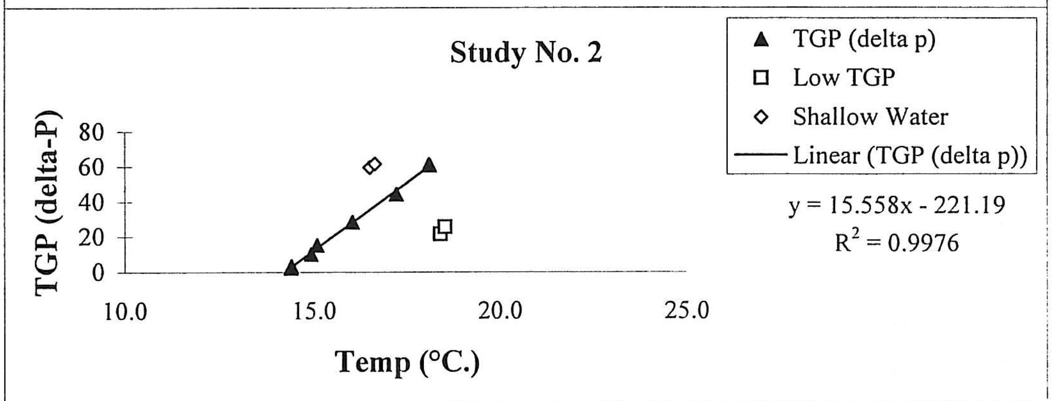
Appendix 7. Summary of mean increase in length for control and treated groups of juvenile chum salmon in 1998.

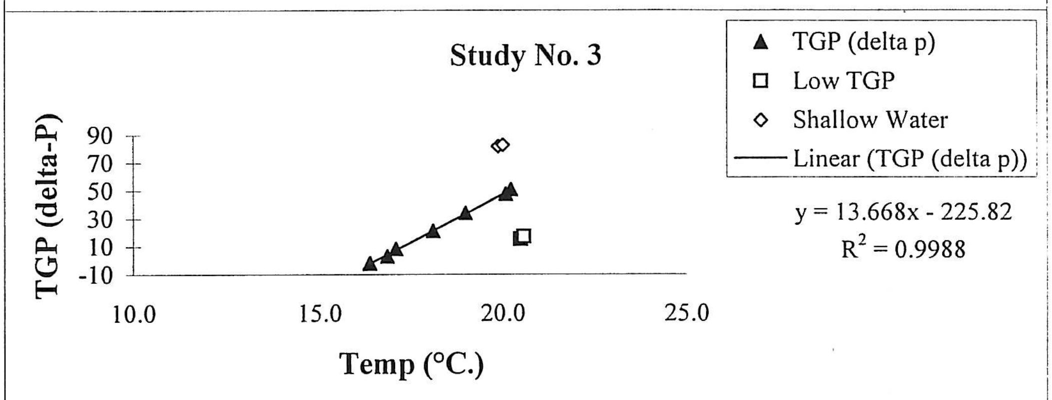
	INCREASE IN LENGTH (mm)			
TREATMENT	**STUDY 1**	**STUDY 2**	**STUDY 3**	**STUDY 4**
CONTROL	17	17	25	14
CONTROL	16	17	23	14
6% COOLING WATER	17	18	29	-
12% COOLING WATER	17	20	29	-
25% COOLING WATER	22	21	28	13
35% COOLING WATER	20	22	28	11
50% COOLING WATER	19	22	28	9
50% COOLING WATER	21	23	28	10
65% COOLING WATER	-	-	-	2
75% COOLING WATER	-	-	-	-
50% CW:LOW TGP	18	22	22	9
50% CW:LOW TGP	20	20	22	4
SHALLOW WATER	18	18	25	11
SHALLOW WATER	19	19	24	11

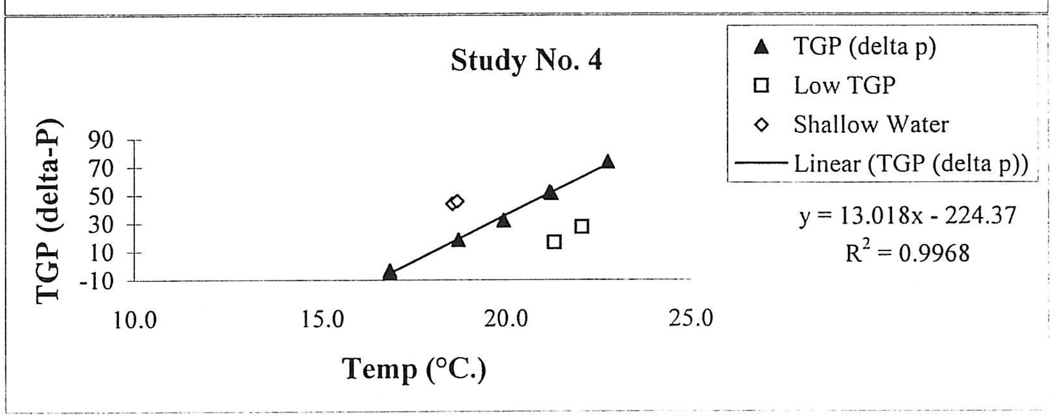
- Not Tested

Appendix 8. Mean total gas pressure vs mean temperature for each study in 1998.









Appendix 9. Moisture content and dry weights of chum salmon, for each treatment, at the end of each study in 1998.

	Moisture Content (%)				Dry Weight			
Treatment	Study 1	Study 2	Study 3	Study 4	Study 1	Study 2	Study 3	Study 4
0% CW	77.0	74.1	75.2	75.3	0.97	2.93	4.88	7.27
0% CW	76.9	74.5	75.0	74.6	0.94	2.86	4.72	7.44
6% CW	77.2	73.7	75.9	-	0.92	2.96	5.19	-
12% CW	76.5	73.7	76.0	-	0.98	3.13	5.19	-
25% CW	75.5	73.6	75.8	73.3	1.26	3.38	5.32	7.51
35% CW	75.7	73.5	74.7	75.4	1.19	3.44	5.55	7.35
50% CW	73.2	73.1	73.8	73.2	1.25	3.53	5.91	7.15
50% CW	75.2	73.5	73.9	73.8	1.2	3.61	6.05	7.37
65% CW	-	-	-	74.7	-	-	-	5.63
75% CW	-	-	-	-	-	-	-	-
50% CW: Low TGP	76.4	73.3	74.0	73.5	1.12	3.66	4.7	7.47
50% CW: Low TGP	75.6	73.9	74.3	74.3	1.22	3.24	4.82	5.44
Shallow Water	77.5	74.1	74.5	74.9	1.03	3.05	5.31	6.83
Shallow Water	75.6	73.7	75.8	74.8	1.13	3.07	4.76	6.67

- Not Tested