# Quantitative Performance Measurement Of Alternative North American Salmonid Strains For Newfoundland Aquaculture

V.A. Pepper, T. Nicholls, C. Collier, V. Watkins, E. Barlow and M.F. Tlusty

Science, Oceans and Environment Branch
Fisheries and Oceans Canada
P.O. Box 5667
St. John's NL Canada A1C 5X1

2003

**Canadian Technical Report of Fisheries and Aquatic Sciences No. 2502**

Fisheries and Oceans / Pêches et Océans

Canada

## Canadian Technical Report of Fisheries and Aquatic Sciences

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

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

Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. Numbers 457-714 were issued as Department of the Environment, Fisheries and Marine Service, Research and Development Directorate Technical Reports. Numbers 715-924 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

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

## Rapport technique canadien des sciences halieutiques et aquatiques

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

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

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

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

Canadian Technical Report of
Fisheries and Aquatic Sciences 2502

2003

# Quantitative Performance Measurement of Alternative North American Salmonid Strains for Newfoundland Aquaculture

by

V.A. Pepper[1], T. Nicholls[1], C. Collier[2], V. Watkins[3], E. Barlow[4] and M.F. Tlusty[5]

[1]Science, Oceans and Environment Branch
Fisheries and Oceans Canada
Northwest Atlantic Fisheries Centre
P.O. Box 5667
St. John's NL A1C 5X1

[2]Markland Seafoods Ltd.
P.O. Box 98
St. Alban's NL A0H 2E0

[3]Long Island Resources Ltd.
P.O. Box 378
St. Alban's NL A0H 2E0

[4]Newfoundland and Labrador Department of Fisheries and Aquaculture
PO Box 340
St. Alban's NL A0H 2E0

[5] New England Aquarium
Central Wharf
Boston MA 02110

Cat. No. Fs 97-6/2502E ISSN 0706-6457

Correct citation for this publication:

Pepper, V.A., Nicholls, T., Collier, C., Watkins, V., Barlow, E. and Tlusty, M.F. 2003. Quantitative performance measurement of alternative North American salmonid strains for Newfoundland aquaculture. Can. Tech. Rep. Fish. Aquat. Sci. 2502: vi + 53 p.

# TABLE OF CONTENTS



## LIST OF TABLES

LIST OF FIGURES



LIST OF APPENDICES

# ABSTRACT

Pepper, V.A., Nicholls, T., Collier, C., Watkins, V., Barlow, E. and Tlusty, M.F. 2003. Quantitative performance measurement of alternative North American salmonid strains for Newfoundland aquaculture. Can. Tech. Rep. Fish. Aquat. Sci. 2502: vi + 53 p.

In 1999, industry and government undertook quantitative evaluation of alternative strains of North American-origin Atlantic salmon for use in marine cage culture in Bay d'Espoir. As a result of salmonid aquaculture industry aspirations to determine the pros and cons of alternative approaches to salmon-strain performance improvement, the Bay d'Espoir industry had five separate strains of Atlantic salmon in its hatchery inventory in 1999. This strain-evaluation research endeavour identified two significant economic challenges to Atlantic salmon aquaculture for the Bay d'Espoir industry, namely mortality and early maturation.

Atlantic salmon mortality pattern was consistent between the two years of this aquaculture experiment. Major mortality peaks, attributed largely to Bay d'Espoir pathogens, took place in early July of each year. This, together with an incidence of early maturity that ranged 31-58% among the reproductively-competent strains, resulted in a clear winner in strain performance. The only Atlantic salmon to generate a net economic gain for the sponsoring aquaculture company was the Gaspé strain of reproductively-incapacitated (triploid) salmon (Cascade Aqua Farms). All four of the other strains resulted in a significant economic loss to the aquaculture business. Gaspé triploid salmon were the first of the five strains to reach marketable size. These triploid salmon also had the best Performance Index and Food Conversion Ratio.

In addition to Atlantic salmon strain evaluations, the Bay d'Espoir salmonid aquaculture industry undertook comparative-performance evaluations of triploid rainbow trout and triploid steelhead starting in 1997. In parallel with evaluation of the freshwater and anadromous trout strains, the growers mounted a new initiative to examine the relative performance of all-female, diploid steelhead relative to the triploid livestock used up to that time. At the time of these performance evaluations, the industry aspiration for steelhead aquaculture was to produce a market fish of 1.71 kg (i.e. 1 lb fillets) within one growing season, an aspiration that did not appear achievable with triploid livestock.

Though much of the rainbow trout data were equivocal, all-female diploid steelhead-performance indicators through 2000 were sufficient to support some general conclusions. It was apparent that industry's goal of achieving 454 g fillets at the end of one summer of on-growing in the Bay d'Espoir estuarine fjord was achievable. However, the only steelhead observed to attain this size threshold were produced from fish that were placed into the estuarine cages early in the growing season (i.e. April 30) at a mean weight of >100 g.

# RÉSUMÉ

Pepper, V.A., Nicholls, T., Collier, C., Watkins, V., Barlow, E. and Tlusty, M.F. 2003. Quantitative performance measurement of alternative North American salmonid strains for Newfoundland aquaculture. Can. Tech. Rep. Fish. Aquat. Sci. 2502: vi + 53 p.

En 1999, l'industrie et le gouvernement entreprirent des évaluations quantitatives de diverses souches de saumon atlantique originaires d'Amérique du Nord et destinées à des cages de mariculture de la baie d'Espoir. Comme l'industrie de la salmoniculture cherchait à déterminer les avantages et les inconvénients de nouvelles approches à l'amélioration du rendement des souches de saumon, les aquaculteurs de la baie d'Espoir utilisaient cinq souches distinctes de saumon atlantique dans leur écloserie en 1999. Ces travaux d'évaluation des souches mirent en évidence deux défis économiques importants qui se posaient aux aquaculteurs de la baie d'Espoir dans l'élevage du saumon atlantique, soit la mortalité et la maturation précoce.

Les tendances de la mortalité du saumon atlantique se révélèrent cohérentes pendant les deux années de cette expérience d'aquaculture. Les grands pics de mortalité, largement attribués à la présence de pathogènes dans la baie d'Espoir, se produisirent au début de juillet chaque année. Face à ce phénomène, combiné à une incidence de maturité précoce de l'ordre de 31 à 58 % parmi les souches aptes à la reproduction, une souche se démarqua nettement des autres en matière de rendement. Il s'avéra, en effet, que le seul saumon atlantique capable de générer un gain économique net pour l'entreprise qui l'élevait (Cascade Aqua Farms) était celui issu de la souche de Gaspé, souche de saumons triploïdes incapables de se reproduire. Les tentatives d'élevage des quatre autres souches se soldèrent par des pertes économiques importantes pour l'industrie aquacole. Le saumon triploïde de Gaspé fut le premier des saumons issus des cinq souches à atteindre la taille commerciale. Ce saumon triploïde avait aussi le meilleur indice de rendement et le meilleur indice de consommation (taux de conversion alimentaire).

Outre les évaluations de souches de saumon atlantique, l'industrie de la salmoniculture de la baie d'Espoir procéda à des évaluations comparatives de rendement de truites arc-en-ciel triploïdes et de saumons arc-en-ciel triploïdes à compter de 1997. Parallèlement à l'évaluation des souches de truites d'eau douce et anadromes, les éleveurs entreprirent d'examiner le rendement relatif d'une composante de saumons arc-en-ciel diploïdes constituée exclusivement de femelles par rapport au stock de triploïdes utilisé jusqu'alors. À l'époque de ces évaluations de rendement, les éleveurs de saumon arc-en-ciel aspiraient à produire un saumon de taille commerciale pesant 1,71 kg (c.-à-d. 1 lb de filets) en une saison de croissance, ce qui ne semblait pas réalisable avec le stock de triploïdes.

Quoiqu'une bonne partie des données sur la truite arc-en-ciel ait été équivoque, les indicateurs de rendement de la composante de saumons arc-en-ciel diploïdes femelles tout au long de 2000 étaient suffisants pour tirer quelques conclusions générales. Il apparaissait que l'objectif visé par l'industrie, à savoir la production de 454 g de filets à la fin d'un été de croissance dans le fjord estuarien de la baie d'Espoir, était réalisable. Toutefois, les seuls saumons arc-en-ciel dont on a constaté qu'ils atteignaient ce seuil de taille avaient été placés dans des cages mouillées dans l'estuaire tôt au début de la saison de croissance (le 30 avril), à un poids moyen >100 g.

# INTRODUCTION

The Bay d'Espoir aquaculture industry in Newfoundland and Labrador currently is structured around rainbow trout, *Oncorhynchus mykiss* (75%) and Atlantic salmon, *Salmo salar* (25%). Based on industry-development experience of almost 20 years, there is much enthusiasm among the salmonid growers for the growth potential of this industry. To date, growth has been limited, at least in part, by challenges in refining husbandry practices to capitalize on the environmental regime of Bay d'Espoir (Tlusty et. al. 2000a; Tlusty et al. 2000b) and by restricted access to aquaculture strains used elsewhere. As part of its ongoing efforts towards salmonid-aquaculture industry refinement and expansion, the Newfoundland Salmonid Growers Association (NSGA) has pursued evaluation of alternative strains of Atlantic salmon and rainbow/steelhead trout, gender manipulation, reproductive control, pedigree breeding and refinements to husbandry practices.

An estuarine fjord of some 250 $km^2$, Bay d'Espoir (Fig. 1) presents ample space for salmonid-farm siting and aquaculture-industry development but also presents salmonid-physiology challenges for livestock confined to the finite space of aquaculture nets. The inner estuary of Bay d'Espoir runs seaward at about 190° true (i.e. head of Bay d'Espoir to Riches Island), then angles towards the west (~255° true towards Goblin Head/Green Point), presenting a linear distance of about 40 km. With local-river discharge and a hydroelectric facility at the head of the bay, freshwater input to the fjord can reach 350 $m^3 \bullet sec^{-1}$. The inner estuarine part of the fjord is subject to considerable physical and chemical water-column variability due to stratification of fresh water at the surface and underlying marine waters (Tlusty et al. 2000a). Both the subarctic winter-marine conditions and the dynamics of the estuarine-fjord water column have provided many challenges to Bay d'Espoir aquaculture entrepreneurs.

Initial efforts to evaluate the aquaculture potential of rainbow trout started in Bay d'Espoir in 1988. During the first 10 years of rainbow-trout aquaculture development, the trout farmers relied mainly on all-female, triploid rainbow trout from Quebec. Since the first demonstration of encouraging aquaculture performance of rainbow trout in Bay d'Espoir in 1989, industry development in Newfoundland has been restricted under the *Fisheries Act* and *Fisheries (General) Regulations* to the use of all-female, triploid strains. Within a matter of years of first introducing this reproductive-control technology to the Bay d'Espoir aquaculture industry (Pepper 1991a, 1991b) controversy developed regarding the aquaculture-performance potential of such artificially-induced, non-reproductive salmonids (Benfey 1998). Both industry and provincial Department of Fisheries and Aquaculture (DFA) representatives in Newfoundland maintained that use of non-reproductive rainbow trout presented an impediment to Newfoundland salmonid aquaculture viability. The industry aspiration for this species was to produce a market fish of ~1.71 kg (i.e. 1 lb. fillets) within one growing season, a goal that did not appear achievable with triploid trout. In pursuit of this aspiration, starting in 1998, an anadromous strain (Silver Bullet) was incorporated into the evaluation inventory, under the caveat that the imported eggs/juveniles had to be genetically all female.

On March 8, 1999, after much debate on the matter, the Minister of Fisheries and Oceans Canada authorized the use of all-female, reproductively-competent rainbow trout for commercial-scale aquaculture trials within the Bay d'Espoir fjord. This approval was conditional on both levels of government carefully evaluating their commercial aquaculture performance and determining if the requested strain offered significant advantages over reproductively-incapacitated strains in the Bay d'Espoir environment. In the interval since 1999, a market niche for 300 g steelhead fillets has changed the industry perspective somewhat. However, the overarching goal for the Bay d'Espoir industry still is to achieve a marketable product in as short a period of time as possible for the lowest possible cost of production. This report documents results of Bay d'Espoir industry endeavours towards this end.

In parallel with this work on rainbow trout, industry and government commenced quantitative evaluation of alternative strains of North American-origin Atlantic salmon for use in marine cage culture in Bay d'Espoir. Some of this work to identify and develop a Newfoundland strain for application to local aquaculture-industry development actually started in 1989 (Pepper et al. 2003). As a result of Bay d'Espoir salmonid aquaculture industry aspirations to determine the pros and cons of alternative approaches to salmon strain-performance improvement, the Bay d'Espoir industry had five separate strains of Atlantic salmon in its hatchery inventory in 1999.

Evaluation of the five strains of Atlantic salmon and three strains of rainbow trout is documented in this report.

## METHODS

### FJORD PHYSICAL/CHEMICAL CHARACTERISTICS

Recognizing its estuarine-fjord environmental situation as one of potential significant impact on its aquaculture operations, the NSGA and both federal and provincial levels of government have invested in documenting fjord physical and chemical variables of significance to salmonid aquaculture. Much of this work has been documented by Tlusty et al. (2000a). Strategic to the Bay d'Espoir aquaculture industry are: a nearly-full description of the seafloor topography via high resolution multi-beam side-scan sonar bathymetric analyses (SWATH), (Tlusty et al. 2000c); current monitoring (Acoustic Doppler); CTD profiling; and, continuously-recording deployments of fixed gear (YSI6600) at depths in the water column of significance to salmonid aquaculturists. Emphasis on the upper-water column for this physical/chemical monitoring stems from the fact that, through the last decade of the $20^{th}$ century, net depth of aquaculture cages in Bay d'Espoir typically was 10 m during the summer and only 6 m during the winter. Data from the various environmental-monitoring initiatives are critical to understanding salmonid-husbandry requirements and strain performance under Bay d'Espoir aquaculture conditions. For the present salmonid-strain performance evaluations, these sources of historical data were supplemented with periodic deployments of both fixed and mobile gear for collection of data on temperature, oxygen and salinity.

TROUT

All-female, triploid rainbow trout eggs were imported into Bay d'Espoir in 1997. These eggs were incubated at the Bay d'Espoir hatchery where resulting fry underwent first feeding and early on-growing. Juvenile rainbows of this group were transferred from the hatchery to Jeddore Lake (i.e. the water supply to the Bay d'Espoir Hydro Station) on June 15, 1998 where they were vaccinated against *Vibrio* sp and *Aeromonas salmonidica* in October. This year-class was retained in the lake cages until the following May. The group then was transferred to estuarine cages at Muddy Hole (47.815°N, -55.856°W) to complete the on-growing cycle. In 1998 the Bay d'Espoir industry imported eggs of both all-female, triploid rainbow trout and all-female, triploid steelhead into its hatchery where the two groups underwent incubation and early rearing until the fall of that year. Once again, these groups were transported to lake cages in Jeddore Lake and vaccinated in the fall. These groups were retained in the lake cages through the winter months, then sampled in the spring prior to transfer to estuarine aquaculture pens.

Juveniles from these importations were monitored by industry personnel. Individual weight samples for these groups were taken at the Jeddore Lake cages in April of 1998 and 1999 before transfer to estuarine cages. Batch weighings of trout in the estuarine nets were performed by farm-site workers on a monthly basis throughout the on-growing interval. Additional data recorded by the farm-site workers included daily mortality and the amount of feed distributed to the individual cages of fish. All of these data subsequently were forwarded to Fisheries and Oceans Canada for analysis. Unfortunately, individual weight samples were not taken from the various groups of pre-harvest trout, thereby limiting the scope of statistical analyses and precluding quantitative statements of gain in biomass.

Juvenile, all-female diploid steelhead were imported directly to estuarine pens in 2000. These groups of juvenile steelhead (smolts) arrived in Bay d'Espoir on April 30, May 30, June 2 and June 15 and were placed directly into estuarine cages. Mean weight on arrival of these groups was determined by batch weighing by the recipient companies. These imported juveniles were transferred to fjord sites at May Cove (47.749°N, -55.880°W), Hardy Cove (47.795°N, -55.848°W) and Jersey Cove (47.855°N, -55.831°W) (Fig. 1).

Cages of diploid trout at the three farm sites were monitored on a monthly basis through the summer months. Most often, steelhead specimens were obtained from the cages by dip net during feeding. They were anaesthetized (TMS), most often in lots of 5-10 specimens before data capture. Records were kept of live weight and fork length of individual specimens. Sampled steelhead were allowed to recover from the anaesthetic before being returned to the cages. In conformance with industry practice, all cages were stocked with a starting inventory ranging from ~19,000 to 25,000 specimens (regardless of weight).

A recording thermograph was attached to one of the steelhead cages at each of the three sites in 2000 and positioned at a depth in the water column occupied by most of the steelhead most of the time (i.e. 8 m as determined by divers). A YSI 6600 meter was suspended from one of the cages at May Cove to determine environmental variability in oxygen, temperature and salinity at the depth of the instrument. This meter initially was positioned at a depth of 10 m (bottom of the cage), but subsequently was repositioned (September 13) at 5 m. CTD (Seabird SBE25) profiles were taken from each farm site on a monthly basis.

During the course of the sampling program for 2000, controversy arose among the strain-evaluation participants as to the adequacy of the sampling methodology. The sampling routine adopted in support of salmonid-growth monitoring, namely attracting salmonids to the surface with food so that they could be captured by dipnet, potentially introduces a size bias to the resulting data (Shieh and Petrell 1998). Accordingly, an experiment was conducted to examine the potential for systematic bias due to sampling procedure.

For this comparison of weight, determined from individual measurements relative to batch weighing, May Cove steelhead were examined initially as per the adopted sampling methodology of using food to attract the fish. The 35 specimens procured in this manner were weighed and measured individually and released back to the cage subsequent to recovery from the anaesthetic. Shortly thereafter, the cage was seined by participating-company personnel. Three subsets of fish (20, 29 and 21 specimens respectively) were weighed in batches to determine mean weights. A total of 35 specimens, selected randomly from these batch weighings, then was subjected to individual weight measurements to interpret adequacy of the sampling methodology.

## ATLANTIC SALMON

As a result of its endeavours to evaluate alternate salmon strains for Bay d'Espoir aquaculture, the NSGA had in its hatchery inventory in 1999 five groups of salmon as per Table 1.

Subsequent to smoltification in early May 1999, these five groups of Atlantic salmon were transferred to an estuarine-staging area (Snook's Cove, Fig. 1) and placed initially in nets that were 5 m deep. A recording thermograph was attached to each of the five cages at a depth of 2 m.

Table 1. Atlantic salmon strains for performance evaluation.

| Strain | Gender | Ploidy | Designation[a] |
|---|---|---|---|
| Saint John (SJR) | All-female | 2n | SJR, all-female |
| Gaspé Peninsula[b] | All-female | 3n | Gaspé, triploid |
| Grand Codroy (GCR) | Mixed-sex | 2n | GCR, mixed-sex |
| GCR x SJR | All-female | 2n | GCRxSJR, all-female |
| Saint John | Mixed-sex | 2n | SJR, mixed-sex |

[a]Strain identification for this document.
[b]Cascade Aqua Farms, 170 Harkins Rd., Winlock, WA 98596, USA.

Salmon specimens (n = 35) from each cage were anaesthetized with TMS and were weighed and measured individually by DFO personnel on an opportunistic basis through the summer months. Initial weight samples were taken on May 19 at the temporary staging area at Snook's Cove. Cages subsequently were relocated further out the bay to May Cove in late May, at which time the five groups were placed in square Hercules Cages measuring 15 m per side. Nets used initially at this site were of 28.6 mm stretch mesh and were 5 m deep. In response to a July fish-health crisis at the site, in anticipation that the dynamics of the freshwater layer of the upper fjord may be imposing a stress load on the fish, deeper nets were installed for all of these groups of fish.

The 5 m nets were replaced with 10 m deep nets during the last week of July. The cages containing the five groups of Atlantic salmon were moored at a position in May Cove that was well removed from steelhead operations that were ongoing at this site. Salmon-farm personnel maintained daily records of cage inventory, mortality and food dispensed.

The 1999 sampling of Atlantic salmon strains at May Cove was completed in October. Recording thermographs were recovered from the May Cove cages on October 14 and replaced with new units for operation through the winter. The five groups of Atlantic salmon, carried forward from the 1999 inventory, were removed from their first summer's growing site at May Cove on November 6, 1999 and towed to the participating-company site in Roti Bay for over-wintering (pertinent sites identified in Fig. 1). Recording thermographs were installed, one unit on each of the five, 15 m square Viking steel cages, at a depth of 8 m. These units provided continuous records of water temperature from October 14, 1999 to May 16, 2000, at which time the units were refurbished and reinstalled.

In May, 2000 the five strains were transferred to 70 m diameter, plastic circular cages and subsequently relocated (June 23) from their over-wintering location to Deer Cove, Little Passage (47.674°N, -55.927°W). It is significant to note that, prior to 2001, towing of cages was a standard practice for relocating salmonid livestock between summer and winter aquaculture sites.

Salmon nets used during the second summer were of 64 mm stretch mesh and were 10 m deep. Fish-farm personnel maintained daily records of cage inventory, mortality and food dispensed. Again, specimen morphometrics were measured on a monthly interval, environmental conditions permitting. On only one occasion (August 15, 2000) during the two-year study did sampling-personnel activities at the Deer Cove site coincide with the diver schedule for removal of mortalities from the cages. Mortality at the site at that time was slight and provided only 13 specimens for comparison of mean weights of dead salmon to those of the live samples.

A requirement of the Bay d'Espoir aquaculture industry code-of-practice for salmonid farmers is removal and immediate cremation of fish mortalities in provincially-approved incinerators located at strategic locations around the fjord. During the August sampling, the 13 dead salmon were weighed and measured prior to incineration to provide some insight into potential size discrepancy between live specimens and those lost due to mortality. This comparison of live vs. mortality weight was conducted by strain.

The 2000 sampling of Atlantic salmon strains at Deer Cove was completed in September, after which time the cages were relocated to the fish processing plant (Ship Cove). Maturing salmon were removed from the cages at the time of processing by seining the freshwater layer of the cage. Final samples were taken from the seined grilse and from the processing line at the fish plant as markets demanded. This resulted in an interval of 105 days between collection of the data for the initial strain of salmon to be processed (October 11, 2000) and the last samples taken for this strain-evaluation experimentation (January 24, 2001). The fastest-growing strain was processed first to leave time for the smaller specimens to achieve greater market value. To facilitate analysis, final sample weights were adjusted to a common harvest date (October 11, 2000) by determining the daily instantaneous rate of growth between the penultimate (September) and final (harvest) samples, then adding the calculated weight increment for the interval to the penultimate sampling weights.

## ANALYSES

On completion of the salmonid strain monitoring for 2000, the project database consisted of four disparate data sets:

1. Daily records of inventory, mortalities removed from each cage and food dispensed to each cage as recorded by fish-farm personnel;
2. Hourly records of water temperature (and for one location, oxygen and salinity) in the lower region of the cage as collected by DFO personnel;
3. Intermittent records (opportunistic sampling, where possible at monthly intervals) of live-fish fork length and wet weight as determined jointly by DFO, DFA and industry; and,
4. Periodic CTD profiles (temperature, oxygen and salinity) procured jointly by DFO and DFA.

The suite of performance indicators for this aquaculture experiment included growth, survival and food conversion ratio (FCR; both economic and biological versions). Data collected during the experiment were examined for overall patterns of strain performance. Comparison statistics were developed as per Table 2 (Pepper et al. 2003).

As well, regression analysis was used to examine relative strain condition among the five groups of salmon. The regression was of the form:

$$Log_{10}Weight_g = Log_{10}a + bLog_{10}ForkLength_{cm.}$$

where

a = intercept

and,

b = slope (regression coefficient)

In this equation, the slope of the regression provides an overall indicator of salmon-strain condition (Ricker 1975).

Actual quantitative analyses performed in the present report focused on weights of the various groups of salmonids from May 1999 through October 2000. This required a simple one-way analysis of variance of weights (STATISTICA™ V6, StatSoft Inc.) plus analysis of covariance of increase in biomass relative to food consumed. Confidence intervals for the estimates of increase in mean weight, increase in biomass and $FCR_{(economic)}$, between the start and end of the experiment, were determined as per Milliken and Johnson (1984; STATISTICA macro 'confidence intervals.svb') and Neter et al. (1990).

Table 2. Performance evaluation statistics applied to Bay d'Espoir salmonid strain evaluations.

| Performance Indicator | Calculation | Input Variables |
|---|---|---|
| Daily rate of mortality[a] | $Z = \frac{-(\ln N_t - \ln N_0)}{t}$ | $N_0$ is the number of individuals in the population at the beginning of the specified time interval; |
| Daily rate of growth[a] | $G = \frac{(\ln W_t - \ln W_0)}{t}$ | $N_t$ is the number of individuals in the population at the end of the specified time interval;<br>t is the time interval (in this case, days); |
| Daily rate of change in biomass[a] | $R = G - Z$ | ln is the natural logarithm;<br>$W_t$ is the mean weight of individuals in the cage at the end of the specified time interval; |
| Food Conversion Ratio:<br>FCR(biological)[b] | $FCR = \frac{FoodTaken_{(kg)}}{(B_t + B_{dead} - B_0)}$ | $W_0$ is the mean weight of individuals in the cage at the beginning of the specified time interval;<br>$B_t$ is the biomass (kg) of fish at the end of the interval; |
| FCR(economic)[b] | $FCR = \frac{FoodTaken_{(kg)}}{\Delta B_{(kg)}}$ | $B_{dead}$ is the biomass (kg) of fish that died during the interval;<br>$B_0$ is the biomass (kg) of fish at the beginning of the interval. |
| Growth Factor[c] | $GF_3 = \frac{(Wt_t^{1/3} - Wt_0^{1/3})}{\sum TU} x1000$ | $\Delta B$ is the change in biomass between the start and the end of the on-growing interval (= $B_t$ - $B_0$); and, |
| Performance Index[d] | $PI = \frac{\Delta Weight_{(kg.)} x100}{FCR_{economic}}$ | $\Sigma TU$ = accumulated thermal units (i.e. mean daily temperature in °C x number of days) during the time interval. |

[a] Ricker (1975)
[b] Sveier and Lied (1998)
[c] Holmefjord, et al. (1995).
[d] McCluskey and Johnson (1958).

# RESULTS

## FJORD PHYSICAL/CHEMICAL CHARACTERISTICS

Fjord morphometric surveys (i.e. SWATH) of Bay d'Espoir have revealed a complicated hydrographic situation of multiple-fjord basins, typically of steep sides and depths to 525 m. Sills of varying depth separate these basins. Tides (http://www.irbs.com/tides/locations/5177.html; last accessed on 19 November 2003) typically are 0.63-1.42 m, averaging 1.11 m on an approximate 12h cycle (high tide to high tide). Water-column stratification varies considerably along the length of the fjord, most often showing greater depth of the freshwater layer towards the head of the bay than further seaward (Fig. 2). This stratification varies also with local weather conditions, southeasterly winds tending to pile up fresh water on the surface at the head of the bay. Northwesterly winds tend to blow fresh water out the bay and result in higher salinities and a thinner freshwater layer towards the head of the bay. Storm conditions can result in considerable agitation of the water column, even to depths of 10 m (Fig. 3) half way out the bay. Such estuarine-fjord dynamics are further complicated during the winter when parts of the fjord freeze over and, depending on the severity of the winter, occasionally necessitate under-ice salmonid farm operations.

Water-column superchill conditions for Atlantic salmon (i.e. –0.70°C per Saunders et al. 1983, -0.76°C per Fletcher et al. 1988) within the fjord are not common. Winter water-column temperatures as low as –1.3 °C occasionally have been encountered further seaward from the fjord entrance, usually in the upper 4 m of the water column. Surface waters during the summer months are highly variable and, especially in August, can reach temperatures of 20°C. Such surface conditions, irrespective of salinity, encourage salmonids to remain lower in the water column.

Thermal characteristics for the main marine over-wintering site in Roti Bay, as per the five thermographs deployed, are summarized in Appendix 1 and Table 3. The lowest water temperature at this site was recorded on January 2 at 0.6°C. For that particular day, the mean temperature recorded for all five thermographs was 4.6, with a maximum of 5.0°C. The greatest variability in daily temperature was recorded in October. Mean daily temperature "stabilized" at ~+2°C during much of March and April. Other than for periodic feeding of a maintenance ration, the fish were undisturbed (i.e. not sampled) during the coldest weeks of the winter.

Measurements of temperature were made on an hourly basis at selected sites in Bay d'Espoir (Fig. 4) to document the thermal environment in the area of the cages. Located at approximately 47.749°N, -55.880°W, May Cove is about one half the distance along the longest axis of the Bay d'Espoir fjord from the head of the bay to an imaginary line connecting the headlands at Goblin Head and Green Point (Fig. 1). CTD profiles at the May Cove site revealed a characteristic pattern of water column stratification as illustrated by an instrument cast performed on August 1, 2000 (Fig. 5).

Table 3. Thermal characteristics at 6 m for salmon cages in Roti Bay (October 14, 1999 – May 16, 2000).

| Duration | Minimum daily Temperature | Mean daily temperature (°C) | | | | Daily range (°C) |
|---|---|---|---|---|---|---|
| | <2.0 | <2.0 | <3.0 | <4.0 | <5.0 | <2.0 |
| # days | 61 | 18 | 68 | 116 | 152 | 192 |
| % of days | 28 | 8 | 31 | 53 | 70 | 89 |

Deer Cove, where the salmon pens were located during the second summer of this experiment, is ~ 35 km from the head of Bay d'Espoir. Although well removed from the main freshwater input sources to Bay d'Espoir, there is some surface runoff in the area. Even at this location, typical estuarine layering of the water column is evident (Fig. 2, panel 4). A layer of lower-salinity water at Deer Cove varied considerably with wind direction but, typically, was limited to the upper 3 m of the water column.

Summer temperature fluctuations at 8 m for selected sites in the fjord are illustrated in Fig. 4, the vertical bars representing temperature range within a 24 h period. At 8 m, optimal thermal conditions occur during July and August. On the basis of hourly thermograph records at 8 m (Table 4), depending on site location within the bay, optimal thermal conditions occurred during 11-30% of the summer on-growing interval.

TROUT

All-female, triploid rainbow trout in the Bay d'Espoir hatchery in 1998 were transferred to a cage in Jeddore Lake in mid June to free up hatchery space. These trout spent the next 10 months in the lake cage. Of the almost 18000 trout remaining in the lake cage at the end of the following April, 15000 were transferred to a marine cage (726 L, Table 5) at Muddy Hole at about 600 g mean weight. The following year class of trout at the hatchery also was transferred to cages in Jeddore Lake for overwintering in 1998 (cage 501), this time in October. This resulted in two successive year classes at Muddy Hole during the summer growing season in 1999. A summary of the performance of these two groups is presented in Table 5. Due to the industry practice of batch weighing without replication, there are no confidence intervals associated with these estimates.

Data for the all-female, diploid-trout monitoring of 2000 are more amenable to statistical analyses. For the three sites of the 2000 monitoring (Fig. 1) of all-female, diploid steelhead, pertinent data are as per Table 6.

Table 4. Hourly temperature recordings for selected Bay d'Espoir salmon farms and frequency of observed water temperatures relative to optimal thermal regimes for Atlantic salmon (Dwyer and Piper 1987).

| | | Water temperature at 8 m[a] | | | | | |
|---|---|---|---|---|---|---|---|
| | | < 13.0 °C | | 13.0 to 16.0 °C | | > 16.0 °C | |
| Site Location | Monitoring Interval | Number records | % records | Number records | % records | Number records | % records |
| Roti Bay | May 16- Nov. 21 | 3043 | 79.24 | 409 | 10.7 | 120 | 3.13 |
| Deer Cove | Jun. 25- Sept. 30/00 | 2396[b] | 66.2 | 657 | 18.2 | 566 | 15.6 |
| May Cove | Jun. 14- Nov. 22/00 | 2221 | 57.84 | 1160 | 30.21 | 459 | 11.95 |
| Hardy Cove | Jun. 14- Nov. 14/00 | 2950 | 76.82 | 808 | 21.04 | 82 | 2.14 |

[a] Depth in the water column occupied by most of the salmon most of the time,
[b] Represents data from two thermographs on two different cages.

Table 5. Muddy Hole trout performance summary for the 1997 and 1998 year-classes.

| Year/ Cage | Days | Live weight (g) End | Live weight (g) Start | G | Number of fish End | Number of fish Start | Z | Feed (kg) | Increase in biomass | Economic FCR |
|---|---|---|---|---|---|---|---|---|---|---|
| 1997/ | | | | | | | | | | |
| 507 | 319 | 596.7 | 60.0 | 0.00720 | 17956 | 18540 | 0.0001 | 9768.75 | 9582.1 | 1.02 |
| 726L | 155 | 2017.4 | 600.0 | 0.00782 | 13614 | 15001 | 0.0006 | 31712.50 | 18464.0 | 1.72 |
| 1998/ | | | | | | | | | | |
| 501 | 349 | 991.5 | 78.0 | 0.00729 | 19240 | 19950 | 0.0001 | 21181.25 | 17520.6 | 1.21 |
| 503 | 349 | 1163.4 | 70.0 | 0.00805 | 19186 | 19991 | 0.0001 | 22525.00 | 20922.2 | 1.08 |

Table 6. Steelhead weights and growth during the 2000 on-growing season.

| Location | Cage # | Weight (g) End | Weight (g) Start | Days | G |
|---|---|---|---|---|---|
| May Cove | Cage 10 | 1741.6 | 114 | 170 | 0.0160 |
| | Cage 20 | 1462.6 | 85 | 140 | 0.0203 |
| | Cage 22 | 1181.9 | 71 | 140 | 0.0201 |
| Hardy Cove | | 1032.4 | 108 | 102 | 0.0221 |
| Jersey Cove[a] | | 758.9 | 120 | 73 | 0.0253 |

[a] Last successful sample completed August 17, 2000.

Although the trout evaluations for 2000 were undertaken on five cages of steelhead at three sites, specimen sampling proved challenging at the site of the greatest freshwater influence (Jersey Cove, Fig. 1). It was difficult to capture steelhead specimens in these cages as the fish tended to avoid the freshwater layer at the surface and the cage flotation collar was not sufficiently sturdy to support the combined weight of investigators during the specimen-capture process. Thus, it is only the May Cove cages for 2000 for which the data are sufficient to support quantitative statements of performance. An overview of trout growth for the three years for which data are available is presented in Fig. 6.

Evaluation of the specimen-sampling protocol for May Cove steelhead is illustrated in Fig. 7. There was no difference in mean weight between the food-attracted and seined samples when examined on an individual weight basis ($t = 1.07$, $p = 0.28$; food attracted vs. seined). Homogeneity of variance of the two samples was confirmed (Levene F-ratio = 1.27, $p = 0.49$). The mean weight obtained from the three batch weighings did not differ significantly from the mean weight calculated for the 70 specimens that were weighed individually ($t = 0.156$, $p = 0.87$).

An overview of the weight distribution of steelhead from May Cove and Hardy Cove as of the final sampling on October 17, 2000 is provided in Fig. 8. Raw weights illustrated a moderate departure from homogeneity of variance. ANOVA of log-transformed weights revealed highly significant differences among the three May Cove cages ($F = 28.04$, $p < 0.0001$) at the time of final sampling. The transformed weight values conformed with assumptions of homogeneity of variance (Levene test; $F = 0.28$, $p = 0.75$). Economic FCR and relative increase in biomass among the three May Cove cages of all-female, diploid steelhead is illustrated in Fig. 9. These data are presented in Table 7.

Table 7. All-female, diploid steelhead trout performance at May Cove, 2000.

| Cage | Estimated biomass (kg) End | Estimated biomass (kg) Start | Estimated biomass (kg) Increase | 95% Confidence on biomass increase Lower | 95% Confidence on biomass increase Upper | Food dispensed (kg) | Economic FCR Point estimate | Economic FCR 95% Confidence Worst | Economic FCR 95% Confidence Best |
|---|---|---|---|---|---|---|---|---|---|
| 10 | 39279.4 | 5463.2 | 33816.2 | 31163.2 | 36469.1 | 47600 | 1.41 | 1.53 | 1.31 |
| 20 | 25818.8 | 3215.7 | 22603.1 | 20792.6 | 24413.6 | 38775 | 1.72 | 1.86 | 1.59 |
| 22 | 20954.7 | 2263.9 | 18690.8 | 17452.8 | 19928.7 | 40450 | 2.16 | 2.32 | 2.03 |

In addition to quantitative analyses, observations of trout behaviour also were of significance. Of all the observations of trout behaviour during the interval of these experiments, the most obvious difference between strains was their distribution in the water column. Rainbow trout were seen most often to mill around at the surface, often with their dorsal fins breaking the surface of the water. In contrast, steelhead strains avoided the surface layers and were much more difficult to capture for purposes of live sampling.

ATLANTIC SALMON

The hatchery phase of the production cycle for salmon strains was routine and demonstrated little of significance aside from confirming that often there is an inverse relation between the numbers of salmon raised and the size attained (Table 8).

Table 8. September 1998 sampling of four Atlantic salmon strains in the Bay d'Espoir hatchery.

| Group | Number | Mean weight (g) | Biomass (kg) |
|---|---|---|---|
| SJR, all-female, 2n | 35063 | 12.4 | 435 |
| Gaspé, all-female, 3n | 9939 | 25.5 | 845 |
| Grand Codroy, mixed-sex, 2n | Hatchery data not available | | |
| GCR x SJR, all-female, 2n | 106038 | 11.0 | 117 |
| SJR, mixed-sex, 2n | Hatchery data not available | | |
| 3n GCR | 9758 | 12.5 | 637 |

Starting inventories for the five groups of salmon transferred from the hatchery to Snooks Cove varied considerably, as did mean weight of the smolts. This resulted in different densities among groups (Table 9).

An analysis of variance of the starting weights confirmed homogeneity of variance of the five strains ($F = 0.24$, $p = 0.91$) and a significant difference in mean starting weight among the various groups ($F = 53.51$, $p < 0.001$). A multiple range test (Duncan's) suggested three clusters. At the start of the experiment, Gaspé Peninsula and SJR mixed-sex smolts were similar in weight (heaviest) as were SJR all-female and GCR mixed-sex smolts. Smolts of the SJR (sex-reversed) x GCR female cross (lightest) differed from the other two groups in mean weight.

Table 9. Strain identification and starting inventories. Superscripts denote statistical similarity (Duncan's $p > 0.05$).

| Strain | Starting inventory (number) | Mean smolt weight (g) | Starting density (kg/m$^3$) |
|---|---|---|---|
| SJR, all-female, 2n | 9050 | 83.7[b] | 0.32 |
| Gaspé, all-female, 3n | 8198 | 97.8[a] | 0.33 |
| Grand Codroy, mixed-sex, 2n | 7989 | 80.5[b] | 0.28 |
| GCR x SJR, all-female, 2n | 6246 | 42.3[c] | 0.11 |
| SJR, mixed-sex, 2n | 7720 | 95.4[a] | 0.32 |

Monthly monitoring of salmon through the summers of 1999 and 2000 was interrupted by mortality peaks that took place in both years in early July (Fig. 10) and corresponded with outbreaks of atypical furunculosis. Specimen handling at such times was avoided to minimize anthropogenic stressors. Total salmon mortality during the study interval of 1999 ranged from a low of 9% to about 17% and averaged 14% across all groups. About 69% (ranging among groups from 56 to 78%) of this first-year mortality took place during early July.

An overview of numbers of fish and overall biomass accumulated during the interval of the experiment is presented in Figure 11. Differences in performance among the five strains at the end of the first summer were slight. It was not until the August, 2000 sample at Deer Cove that differences in size were apparent among strains ($F = 8.17$, $p<0.001$). Homogeneity of variance of weight among the strains was confirmed (Levene's test; $F = 1.12$, $p=0.35$). In recognition of the size discrepancy among strains at the time, analysis of weights of dead salmon at the site was conducted by strain to determine the reliability of the $FCR_{(biological)}$ calculations, as this indicator requires an estimate of biomass lost to mortality. Students t-test statistics suggest that there was no difference in mean weight between live samples and mortalities for SJR mixed-sex and Gaspé strain triploids. For the three other strains, mean weight of the mortalities was less than the weights of the live samples. For all strains, elaboration of biomass was compromised by mortality. For at least two of the strains, (i.e. Grand Codroy and Saint John mixed-sex strains), this daily mortality amounted to a significant loss to the aquaculture business (Fig. 12a) and therefore greatly depreciated daily gains in biomass (Fig.12b).

At the end of the 2000 growing season, the five strains of salmon from Deer Cove were relocated to a staging area immediately adjacent to the fish-processing plant in Ship Cove. This staging area subjected the fish to a much greater degree of water-column stratification than was normal for the Deer Cove site. Extreme rainfall during the interval in which these salmon were awaiting harvest, together with the location of the site much closer to the head of the bay and the associated river discharge, resulted in a pronounced freshwater layer at least two meters in depth throughout much of the pre-harvest interval. This discrete freshwater lens served as a natural grading mechanism in which maturing salmon took up residence in the freshwater layer while non-maturing salmon stayed deeper in the water column.

As a consequence of varying salmon-market demand, the five strains of salmon were harvested over a time interval ranging from October 11 to January 24 (i.e. 105 days). Being the largest (i.e. most marketable) of the five strains, the Gaspé-strain triploids were harvested first, followed by the SJR, mixed-sex salmon (industry-standard strain). The last group to be harvested (lowest mean weight as of October 11) was the SJR, all-female strain.

Due to the drawn-out harvest interval, for purposes of illustration, all data have been adjusted to the October 11 harvest date for the Gaspé-strain triploids. Sampling of the five strains of salmon from May 24, 1999 through to the October 11 termination date of the first harvest resulted in the performance indicators of Table 10.

The Table 10 representation of strain performance is highly influenced by the significant incidence of maturation (31–58%) experienced by all four of the reproductively-capable strains that rendered maturing specimens unfit for market. Elimination of the grilse component from the final harvest figures (Table 11) results in an adjustment to the performance evaluations for all but the triploid strain that did not show any indications of maturation.

One trait that was apparent among triploid salmon at the time of harvest, that was not observed in reproductively-competent strains, was various forms of jaw deformity ranging from eroded opercula to grossly malformed lower jaws. Of the total harvest sample of 117 specimens, 17 (14.5%) had mild-to-severe deformities of the head region. Mean weight of specimens with jaw deformities was similar to that of normal-looking production salmon ($t = 1.91$, $p = 0.058$). Variance in weights between these two groups of triploid salmon was homogeneous ($F = 1.62$, $p = 0.205$). All of the triploid salmon were marketed in filleted form. Condition of the salmon at the time of harvest, illustrated in Fig. 13 by the relationship ($\log_{10}$ transformed) between weight and fork length among the five strains, generated considerable comment among fish-plant workers. Of the five strains, only the Gaspé-strain triploid salmon were characterized by site workers as "chunky". This is confirmed by the regression statistics for these data as presented in Table 12.

Examination of sample weights, adjusted to the common harvest date after elimination of all maturing specimens, revealed a significant departure from the assumption of homogeneity of variance among strains ($F = 8.3$, $p < 0.001$). Hence all weight data were subjected to $\log_{10}$ transformation. This was successful in homogenizing variance ($F = 2.08$, $p = 0.08$) among strains. One-way ANOVA of the resulting data set confirmed significant differences among the five strains ($F = 21.7$, $p < 0.001$). The overall progression in mean weight from the time of initial estuarine sampling to the time of final harvest is represented in Figure 14. However, perhaps more informative, given the significant incidence of early maturation and therefore lost market opportunity, is the progression of biomass to the common harvest date of October 11. Overall, sample weights during the salmon strain-evaluation experiments increased through the experiment as per Figure 15.

As an alternative to the ratio estimators for FCR and PI, an attempt was made to examine increase in strain biomass between June 23, 1999 and October 11, 2000 as a function of the amount of food consumed. A separate-slopes analysis of covariance ($\log_{10}$ biomass increase regressed on $\log_{10}$ food consumed) failed to meet the assumptions of homogeneity of variance of the starting biomass estimates (Levene's test: $F = 7.01$, $p < 0.0001$). A Kruskal-Wallis ANOVA by ranks, based on the sampling data collected at the time of harvest, confirmed a significant difference among strains with respect to estimated starting biomass ($H(4, 175) = 99.47$, $p < 0.0001$) and final estimated biomass harvested (grilse eliminated; $H(4, 571) = 469.45$, $p < 0.0001$). Start and end biomass comparisons are illustrated in Figure 16.

Table 10. Indicators of strain performance to common harvest date.

| Strain | Weight (g) End | Weight (g) Start | Number End | Number Start | $G^*$ | $Z^*$ | $R^*$ | FCR Bio | FCR Eco | PI | GF3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SJR, all-female | 3199.4 | 85.8 | 6517 | 9050 | 0.00311 | 0.0003 | 0.0028 | 1.68 | 1.85 | 11.3 | 2.31 |
| Gaspé, triploid | 4059.2 | 102.1 | 6962 | 8198 | 0.00316 | 0.0001 | 0.0030 | 1.25 | 1.34 | 21.1 | 2.52 |
| GCR, mixed-sex | 3269.7 | 84.4 | 3813 | 7989 | 0.00314 | 0.0006 | 0.0025 | 1.79 | 2.46 | 5.1 | 2.34 |
| GCRxSJR, all-female | 3422.2 | 46.9 | 4817 | 6246 | 0.00368 | 0.0002 | 0.0035 | 1.86 | 1.98 | 8.3 | 2.56 |
| SJR, mixed-sex | 3987.2 | 98.0 | 5248 | 7720 | 0.00318 | 0.0003 | 0.0029 | 1.42 | 1.64 | 12.7 | 2.52 |

End Date 10/11/00 Duration = * 506 days

Start Date 05/24/99

Table 11. Salmon strain evaluations adjusted for lost market value due to early maturation.

| Strain | End Weight (g) | End Number | G | Z | R | FCR Bio | FCR Eco | PI | GF3 |
|---|---|---|---|---|---|---|---|---|---|
| SJR, all-female | 3183.5 | 4497 | 0.00313 | 0.0006 | 0.0025 | 1.76 | 2.65 | 5.6 | 2.34 |
| Gaspé, triploid | 4059.2 | 6962 | 0.00316 | 0.0001 | 0.0030 | 1.25 | 1.34 | 21.1 | 2.52 |
| GCR, mixed-sex | 3261.6 | 1602 | 0.00316 | 0.0014 | 0.0018 | 1.84 | 6.20 | 0.9 | 2.37 |
| GCRxSJR, all-female | 3408.2 | 2746 | 0.00371 | 0.0007 | 0.0030 | 1.94 | 3.40 | 2.9 | 2.60 |
| SJR, mixed-sex | 4055.8 | 2939 | 0.00320 | 0.0008 | 0.0024 | 1.44 | 2.95 | 4.1 | 2.54 |

Table 12. Atlantic salmon strain evaluation (1998 year-class) weight-length regression statistics at harvest (unadjusted):
( $Log_{(10)}$ $Weight_{(g)}$ = intercept + (Regression Coefficient * $Log_{(10)}$ Fork $Length_{(cm)}$)

| Strain | Intercept | Regression Coefficient | SEE | r | F[a] | N |
|---|---|---|---|---|---|---|
| Non-maturing harvest salmon | | | | | | |
| SJR, all-female | -1.045 | 2.573 | 0.177686 | 0.83 | 209 | 100 |
| Gaspé, triploid | -3.541 | 3.889 | 0.165882 | 0.91 | 549 | 117 |
| GCR, mixed-sex | 0.220 | 1.891 | 0.566922 | 0.67 | 94 | 116 |
| GCR x SJR, all-female | -1.263 | 2.712 | 0.128572 | 0.90 | 445 | 103 |
| SJR, mixed-sex | -0.894 | 2.505 | 0.110939 | 0.89 | 510 | 135 |
| Grilse (maturing) | | | | | | |
| SJR, all-female | -2.014 | 3.092 | 0.199116 | 0.94 | 241 | 35 |
| Gaspé, triploid | -- | -- | -- | -- | -- | -- |
| GCR, mixed-sex | -0.967 | 2.485 | 0.176462 | 0.93 | 198 | 35 |
| GCR x SJR, all-female | -1.731 | 2.941 | 0.196940 | 0.92 | 223 | 41 |
| SJR, mixed-sex | -1.719 | 2.934 | 0.199024 | 0.92 | 217 | 39 |

[a]All regressions significant at $p < 0.0001$.

Quite aside from all statistical interpretations of the data, the essential fact of the strain-evaluation experimentation is that only the Gaspé strain of triploid salmon provided a return on investment to the fish farmer. All other Atlantic salmon strains of this year class resulted in a net economic loss to the aquaculture business.

# DISCUSSION

## FJORD PHYSICAL/CHEMICAL CHARACTERISTICS AND SALMONID PERFORMANCE

Figures 2-5 provide fjord characterization against which to interpret salmonid performance under Bay d'Espoir aquaculture conditions. It is apparent (Fig. 2) that the water-column is stratified but that the depth of the halocline varies considerably with location. Tide, wind speed and direction are significant factors in the depth of the halocline. Relative to recommended optimum temperature conditions for Atlantic salmon (Dwyer and Piper 1987), it is apparent that the fluctuating water-column conditions typical of the fjord often impose conditions outside the thermal preferences for optimal growth. It is apparent also (Fig. 3), that storm events can extend the zone of upper water-column variability to greater depths in a very short time interval.

Dwyer and Piper (1987) recommended growing conditions for Atlantic salmon be regulated to the range of 13°C to not more than 16°C. During July 1999, water temperature at the level of the water column occupied by most of the fish most of the time (i.e. 8 m) was >16°C for 40% of the temperature recordings. With a maximum-recorded temperature of 19.9°C in August, it is clear the thermal regime (Fig. 4) of May Cove in 1999 was pushing the limits of preferred farm-operating conditions.

Optimal thermal conditions for Atlantic salmon in Bay d'Espoir most often are encountered in the interval of July and August. In June, both the minimum and mean water temperatures (5.6°C and 12°C respectively) are too low for physiological efficiency. In July, both the minimum and mean water temperatures (9.6°C and 15.6°C) are conducive to improved performance and the digestive system may be "gearing up" for optimal performance. In August, the minimum and mean water temperatures (8.6°C and 14.9°C) are within optimal parameters. Being pre-conditioned by an adequate thermal regime in July, the digestive system may be at its optimal performance, leading to compensatory growth and most efficient FCR. During September, the minimum and mean water temperatures (9.5°C and 14.1°C) are adequate but the maximum temperature is reduced (15.9°C, down from 19.9°C in August) so core body temperature may not have the advantage of occasional temperature stimulation. While this is pure speculation, the reasoning warrants investigation. If shown to be tenable, this concept of thermal progression could provide a relatively simple base for refining husbandry practices through feeding regime.

This observation must be tempered with the fact that penned fish do have access to shallower areas of the aquaculture nets and healthy salmon are able to access higher water temperatures whenever summer temperatures at 8 m are lower than required. However, when viewed in the context of decreasing salinity with decreasing depth, penned salmon face a compromise between preferred temperature and preferred salinity. These observations suggest the need for considerable insight into fish physiology in order to assure that husbandry practices are implemented so as to encourage the best possible fish health and comply with metabolic requirements for optimal performance.

TROUT

Much of the available industry data on this species in Bay d'Espoir are equivocal in one way or another. In spite of these deficiencies, there are some interesting observations regarding freshwater and anadromous forms of this species and diploids relative to triploids. The most obvious behavioural dichotomy between the anadromous and freshwater forms of the trout was preference of the latter for lower salinity. Given higher variability in environmental conditions of this upper layer of the estuarine water column, rainbow trout strain performance likely is negatively impacted by the necessity of physiological adjustments to basal metabolism that are likely to manifest themselves as eroded feeding efficiency. Unfortunately, there is little to be deduced relative to ploidy consequences on these two forms as the opportunistic data sets for diploids and triploids are not directly comparable (i.e. once having access to all-female steelhead, the Bay d'Espoir industry stopped importing triploids). What was observed, though in different years, was that triploid rainbow trout mortality attributable to Bay d'Espoir pathogens was much greater than for diploid steelhead.

With respect to planned comparisons of this aquaculture research, sampling methodology is always of concern when there are systematic behavioural dichotomies among experimental groups. If there are distinct behavioural groups of fish in a given cage (e.g. feeding intensity or depth distribution), using feed to attract specimens for capture could result in non-random sampling. In the absence of suitable video equipment for monitoring fish size, the sampling methodology applied here was adopted as a compromise to avoid excessive interference with the fish in an attempt to minimise fish stress. Although this compromise was expected to result in a slight positive size bias to the sampling statistics (Shieh and Petrell 1998), industry personnel expected a negative bias on the basis of a perceived preference by larger specimens for deeper (i.e. cooler) water.

It is apparent from observations of salmonid behaviour that aquaculture salmonids actively avoid extremes of environmental conditions by adjusting their position in the water column, thereby making simple statements of relative suitability of estuarine ongrowing conditions tenuous. For fjord sites further seaward, generally cooler conditions prevail. An over-wintering experiment at the Matchums (Little Passage; Fig. 1) in 2000 and 2001 (Pepper et al. 2002), revealed winter-water temperatures that occasionally dipped below zero (minimum temperature recorded was –0.8°C, at 2 m) and were less variable with depth (Fig. 17).

For the trout-data sets provided by industry (i.e. 1997 and 1998 year-classes), the absence of final-sample data precludes succinct, quantitative statements of relative performance. Based on batch determinations of mean specimen weight as monitored by industry personnel for these year-classes of triploid trout, and comparison with the more comprehensive marine-cage sampling of the 1999 year-class of diploids, growth of triploid trout was inferior to that for diploids. Unfortunately, this is confounded by the fact that most of the triploids were rainbow trout while most of the diploids were steelhead and that the two ploidy groups were monitored at different sites and in different years. For the comprehensive sampling of the 1998-year-class (i.e. 2000 data) of diploid steelhead, analyses suggest that all previous year classes had inferior performance that may be attributed to strain and/or triploidy. Figure 6 suggests diploid steelhead have growth advantages over triploid rainbows and Figure 9 indicates, for the diploid steelhead of the 2000 May Cove samples, the importance of getting large smolts (i.e. 100 g+) into the marine cages early in the on-growing season.

The present data record for steelhead operations in Bay d'Espoir is insufficient to support much more than an opportunistic description of performance. However, on-site interactions with farm workers and the fish at both salmon and steelhead operations suggest that steelhead farmers are not subject to the same burden of challenges faced by the Atlantic salmon operations. Present experience suggests steelhead operations have benefited greatly from the following industry innovations of the past two years:

1. Change of strain. It is only in recent years that the Bay d'Espoir salmonid growers have switched to a true steelhead strain. Pervious operations were based on a freshwater strain that demonstrated a marked preference for lower-salinity water. The steelhead strain used more recently typically remains in the deeper parts of the cages, thereby avoiding the more rapid fluctuations of environmental variables often associated with the freshwater lens.

2. Grading of fish prior to introduction to estuarine cages. By moving to fish of ~100 g mean weight for introduction to on-growing pens in the Bay d'Espoir fjord, farmers take advantage of the exponential growth potential of these fish. This results in both a hardier fish, potentially capable of tolerating a greater load of environmental variation and associated physiological stress, and a fish with a greater probability of achieving marketability within a nine month on-growing interval.

3. Increased depth of estuarine net pens to provide aquaculture fish access to a greater pen volume below the halocline. Although the on-growing environment can fluctuate, at times even to the bottom of a 10 m net (Fig. 3), the frequency of radical fluctuations tends to decrease with increasing depth. Increased net depth provides cage inventory with a refuge against physiologically-stressful conditions without subjecting fish to negative impacts of crowding.

Data regarding steelhead performance through 2000 are sufficient to support some basic conclusions. These are:

- Industry preference for batch weightings of random samples of fish provides an adequate representation of the mean weights of the cage inventory as there was no significant difference observed between the mean weights calculated from individual measurements and those calculated from batch weights. However, this approach should to be tempered with the need for multiple batch weighings to support quantitative analyses (see below);

- The industry's goal of achieving 1 lb fillets at the end of one summer of on-growing in the Bay d'Espoir estuarine fjord is achievable. Given industry experience that fillet weight at harvest is 53% of live weight, this translates into an overall mean steelhead target weight at time of harvest of ~1.7 kg. The only steelhead observed to achieve this size threshold were produced from fish that were placed into the estuarine cages early in the on-growing season at a mean weight of >100 g. Due to the fact that mean weight on arrival of steelhead juveniles in Bay d'Espoir is determined by batch weighing by individual Bay d'Espoir companies, generalizations regarding the potential for growth performance are tenuous. If the industry goal is to achieve the desired 1-pound fillet threshold by the end of the first on-growing season, industry practitioners will have to assure an adequate size at the time of saltwater entry and sufficient time in the growing season to achieve the desired results. For the 2000 on-growing season, the on-growing interval was 170 days. With a sustained daily instantaneous growth rate of 0.016 (i.e. the lowest observed daily instantaneous growth recorded for the fish of Table 12), the mean weight at time of saltwater entrance would have to be 113 g (i.e. $W_0 = EXP(Ln(W_t - G \bullet t)$.)

While these observations and conclusions are significant to industry, presented in bullet form they are simplistic. The conclusion on sampling protocol and observations of growth performance merit further comment.

Need for industry assessment of mean weight of fish in the respective cages is imposed largely in the context of feed-strategy planning. Mean weight of fish in a cage determines the size of the pellet appropriate to feed the fish at a given stage in their captivity. Mean weight, together with inventory and temperature records, also serves to anticipate the overall amount of feed the fish are likely to require in a given interval. For such purposes, batch weighing is satisfactory. However, were industry to want to compare FCR among cages or strains, a single batch weighing is not sufficient, as this will not provide a base for quantitative comparison. If comparison is required among production units (i.e. cages, strains, and locations), either the batch-weighing protocol as identified by Smart et al. (1998) should be used (i.e. at least 10 replicates of the batch weight measurement per unit) or video-monitoring and size-determination equipment should be installed.

A second aspect worth further elaboration is observed growth rates among the various steelhead groups. It is apparent that juvenile steelhead of >100 g, introduced to the marine cages by the end of April, resulted in a marketable product by the end of one growing season. In contrast, steelhead with a mean weight of >100 g, introduced to the cages in June, did not have sufficient time to reach the market threshold expected by industry at the time of this experiment. Instantaneous growth calculations of Table 5 suggest it is not merely growth rate that matters but rather the length of time the fish are in the water and actively feeding. Fish of >100 g introduced in June demonstrated greater daily instantaneous growth than those placed in the cages on April 30, yet did not achieve the desired market size. In light of the more recent niche market for 300 g steelhead fillets, the aspiration for the salmonid growers is to attain sufficient specimen live weight (i.e. ~1130 g) to support this market in as short a time interval as possible. For the May Cove diploid steelhead in 2000, Cage 10 fish reached this mean weight on September 1.

Cages 20 and 22 attained this threshold on September 22 and October 11 respectively. Irrespective of varying market opportunities, industry's aspiration has been to achieve a marketable product without having to over-winter fish, largely due to an unacceptable level of over-wintering mortality that has been a challenge to industry's pursuit of performance improvement.

It is industry's perception, particularly in light of their demonstration that one-pound steelhead fillets can be produced without the need to over-winter fish, that these innovations in steelhead husbandry have addressed the main impediments to economically-viable steelhead aquaculture in Bay d'Espoir. It appears that the industry move away from triploid rainbow trout in favour of diploid steelhead trout is paying off.

ATLANTIC SALMON

It is apparent from Table 8 that this Atlantic salmon strain-performance experimentation was compromised from the outset by differing numbers of fish in each cage and significant differences in start weight among the five strains. As well, analysis of these strain-evaluation data is confounded further by the differing harvest times for the various salmon groups in the strain evaluations. With the caveat that these challenges to experimental design must be accommodated in the interpretation of relative merits, there are clear indications that only one of the strains demonstrated economically-satisfactory performance. In fact, the remaining four strains all proved to be a liability to the aquaculture business. Visual comparison of the PI values of Tables 9 and 10 give an indication of the relative ranking of the five strains and the detrimental consequences of mortality and early-maturity in the 2$^{nd}$ year of marine on-growing.

A challenge to quantitative interpretation of the performance measures (e.g. FCR, GF3) favored by industry is that these indicators are ratio estimators and therefore not well suited to statistical analysis (Atchley et al. 1976; Atchley 1978; Atchley and Anderson 1978; Sokal and Rohlf 1997). As well, given the concerns expressed about thermal growth coefficients (Jobling 2003), concerns that are particularly appropriate to the Bay d'Espoir estuarine fjord, these measures may be of questionable value.

Regarding FCR, quantitatively the question is whether the ratio values calculated, the numerator and denominator of each ratio being of potentially different statistical distributions, are significantly different from one another. To some extent, we have circumvented this problem by basing performance calculations on increase in biomass using the paired t-test confidence calculations of Milliken and Johnson (1984), thereby facilitating assignment of upper and lower confidence intervals to the FCR indicators of strain performance. It is apparent from Figure 16 that the FCR values of Tables 9 and 10 reflect the same interpretation. In consideration of both the statistical analyses, and the financial perspective documented by the aquaculture business, it is apparent that the Gaspé strain of triploid Atlantic salmon was the clear winner in these Atlantic salmon strain-comparison experiments.

It is significant that the two highest-ranked strains at the end of the overall experiment were those that started the experiment with the greatest average body mass. It is apparent that the greatest setback experienced in on-growing of this year-class of salmon is the significant loss of production due to mortality and to early maturation. The mortality peak on July 4 of each of the growing seasons removed alarming numbers of salmon from the inventory of each of the strains. However, the significance of the economic loss represented by this mortality is most evident in the second year of on-growing (Fig. 12a) once the fish have achieved greater weight and consumed more food.

Grilsing rates of up to 58% represent an intolerable economic loss to the farming enterprise. This grilsing rate was most pronounced in the GCR, all-female salmon, a startling loss considering monosex lines were developed with the expectation of reducing grilsification. The early-maturation problem, that amounted to 44% even in the industry-standard strain (SJR, mixed-sex), is clearly a challenge that must be addressed by the aquaculture businesses. The implications of grilsification on the strain weight statistics can be seen in the harvest sample (October 11) of Tables 9 and 10. Between the production losses due to mortality in the second on-growing season, and the losses incurred due to early maturation, it is apparent that much of the food provided to the salmon in 2000 ended up as ashes in the site incinerators.

Through the latter years of the 20$^{th}$ century, the amount of salmon production lost due to early maturation had been increasing. In the early stages of industry development in Newfoundland, grilsification typically accounted for 10–12% (C. Collier; in Pepper 1991b) of the inventory at harvest. At harvest in 2000, grilsing rates of >50% were recorded in several groups of Atlantic salmon from several different farm sites in Bay d'Espoir. Speculation within the Bay d'Espoir industry at time of harvest for the five salmon strains of this report was that the increased incidence of maturation was a consequence of both breeding and husbandry practices and of environmental conditions during the somewhat milder winters of the past few years (Pepper et al. 2002). The husbandry context of mild winters, and physiological conditions for early maturation are described by Saunders et al. (1983). These observations highlight the need for improvements in salmon-farming efficiency and broodstock management. Placed in the context of economics, it became apparent that industry investment in alternative husbandry practices and maturation-manipulation techniques such as photoperiod control (Harmon et al. 2003) would be warranted. As an aside to analyses of this report, in light of deficiencies in these strain-performance results, the Bay d'Espoir industry since 2001 has moved away from brackish waters and now stocks salmon smolts only into full-salinity sea water. For the past three summer seasons in Bay d'Espoir, maturation rates have diminished to <5% and mortality incidents due to aytpical furunculosis have all but disappeared.

A challenge to commercially-viable aquaculture in Newfoundland is the sub-arctic marine environment typical of most of Newfoundland's coastal zone (Tlusty et al. 2000b). It is this constraint that has limited commercial salmonid-aquaculture development to Bay d'Espoir on the south coast of the island. Newfoundland is one of few areas in the world where salmonid aquaculture occasionally must contend with a four-to-five month interval of winter ice cover. With Atlantic salmon, the necessity of over-wintering fish in order to achieve a suitable market size imposes biological constraints (Tlusty et al. 2000b) on the industry that must be viewed in the context of salmon physiology. Since inception of the salmonid aquaculture industry in Bay d'Espoir in the mid-1980s, industry viability has been challenged by over-wintering mortality.

Much of the observed mortality is attributable to pathogens (predominantly *Aeromonas salmonicida nova*), an observation that stimulated the Newfoundland industry to implement annual vaccination programs. The pattern of this mortality (Fig. 10) suggests there may be an opportunity to identify environmental conditions that predispose the aquaculture inventory to susceptibility to these pathogens. In this regard, the environmental-monitoring records of Figure 3 are appropriate for further interpretation. It is important to recognize that the observed fluctuations are recorded at 10 m (i.e. the bottom of that generation of aquaculture cages). At this depth, temperature fluctuation reached 8.3°C within a 24 h interval while oxygen fluctuation was a maximum of 1.25ppm. Salinity at 10 m fluctuated a maximum of 5.6‰ in 24 h.

While these data are for May Cove (i.e. 2000 steelhead site), they illustrate fluctuations in the on-growing environment that may serve to challenge salmonid physiology. Hourly patterns of fluctuation in key environmental variables are readily apparent at 10 m and are assumed to be greater with decreasing depth. Such fluctuations may contribute to physiological challenges that impose cumulative stresses to erode salmon resistance to pathogens that are a normal part of the estuarine-fjord environment (Fox 1982). Mortality of aquaculture salmonids often is the end result of a chronic accumulation of departures from the species' physiological optima; the greater the deviation from optimal, the greater the stress on the organism (Wedemeyer et al. 1990). The more rapid the accumulated stresses (Barton et al. 1986), the greater the behavioural departure (i.e. stuporous behavior; Sigismondi and Weber 1988) of the aquaculture inventory from behaviour patterns exhibited under optimal conditions (Tomasso 1996; Poppe et al. 1997; Ang and Petrell 1998). Fluctuation in water-column properties during the storm event of July 8 (Fig. 3) provide an example of environmental stresses that can impact on salmonid physiology.

The early-July mortality peak appears consistent between the two years of this salmon study and elicits suspicion about cage towing practices and/or environmental impacts on aquaculture species. We hypothesize that environmental/husbandry stressors in the interval of mid-May to July may be avoidable precursors to mortality. A common observation at salmonid farms is that not all fish swim at the same depth within a cage, and vertical fish distributions are variable both among cages and within cages (Juell et al. 1994; Fernoe et al. 1995). Establishing a cause-and-effect relationship between fish distribution and environmental variables is a prerequisite to biologically-meaningful refinements to husbandry practices. As noted by Juell (1995), understanding the behaviour of farmed salmon is essential as this could suggest ways of preventing stress and diseases rather than merely treating their symptoms. In this regard, the following research endeavours are being planned for consideration by industry:

1. Non-invasive indicators of stress in salmonids;
2. Near-field survey (water column) of possible biological, chemical and physical contributors to fish stress:
   - Water sampling and vertical plankton tows in immediate proximity to Bay d'Espoir aquaculture cages to document seasonal abundance of planktonic organisms in the water column;
   - Data Storage Tag (DST) evaluation of the temperature, salinity and depth actually chosen by the fish in a cage;
   - telemetry positioning of salmonids within an aquaculture cage to document temporal and spatial (3D) variability in fish distribution and possible correlation to environmental variables;
   - Fixed-gear environmental monitoring (temperature, oxygen, salinity) in both the upper (freshwater lens) and lower (marine) layers on both the upstream and downstream (relative to tide) sides of the cages;
3. CTD surveys of water column profile characteristics in immediate proximity to and below aquaculture cages.

The purpose of these studies is to identify a cause-and-effect relationship between the behaviour of fish in the cages and the dynamics of the estuarine-fjord environment in which they are being cultured. Our expectation is that a proper understanding of the aquaculture milieu of specific salmonid cage operations in Bay d'Espoir will facilitate refinements to husbandry practices and that this, in turn, will help develop measures to address husbandry challenges to Bay d'Espoir aquaculture-industry viability.

Atlantic salmon strain-performance analyses of this report suggest that continued industry use of triploid Atlantic salmon is warranted. Reproductively-incapacitated salmon obviously did not show any performance erosion due to early maturation. It is apparent also (Fig. 12a) that mortality of the Gaspé triploid salmon was lower than that of the Saint John River, mixed-sex strain (control group). Although jaw deformities were noted among the triploid salmon, deformities that were not common among reproductively-competent salmon, this defect did not impact on the growth of the fish or the quality of the fillets, all of which were marketed as "prime".

Our previous work with Atlantic salmon aquaculture development in Bay d'Espoir (Sutterlin and Collier 1991; Pepper et al. 1996; Pepper et al. 1998; Pepper and Collier 1998) provides an historic base for comparison. Considering this previous experience, and on the basis of analyses of the present study, we conclude that Gaspé strain triploid salmon present the Bay d'Espoir industry with economic potential not observed among the other strains of this report. This triploid strain, that originated from the Gaspé Peninsula (Quebec), is of eastern North American origin. The gene pool of this Multiple Sea-Year stock may well have genetic characteristics desirable for Newfoundland marine conditions. A common belief among the Bay d'Espoir salmonid farmers is that their unacceptable grilsing rates of recent years have a high genetic influence. Considering the early importations (late 1980s, early 1990s) of limited numbers of eggs of the Saint John River strain into Newfoundland, and the lack of facilities from which to support a structured breeding program, there is a substantial amount of biological rationale in support of this argument.

The Cascade Aqua Farms, Gaspé strain of Atlantic salmon has seen the benefits of a structured breeding program for several generations. This is in contrast with the Saint John River strain that has been imported into Newfoundland under ad hoc conditions of low genetic variability and no structured program of adaptation to the Bay d'Espoir estuarine-fjord environment. It appears that the multiple generations for which the Gaspé Peninsula strain of Atlantic salmon has been under domestication by Cascade Aqua Farms has produced a superior aquaculture strain. Industry concerns about the performance characteristics of triploids now should be secondary to interest in the performance of the strain from which the triploids are produced. We interpret that triploid salmon, produced from a superior (selected) strain of salmon, present production advantages to the Newfoundland industry.

Based solely on data of this report, optimism for significant improvement in the near term regarding Atlantic salmon production efficiency would be unwarranted. However, experience (i.e. 2001 through 2003) since completion of the experiments described has seen improvements in fish health sufficient to eliminate the need for antibiotics. Incidence of maturation has diminished to <5%. These observations suggest industry strategy to improve economic performance is working. The Bay d'Espoir industry attributes these more recent production improvements to the use of generally deeper nets (i.e. 15 m), relocation of farms generally further out the bay (i.e. greater water-column stability), and an overall policy not to tow livestock between summer and winter sites.

## SYNOPSIS

Quantitative broodstock development and performance testing could foster sustainability of the Newfoundland salmonid-aquaculture industry. Development and preservation of broodstock specifically adapted to Bay d'Espoir through systematic breeding could provide growers with a competitive advantage. This is a challenging goal that cannot be achieved without significant investment of time, effort and new funding for broodstock facilities.

Expression of the genetic potential of any organism is influenced considerably by the environment in which the organism resides. Performance of salmonid strains in other parts of the world is no guarantee of performance in significantly-different environments. It is apparent that the salmon strains of greatest interest to the NSGA are those that have a lengthy history of captive breeding. As noted by Gjedrem (1998), "For all economically important traits studied, there was relatively large additive genetic variance. Therefore, selection should be a central part of the breeding programme.". For one of the strains of particular interest to salmonid aquaculturists throughout the world, Gjedrem (1998) reported "A comparison of improved Atlantic salmon from the fourth generation of selection and a sample of wild fish from the river Namsen showed that the improved fish grow 77% faster than the wild. This makes a gain per generation of over 15%.". World experience confirms that breeding is an important component of aquaculture-industry strategy development and must not be overlooked.

Critical to meaningful interpretation of salmonid performance in finfish aquaculture operations is identification of overall biomass elaborated between the start and end of the experiment, complete with confidence limits for the estimate. Adequate weight sampling at the beginning and end of the experiment, properly identified as to start and end dates, is essential to this task. This, together with accurate daily-feeding and inventory records, provides a sound base from which to conduct strain-performance analysis. Given quantification of the thermal regime experienced by the fish, confirmation of dissolved oxygen and measurements of salinity fluctuations, these data provide the means for fish farmers to make their own decisions on the viability of their operations.

Relative to the daily-operations requirements of fish farming, the level of effort required to secure data necessary for quantitative analyses of broodstock performance (Table 13) is insignificant. There is nothing particularly difficult or challenging about the task. There are precautions that are critical to achieving meaningful analyses. Perhaps the most important aspect of performance evaluation is communication to site workers and industry managers regarding the importance of effective data capture, recording and reporting. The best data imaginable will be meaningless without proper recording of the necessary identifiers (i.e. unit, location, strain, and date) from which it was procured. The best time series imaginable will be meaningless if the cage inventories have been reallocated to other sites and multiple cages without proper recording of the history of the particular group of fish.

The goals of a broodstock program should not be simply to maintain (a) broodstock(s) free of inbreeding depression, but to conduct actual systematic and quantitative breeding to improve performance traits. Genetic profiling is an essential component of a broodstock program. Such programs necessitate long-term commitment but are essential to profitability. If such programs cannot be maintained in Bay d'Espoir, negotiations should be attempted with existing suppliers of salmonid eggs regarding an out-of-province breeding program tailored to the needs of Newfoundland salmonid aquaculture.

Table 13. Strain performance-monitoring variables.

| Variable | Necessary Activity |
|---|---|
| Start Date | All fish in the experiment should be allocated to their marine cages on the same day at an equal starting biomass per cage. |
| Inventory | Accurate count of the number of fish placed in a cage and routine removal, counting and tabulation of mortalities by day. |
| Mean Weight | Either batch weighing (minimum of 10 batch weights) or random samples of at least 35 specimens should be weighed at the beginning and end of the on-growing interval for each salmonid group of interest to the NSGA. All weights must be tabulated by date, species and strain. Calculations of $FCR_{(biological)}$ require quantification of weight lost to mortality. Recently dead fish should be weighed periodically to provide this lost-biomass estimate. |
| Food Consumed | This should be monitored with an underwater video camera to assure that the fish are consuming the feed offered. Measured amounts of food consumed by the fish must be tabulated on a daily basis. |
| Thermal Units | Continuously-recording thermographs should be located at strategic levels in the water column in close proximity to the experimental cages. If sufficient thermographs are not available with which to characterize the water column through the depth of the aquaculture nets, periodic vertical water-column profiles (i.e. temperature, salinity and oxygen by depth) should be procured by CTD cast and analyzed for indicators of site-condition stability. |
| End Date | Recorded at the time of final sampling, preferably immediately prior to harvest. In anticipation of three categories of fish (i.e. grilse, small, large) from each cage at the time of grading, weight samples need to be obtained ($n \cong 35$) for each of the grades from each of the experimental groups. |

## PERSPECTIVE

The two species of this report have revealed performance characteristics that, at least superficially, are at odds. For rainbow trout, all-female triploid groups have performed poorly relative to the all-female diploid strains. For Atlantic salmon, the all-female triploid, Gaspé-Peninsula strain demonstrated a clear performance advantage. As much as the biology of the strain-evaluation results is interesting, the human element in development of the Bay d'Espoir industry is of much greater significance to future directions. Industry views on triploid salmonids are moulded entirely by public opinion on what constitutes a genetically-modified organism (GMO) and the view that "...perception is often reality to the public." (Gene Henderson, in Pepper 1991a). This is unfortunate in that triploid salmonids do not conform with the GMO label in that there are no "foreign" genes introduced to these aquaculture animals from outside the species. The extra set of chromosomes of these triploid salmonids, relative to their diploid counterparts, is entirely of maternal-parent origin and therefore not subject to the same level of uncertainty regarding potential consequences to offspring or of "risks" to human health. However, given that the Bay d'Espoir salmonid growers cater only to what the market requires, they have no interest in further examination of triploid-fish performance.

Industry efforts to refine steelhead aquaculture practices for Bay d'Espoir have produced results that suggest benefits to: adopting a true anadromous strain of trout; introducing 100+ g juveniles to estuarine cages early in the growing season; and, increasing the depth of on-growing nets. Given that deeper nets are more costly to industry, it would be useful to implement a quantitative evaluation as to the spatial distribution of the fish both seasonally and diurnally. It would be appropriate to attempt to determine causal factors in the distribution of the fish with time as a means potentially to refine husbandry practices and define an optimal net depth for the different estuarine locations, given that the various farms differ greatly in their water column dynamics.

In consideration of public perceptions, and the industry's very real wish to provide the public with assurances about the quality and health benefits of Bay d'Espoir aquaculture products, continued production of all-female diploid steelhead based on large smolts is warranted. The situation with Atlantic salmon is somewhat more tenuous and needs to be examined in the context of performance of a diploid strain of the Gaspé-Peninsula strain.

As Bay d'Espoir does not have the hatchery facilities to support a structured-breeding program, it is prudent to look closely at the breeding practices of Atlantic salmon-smolt suppliers to determine which of the commercial breeding strategies may be most suited to Bay d'Espoir needs.

## RECOMMENDATION

On the basis of observations and analyses of this report, we suggest the following initiatives:

1. Assure that salmonids placed in on-growing enclosures in Bay d'Espoir are transferred to on-growing sites by mid May.
2. Utilize only those juvenile steelhead that have achieved a mean weight of >100 g in their freshwater (hatchery) on-growing cycle (significantly smaller specimens are not likely to result in a marketable product by the end of the first growing season). It is only in the context of speciality markets for large trout (i.e. the Japanese market), for which the on-growing cycle inherently will require more than one growing season, that using fish of less than 100 g may be warranted. The validity of a large-fish market strategy will depend on achieving winter mortality rates that are consistent with the economic requirements of such an approach.

3. Immediate effort to access selected strains of all-female, diploid, Gaspé-origin Atlantic salmon.
4. Those companies intent on growing Atlantic salmon should look closely at the broodstock-management and breeding practices of commercial suppliers of eggs to determine which supplier(s) are most compatible with Newfoundland needs. Use of photoperiod manipulation to deter maturation of existing inventory also should be investigated.
5. Intensive environmental monitoring (temperature, oxygen, salinity, plankton) should be conducted at summer growing sites from early-May to the end of July in an attempt to quantify mechanisms of environmental impact on salmonid physiology.
6. Research should be conducted into non-invasive indicators of stress in salmonids as an aid to understanding salmonid physiological response to the estuarine-fjord environment and a tool for further refinement of Bay d'Espoir salmonid husbandry practices.
7. Given that deeper nets have proven useful to industry but are more costly, it would be useful to implement a quantitative evaluation of the spatial distribution of the fish in aquaculture nets, both seasonally and diurnally. Research should attempt to determine causal factors in the distribution of the fish with time as a means potentially to refine husbandry practices and define an optimal cage depth for the different estuarine locations.

## ACKNOWLEDGMENTS

Prosecution of the Atlantic salmon strain evaluation project described in this document would not have been possible without funding from the Aquaculture Component of the Canada-Newfoundland Economic Renewal Agreement. Cooperation of both levels of government in Newfoundland & Labrador in providing this technical support to industry is greatly appreciated. Activities in support of the strain-evaluation research drew heavily on the field assistance and goodwill of the participating Bay d'Espoir salmonid farmers. Thanks are due particularly to the site workers of Miawpukek Aquaculture Inc., Nova Fish Farms and Bonne Bay Fish Farms Ltd. The Newfoundland Salmonid Growers Association kindly provided access to their electronic database of salmonid inventory records. The contribution of these various groups to this work is acknowledged and greatly appreciated. The draft manuscript was edited by Drs. M.F. O'Connell and A.A.H. Mansour. Their attention to detail in the manuscript proved helpful and beneficial and is gratefully acknowledged.

## LITERATURE CITED

Ang, K.P. and Petrell, R.J. 1998. Pellet wastage, and subsurface and surface feeding behaviours associated with different feeding systems in sea cage farming of salmonids. Aquac. Eng. 18(2): 95-115.

Atchley, W.R. 1978. Ratios, regression intercepts, and the scaling of data. Syst. Zool. 27(1) 78-83.

Atchley, W.R. and Anderson, D. 1978 Ratios and the statistical properties of ratios. I. Empirical result. Syst. Zool. 25: 71-78.

Atchley, W.R., Gaskens, G.T., and Anderson, D. 1976. Statistical properties or ratios. I. Empirical result. Syst. Zool. 25: 137 – 148.

Barton, B.A., Schreck, C.B., and Sigismondi, L. A. 1986. Multiple acute disturbances evoke cumulative physiological stress responses in juvenile chinook salmon. Trans. Am. Fish. Soc. 115: 245-251.

Benfey, T. 1998. Use of triploid Atlantic salmon (*Salmo salar*) for aquaculture. DFO Canadian Stock Assessment Secretariat Research Document 98/166. (Abstract available at:http://www.dfo-mpo.gc.ca/csas/csas/resdoc/1998/a98_166e.htm )

Dwyer, W.P. and Piper, R.G. 1987. Atlantic salmon growth efficiency as determined by temperature. Prog. Fish-Cult. 49: 57-59.

Fernoe, A., Huse, I., Juell, J-E., and Bjordal, A.. 1995. Vertical distribution of Atlantic salmon (*Salmo salar* L.) in net pens: Trade-off between surface light avoidance and food attraction. Aquaculture 132: 285 – 296.

Fletcher, G.L., Kao, M.H., and Dempson, J.B. 1988. Lethal freezing temperatures of Arctic char and other salmonids in the presence of ice. Aquaculture 71: 369-378.

Fox, A.C. 1982. The importance of the environment, stress, and disease relationship in aquaculture. p. 15-19 *In*: C.J. Sindermann (ed.). Proceedings of the eleventh U.S. – Japan meeting on aquaculture, salmon enhancement. Tokyo, Japan. October 19-20. NOAA Tech. Rep. NMFS27.

Gjedrem, T. 1998. Selective breeding in aquaculture. INFOFISH International 3: 44-48.

Harmon, P.R., Glebe, B.D., and Peterson, R.H. 2003. The effect of photoperiod on growth and maturation of Atlantic salmon (*Salmo salar*) in the Bay of Fundy. Project of the Aquaculture Collaborative Research and Development Program. Can. Tech. Rep. Fish. Aquat. Sci. 2458: iv + 16 p.

Holmefjord, I. Åsgård, T., Einen, O., Thodesen, J., and Roem, A. 1995. Growth factor, GF3. ARC Update 2/95. Published in Norsk Fiskeoppdrett 4/95. 2p.

Jobling, M. 2003. The thermal growth coefficient (TGC) model of fish growth: a cautionary note. Aqu. Res. 34, 581 – 584.

Juell, J.-E., Fernö, A., Furevik, D., and Huse, A. 1994. Influence of hunger level and food availability on the spatial distribution of Atlantic salmon, *Salmo salar* L. in sea cages. Aqu. Fish. Mgmt. 25: 439–451.

Juell, J-E. 1995. The behaviour of Atlantic salmon in relation to efficient cage-rearing. Rev. Fish Biol. and Fish. 5: 320-335.

McCluskey, W.H. and Johnson, L.E. 1958. The influence of feeder space upon chick growth. Poult. Sci. 37: 889-892.

Milliken, G.A. and Johnson, D.E. 1984. Analysis of Messy Data. Volume 1: Designed Experiments. Wadsworth, Inc. USA. 473pp.

Neter, J., Wasserman, W., and. Kutner, M.H. 1990. Applied Linear Statistical Models. Regression, Analysis of Variance, and experimental Designs. 3rd Edition. Irwin. Homeworld and Boston. 1181 pp.

Pepper, V.A. (ed). 1991a. Proceedings of the Atlantic Canada workshop on methods for the production of non-maturing salmonids: February 19-21, 1991. Dartmouth, Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. No. 1789. vi + 152p.

1991b. Report of the government-industry meeting to discuss a Newfoundland program on non-maturing salmonids for local aquaculture performance evaluation. Can. Ind. Rep. Fish. Aquat. Sci. No. 208: v + 26 p.

Pepper, V.A., Sutterlin, A.M., Nicholls, T., and Collier. C. 1996. Newfoundland experience with development of all-female and non-reproductive Atlantic salmon for marine aquaculture. Bull. Aquacul. Assoc. Canada 96-2: 14 - 23.

Pepper, V.A. and Collier, C. 1998. Atlantic salmon reproductive control research in Newfoundland. Northern Aquaculture. 4(5): 7-23.

Pepper, V.A., Collier, C., and Nicholls, T. 1998. Performance of a Newfoundland Atlantic salmon strain for Aquaculture. Bull. Aquacul. Assoc. Canada 98-3:24-29.

Pepper, V.A., A.A.H. Mansour, T. Nicholls and D. Whelan. 2002. Optimal net depth for over-wintering Bay d'Espoir aquaculture salmonids. Can. Tech. Rep. Fish. Aquat. Sci. 2455: vii + 55 p.

Pepper, V.A., Collier, C. and Withler, R. 2003. Newfoundland experience with salmonid broodstock for application to aquaculture industry needs. Aquacul. Assoc. Canada, Spec. Publ. (6): p 27 – 30.

Poppe, T.T., Hellberg, H., Griffiths, D. and Meldal, H. 1997. Swimbladder abnormality in farmed Atlantic salmon *Salmo salar*. DIS. AQUAT. ORG.,. 30(1): 73-76.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can. Bul. 191. 382 p.

Saunders, R.L., Henderson, E.B. Glebe, B.D. and Loudenslager, E.J. 1983. Evidence of a major environmental component in determination of the grilse : larger salmon ratio in Atlantic salmon (*Salmo salar*). Aquaculture 33: 107-118.

Shieh, A.C.R. and R.J. Petrell. 1998. Measurement of fish size in Atlantic salmon (*Salmo salar* L.) cages using stereographic video techniques. Aquacultural Engineering 17: 29 – 43.

Sigismondi, L.A. and Weber, L.J. 1988. Changes in avoidance response time of juvenile chinook salmon exposed to multiple acute handling stresses. Trans. Am. Fish. Soc. 117: 196-201.

Smart, T.S., Riley, J., and Edwards, P. 1998. Statistical aspects of aquaculture research: sample sizes for pond experiments. Aquac. Res. 29(5): 373–379.

Sokal, R.R. and Rohlf, F.J. 1997. Biometry. W.H. Freeman and Company. New York. Third Edition. 887p.

Sutterlin, A.M. and Collier, C. 1991. Some observations on the commercial use of triploid rainbow trout and Atlantic salmon in Newfoundland, Canada. *In* Pepper, V.A. [ed]. Proceedings of the Atlantic Canada workshop on methods for the production of non-maturing salmonids: February 19-21, 1991. Dartmouth, Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. No. 1789. vi + 152 p.

Sveier, H., and Lied, E. 1998. The effect of feeding regime on growth, feed utilisation and weight dispersion in large Atlantic salmon (*Salmo salar*) reared in seawater. Aquaculture 165: 333-345.

Tlusty, M.F., Snook, K., Pepper, V.A., and Anderson, M.R. 2000a. The potential for soluble and transport loss of particulate aquaculture wastes. Aquac. Res. 31: 745-755.

Tlusty, M.F., Pepper, V.A., and Anderson, M.R. 2000b. Assimilative capacities in a frontier region –the Newfoundland Salmonid Experience. World Aquac. 31: 50-54, 64.

Tlusty, M. F., Hughes-Clark, J.E., Shaw, J., Pepper, V.A., and Anderson, M. R. 2000c. Groundtruthing multibeam bathymetric surveys of finfish aquaculture sites in the Bay d'Espoir estuarine fjord, Newfoundland. MTS Journal 34(1): 59–67.

Tomasso, J.R. 1996. Environmental requirements of aquaculture animals – a conceptual summary. World Aquaculture, 27(2): 27–31.

Wedemeyer, G.A., Barton ,B.A., and McLeay, D.J.. 1990. Stress and acclimation. p451-489. In Schreck, C.B. and P.B. Moyle [eds.]. Methods for Fish Biology. American Fisheries Society. Bethesda, Maryland. 684p.

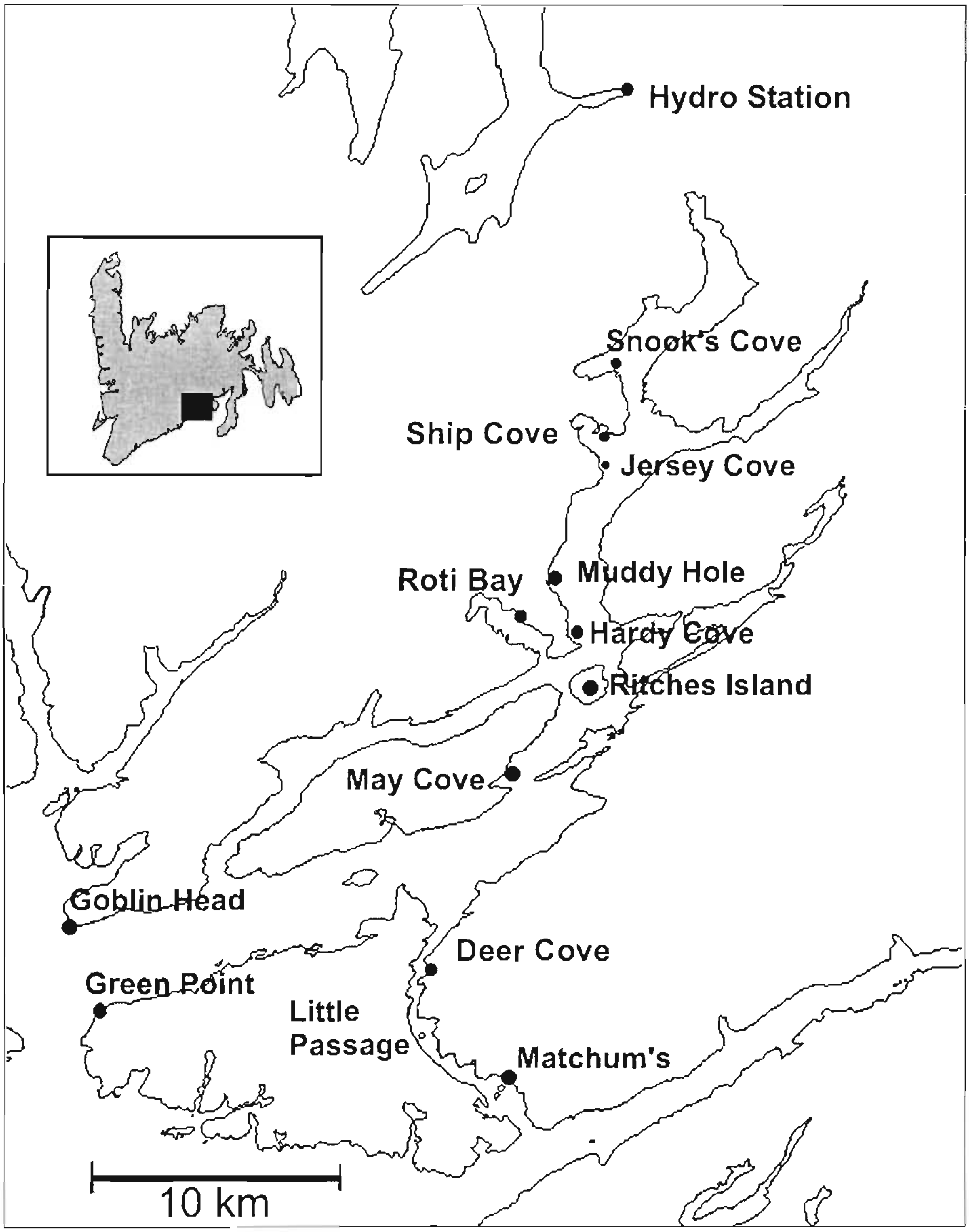



Figure 1. Location map for geographical features and salmon farms of Bay d'Espoir.

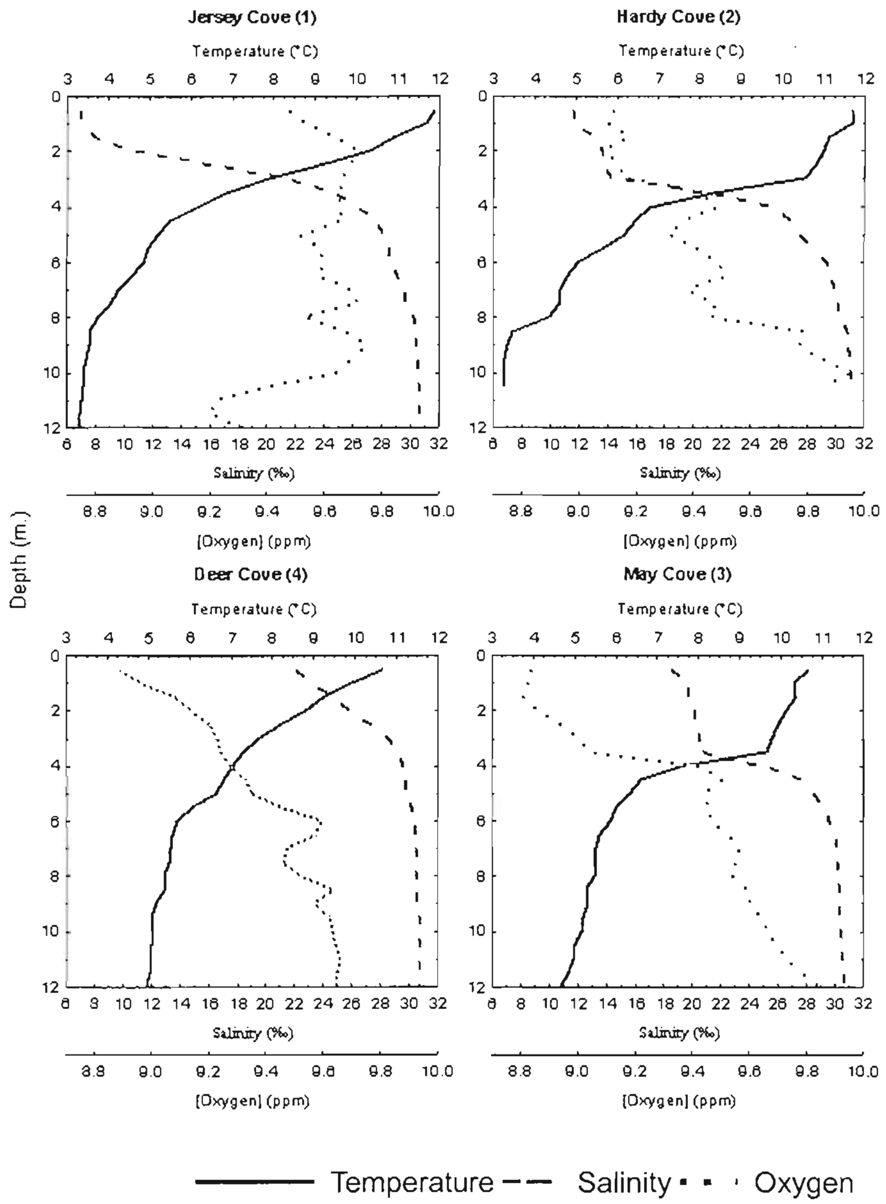



Figure 2. Illustration of water-column variability among Bay d'Espoir aquaculture-farm sites.

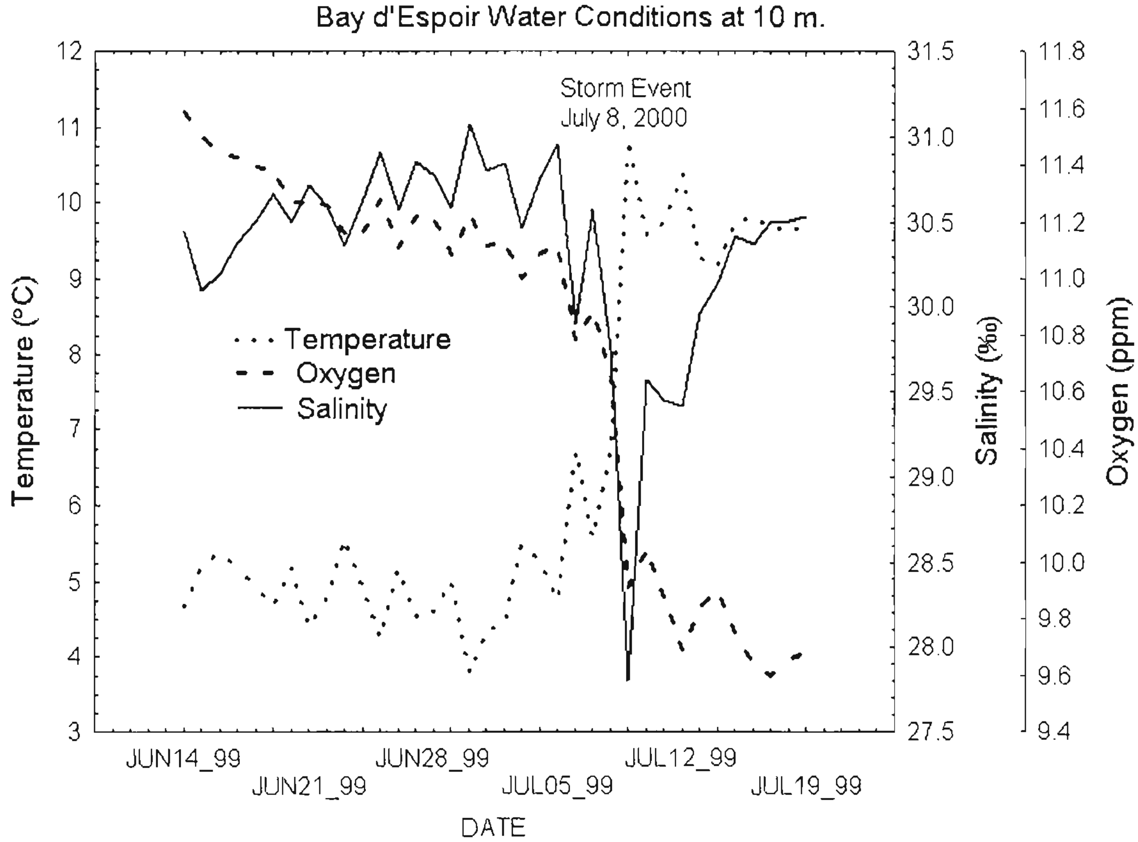



Figure 3. Temperature, oxygen, and salinity variability at 10 m depth at May Cove, 1999.

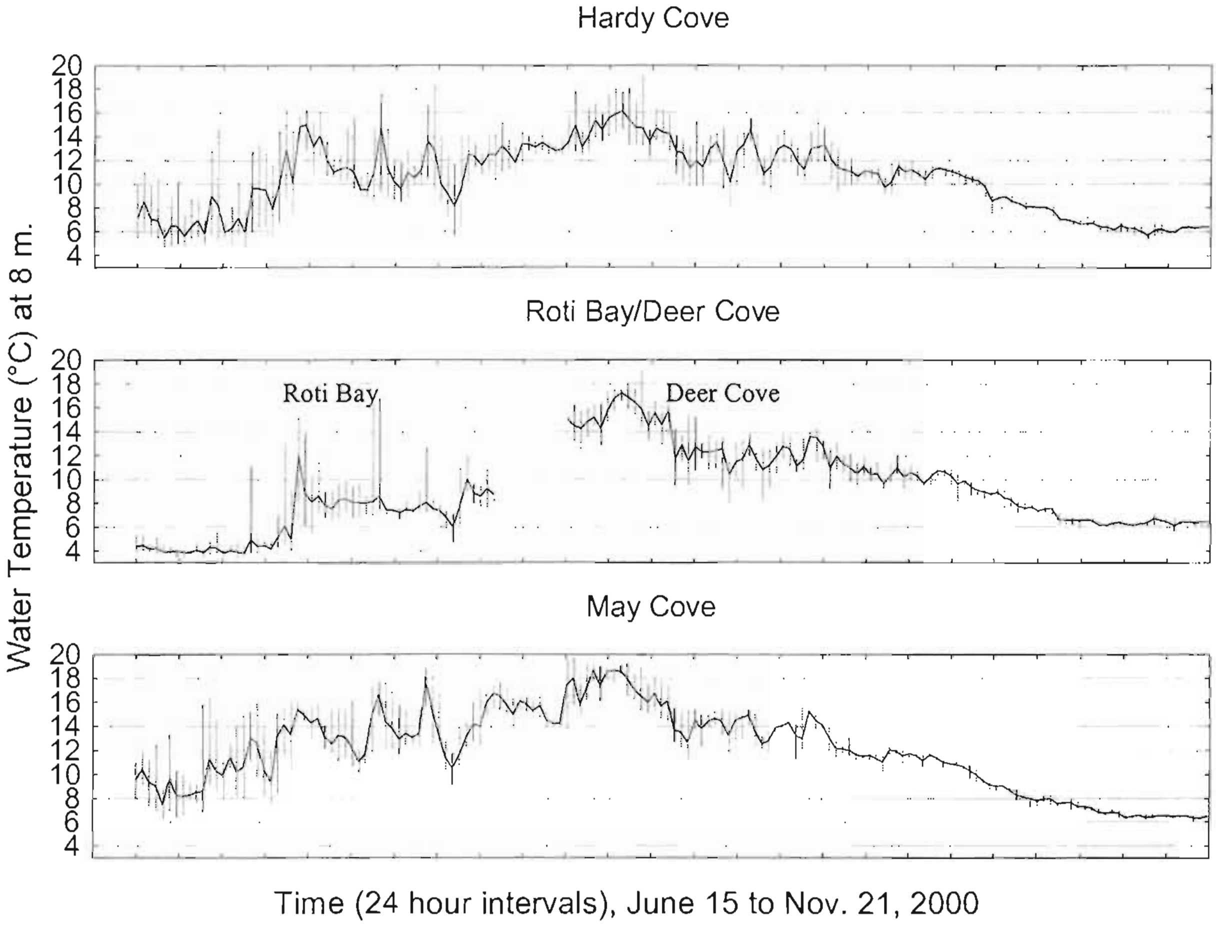



Figure 4. Temperature fluctuations at 8 m for selected sites in Bay d'Espoir (see Fig. 1 for locations). Cages in Roti Bay were relocated to Deer Cove on June 23, 2000. Vertical bars represent temperature fluctuation in a 24 h interval.

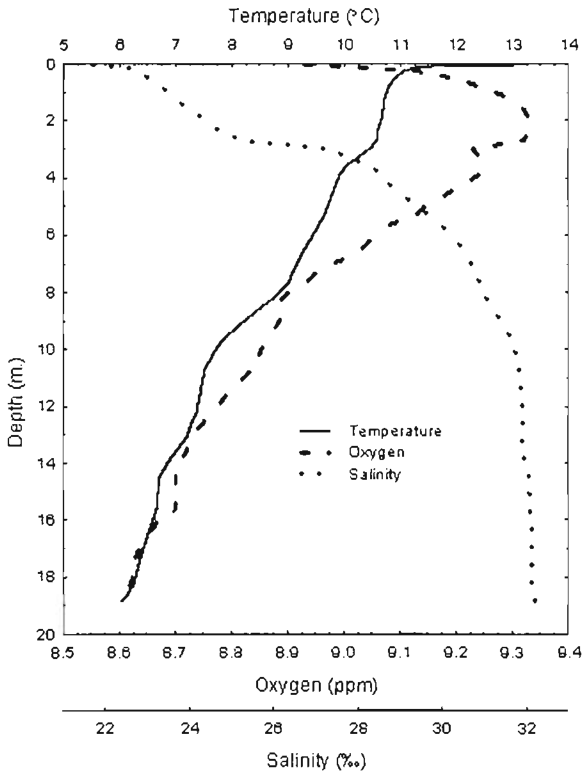



Figure 5. August 1, 2000 water column profile of May Cove.

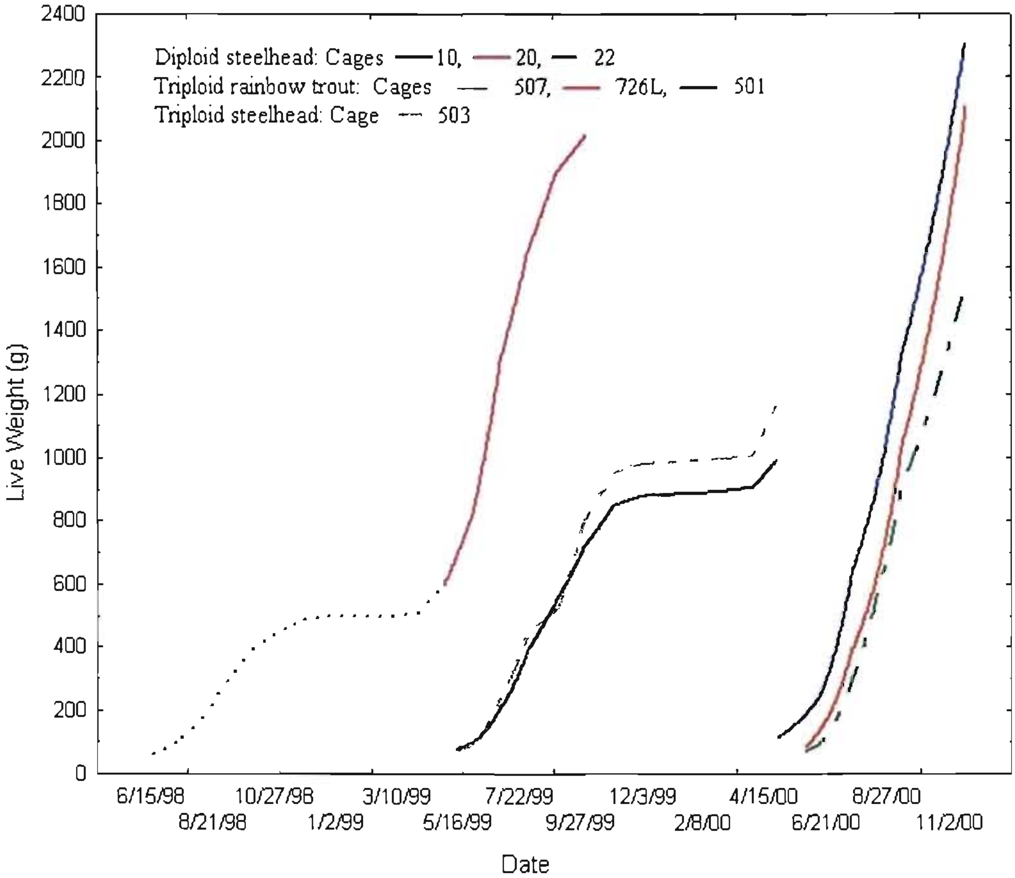



Figure 6. Trout growth profiles for three year-classes.

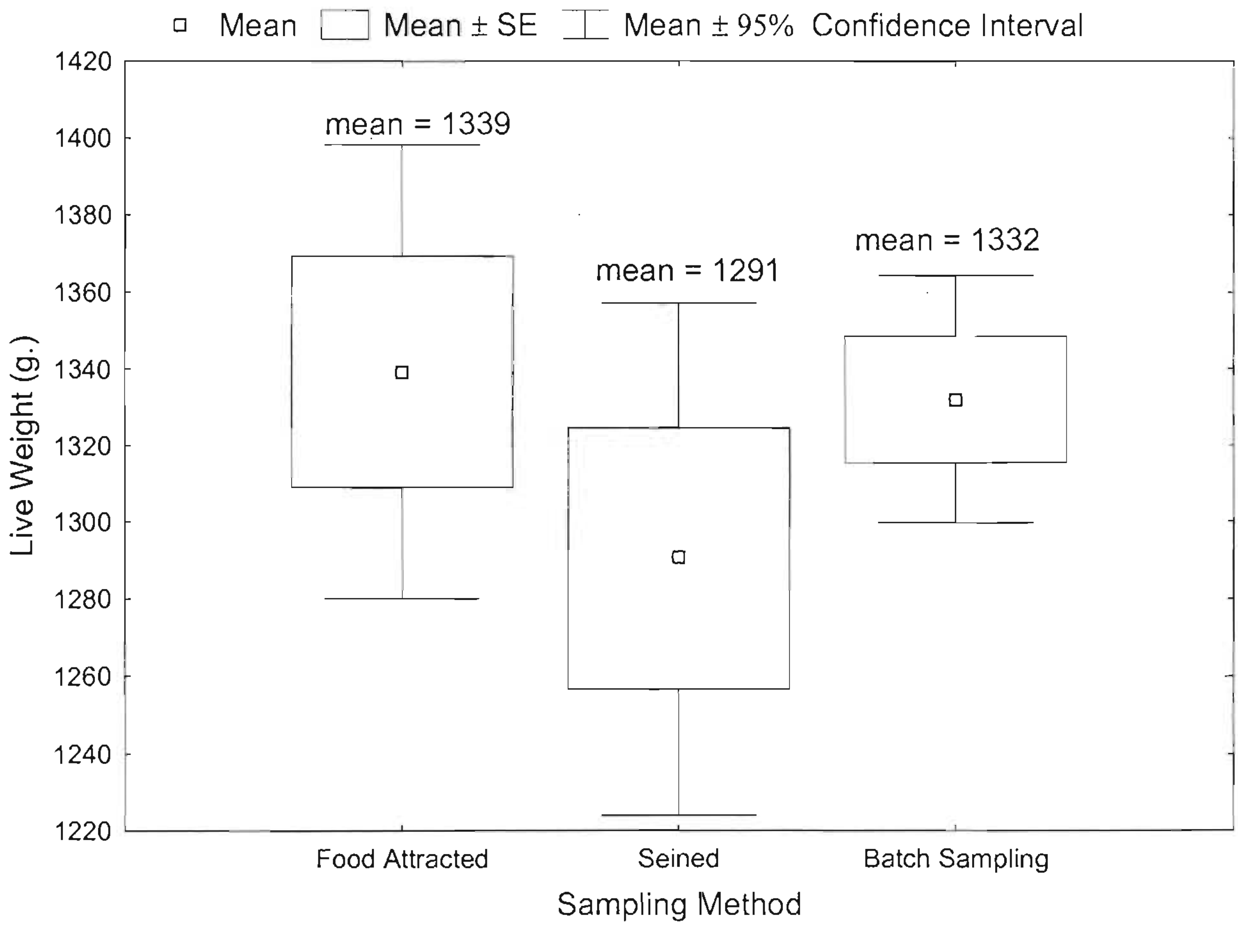



Figure 7. Comparison of statistics for specimen-sampling methodology for May Cove steelhead

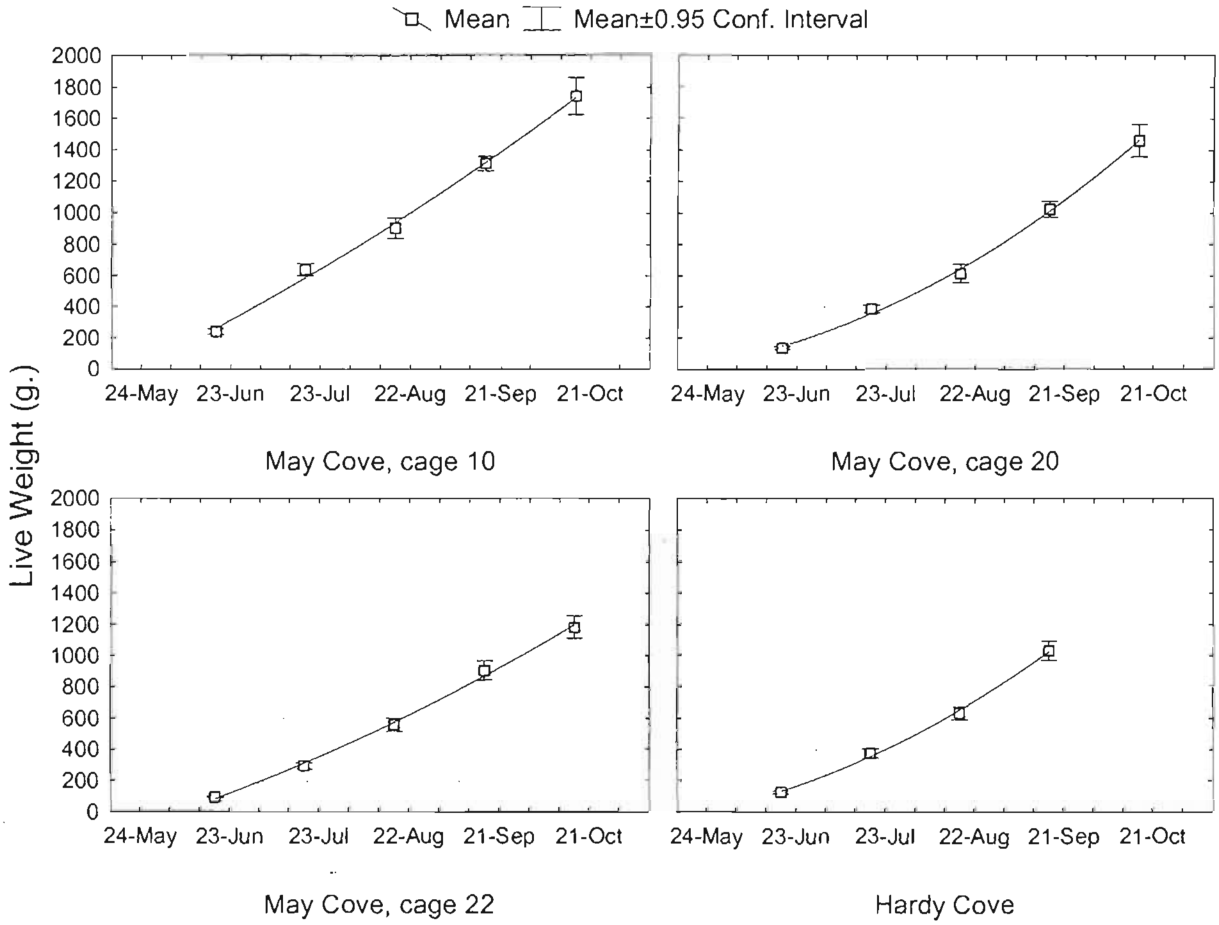



Figure 8. Progression of steelhead body weight with time from May Cove and Hardy Cove.

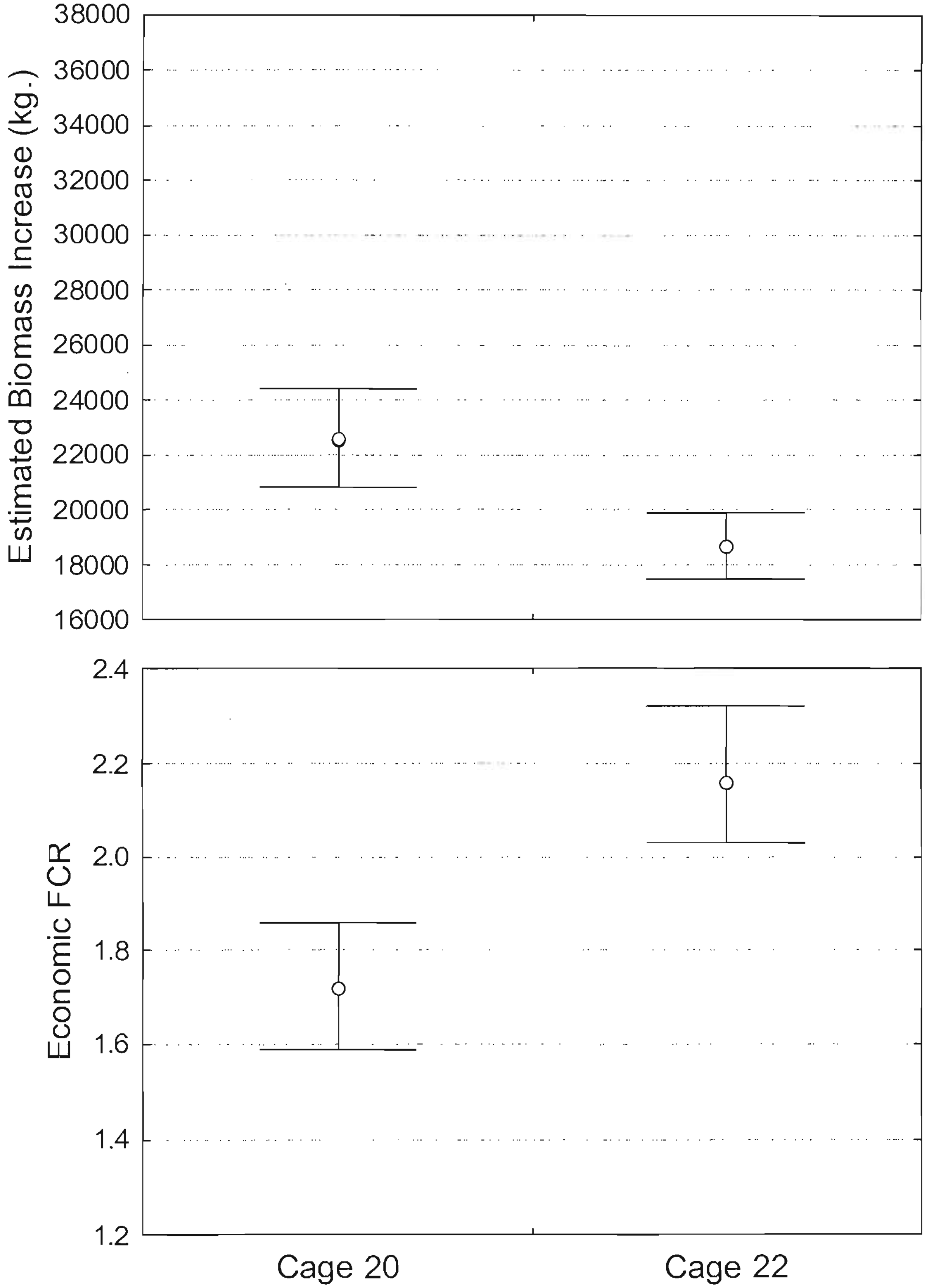



Figure 9. May Cove, all-female, diploid steelhead performance comparison.

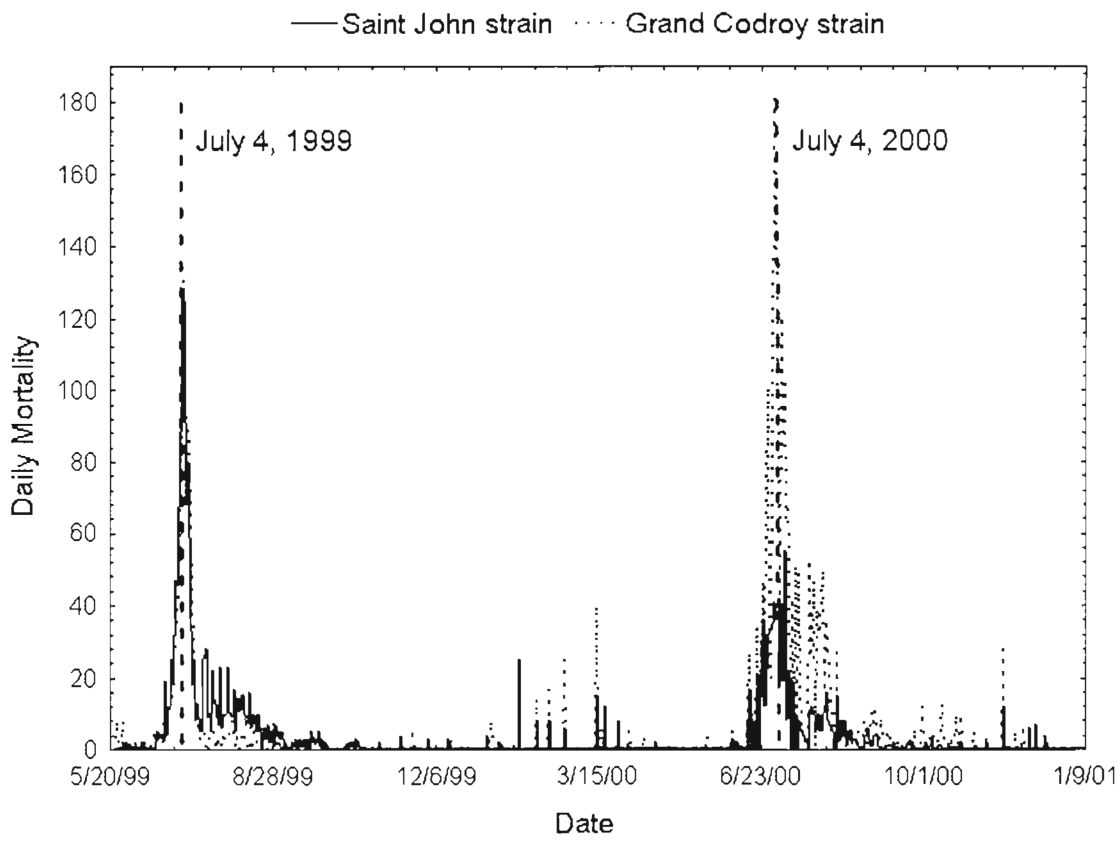
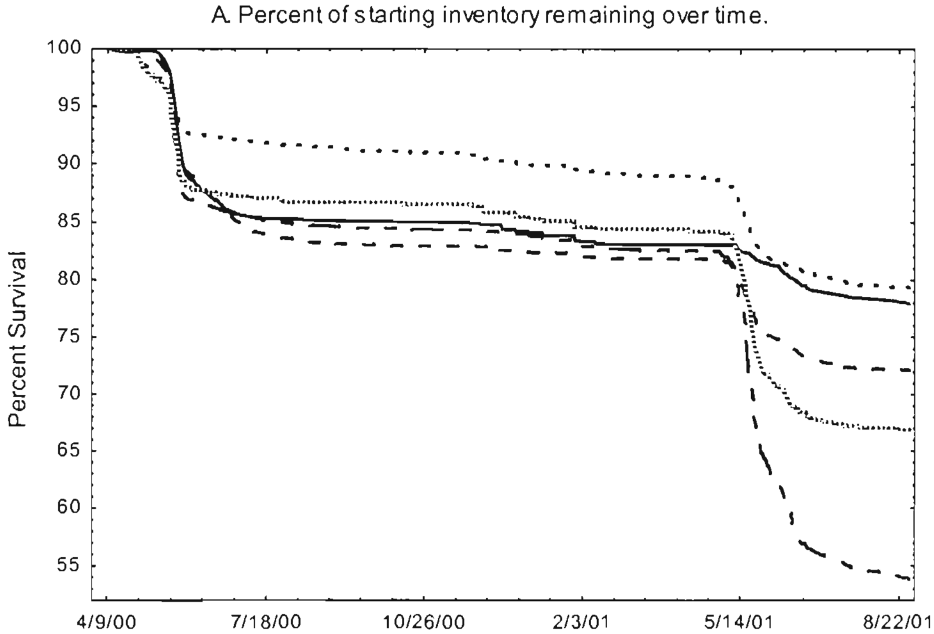



Figure 10. Salmon mortality events in 1999 and 2000.



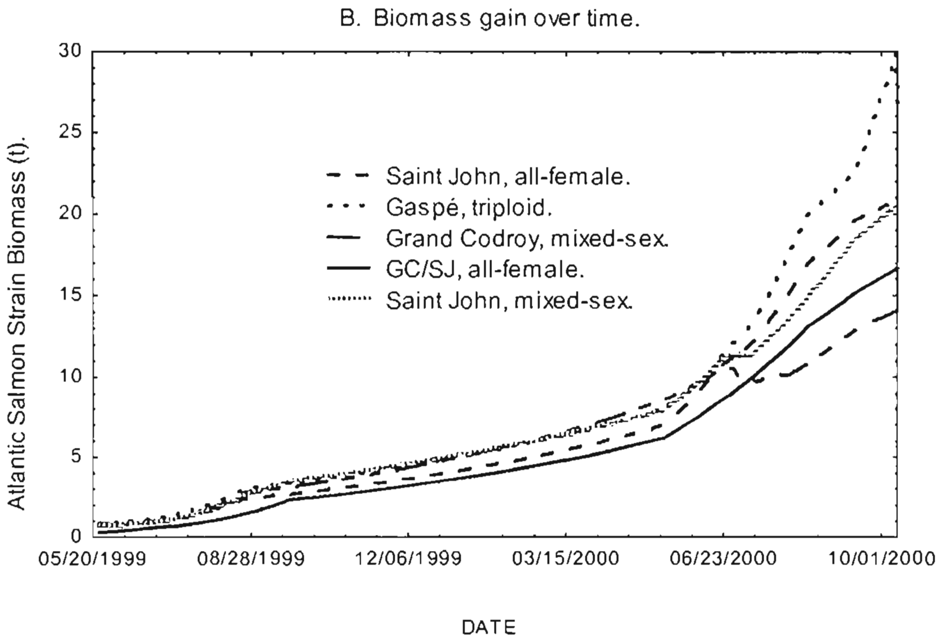




Figure 11. Numbers of fish and overall biomass accumulated.

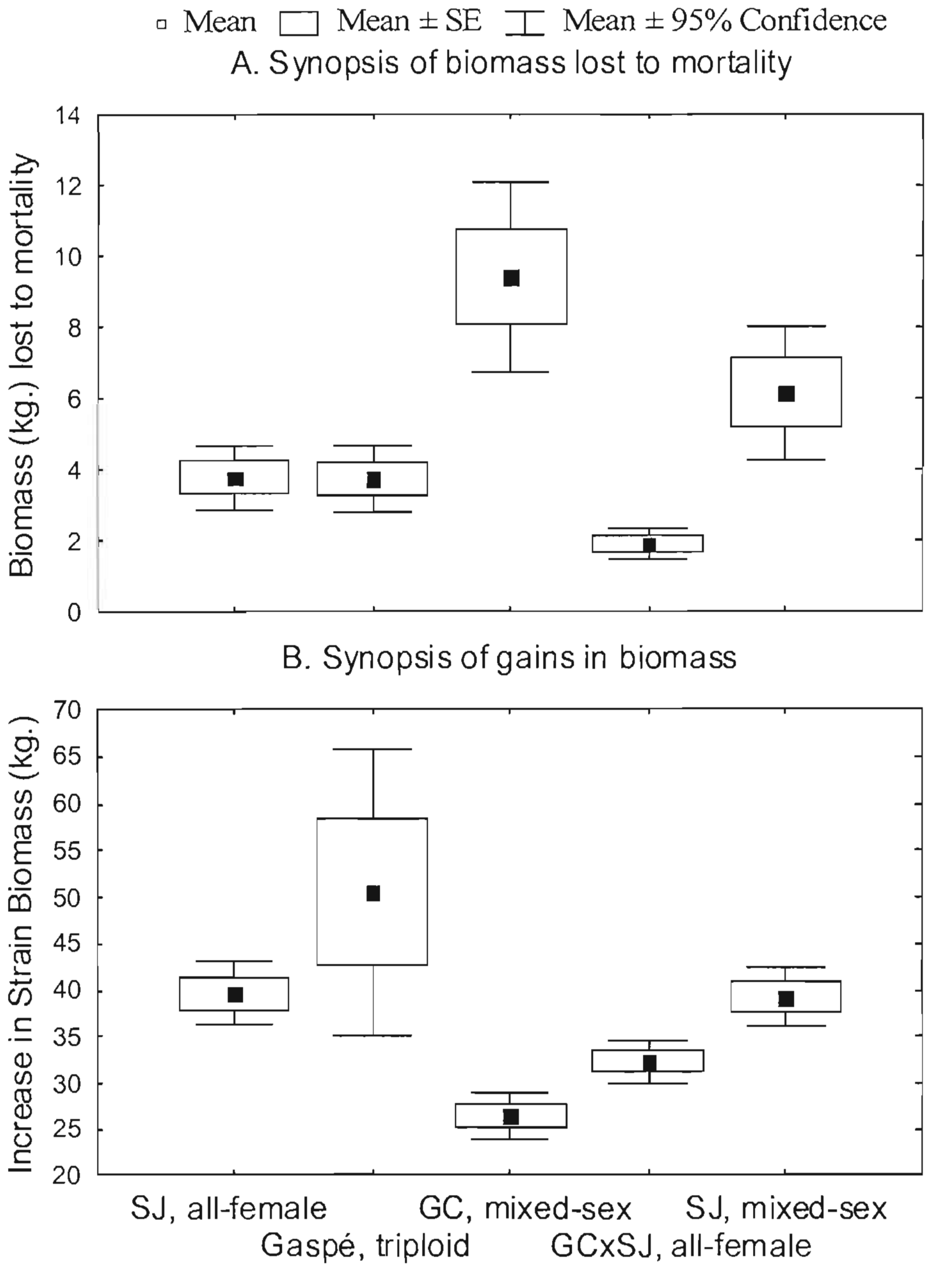



Figure 12. Biomass gains and losses among strains.

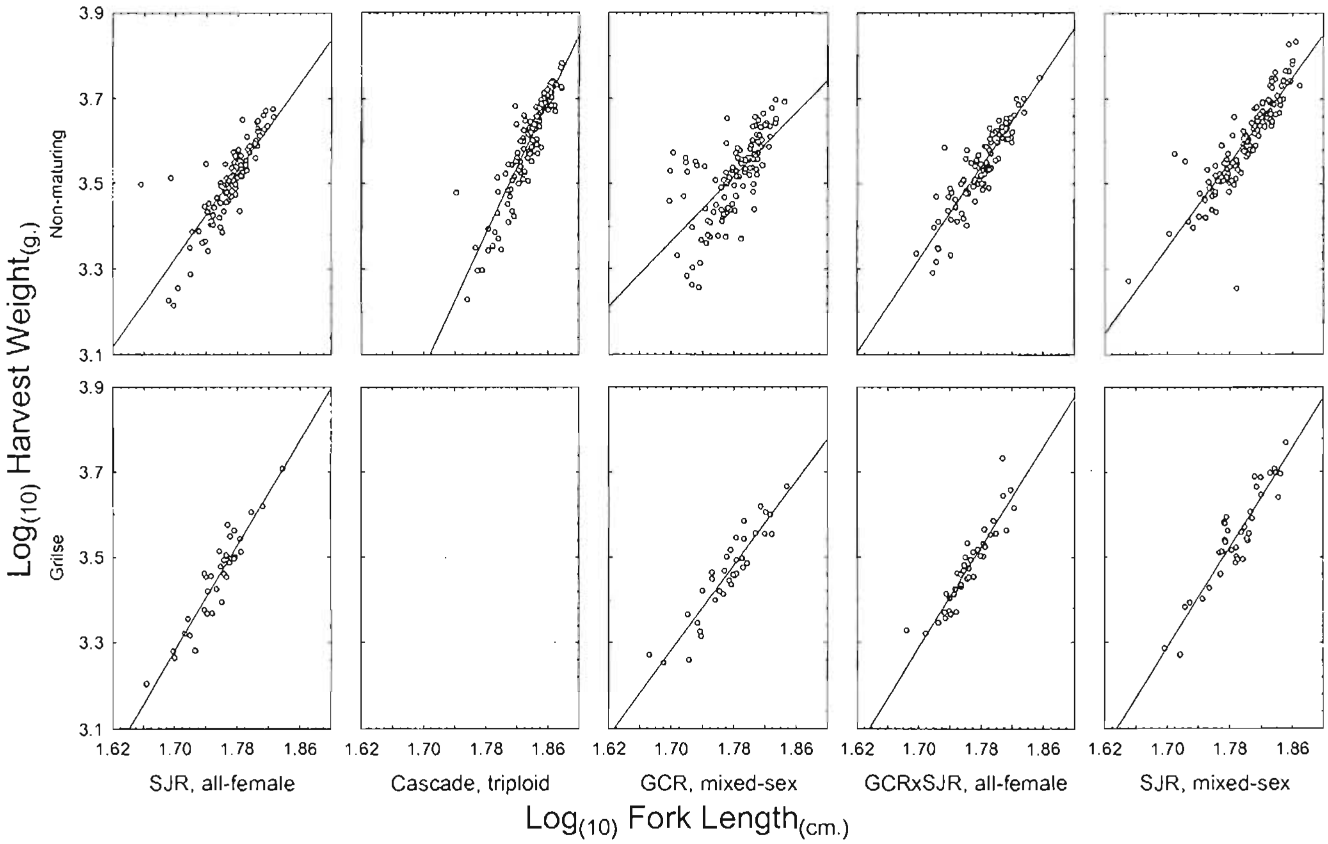



Figure 13. Weight-length regressions for salmon strains (adjusted to common harvest date).

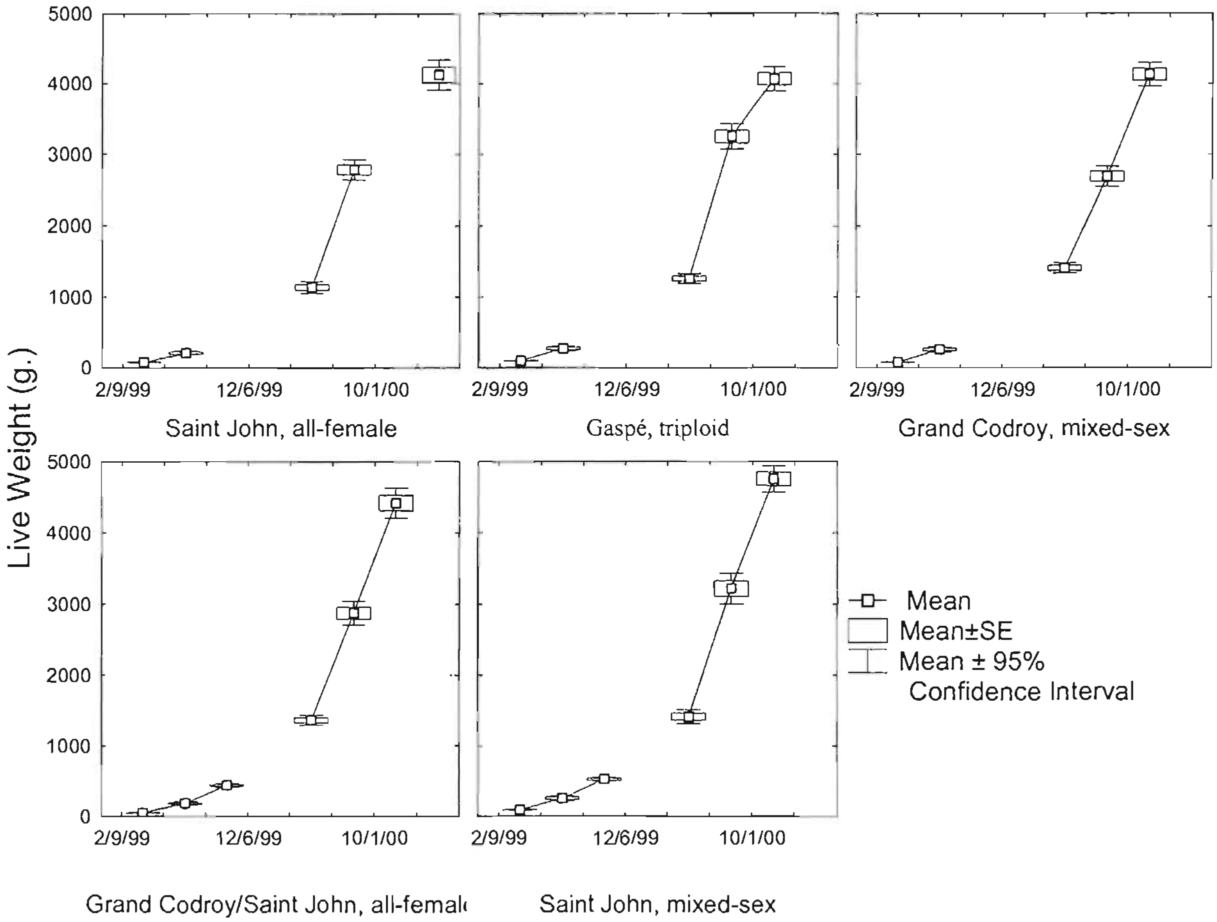



Figure 14. Progression in mean weight among salmon strains. Based on observed growth rate, the lowest weight at time of saltwater entry to result achieve the target of 454 g fillets is 113 g (see Discussion).

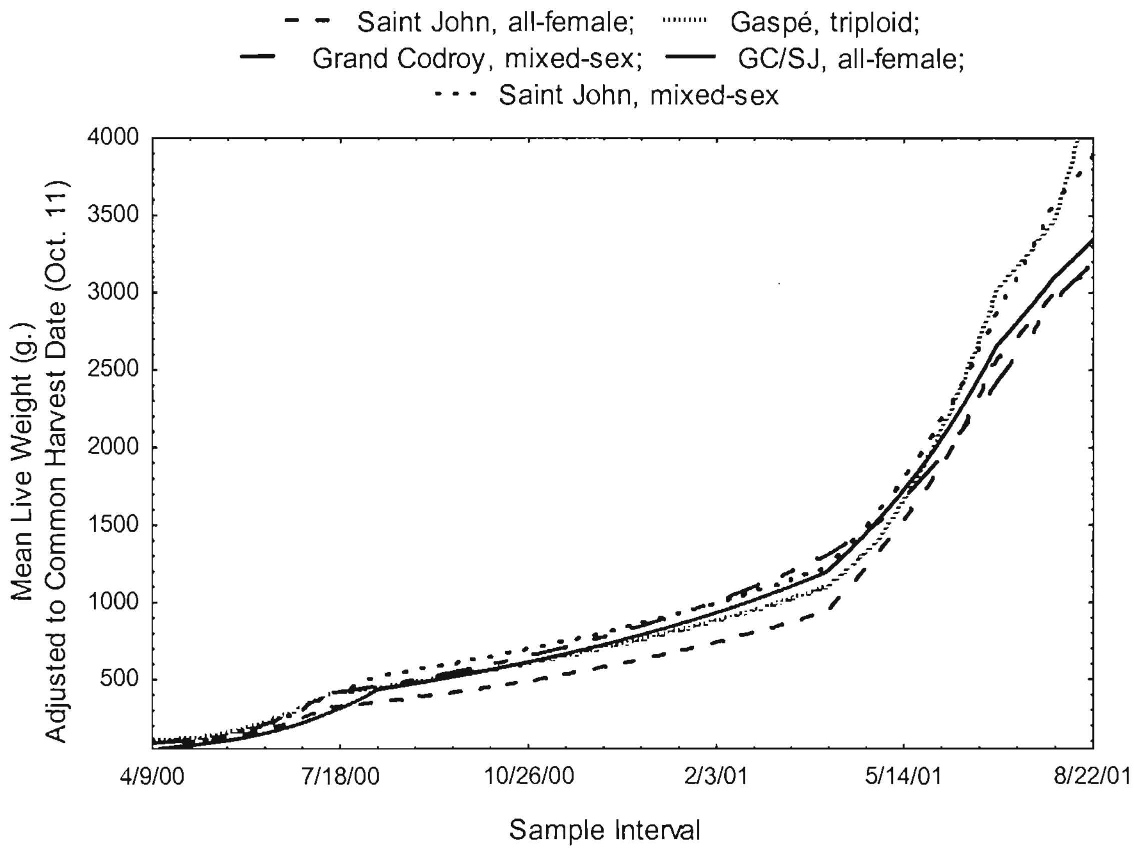



Figure 15. Progression in mean weight among salmon strains adjusted to common harvest date.

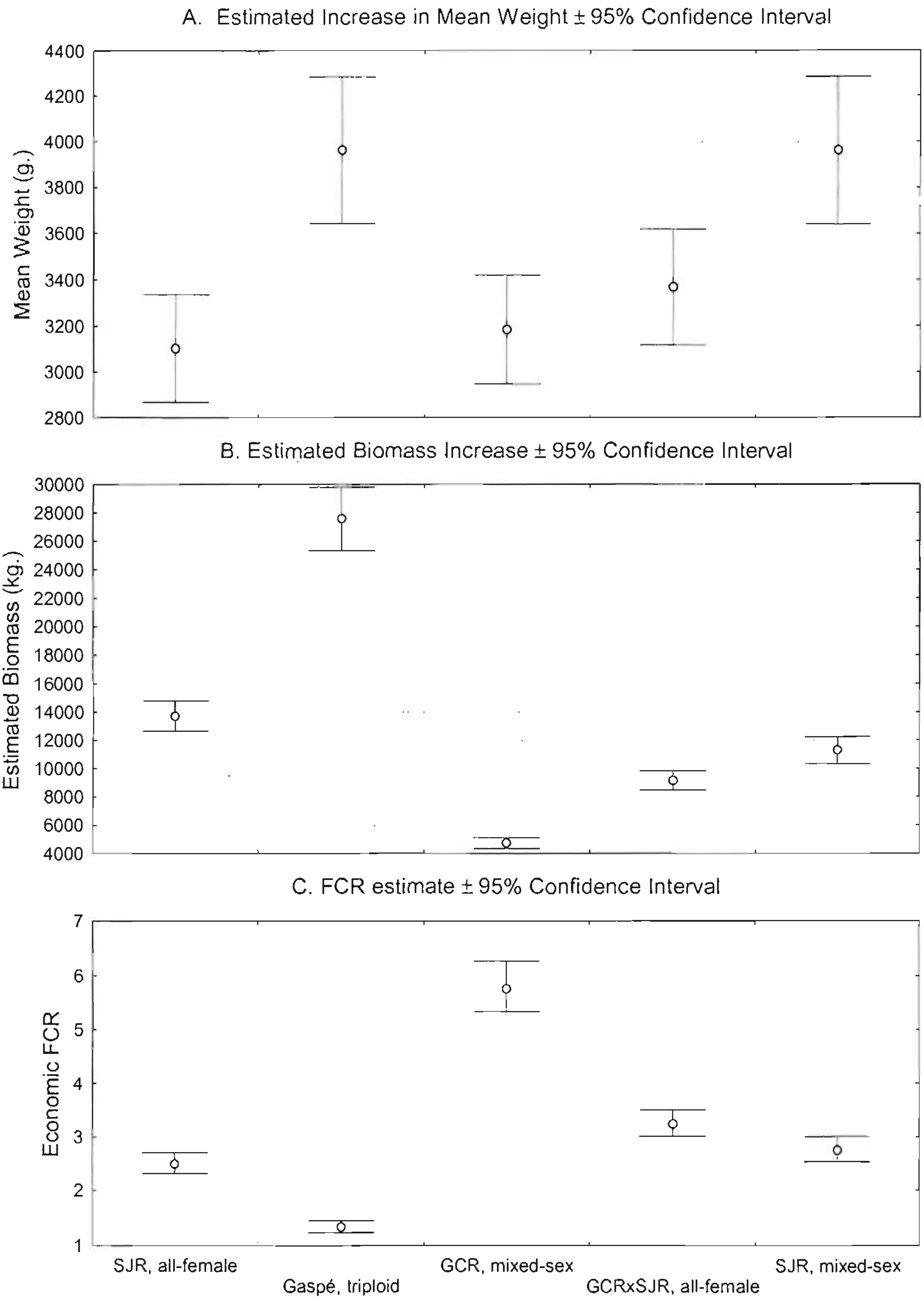



Figure 16. Performance indicators for Bay d'Espoir Atlantic salmon. These estimates take into account the variance in mean weight statistics captured at the beginning and end of the experiment.

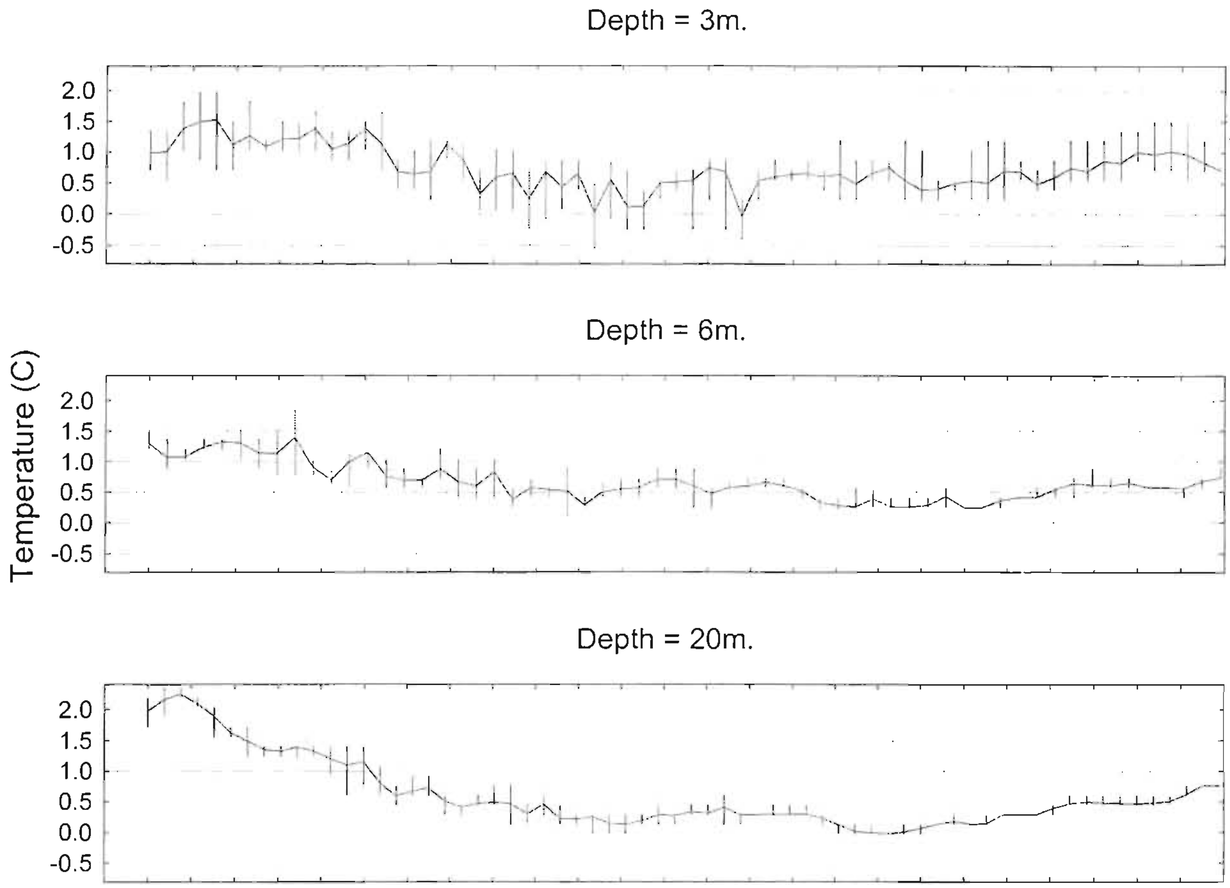



Figure 17. Winter water temperature fluctuations at the Matchums, January through March 2001. Vertical bars represent temperature fluctuation in a 24 h interval.

Appendix 1. Thermograph summary, Roti Bay: winter 1999/2000.

| Thermograph Unit | Month | Thermal Units[a] | Water Temperature (°C at 9 m) | | |
|---|---|---|---|---|---|
| | | | Mean | Min. | Max. |
| 1446 (Gaspé, 3n) | October | 287 | 9.3 | 7.2 | 11.9 |
| | November | 200 | 6.7 | 4.7 | 8.3 |
| | December | 151 | 4.9 | 0.8 | 5.8 |
| | January | 123 | 4.0 | 0.6 | 4.6 |
| | February | 89 | 3.2 | 0.8 | 4.1 |
| | March | 77 | 2.5 | 1.4 | 3.8 |
| | April | 57 | 1.9 | 1.6 | 3.9 |
| | May | 70 | 2.3 | 1.9 | 4.6 |
| | Total Units | 1054 | | | |
| 6248 (SJR mixed) | October | 296 | 9.5 | 7.5 | 11.7 |
| | November | 210 | 7.0 | 5.3 | 8.6 |
| | December | 160 | 5.2 | 3.8 | 6.1 |
| | January | 134 | 4.3 | 2.8 | 4.9 |
| | February | 99 | 3.5 | 2.3 | 4.4 |
| | March | 86 | 2.8 | 1.6 | 4.0 |
| | April | 66 | 2.2 | 1.9 | 3.2 |
| | May | 79 | 2.5 | 2.2 | 3.5 |
| | Total Units | 1129 | | | |
| 6435 (GCRxSJR) | October | 297 | 9.6 | 7.5 | 11.7 |
| | November | 211 | 7.0 | 5.6 | 8.6 |
| | December | 162 | 5.2 | 3.8 | 6.1 |
| | January | 135 | 4.4 | 3.1 | 4.9 |
| | February | 100 | 3.6 | 2.3 | 4.4 |
| | March | 88 | 2.8 | 1.7 | 4.1 |
| | April | 67 | 2.2 | 1.9 | 3.1 |
| | May | 80 | 2.6 | 2.2 | 3.5 |
| | Total Units | 1141 | | | |
| 6439 (GCR mixed) | October | 300 | 9.7 | 7.7 | 11.7 |
| | November | 214 | 7.1 | 5.6 | 8.7 |
| | December | 164 | 5.3 | 4.0 | 6.1 |
| | January | 138 | 4.5 | 2.9 | 5.0 |
| | February | 102 | 3.7 | 2.5 | 4.6 |
| | March | 90 | 2.9 | 1.7 | 4.3 |
| | April | 70 | 2.3 | 2.0 | 4.0 |
| | May | 83 | 2.7 | 2.3 | 3.5 |
| | Total Units | 1161 | | | |

Appendix 1 (cont'd.)

| Thermograph Unit | Month | Thermal Units[1] | Water Temperature (°C at 9 m) | | |
|---|---|---|---|---|---|
| | | | Mean | Min. | Max. |
| 8549 (SJR female) | October | 288 | 9.3 | 7.3 | 12.0 |
| | November | 200 | 6.7 | 5.3 | 8.3 |
| | December | 149 | 4.8 | 3.6 | 5.7 |
| | January | 121 | 3.9 | 2.6 | 4.5 |
| | February | 87 | 3.1 | 2.2 | 4.0 |
| | March | 76 | 2.4 | 1.4 | 3.7 |
| | April | 57 | 1.9 | 1.5 | 2.6 |
| | May | 71 | 2.3 | 1.9 | 3.1 |
| | Total Units | 1049 | | | |

[a]The average measure of thermal units from the five units is 1107 for the October 1999 through May 2000 interval.

Appendix 2. Comparison of salmon live sample weights with those of dead specimens for August 15, 2000.

| Strain | Specimen | Statistics | | | t | p[a] |
|---|---|---|---|---|---|---|
| | | N | Mean Wt. | SD | | |
| | | | | | | |
| SJR, all-female | Live | 35 | 2565.1 | 377.6 | 2.69 | 0.006 |
| | Dead | 2 | 1840.0 | 240.4 | | |
| | | | | | | |
| Gaspé, triploid | Live | 35 | 3025.0 | 551.3 | 0.80 | NS |
| | Dead | 2 | 2710.0 | 268.7 | | |
| | | | | | | |
| GCR, mixed-sex | Live | 35 | 2418.1 | 437.7 | 2.86 | 0.004 |
| | Dead | 4 | 1775.0 | 306.2 | | |
| | | | | | | |
| GCRxSJR, all-female | Live | 35 | 2656.4 | 515.3 | 2.09 | 0.021 |
| | Dead | 3 | 1986.7 | 693.9 | | |
| | | | | | | |
| SJR, mixed-sex | Live | 35 | 2863.6 | 580.4 | 1.69 | NS |
| | Dead | 2 | 2167.5 | 17.7 | | |

[a]1-sided test.