FINAL REPORT

to the

Fishing Research and Development Corporation (FRDC)

January 1996

Optimisation of feed distribution to salmon in sea cage culture (T93/233)

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CONTENTS

1. Summary

1. The uniquely designed Adaptive feeder system was used as a tool to identify feeding patterns of Atlantic salmon in sea cages in Tasmania during the period of seawater intake to harvest. These patterns varied in relation to season and fish size.

2. In summer, juvenile salmon (700g) tended to feed throughout the day in small meals.

3. By the end of summer, 2 kg salmon showed more pronounced feeding peaks in early morning and late afternoon, with a number of smaller meals throughout the day.

4. By autumn, a mid-morning feeding peak had developed in addition to the two existing peaks, possibly in response to the shortening daylength.

5. By the following summer when fish were at harvest size, the feeding pattern showed two distinct feeding peaks: early morning and late afternoon.

6. The patterns exhibited throughout the production cycle may vary from year to year possibly depending on environmental conditions.

7. The number of meals displayed as feeding peaks changes in relation to season and fish size, from 6+ in newly introduced fish (60-700g) in spring/summer to 3-3+ in summer/autumn (2-3.2 kg) to 2-3 in harvest size fish (4.6-6.4 kg). This is close to the feeding frequency expected in some salmon industries.

8. Large salmon display a very poor feeding efficiency at night (moonlit) confirming that night feeding is not an option for extending feeding hours.

9. In the trials on feeding frequency, little difference in growth was found in cages of fish fed throughout the day to satiation compared with either two or three bouts to satiation.

10. Although general patterns of feed intake can be demonstrated for a particular size salmon, daily variability in this intake does occur.

11. A large range of environmental variables were monitored in conjunction with feeding patterns. These data have as yet not been analysed to the degree of resolution required. As these studies have not been conducted in this manner before, new computer software must be developed to handle this information. Results will be presented in the form of a supplementary report once this has been conducted.

2. Background to Research and Development

A percentage of the pelleted feed distributed to salmon in sea-pens is wasted because the feed distribution methods do not always satisfy the requirements of the fish in terms of feed frequency and quantity. This wastage may be reflected in the feed conversion efficiency and contributes to farm production costs and environmental pollution. Similarly, if feed is not provided in a sufficient quantity, less than optimal growth may be experienced. The general aims of this research program is to further improve our understanding of the feeding behaviour and requirements of Atlantic salmon (*Salmo salar*) in commercial seacage culture which in turn may be used as a management technique to improve feeding performance.

The core group of researchers involved in this project have been involved with aspects of salmon feeding since 1989 when a Teaching Company Training Scheme (DITAC), involving Gibson's Ltd, University of Tasmania (Department of Aquaculture) and Salmon Enterprises of Tasmania (Saltas) Pty Ltd, funded a program which initially investigated the compensatory growth effects of a range of restrictive feeding regimes (Blyth et al., 1992). This developed into a program with Aquasmart Pty Ltd (then JonJo Pty Ltd) incorporating the development and testing of the adaptive feeding system. The results from the initial trials with the adaptive feeding system have been released (Blyth and Purser, 1992; Blyth et al., 1993; Russell, 1991, 1992). As a consequence of these reports and active marketing by Aquasmart, companies and research organisations in Australia and overseas have enquired about the use of the technology for research purposes and as a means of improving production efficiencies on commercial seacage fish farms. Some companies and institutions are currently trialing the technology. In addition to its potential to improve feed conversion ratios and reduce wasted feeds, the technology also has the potential to reduce labour, promote faster growth rates in the fish and reduce site enrichment. Due to its unique configuration, the adaptive feeder system has the ability to detect and record feed waste, and through its feedback loop can self-regulate the quantity of feed distributed on the basis of the waste detected.

The configuration of the feeding system, including a sequence on how the information is collected, is illustrated in Plates 2-8. The rationale behind the development was based on the need to better match the feed delivery to the requirement of the fish without human intervention. This was accomplished through the development of computer software linked to an underwater electronic sensor, assisted by a cone, which sub-samples any pellets falling through the water column. It has the ability to detect individual pellets to a minimum size of about 3 mm in diameter and can differentiate pellets from faecal and detrital material. The software subsequently uses this information (on detected pellets), together with some predetermined calibration settings, to "decide" how to best match the feed input to the actual feeding rhythm of the fish in the cage. The equipment also has the ability to simultaneously record the feed data. It is this last feature which enables the feeding patterns to be quantified and displayed.

Although this technology had been developed and tested by the investigating group prior to the FRDC grant application, it was used in this study as a tool primarily to detect the relationship between feeding rhythms and environmental conditions, and between pre-set feeding regimes and performance. In addition, the technology was utilised to monitor possible feeding activity at night and changes in feeding patterns in relation to fish size and season during the year. The trials were undertaken at the Hideaway Bay site operated by Huon Aquaculture (previously Huon Atlantic Salmon) (Plate 1), a commercial farm producing about 700 tonnes of Atlantic salmon per annum. The site is located in the Huon estuary near Dover in southern Tasmania (43°16'S, 147°04'E). Huon Aquaculture has contributed a considerable amount of effort and equipment during the trialing and utilising these feeders in both experimental and commercial situations.

3. Objectives

The original objectives of the study were:

> To use the 'AquaSmart' feeder controls (adaptive feeder system), in conjunction with standard auto-feeders as a tool to
>
> (i) identify the diel and circannual feeding profiles of salmon in relation to fish size and season;
>
> (ii) identify the effect of specific environmental conditions on the feeding patterns of salmon;
>
> (iii) identify the feeding behaviour of salmon (in conjunction with video equipment and tags); and
>
> (iv) quantify the level of wastage associated with specific feeding techniques.

The first three objectives are addressed in the sections outlined below; objective (iv) was not addressed in the manner originally intended as the farm on which the work was undertaken was not prepared to compromise the performance of the fish by introducing "out-dated" feeding practices for experimentation. To some extent this objective was replaced by the preliminary study of the fish performance under pre-set feeding regimes.

In terms of how the experimental trials address the objectives: Experiment 1 relates to Objective (i), Experiments 1 & 2 to Objective (ii), Experiment 4 to Objective (iii) and Experiment 3 to the modified Objective (iv). Experiment 5 is a smaller trial used to investigate any background "noise" and Experiment 6 was conducted to identify the sensitivity of the sensor in detecting pellets under a variety of equipment configurations, the results of which may be used to calibrate the equipment to absolute rather than detectable waste, provide a more accurate determination of feed conversion and give an indication of the working limitations of the feeding configurations.

4. Introductory technical information concerning the problem or research need

All animals including fish display preferential feeding patterns and behavioural rhythms which relate to biological and environmental conditions (Boujard and Leatherland, 1992a; Kavaliers, 1986).

It would therefore appear desirable under culture conditions to match the feed delivery with the feeding requirements and rhythms of the fish; firstly by identifying (visualising) these patterns and secondly by better understanding the factors which influence these times of feeding preference. Until recently, however, pellet delivery to the fish has been based more on employee shifts and logistics rather than on the preferences of the fish. Traditionally, culturists employed either hand delivery or automatic feeding techniques or a combination of the two to distribute pellets to fish.

Feeding rates are recommended by manufacturers in relation to water temperature and fish size and are based on estimates of growth, feeding efficiency and nutritive value (energy content). These feeding rates are usually set but are periodically adjusted in relation to growth. This concept does not take into account any daily variation in feed intake by the fish in response to disturbances or environmental changes. As an example, previous work (Blyth et al., 1993) has demonstrated that the daily intake of about 9 tonne of Atlantic salmon over a 50 day period in winter in a sea cage fell in the range 20-180 kg/day. Obviously, delivering a set amount of feed during this time may have resulted in sub-optimal feeding practices.

During hand delivery, personnel are able to visually monitor the surface feeding response of the fish but may find it difficult to detect feed intake at depth in the cage, during times of turbid water or during different pellet delivery rates. Usually large proportions of the daily feed are delivered during a few visits to the cage. On each of these occasions, the feed is offered at a level which is considered at or slightly below satiation. With this in mind it is impractical to be present at each cage to feed the fish at the best time suited to the fish, particularly if this time is the same for all cages. Recent advances in feed distribution technology (e.g. air blown or water cannon feeders) have assisted with these limitations to an extent by enabling personnel to deliver large quantities of feed more frequently to a number of cages but it may still fall short of optimising feed delivery to individual pens.

Automatic feeders are usually mechanical or computer controlled to deliver small amounts of feed to the fish at regular intervals. Many do not take into account the preferential feed times of the fish, but rely on the fish "learning" the timing of feed delivery and assume that the fish have a constant or pre-determined appetite throughout the day. As the feed intake of salmon varies throughout the day and between days (Blyth et al., 1993), wastage of feed during times of low appetite and underfeeding when the fish are hungry, will occur. Overfeeding not only results in waste feed and higher costs but also contributes to environmental problems. Excessive buildup of uneaten feeds (and faeces) under cages may produce adverse water quality conditons, leading to a reduction in fish performance and health. It also has wider company and industry implications in relation to the number of sites available to the grower, fallowing protocols, separation of year classes and site recovery times.

A farm that entirely uses the hand feeding method, typically shows a good feed conversion figure but poorer growth than a farm that uses a combination of the two methods. It may also utilise more labour.

Although the concept of matching feed input with the requirements of the fish has been acknowledged by growers, the difficulty was actually in the detection of these patterns or rhythms and how they change. Many 'new' feeder systems being developed overseas (Juell, 1991; Bjordal et al., 1993; Skjervold, 1993) attempt to deliver the feed at the preferential feeding times or detect waste pellets but do not have the capabilities of recording the intake patterns and feeding behaviour of the fish.

The Aquasmart Adaptive feeder system developed in Tasmania has the ability to control a standard autofeeder by the detection and, through the subsequent feed-back loop, the self-regulation of the pellet delivery in response to the feeding behaviour of the fish. Preliminary experiments by the participants using this technology were undertaken prior to this FRDC funded program (Blyth, 1992; Blyth and Purser, 1993; Blyth et al., 1993; Russell, 1991, 1992).

This project builds on the previous experiments using the adaptive feeding system as a tool to detect feeding behaviour and rhythms, and in combination with environmental monitoring equipment, attempts to identify the factors which influence these intake patterns. Previous studies on the influence of environmental factors on the feeding behaviour and patterns in salmonids, in particular, have been conducted overseas but have not attempted to monitor the variables and correlate them to the feed intake to the same resolution that this study has undertaken. Studies on the effect of light (Boujard and Leatherland, 1992a,b; Boujard et al., 1992; Kadri et al., 1991), tidal cycle (Kadri et al., 1991; Smith et al., 1993), water temperature, cloud cover, water clarity (Smith et al., 1993), lunar cycles (Farbridge and Leatherland, 1987) and oxygen, atmospheric pressure, wind speed/direction and rain (Anras, 1994) have been conducted on salmonids (and marine fish).

As feed associated costs on salmon seafarms may be in the range of 40-60% of the farm operating costs, it is desirable to identify ways of reducing this figure. The means available include the optimisation of

(i) the diet composition through nutritional studies,
(ii) feed delivery to the pens and fish,
(iii) the utilisation of the feeds by the fish.

This program mainly encompasses point (iii) and some aspects of point (ii).

Some preliminary trials suggested that an improvement of 5-15 % on growth and FCR using the adaptive feeder technology compared with standard automatic feeder systems, was achievable.

It is probably optimistic to suggest that the adaptive feeding system would be used by the whole Tasmanian salmon industry, mainly because of alternate feeder preferences, unsuitability of various sites (high current flow), small size of fish and therefore pellets or because of logistical difficulties. However, the information obtained by this study is applicable to other sites in that assists in the understanding of aspects such as feed behaviour, preferential feeding times, effects of disturbances on feed intake and environmental influences on feed intake in the Tasmanian context.

Major disturbances on farms such as grading, handling, predator presence and disease treatment do interfere with feeding behaviour and intake (Blyth et al., 1993). Little is known, however, about the effect of minor disturbances such as net changing, change of feeding regimes on weekends or boating which may be considered more chronic in their influence. It was hoped to identify more closely the influence these activities have on the feeding patterns.

The Tasmanian industry has supported the principle of the study by giving it a moderate-high ranking in the Saltas Research and Development surveys in 1993.

PLATE 1

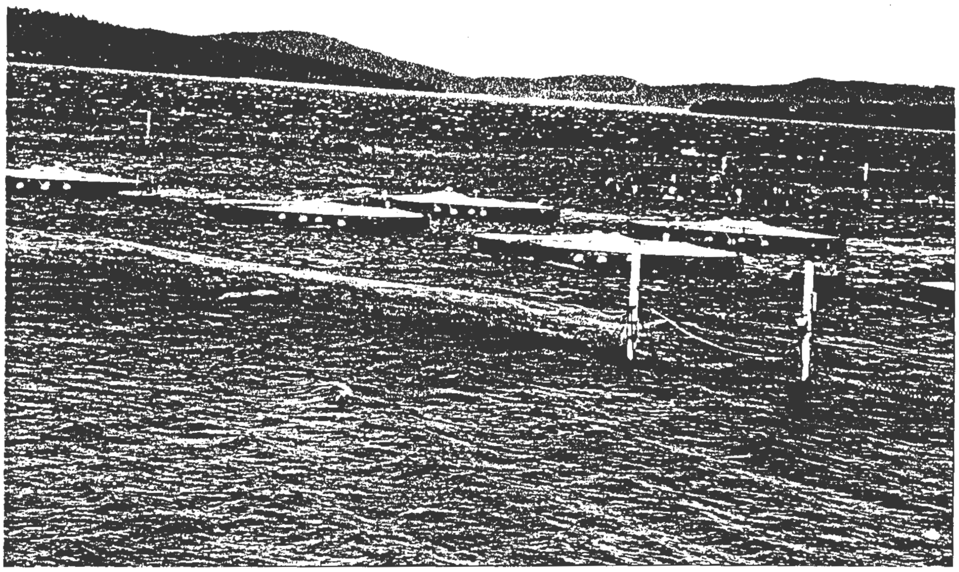
Huon Atlantic seacage site at Hideaway Bay, southern Tasmania, where the feeding, feed behaviour and environmental monitoring trials were undertaken.

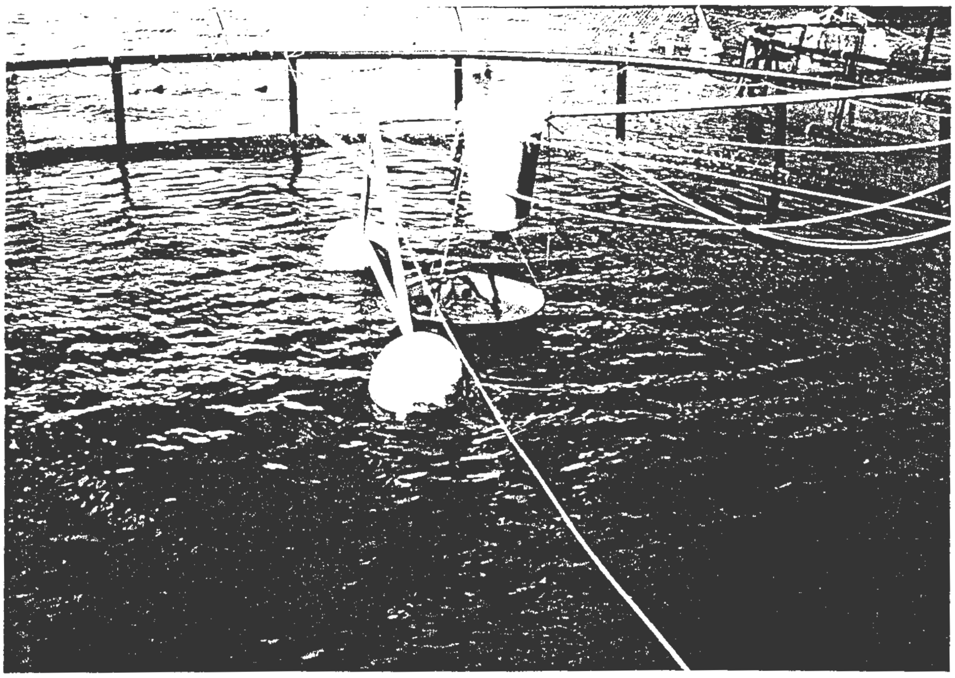
PLATE 2

The funnel used to detect uneaten pellets was positioned immediately below the automatic feeder but at a working depth of about 5 m.

PLATE 3

The configuration of the funnel used to sub-sample the water column for uneaten pellets. The sensor, past which the pellets fall, can be seen at the base of the cone.





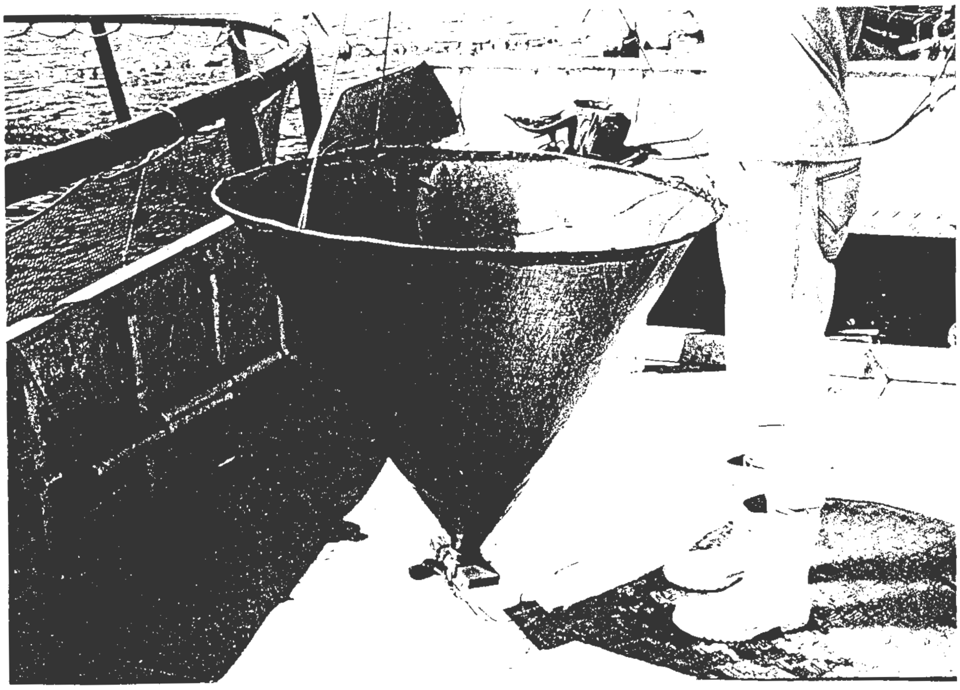
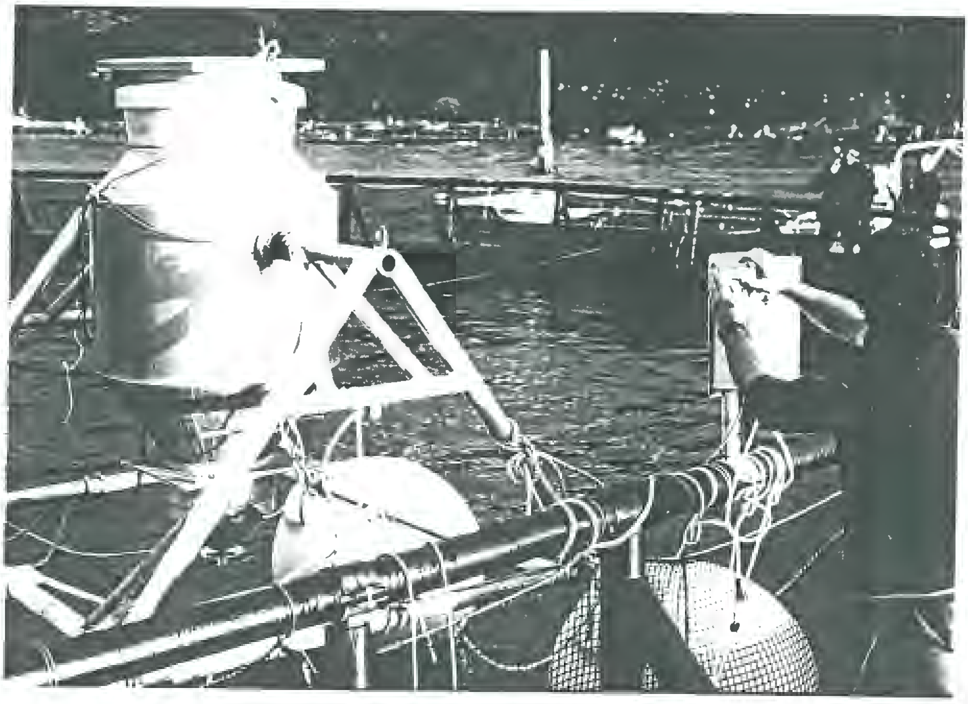


PLATE 4

The adaptive feeder controller was positioned on the hand rail of the cage and was connected to the funnel and the automatic feeder system.

PLATE 5

The data was down-loaded from the control/recording system via a datalogger system and transferred to the PC for analysis.



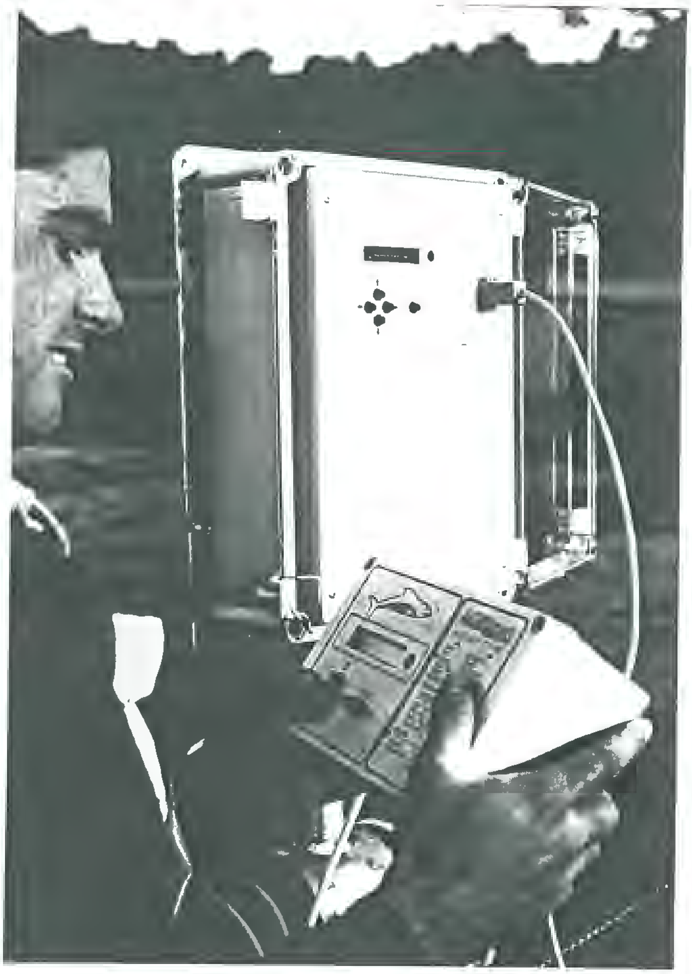
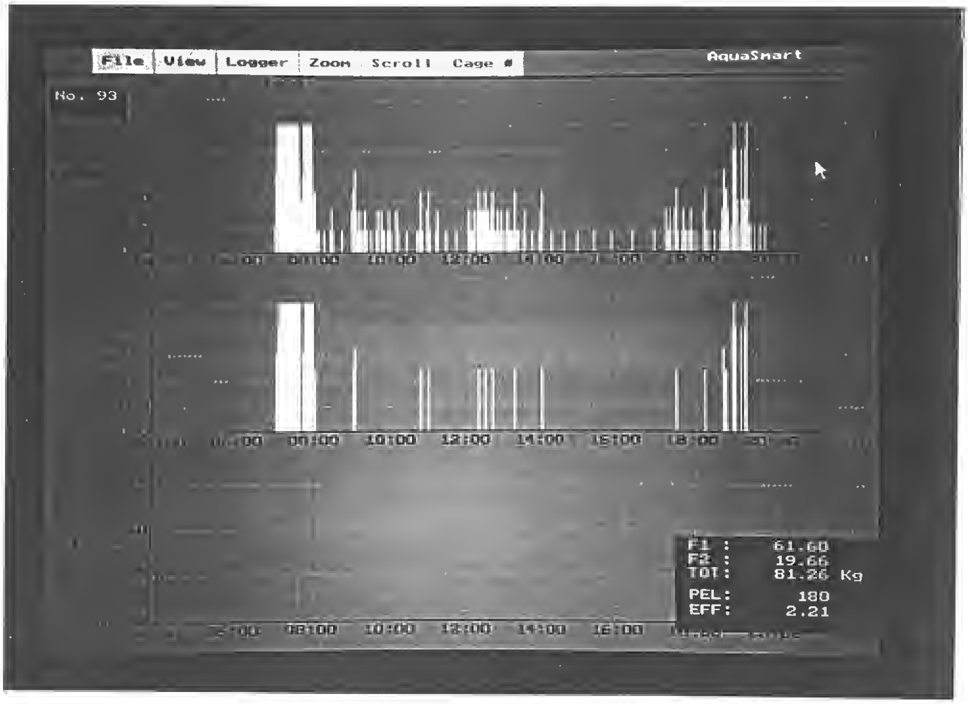


PLATE 6

An example of the 'raw' data displayed on the PC screen; the peaks represent the pellets detected by the funnel.

PLATE 7

An example of the three dimensional display of the salmon feeding patterns following transformation of 'raw' data. This graph represents feed intake as a percentage of the maximum daily intake.


File View Logger Zoom Scroll Cage #
AquaSmart
No. 93
08:00 10:00 12:00 14:00 16:00 18:00
F1 : 61.60
F2 : 19.66
TOT: 81.26 Kg
PEL: 180
EFF: 2.21

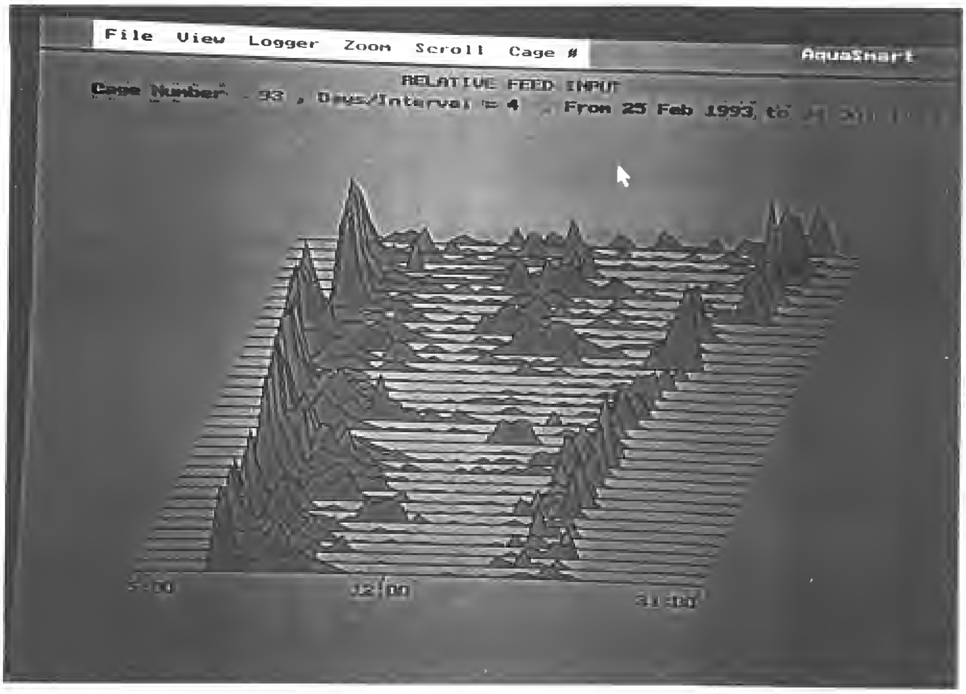
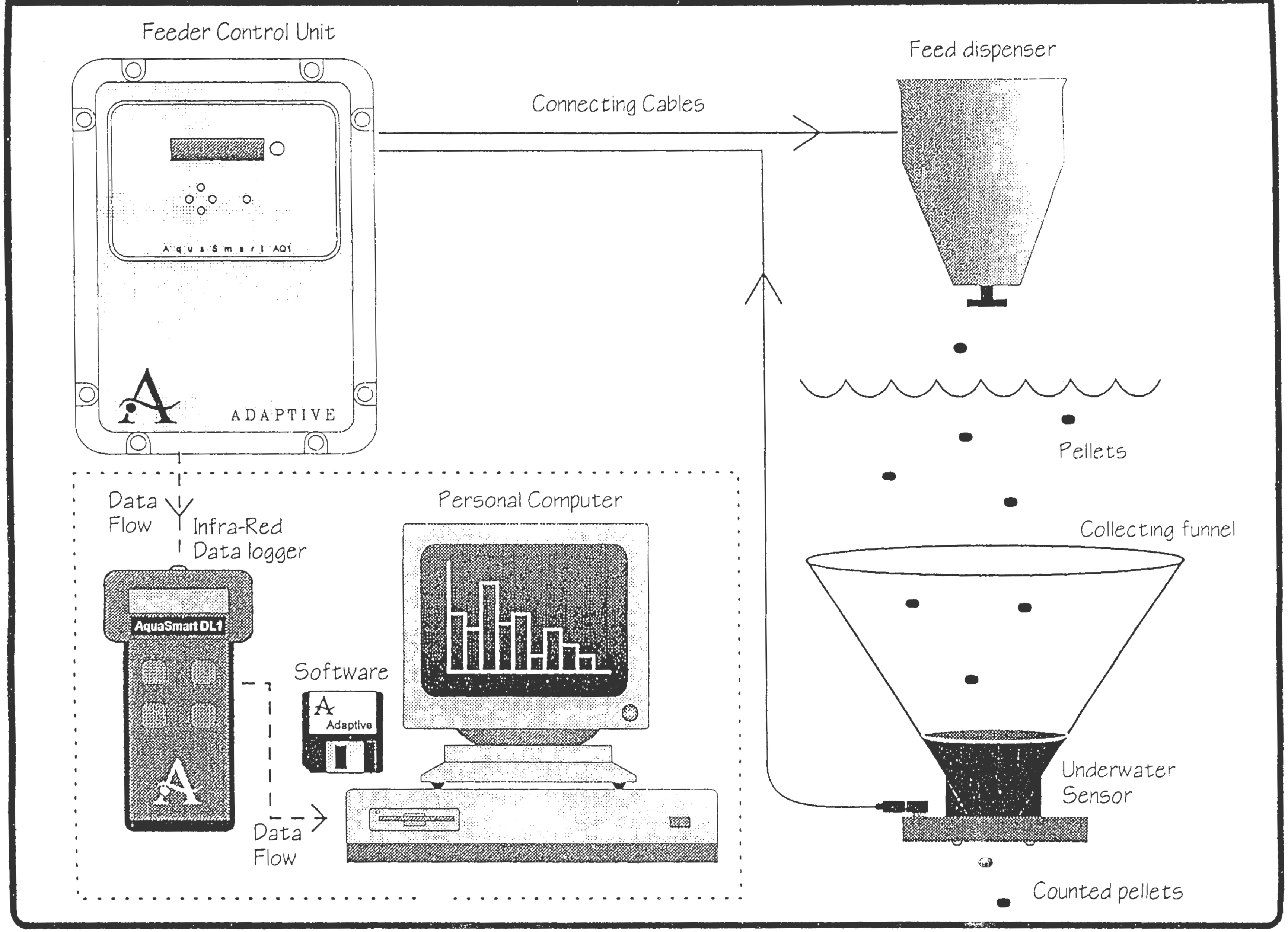

File View Logger Zoom Scroll Cage #
AquaSmart
RELATIVE FEED INPUT
Cage Number 93 , Days/Interval = 4 From 25 Feb 1993 to
12:00

PLATE 8

Schematic diagram of the Aquasmart adaptive fish feeding system used in the study to record the feeding patterns of the Atlantic salmon in seacages.

SCHEMATIC DIAGRAM OF AQUASMART ADAPTIVE FISH FEEDING SYSTEM



5. Research Methodology, Results and Discussion

Experiment 1

The effect of environmental factors on the frequency and quantity of feed intake in Atlantic salmon in sea cages.

Introduction

The purpose of this work was to study the main environmental influences on feeding behaviour. The adaptive feeder was used to monitor feed intake and this information was then compared to environmental factors to assess the importance of seasonal, daily and other cyclical factors on feeding behaviour. Circa-annual variation in feed intake patterns was also investigated.

Methods and Materials

Feeding equipment

The Adaptive feeding system (Figure 1) was used to automatically control feed delivery, storing this information. The system utilised an underwater sensor in combination with a 'feedback' algorithm, to self regulate the rate of feed input based on the detection of small amounts of feed. This matched the actual rate of feed output to that ingested by the fish. System settings were periodically adjusted to compensate for growth, seasonal conditions and diel fluctuation of other environmental factors such as currents. Settings were constant for each feed size but were adjusted at the size transition to accommodate re-calibration of the sensor, different sinking rates and different outputs per spin. The Adaptive system was linked to a standard 12V DC circular spinning disc type feeder. Two hoppers were used during peak feed demand to cope with the daily output.

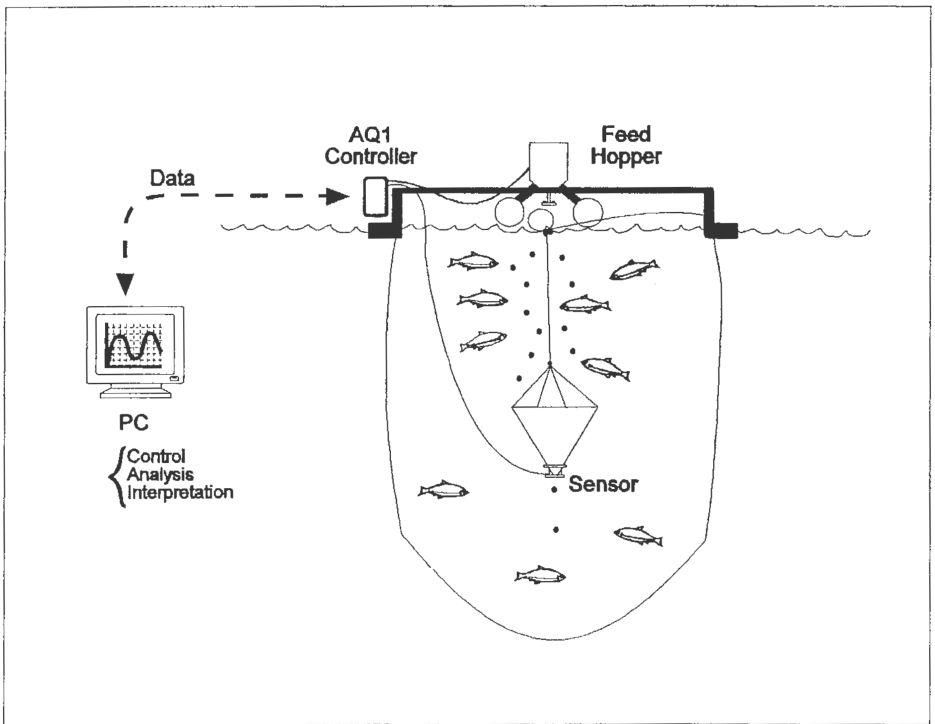


Figure 1. Schematic showing the configuration of the Adaptive feeding system in a 65m circumference polar circle.

System function and definitions
The Adaptive feeding algorithm utilised an underwater sensor to discriminate pellets and then "decided" (see figure 2) on an appropriate feeding level. The following section covers the parameters that were used to establish ranges within which the algorithm functioned.

All operations were based on a daily feeding program (see Tables 1a-d). Each program divided the day into time intervals or steps, during which feeding activity was expected to occur. In the case of Atlantic salmon feeding was assumed to occur in daylight hours, so steps were set accordingly. The following list describes the functions of each of the program parameters utilised in the experiment.

Start Time: The step start time
Stop Time: The step stop time
Mode: Two settings were used either Slow or Burst. Slow made the sensor operate after each feed actuation whereas burst inserted another non-sensor verified feed actuation when the algorithm had reached maximum feed. **Pause** was to regulate the time between non-sensed actuations
Pause: Pause time was the minimum time between each feeder actuations during burst mode.
Minimum sleep: The minimum sleep time was the smallest time that the feeder remained inactive after a feeding bout was completed. This time ensured that fish had a sufficient rest period after active feeding and at the same time were able to feed during less predictable times. This resulted in slightly more testing than is normal in order to establish the feeding rhythms
Maximum sleep: The maximum sleep time was the longest period operations were suspended after a feeding bout. Over the feeding period, the *Sleep* period auto- ranged between the minimum and maximum sleep settings to home in on the preferred temporal feeding pattern of the fish.
Minimum feed: The minimum amount of food delivered.
Maximum feed: The maximum amount of food delivered. The appropriate instantaneous intake rate was determined by auto-ranging between the minimum and maximum feed settings.
Sensitivty: The sensitivity was the level of feed detected that determined whether the feed output increased, decreased, remained the same or ceased. It was set to a particular value
High Repeat: An upper threshold was established to prevent excess output due to failure of equipment or high currents moving pellets away from the sensor.

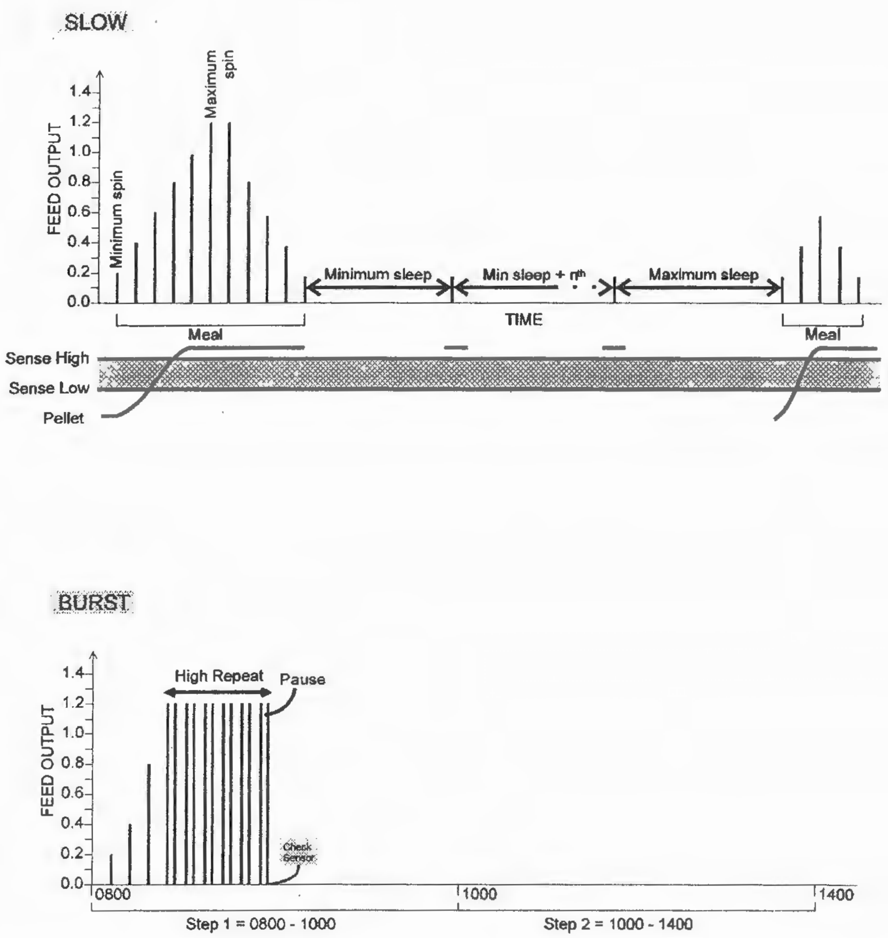


Figure 2. Graphically displaying the operation of the algorithm and the parameters that affect its operation. Burst and slow modes are represented.

System settings

The following tables list the system settings used over the production cycle for Atlantic salmon being fed daily to satiation.

Table 1a. System settings from 5/11/93
Sensor depth=5m, sensetime=30sec, gain=3, pellet size=3mm, sink rate=10cm/sec

	Step 1	Step 2	Step 3
Start	0545	0930	1630
Stop	0930	1630	2030
Mode	burst	slow	burst
Pause	00:30	00.30	00.30
min sleep	2	2	2
max sleep	10	10	10
min feed	0.5	0.5	0.5
max feed	2.5	2.5	2.5
sense low	15	15	15
sense high	15	15	15
high repeat	25	25	25

Table 1b. System settings 8/1/94

Sensor depth=5m, sensetime=30sec, gain=3, pellet size=4mm, sink rate=11cm/sec

	Step 1	Step 2	Step 3
Start	0500	0800	1800
Stop	0800	1800	2115
Mode	burst	slow	burst
Pause	00:30	00.30	00.30
min sleep	2	2	2
max sleep	10	20	10
min feed	0.5	0.5	0.5
max feed	2.5	2.5	2.5
sense low	12	12	12
sense high	12	12	12
high repeat	20	20	20

Table1c. System settings 26/4/94

Sensor depth=6m, sensetime=30sec, gain=2, pellet size=6.5mm, sink rate=13cm/sec

	Step 1	Step 2	Step 3
Start	0700	0745	1715
Stop	0745	1715	1745
Mode	slow	slow	burst
Pause	00:30	00.30	00.30
min sleep	5	10	5
max sleep	20	60	20
min feed	0.4	0.4	0.4
max feed	2.0	2.0	2.0
sense low	3	2	3
sense high	3	2	3
high repeat	20	20	20

Table 1d. System settings 1/7/94

Sensor depth=6m, sensetime=30sec, gain=3, pellet size=8mm, sink rate=15cm/sec

	Step 1	Step 2	Step 3
Start	0730	0815	1630
Stop	0815	1630	1700
Mode	slow	slow	burst
Pause	00:30	00.30	00.30
min sleep	5	10	5
max sleep	20	60	20
min feed	0.4	0.4	0.4
max feed	2.0	2.0	2.0

sense low	3	2	3
sense high	3	2	3
high repeat	20	20	20

Note: The settings established on 1.7.94 were retained until December, except for changes to the start and stop times to reflect increasing day length. One month prior to harvest fish were placed on a restricted intake (maintenance ration) before being starved for one week.

Fish and cages

Three cages were selected from a pool of thirty cages. These cages utilised algorithm settings that regularly tested the fish over the day to determine appetite levels. The aim was to feed these groups daily to satiation which necessitated a certain level of appetite testing which on occasions may have resulted in waste. Future calibration of the system was used to correct for this situation. The other cages had defined periods in which the algorithm was allowed to operate. Feeding patterns and feed intake was recorded daily over the production cycle. Initial weights ranged from 60-65gms. Adaptive feeders were used to feed the salmon to satiation daily. Feeding pattern data was routinely collected from the cages and down loaded onto an IBM compatible PC.

Environmental recordings

A floating pontoon anchored from two points (fixed in a NW-SE direction) supported an array of probes. An Oxyguard system measured water temperature (°C) and oxygen (ppm) at 1m and 5m. A Datatakker data collection unit was connected to an atmospheric temperature gauge, one LI-COR surface light sensor (LI-190SA) quantum sensor), two underwater light sensors (LI-192SA underwater quantum sensor) with the underwater sensors positioned at 1m and 5m beneath the surface. A General Oceanics Inc. flowmeter (2031H) with a low threshold rotor (>2cmsec-1) was also attached to the Datatakker and positioned at 3m beneath the surface of the water. Pre-amplification circuitry was linked to the system to bolster the signal level under low light conditions. A Dataflow recording system was used to measure tide height, temperature(°C)(1m&5m), salinity(ppt)(1m&5m), wind speed and direction. The equipment was regularly cleaned and re-calibrated.

Secchi depth (m) was recorded during July/August 1994 to allow comparison to light levels. As secchi disk is an easier tool to use routinely on a fish compared to the maintenance required for light meters. Sea height and cloud cover were also recorded for a short period July-Sept 1994 to demonstrate whether a correlation existed with feed intake. Weather information was also collected from Bruny Island lighthouse on a three hourly basis over the period of the trial. Information included barometric pressure, rainfall, windspeed and direction.

Events on the farm

When currents were judged too high for successful operation of the Adaptive feeder the staff made a decision to turn the system off. This was logged and when conditions returned to low flow rates the system was re-instated. Feeding also becameerratic when dolphins or seals were near the cages. These periods were eliminated from the normal data set.

Daily sampling regime
Light levels and currents were measured every two minutes, commencing just before dawn and just after dusk. This regime coincided with the minimum duration between feeding events, as determined by the feeding algorithm. Environmental data was collected continuously beginning in July 1994 with several breaks due to equipment failure. Feeding pattern data was collected form Jan 1994 through to July 1995. Water temperature, oxygen, salinity and tide height were recorded continuously every 10 minutes over the day. Data was presented to view long term seasonal trends and in more detail with daily trends and the influence of environmental factors.

Analysis
Analysis to date has consisted of evaluation of the broad patterns, development of an understanding of the data and its relationship to behavioural, physiological and environmental factors. The next part of the project, which forms part of a PhD will develop, using multi variate statistical techniques, a model, to broadly define and predict feed intake against environmental factors. Physiological and behavioural factors will also be considered.

The *relative feed intake* was the quarter hourly intake as a percentage of the total daily intake or summed total daily feed intake of grouped days.

The *efficiency index* was a measure of the number of pellets counted per kg delivered per time. Subsequent analysis will standardise this value into the kg of feed measured (sensor) per kg delivered (feed distributor) per time. The index was a measure of the relative 'efficiency' of the system under a constant set of system parameters, including, spin time, sensor depth, sensitivity. Changes in the index over time highlighted variation due to behavioural, biomass or seasonal factors, when other variables such as pellet size and system parameters remained constant. The effect of these variables on the efficiency index was investigated in a following section.

Results and Discussion

Seasonal and circa annual feeding patterns
The life cycle of Atlantic salmon is well documented (Thorpe, 1988). In this study salmon were grown in polar circle cages (circumference 65m), at stocking densities increasing from 4-10kgm-3. Salmon were fed a steam pressed diet containing 18% oil over the period of the study. In late 1995 higher energy extruded diets started to be used widely in the Tasmanian salmonid industry.

Figure 3 displays the feeding pattern of Atlantic salmon in Tasmania in 1993/94. Salmon were introduced as spring smolt in 1993 at 60gms and grown through to harvest (6.4kg) in December 1994. Data was taken from one 65m polar circle cage.

No harvesting occurred on this cage prior to the December harvest. The Adaptive feeding system was introduced to the fish in November 1993. Juvenile salmon (700gms) in summer tended to feed throughout the day in small meals with a significant meal just after dawn (Figure 3), a similar pattern was also observed on young Atlantic salmon (150-600gms) in Scotland (Blyth et.al., unpub. data). By the end of summer, as fish reached 2kg, feeding shifted to more pronounced morning and evening feed, with several secondary peaks during the day. By early autumn, another meal developed in mid morning and this pattern carried through winter, finally diminishing in spring. This surge in feed intake of Atlantic salmon in autumn has been reported in Scotland (Kadri, 1995) and been linked to early onset of gonad development and muscle/body store deposition. However, Scottish salmon during winter, unlike Tasmanian fish, experience shorter day length and lower water temperatures, resulting in one meal per day taken on average (Smith et al., 1993,). Tasmanian salmon mature after one sea winter which appears to be due to a combination of the genetic line, photoperiod and water temperature.

The three feeding peaks from autumn to spring may represent fish groups differentiated by size or hierarchical factors. Subordinates in the group may take a greater proportion of their daily intake in the second meal. The second meal could be implicated in producing a low coefficient of variation for weight at harvest (15.6%). Winter temperatures in 1994 of 11°C in combination with a winter solstice day length of 10 hours (twilight included) provided good conditions for high feed intake, as reflected by the third meal. By late spring feeding still occurred in the morning and evening but became increasingly spread throughout the day. It is interesting to note another small meal 'budding' from the second meal of the day in winter and shifting gradually later into the day, before merging with the evening meal in late spring. This may represent a third sub-group of fish within the main group and raises the possibility of several categories of dominance/subordination.

Intake increased dramatically in spring as fish prepared body reserves for maturation, a phenomenon noted by others (Kadri, 1995). By summer feeding occurred in two distinct meals, early morning and late in the day. Anorexia, as noted by Kadri, 1995 for maturing Scottish salmon in summer was noted in this study as fish were starved then harvested in December, possibly too early to observe this effect. High summer water temperatures at certain sites, places this species on the edge of its optimal temperature range (18°C+) in Tasmania (Cameron, 1989).

The efficiency index graphs (Figure 4 and 6) demonstrate broad patterns created by combination of factors. Pellet size, output per delivery, sensor depth and sensitivity, all factors that will be corrected for, in order observe more clearly behavioural effects on feed intake and their relationship to the algorithm.

Data from 1995 (Figure 5 and 6) showed circa annual variation possibly due to changes in environmental conditions and/or cage size effects. Salmon during winter 1995 from the 1994 smolt intake, did not display a significant late morning feed. Future research should investigate this effect to determine whether environmental or biotic factors influenced this pattern. Lower stocking densities initially in an 80m circumference polar circle maybe implicated, as stocking density will affect fish behaviour. As fish tag technology improves and tags reduce in size, then the studies in this area will be possible. Data collected over many years will allow longer term prediction of feeding patterns and intake, useful information for global and farm management.

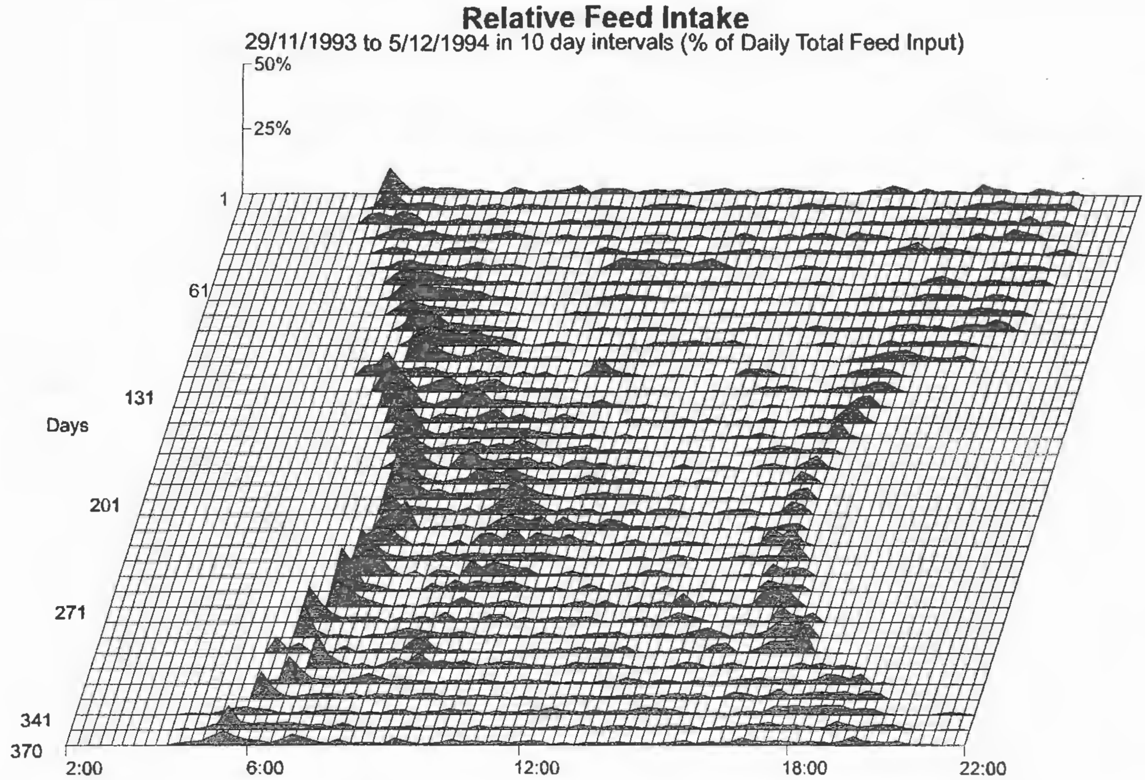


Figure 3. The relative feed intake of Atlantic salmon (500-6400gms) at Huon Atlantic salmon expressed as a percentage of total grouped (10 day intervals) daily intake. Fish are from 1993 spring smolt intake. Note: uncorrected for daylight saving.

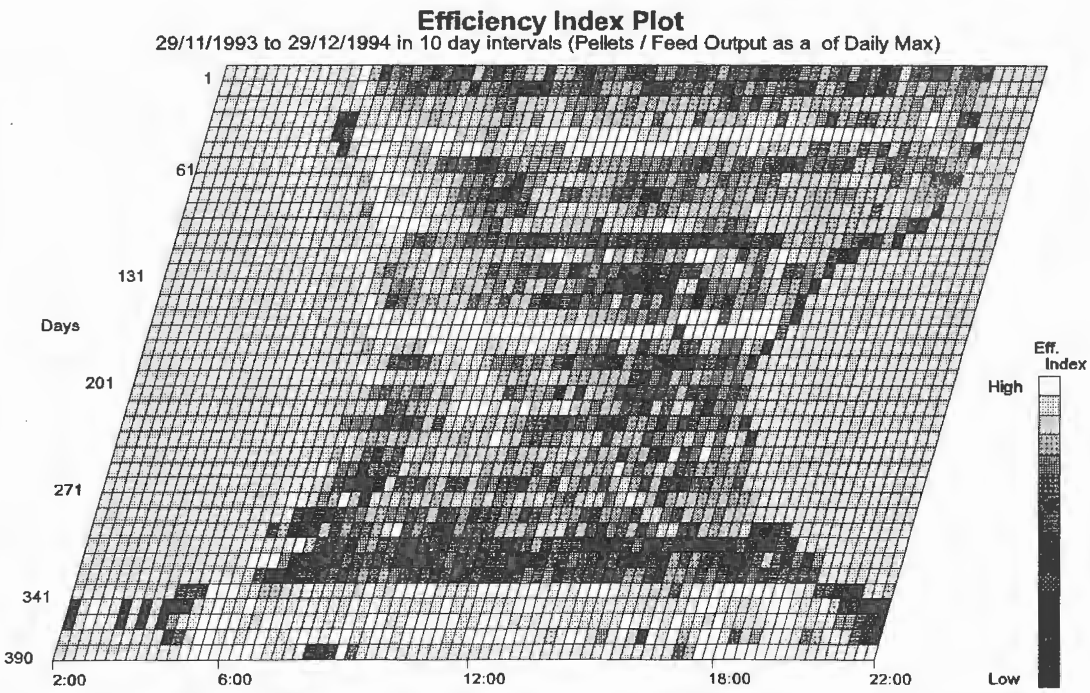


Figure 4. The relative efficiency index of Atlantic salmon (500-6400gms) at Huon Atlantic salmon expressed as a percentage of total grouped, 10 day maximum. Fish were from 1993 spring smolt intake. Note: uncorrected for daylight saving.

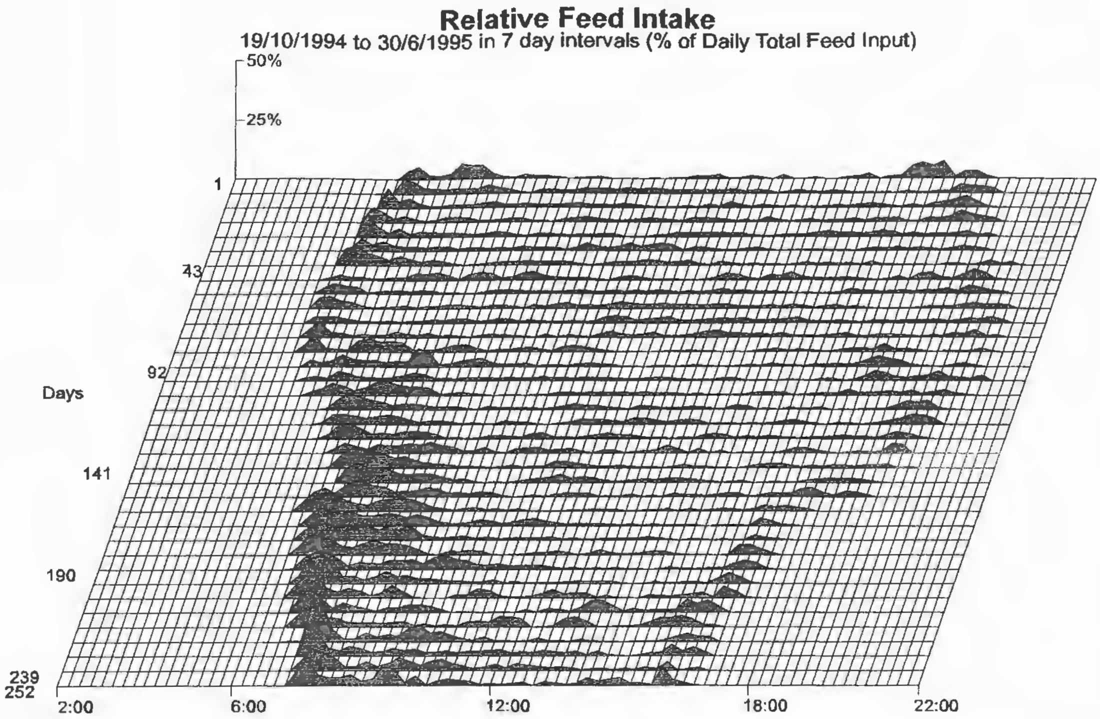


Figure 5. The relative feed intake of Atlantic salmon, 1994 spring smolt at Huon Atlantic salmon expressed as a percentage of total grouped (7 day intervals) daily intake. Note: uncorrected for daylight saving.

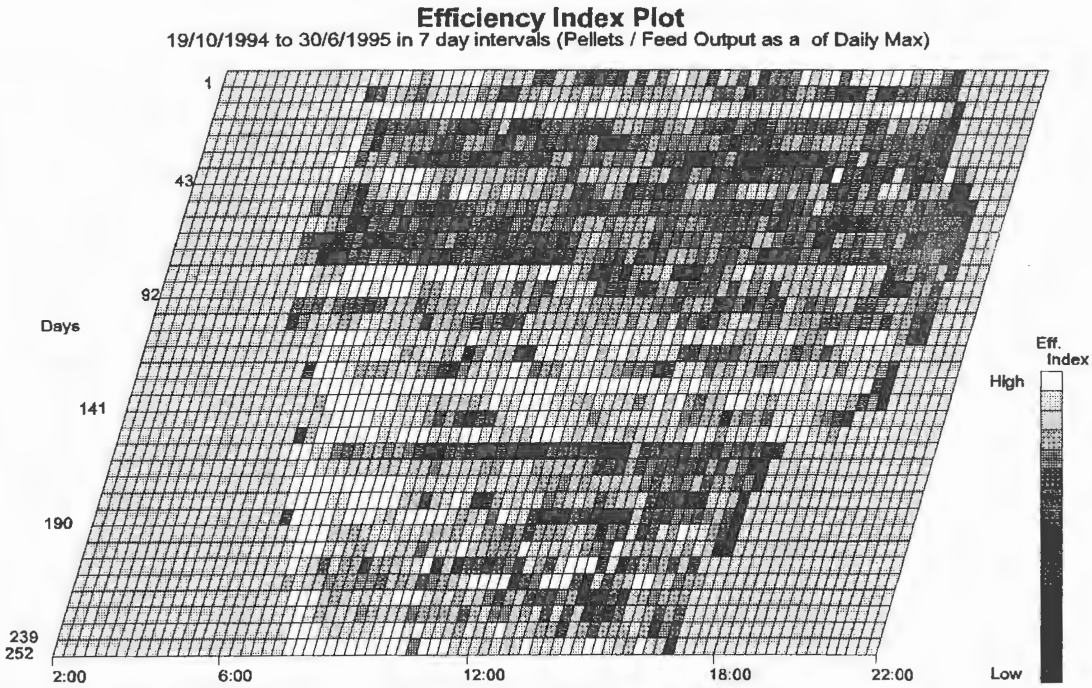


Figure 6. The relative efficiency index of Atlantic salmon 1994 spring smolt at Huon Atlantic salmon expressed as a percentage of total grouped, 7 day maximum. Fish were from 1993 spring smolt intake. Note: uncorrected for daylight saving.

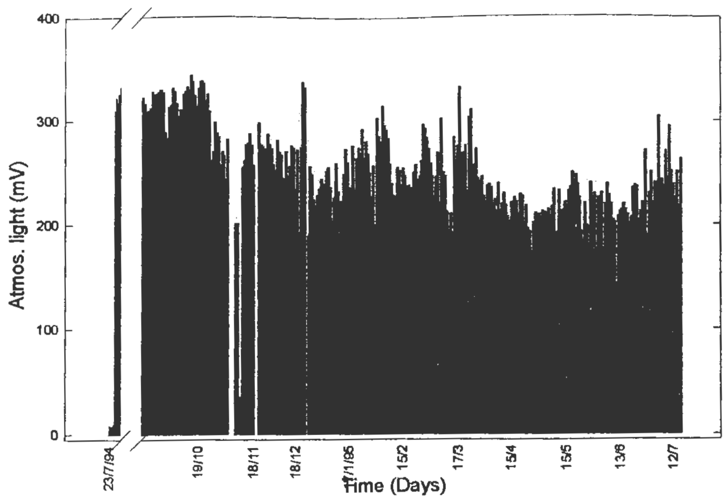


Figure 7. Mean daily atmospheric light levels (mV) at 2m above the sea surface.

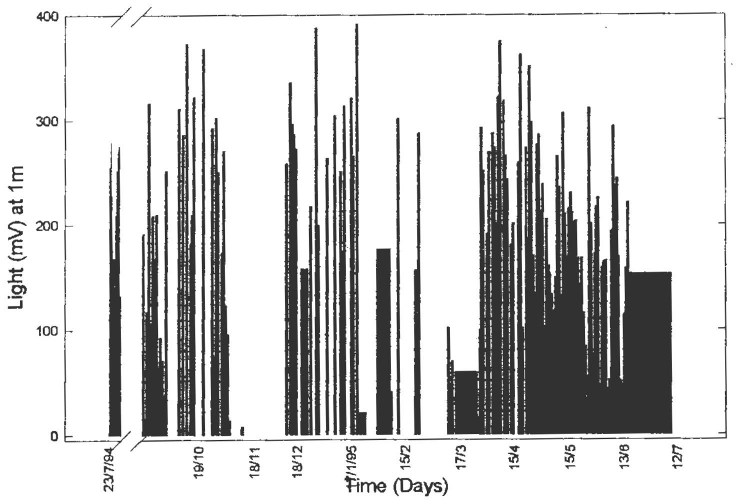


Figure 8. Mean daily atmospheric light levels (mV) at 1m below the sea surface.

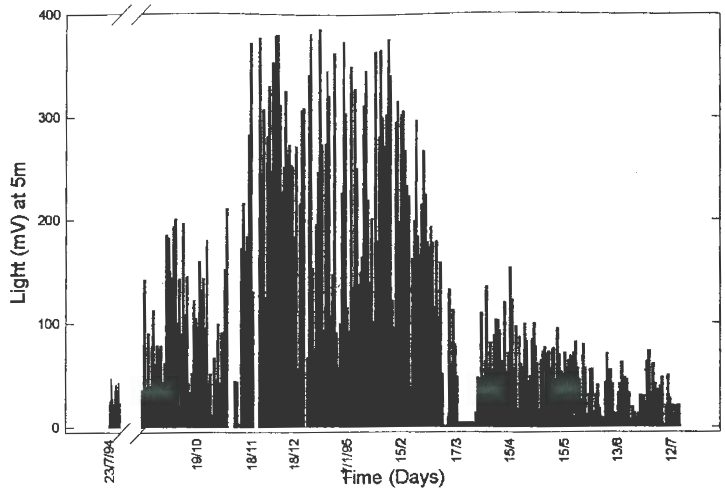


Figure 9. Mean daily atmospheric light levels (mV) at 5m below the sea surface.

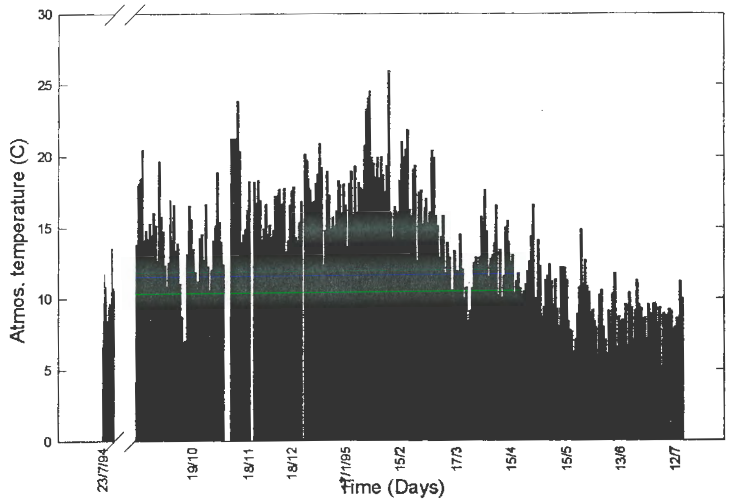


Figure 10. Mean atmospheric temperature (°C) at 1m above sea surface.

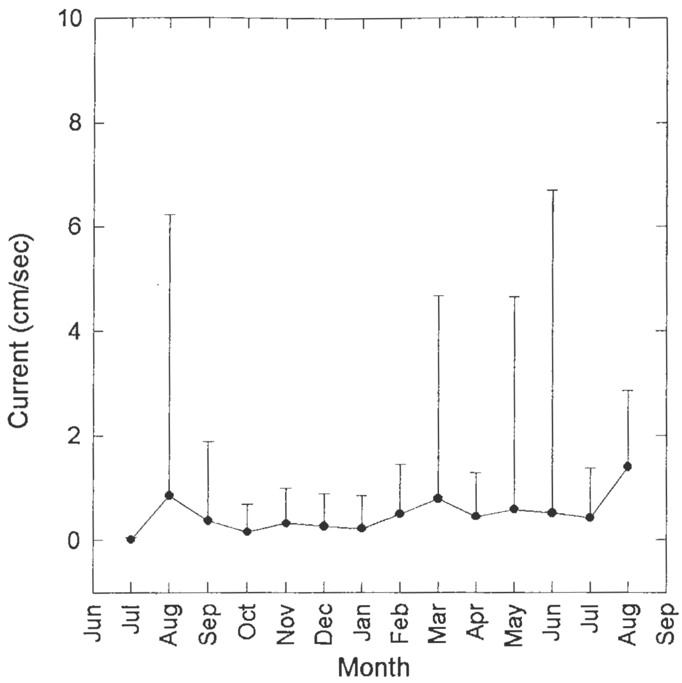


Figure 11. Mean monthly water current (cm/sec) at 3m below the sea surface (μ±SD), from Jul 1993 to August 1994.

Summary Table

Table 2. Table showing the number of meals per day in relation to season, water temperature and fish size. *S. salar* from introduction as spring smolts.

Species	**Location**	**Fish size (gms)**	**Season**	**Temperature (°C)**	**Meals per day**
S.salar	T	60-700	spring	12.1	6+
	T	700-2000	summer	17.3	3+
	T	2000-3200	autumn	15.4	3
	T	3200-4600	winter	11.1	2-3
	T	4600-6400	spring/sum	12.2	2-3

Production performance

The growth of Atlantic salmon has steadily improved over time on this farm (Figure 12). Feeding practice prior to introduction of the Adaptive feeding system involved the use of automatic feeders in combination with hand feeding and almost constant surface observation of the fish. Feeding occurred continually throughout day light hours for juveniles in spring and summer, graduating to meal feeding for larger fish. Feed manufacturer tables were not used, as the strategy employed was one of daily feeding to satiation, ie; until no feeding activity was observed. Historical records provided an indicator of expected daily ration. Adaptive feeding systems were deployed broadly onto the farm in the summer of 1993, when a divergence in growth rate occurred. Results from trials in Scotland are showing similar trends. Fish maintained this difference through to harvest. The growth of salmon 94' was greater than previous years, due to optimisation of system parameters and improvements in husbandry practice. The cumulative feed conversion ratio in 1993 ranged from 1.4-1.6:1 in 1993 (low energy steam pellet 18-20%), a 5% increase on the previous year. Corrections made to the data set based on calibration of the equipment has improved this value by elimination of sample or test outputs of feed (unpub. data). The introduction of a higher energy extruded feed in 1995 and further system settings optimisation has seen further gains in FCR.

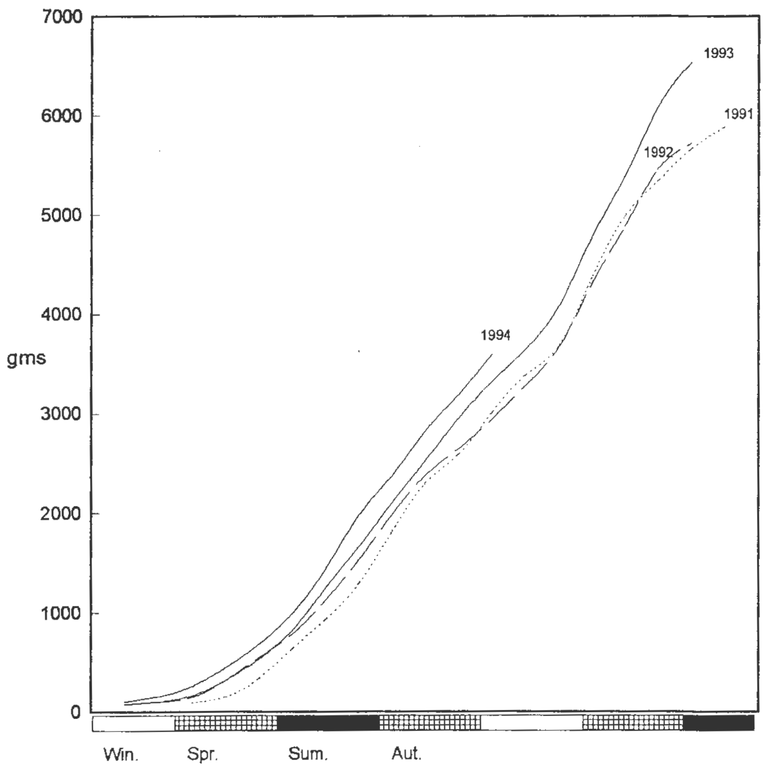


Figure 12. Average monthly weight versus year for smolt intake (1991-1994), at Hideaway Bay.

Diurnal Patterns

An example of diurnal patterns are displayed in figure 13a-d. The rate of change of feed intake will be compared to the rate of change in light levels and water temperature. This factor will also take into consideration the size of the first meal as a percentage of the daily. The analysis will be repeated at each season in order to cover all fish sizes and seasonal effects.

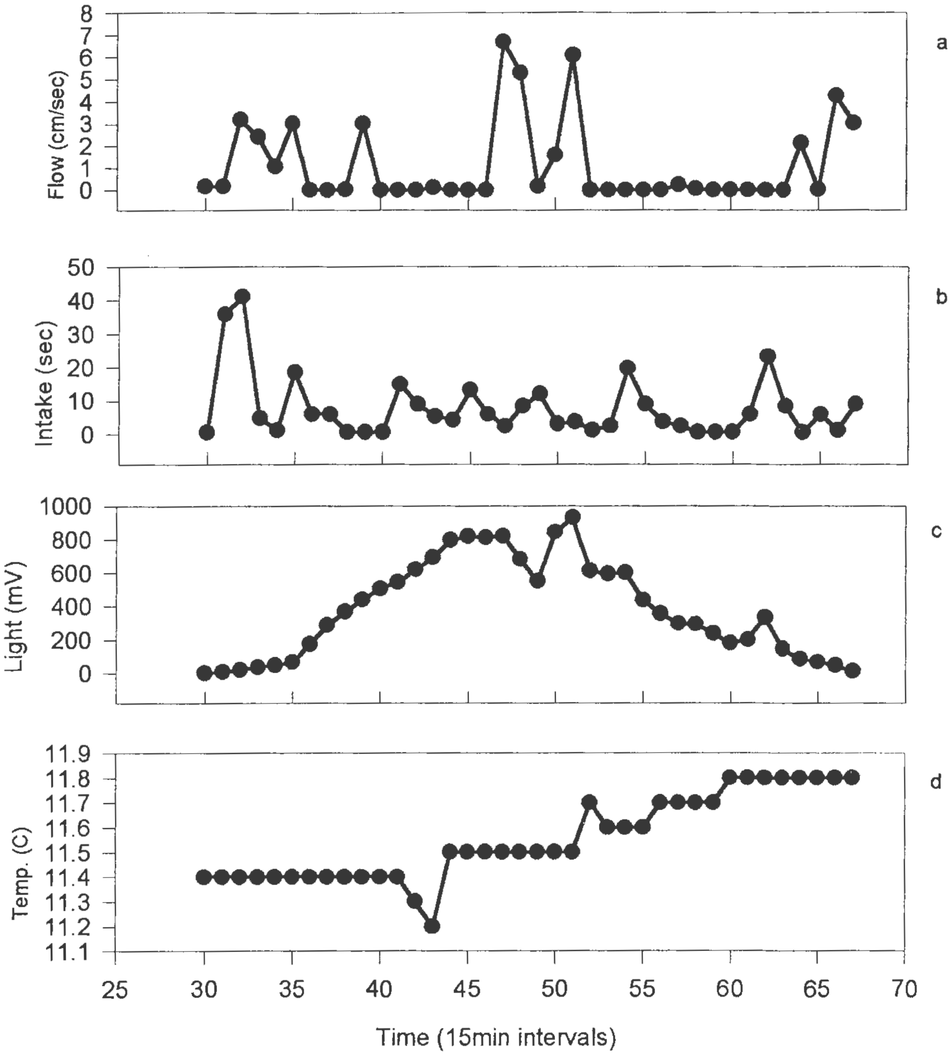


Figure 13. The diurnal water velocity (a), feed intake (b), light level (1m) and water temperature (°C) on 10/6/94, winter at Hideaway Bay.

TABLE 1: A full list of potential parameters that could be monitored in relation to Experiments 1, 2 & 5 - selected factors were used in the study.

Cause parameters

(i) *Environmental measurements taken daily (uncontrolled)*
light
temperature
salinity
oxygen
water clarity (secchi depth)
wind speed
wind direction
wave height
barometric pressure
tide height
current speed
cloud cover

(ii) *Predictable environmental measurements*
lunar phase
daylength

(iii) *Predator disturbance*
dolphins
seals
birds

(iv) *other*
algal blooms
disease (amoebic gill disease)

(v) *controlled procedural effects*
auditory and visual disturbance
-net changing
-cage visitation by boat
-diving- mortality, stock checks
-daily filling of feed hoppers

Response variables

Feed rhythms
* feed intake per 15 minutes
* time between feeding bouts
* duration of feeding bout
* amount taken per bout
* amount taken per day

Swimming speed

TABLE 2: Frequency of sampling for selected parameters

Parameter	*Frequency & position*
Light	2 min, at 1m, 5m & surface as reference
Temperature	10 min, at 1m, 5m & atmospheric
Salinity	10 min, at 1m, 5m
Oxygen	10 min, 1m, 5m
Water clarity	daily, water depth profile - secchi reading
Wind speed	15 min
Wind direction	15 min
Wave height	60 min
Barometric pressure	60 min
Tide height	10 min
Current speed	2 min, 3m
Cloud cover	60 min

Experiment 2

Night Feeding in salmon

Introduction

The purpose of this section was to determine whether salmon of 5kg feed during the night. Research has shown that salmon parr can feed at night under very low light conditions (ie; moon) but that adults do not. This experiment was designed to test whether salmon in Tasmania under full moon conditions fed when water visibility was good.

Methods and Materials

An adaptive feeder was programmed to operate through the night, using settings from the previous day. One test output occurred every 15minutes. Light levels (mV) was measured at the surface, 1m and 5m and current speed was recorded. The experiment was carried out from 18/11/94-22/11/94. The moon was full on 18/11/94 and the evening was cloudless.

Results and Discussion

The data (Figure 1&2) shows that salmon under the low light levels (Figure 3) did not feed during the night over the course of the experiment.

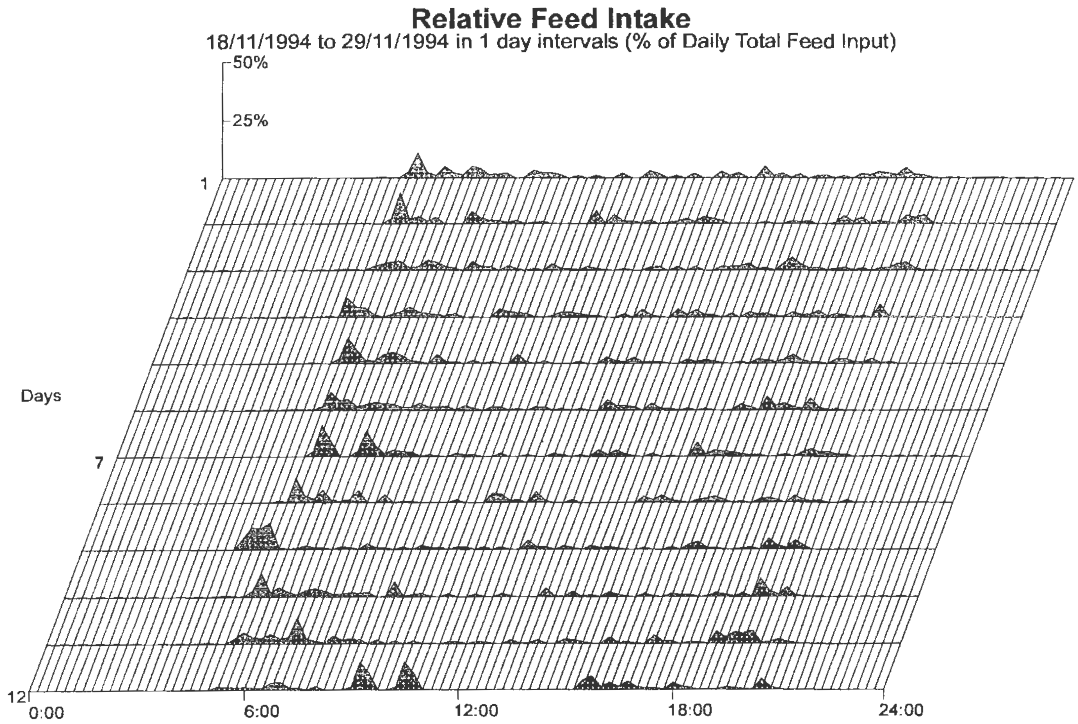


Figure 1. The relative feeding intake of Atlantic salmon at Huon Atlantic salmon expressed as a percentage of total daily intake. Fish were from 1993 spring smolt intake.

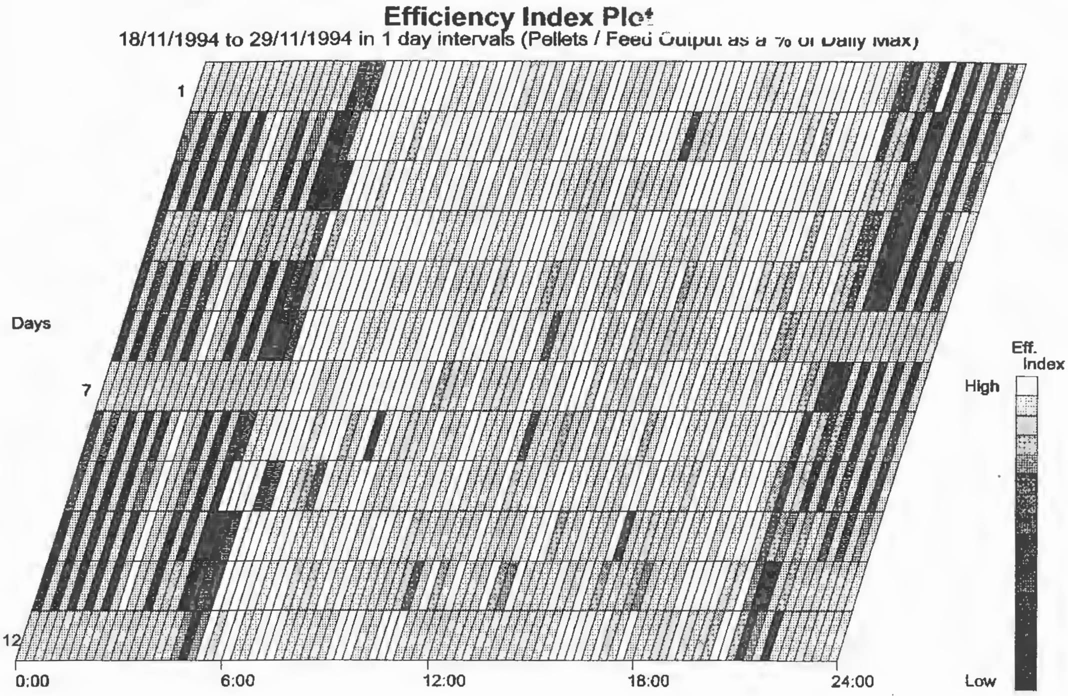


Figure 2. The relative feeding efficiency of Atlantic salmon at Huon Atlantic salmon expressed as a percentage of maximum daily intake. Fish were from 1993 spring smolt intake.

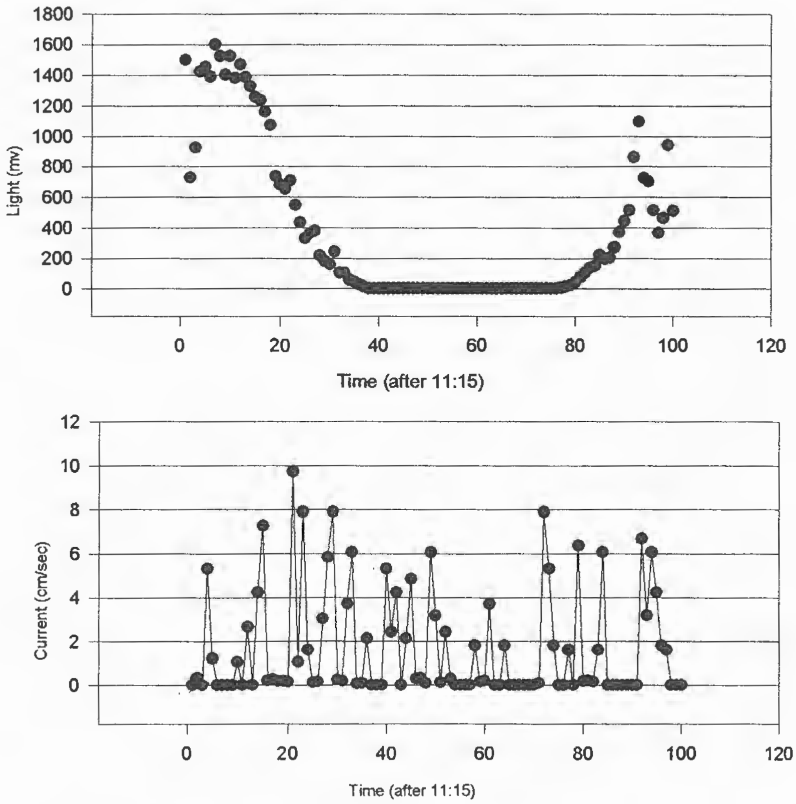


Figure 3. Showing Light levels (mV) at 1m and current speeds during the nightof 18.11.94.

Atlantic salmon are generally regarded as visual feeders, consuming pellets during daylight hours. It has been demonstrated that juvenile Atlantic salmon can feed in darkness (Jorgensen and Jobling, 1992) but appear to require access to the bottom of tanks; the fish probably shift from a visual to an olfactory feeding strategy under these conditions or are relying on a learned response in an enclosed environment. Studies demonstrating feed consumption by parr on moonlit nights have also been undertaken.

The feeding response and associated swimming patterns of large Atlantic salmon in sea cages change quite dramatically around dawn and dusk, with peaks of feeding activity occurring immediately after dawn and immediately before dusk. This suggests that there may be a threshold light intensity below which large salmon are unable to detect pellets. There has been some anecdotal evidence that large salmon do consume pellets at night. Obviously, if this were the case the daily duration during which feed could be offered to the fish could be increased, potentially resulting in increased growth in the fish.

Although feed may be offered over the majority of the day in some northern European countries, this is associated with the long twilight hours in the summer months. Lights have been trialed on some farms but these experiments are usually aimed at controlling maturation rather than increasing feed availability (Marine Harvest, Scotland, pers. comm.).

The results from this study, which was undertaken on moonlit nights to maximise light availability, shows that the feeding efficiency as detected by the adaptive system was very poor. It does not show that pellets were not consumed but indicates that any feeding undertaken at night would be highly inefficient, defeating the aims of the investigation. The approach employed in this study can not demonstrate that the fish do not consume pellets (in absolute terms). Night feeding on salmon sea farms is not considered to be an effective method of improving feed intake and feeding efficiency.

Experiment 3

The effect of pre-set feeding regimes on fish performance - the number of meals per day

Introduction

The aim of this trial was to quantify the impact on salmon growth, feed conversion and size variation of a range of pre-set feeding regimes, under commercial conditions.

Many salmon farmers distribute pellets to the fish on the basis of the feed manufacturer's guide, employees working hours, available settings on automatic feeders or accepted methodology in the industry. The question of the number of meals per day has historically been based on the above factors and has always been a topic of discussion, with trends changing periodically. In the last few years there has been greater emphasis placed on the response of the fish to feed delivery and on the development of feeding systems such as the adaptive feeder and acoustic systems (Bjordal et al., 1993; Juell, 1991) which may monitor the response of the fish and adjust the feed input.

Many autofeeders deliver numerous sub-satiation quantities of feed during the day; the feeder usually activated and de-activated by photo-sensitive cells. Hand delivery may provide numerous meals but is more likely to deliver quantities close to satiation at each delivery in response to the observations of the personnel. In contrast to autofeeders, hand feeding strategies also may be used to deliver only a few meals to satiation. Generally, the number of feeds offered to salmonids under commercial conditions falls in the range 1-6 meals/day to satiation (Talbot, 1994b). The adaptive feeding system challenges these views by delivering the pellets frequently throughout the day to satisfy the needs of the fish. In other words, the fish, not the personnel, determine the delivery.

Preliminary results from Huon Aquaculture prior to this study have indicated that improvements in FCR and growth are significant and are in the order of 5-15%. This experiment was designed to compare the adaptive feeding strategy with one, two, three meals per day. Unfortunately, as the single meal per day was considered a risk to production performance by Huon Aquaculture, it was deleted from the study.

Materials and Methods

Stock movement, history, fish and pre-trial feeding

Atlantic salmon smolt were introduced into the sea at Huon Atlantic Salmon's upper Huon River site, Pillings Bay during September 1993. The smolt originated from the Saltas Wayatinah hatchery and averaged 60-63 g. These smolt were stocked into two 60 m circumference polar circles (cages 14 &15). From release until January 1994 they remained at this site being fed to satiation daily by hoppers controlled by automatic timers (Kemers controllers and Guymac/Huon Atlantic circular feed distributors) in combination with operator supervision. Although satiation feeding was the aim of the feeding strategy, minimisation of waste feed was also an objective. This was achieved by observation of the surface feeding response by the operator and their subsequent adjustment of the automatic controls. However, observation of the feeding behaviour beneath the water was frequently hindered by the tannin discolouration of the water which commonly occurs at this site.

The pens were towed approximately 6.6 km downstream to the Hideaway Bay site on the 16 January 1994, when the fish averaged 390-400 g. Here each cage was split into two cages (60 m circumference polar circles) and on-grown utilising the adaptive feeder systems. These fed to satiation until between 17 - 23 March 1994 when both groups of two cages were mixed and split into three cages of even number, resulting in six cages. The split coincided with freshwater bathing for amoebic gill disease. The fish were fed by adaptive feeders to satiation daily from this time until the commencement of the trial on 4 April 1994.

Equipment and configuration

Six adaptive feeder systems were utilised in this experiment. Each system controlled a single cage (60m polar circle) serviced by two hoppers as detailed above. A pellet sampling cone attached to a pellet sensor was positioned at 5 m beneath the surface of the water under the primary hopper.

The trial protocol

The trial commenced on the 4 April 1994 at which time the fish size was in the range 1.3-1.5 kg. Three duplicate feeding regimes were assigned to the six cages: to satiation all day (1), to satiation over two periods each of a two hourly block per day (2) and to satiation over three periods each of a two hourly block per day (3).

On 20 September 1994 the treatment duplicates were grouped into one 80m circumference polar circle cage. Unfortunately on this day, one replicate from each of treatments 1 and 3 were accidently grouped, effectively eliminating these cages from further analysis. The trial finished on 20 December 1994 when the feeding ceased on all cages which were subsequently harvested during the time period 5-17 January 1995. At harvest, three bins each containing about 80 salmon were selected at the beginning, midway and end of the harvest procedure and fish were individually weighed and measured for fork length with the condition factor being determined from these values. This sampling strategy was designed to eliminatebias caused by uneven size distribution over the harvest period noted from previous harvests. Smaller individuals generally occur earlier in the harvest 'crowd' possibly due to hierarchical effects. Average whole weight was compared to average head on gilled and gutted (HOGG) weight recorded on the processing factory floor to establish loss due to viscera and gills.

Results

The results show there is little difference between salmon fed daily to satiation and those fed in three two hourly time blocks to satiation (Table 3a and b). The group that were fed only twice per day to satiation were slightly smaller than the other groups. The feed conversion ratio and the significance of the group differences for each treatment are currently being analysed.

It appears that the range of restrictive feeding regimes imposed on the fish were not broad enough to establish any clear effects. Preliminary trials indicated that that may have been the case (using hand feeds). The performance of the fish may depend more on the delivery of the pellets to satiation rather than the absolute number of feeding bouts throughout the day (Talbot, 1994b). As all treatments were fed to satiation this may explain the lack of significant differences.

Equally significant though, the dilemma of imposing an experimental regime, that may result in a loss of revenue, on a commercial operation is very real. Future work should consider the effect of feeding to satiation in one single meal a day to determine whether the amount of feed taken per meal increases to compensate for an overall reduction. In addition, the data obtained from the trial was somewhat compromised because two of the cage treatments were accidently mixed, regular sample weight checks in each treatment was not permitted by the company as it potentially interfered with growth and harvest forecasts, and the harvests of the fish from each cage were conducted at different times.

TABLE 3a. Data from the start (4.4.94) and end (5.1.95-17.1.95) of the trial.

Param.		START: WHOLE			END: HOGG	
Treatment	1	2	3	1	2	3
Weight±SD	1.4	1.4	1.35	5.33	5.23	5.27
Length±SD	-	-	-	-	-	-
Cond.±SD	-	-	-	-	-	-
CV (%)	-	-	-	-	-	-
Biomass(t)	5.6	5.6	5.4	-	-	-
no. Fish	3998	4037	3962	-	-	-

TABLE 3b. Sample weights (kg), fork length (cm), condition factor and coefficient of variation between different treatments at harvest.

Param.		END WHOLE	
Treatment	1	2	3
Harvest date (1995)	8.1-13.1	5.1-9.1	13.1.-16.1
Weight±SD	6.02±.939	5.82±.909	6.11±.929
Length±SD	74.78±4.1	74.19±3.8	75.14±3.9
Cond.±SD	1.44±.17	1.42±.12	1.43±.14
CV (%)	15.4	15.6	15.2
sample no.	221	221	222

Experiment 4

The utilisation of electronic tags to monitor behaviour of salmon in relation to environmental parameters.

Protocol of the proposed study

This section of the study could be classed as developmental.

The electronic tags to be used have been developed by CSIRO for Southern Bluefin tuna. The type of tag that was anticipated for use on the salmon would be slightly smaller. Electronic fish tags will be implanted in salmon to monitor depth, temperature and light levels. Three salmon from the cage will be tagged at any one time. A group of pre-harvest salmon will be tagged to monitor the preferential position in the cage and how this relates to all the factors discussed above. Data will be logged continually (every 1 minute for 50 days prior to harvest). The tags will be retrieved from the fish at harvest. The relationship between feeding, light level, depth and temperature will be analysed. The fish will be 'dived on' and observed using the video camera to make sure tags have not adversely affected behaviour.

Results

As outlined in a previous progress report, difficulties were experienced by the manufacturers of the tags to produce one of a suitable size for the salmon. In addition, the circuitry and the pressure transducer needed modification because the depths at which the salmon swam in the cages were much shallower than the depths experienced by tuna in the open ocean.

The internal tags can affect the behaviour of the fish. Preliminary testing to confirm that this is not the case would be a prerequisite for this type of study. Another aspect for future consideration is the ability to recover the tags from the fish because of their cost. Although this may be undertaken at harvest (with the fish being identified with an external mark), it may be desirable to retrieve the fish if its behaviour is being affected, if it contracts a disease, if the tag is not functioning correctly or if the tag needs to be used repetitively on different fish to replicate data. In these instances, frequent recovery would interfere with the performance and behaviour of the all the fish in the cage, something that a commercial farm is reluctant to undertake and something that would compromise the data set.

The behaviour of the fish could be monitored by using an underwater video camera, but searching for a couple of fish amongst a few thousand can prove difficult. Video equipment has been used by the investigators to observe fish behaviour in the cages.

With all these considerations in mind, it was suggested that the significance of the data obtained through the tagging system may be obscured by the problems associated with its use. Although investigative work was undertaken on this topic, no field data was obtained.

Experiment 5

The effect of specific farm procedures on the feeding behaviour of the fish

Introduction

The aim of this work was to analyse farm records to determine the effect of farm procedural factors on the feed intake of the salmon. Three main factors were considered: grading, splitting of fish batches, net changing and fish handling.

Materials and Methods

Pre-treatment feed rates were compared to post-treatment feed rates to establish the short term effect on feeding. The feeding pattern data recorded by the adaptive system is used to detect visually in the first instance any gross changes to the daily feed intake patterns. Originally, this experiment also incorporated a hydrophone which could be used to monitor underwater noises and disturbances (e.g. boats) and how these disturbances influenced the feeding behaviour. Unfortunately, the hydrophone was not available as planned and this component could not be incorporated in the study.

Results

Initial assessment of the data indicated that changes in feeding patterns around farm management activities were observed but were difficult to analyse because of the daily variation in feed intake and because of some background "noise" that is evident in the data. This information will be analysed further once the software to obtain better resolution in the data, is completed.

Experiment 6
Calibration of the feeding system

Introduction

The purpose of this experiment was to calibrate the feeding system to determine the absolute feed waste under different adaptive feeder settings and with different feeding regimes. Feed waste can then be compared with the feed input to establish actual feed eaten hence actual feed conversion efficiency achievable with Gibson's steamed pellet. At present, feed conversion is calculated on feed input and not feed ingested.

This section of the study was designed to answer the following:

The effect of the pellet sensitivity function on absolute waste.
The effect of the sampling cone depth on absolute waste.
The effect of feeding regime on absolute waste.
Did the absolute waste vary between feeding periods and less active feeding periods?

Materials and Methods

Equipment and protocol
A large underwater collection cone was built for this purpose. The cone was 9m deep, had a 60m circumference and was connected to a 2.5" pipe attached to an airlift system to return waste feed to the surface. The system was designed and based on similar systems being used overseas. Two groups of salmon were assessed, an adult cage (6-7 kg av. wt., and a cage of juveniles (0.8-1kg av. wt). Commercial quantities of salmon were used. Over the trial water currents were continually monitored and if threshold exceeded a critical level the data was ignored from that time period and the experiment was extended so as to elminate current as a variable. This work took six weeks to set up and four weeks to run the trial.

Experiment 1: The effect of pellet sensitivity on absolute waste
Pellet sensitivity is a programmable parameter of the adaptive feeding system that sets a threshold of pellets to be counted before the algorithm makes an adjustment to increase or decrease feeding. This experiment was designed to test the effect of different sensitivity values on the resultant absolute waste. Three pellet sensitivity values were set (1,7,14) to establish the relationship between waste and this variable. The fish were fed daily to satiation by the adaptive feeder. Every 15 minutes during daylight hours waste feed collected in the bottom of the cone was pumped to the

surface and counted. This was repeated every day for three days, changing the pellet sensitivity value on each day (1,7,14) to establish the effect of this variable.

Using feeding pattern data the day was defined into periods of feeding, low feeding and no feeding to determine waste from the feeder during each period.

Experiment 2: The effect of cone depth on absolute waste

The above experiment was repeated for the sensor cone placed at 7 metres beneath the hopper utilizing the same set of sensitivity values.

Experiment 3: The effect of feeding regime on absolute waste

The absolute waste was determined on each feeding regime (all day satiation feeding, twice daily satiation feeding in two distinct periods and daily satiation feeding in three distinct periods). The settings used in the restricted feeding trial ie; cone depth of 5m was utilized. This experiment was run over 1995 on salmon fed under the above regimes.

Results

All data in this experiment is currently being summarised and used to adjust existing feed intake levels. Details of this experiment will be included in the supplement outlined below.

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7. General Discussion: Outcomes v. Objectives

This study is the first world-wide to attempt to correlate environmental and feeding pattern data in the manner that has been described in the experiments. The feeding technology developed by Aquasmart and used here as a tool to record feed intake in salmon is unique and is being sourced by farms and research establishments around the world to undertake studies such as this in their locations on salmon and other species of finfish. In that sense, the work presented in this report is at the cutting-edge of feeding technology. It has also, as a consequence, suffered from the need to develop new techniques within the group to analyse the information. This, unfortunately, has produced delays in analysing all of the information collected.

Although all of the four objectives have been addressed, only the tagging experiments failed to be undertaken because of the problems outlined above. The remaining 5 experiments addressing the other 3 objectives have been undertaken in the field but results from the data will continue to be extracted as analytical techniques are developed.

An enormous amount of data was collected during the study due to the nature of the environmental and feeding systems which recorded information every 1-60 minutes (depending on variable) intermittently over an 18 month period. From this total data set, missing or non-usable data needed to be extracted and discarded so that anomalies are not produced. The data also required summarising and visualising both prepared by specialised software which was developed by Aquasmart Pty Ltd. or which is available in multivariate statistical packages.

The results presented in this report are as collected and analysed to date. The work forms part of a PhD study (Mr Peter Blyth) which is being compiled at present and which will be submitted mid-1996. Some of the more advanced analytical techniques are still being developed, as little technology of this type is available for general use. The additional results will be compiled into a supplement which will be forwarded to the FRDC at the time of the thesis submission. Topics to be included in the supplement include:

(i) More precisely defined correlations between feeding behaviour and environmental factors in Experiment 1. Computer software is being written to extract data from the dataloggers in a form that can be utilised in conjunction with the computer formatted feeding patterns. Analysis to this level of resolution has not been undertaken in any previous feeding study worldwide.

(ii) Feed conversion efficiency in the pre-set feeding regimes in Experiment 3.

(iii) More detailed effect of farm activity of feed behaviour in Experiment 5.

(iv) Calibration data from Experiment 6.

One issue that has surfaced continually throughout this project, is the "conflict' between experimental design and farm operations when undertaking trials on commercial farms. On one hand, the scale of operation when using production cages on commercial sites is very realistic; the results should give a true indication of the events that are occurring. On the other hand, however, the trials may be compromised because the economic interests of the farm inevitably take precedent and experimental designs may change at short notice, compromising the aim of the project. This is not a criticism of the growers but is a side-effect of the situation.

8. Implications and recommendations - costs and benefits - future research needs

Grower Benefits

Growers within the Tasmanian salmon industry will benefit directly from the research through an improvement in the understanding of the environmental factors which influence or are associated with the feeding patterns of Atlantic salmon in seacages, without even necessarily installing AquaSmart adaptive systems. The findings will more specifically benefit Huon Aquaculture as the trials have been undertaken on this site. Some companies may not utilise adaptive feeders on their sites because of preferences for other feeding methods, either because of the type of site or because of the wish to use personnel operated equipment rather than "high-tech" systems. Even so, these growers may utilise the data from this trial and adapt it to better use their own methods. As a general example, personnel operating blow feeders may pay particular attention to the first couple of hours post-dawn and pre-dusk to distribute feed rather than evenly throughout the day.

There have been two streams of research with regard to the adaptive feeding system: the development of the feeder technology (funded by Aquasmart Pty Ltd and other grants) and the use of this technology as a tool to better understand the feeding requirements of the salmon (funded by previous grants and this FRDC grant). The Tasmanian salmon industry currently spends in the vicinity of $9 million per annum on fish feed. Estimates of up to 20 % potential savings on operating costs have been proposed within the industry by implementing both developmental streams outlined above.

Environmental Impacts

In addition to the cost benefits and improvements in fish performance, the farms also may reduce the environmental impacts of feed wastage on the farms, in turn improving the sustainability of production on the lease sites.

Other Finfish Species

Although this program has concentrated on refining the performance of the established salmon seacage industry, the techniques developed could also be used as a basis on which to develop programs to better ascertain the suitability of flounder, striped trumpeter and morwong to seacage culture in Tasmania by determining associated feeding patterns and feed wastage. It also would be useful to the tropical barramundi industry and to the warm temperate species being developed: snapper and mulloway.

As it is probable that the flounder developments will be based on tank culture, it would be beneficial to adapt the technology to the outlets of tank systems. Discussions at present indicate that a joint research and development program between Aquasmart and the Japanese International Fisheries and Aquaculture Society (JIFAS) is likely to start within the next couple of months.

Preliminary trials by the company have shown that it is possible to use the system in barramundi pond culture. Developments in this direction would also be applicable to the silver perch trials.

Overseas Interest

Considerable interest in the feeder hardware and its uses has come from overseas countries such as Norway, U.K., Canada, Japan, New Zealand where they wish to apply the technology to Atlantic salmon, Pacific salmon, red sea bream, yellowtail and other marine fish culture systems. Although the developemental work and preliminary scientific trialling, (as part of this FRDC grant and other grants) has been undertaken in Tasmania, with this level of interest from overseas, the scale of their aquaculture industries and the size of the grants that these organisations have access to, it is realistic to suggest that most future work using the feeder system as a farm and research tool will be undertaken outside of Australia. This does not mean however that valuable work concentrating on the feeding behaviour of our species under our conditions cannot continue, particularly if interest from industry (and to a lesser extent grant bodies) improves and continues.

Further Testing and Analysis

As the adaptive system is currently limited to sites with reasonably low current flows, more detailed trialling on the sensitivity of the cone/sensor under various flows would identify the limits of its use and potential system modifications that could be made to provide more confidence for its use over a greater range of sites.

The results of this study have at this stage, crudely examined relationships between specific environmental conditions and feeding pattern data. The amount of information in such a data set is considerable. No other study worldwide has been found which attempts to tackle this issue in such detail, and consequently most of the analytical work applied to this program is new and has required software to be written for it, not only to analyse the data but to also extract it from the dataloggers and summarise it in a usable form. It is for this reason that some of the interpretation of the data still needs to be undertaken to obtain more resolution on identifying the intricacies of these environmental influences.

PhD Study

In addition to the benefits to the growers, the techniques used in, and the results from, this project will benefit Mr Peter Blyth in his PhD studies. FRDC will be acknowledged in all relevant work resulting from the study: in the thesis and resultant scientific papers.

As the results will be published, the technology developed by Aquasmart and used in such an experimental manner will to some extent assist the company in its promotion of the equipment by extolling the benefits of its research applications.

9. Description of the Intellectual Property

The results presented in this report are as collected and analysed to date. The work forms part of a PhD study (Mr Peter Blyth) which is being compiled at present and which will be submitted mid-1996. The additional results (outlined above) will be compiled into a supplement which will be forwarded to the FRDC at the time of the thesis submission.

It is anticipated that approximately 2-3 papers referring to this work and acknowledging the contribution of the FRDC and participant companies and organisations will be submitted to refereed scientific journals in 1996 for publication.

It is important to note that the development of the hardware (including the sensor) and the software used to operate the hardware, had been developed prior to this grant. It is also worth noting that preliminary information on feeding patterns had been collected and published, by the principle investigator and participants, prior to the commencement of this program. All promotional work for the sale of the technology by JonJo Pty Ltd, Integra Systems and/or AquaSmart has been undertaken separately to this program.

10. Acknowledgements

I would like to thank the Tasmanian Fishing Research Advisory Board (TasFRAB) and the Australian Fishing Reseach and Development Corporation (FRDC) for funding this study and the significant "in kind" contribution of cages, fish, personnel, boats, equipment, adaptive feeder systems and software made by Huon Aquaculture and AquaSmart (JonJo Pty Ltd, Integra Systems). Thanks also goes to Saltas for their willingness to assist with the initial experimental design and use of the underwater video equipment and to the University of Tasmania for the administration associated with the grant.

11. Appendix

Copies of papers of direct relevance to this program:

a. Blyth, P.J., Purser, G.J. and Russell, J.F. 1996. Progress in fish production technology and strategies: with emphasis on feeding. Paper submitted and presented at "A new paradigm for Aquaculture", International Conference, Japan Aquaculture Society, Kobe, Japan, February, 1996.

b. Purser, J. 1995. "Smart" feeding systems. Austasia Aquaculture, 9(3):48-49.

c. Blyth, P. 1994. Atlantic salmon feeding behaviour research. Reports from the Saltas 1993-94 Research and Development Programme, p199-206.

Progress in fish production technology and strategies: with emphasis on feeding

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Abstract

The Australian aquaculture industry in 1994/95 was worth about AU$419 million, and grows eleven main species. Significant research effort has been focused on the replacement of fish meal protein, for alternative proteins, more readily available within the country. Considerable research has been directed to techniques for the rearing of marine fish larvae and the adaptation of grow out technology to suit local conditions. Feed distribution technology is also an area receiving attention. The increasing cost of feed, the desire to improve husbandry techniques and a concern for the environment has prompted research into feed management and technology, particularly in the salmonid industry. Feed distribution technology using an underwater sensor with a 'feedback' algorithm was used to grow fish efficiently, displaying significant improvement over historical values. The relationship between fish behaviour/biology/feeding&activity rhythms is discussed in relation to the requirements for optimal growth and feed conversion of cultured fish. Three species were considered (*S.salar, O. tshawytscha and L. calcarifer*) and feeding patterns were demonstrated to relate to size, photoperiod, temperature and. discussed in respect to fish hierarchies.

Overview of Australian Aquaculture

The Australian aquaculture industry on world standards is quite small but is expanding. The value of the industry (not including aquarium fish or hatchery production value) has increased from AU$255 million in 1992/3 to about AU$318 million in 1993/4 (ABARE, 1994) and AU$419 million in 1994/5 (ABARE, 1995; D. O'Sullivan, pers. com.). The major groups are pearl oysters ($206 m), edible oysters (9,000 tonne, $45m), Atlantic salmon (5,000 tonne, $67 m), trout (4,400 tonne, $39 m), tuna (1,300 tonne, $40 m) and prawns (1,600 tonne, $28 m). The major species being produced commercially include pearl oysters (*Pinctada maxima*), Pacific oysters (*Crassostrea gigas*), Sydney Rock oysters (*Saccorestrea commercialis*), mussels (*Mytilus edulis planulatus*), Atlantic salmon (*Salmo salar*), rainbow trout (*Oncorhynchus mykiss*), barramundi (*Lates calcarifer*), southern blue-fin tuna (*Thunnus macoyii*), prawns (*Penaeus monodon, P. japonicus*), and yabby (*Cherax destructor*).

In addition to these species, a number are also at the small scale production or research level: greenback flounder (*Rhombosolea tapirina*), snapper (*Pagrus auratus*), mulloway (*Argyrosomus hololepidotus*), whiting (*Sillago spp.*), mangrove jack (*Lutjanus argentimaculatus*), golden snapper (*Lutjanus johnii*), striped trumpeter (*Latris lineata*), silver perch (*Bidyanus bidyanus*), mahi mahi (*Coryphaena hippurus*), silver bream (*Acanthopagrus australis*), black bream (*Acanthopagrus butcheri*), abalone (*Haliotus rubra* and *H. laevigata*), clams (*Tridacna spp., Venerupis sp., Katelysia sp.*), scallops (*Pecten fumatus*), redclaw (*Cherax quadricarinatus*), marron (*Cherax tenuimanus*), freshwater shrimp (*Macrobrachium rosenbergii*), crabs (*Portunus pelagicus, Scylla serrata*), eels (*Anguilla spp.*), seaweeds and crocodiles.

Research on these species is funded predominantly by the growers, the Cooperative Research Centre (CRC), the Fishing Research and Development Corporation (FRDC), Australian Research Council (ARC) or by local and state government bodies, and is conducted by numerous research institutions in all states and territories around Australia.

Feed

Formulated feeds play a major role in the culture of the majority of the fish and crustacean species because of the use of a predominantly intensive or semi-intensive approach to their production. An estimated 20,000 tonne of feed is used per annum, of which almost all is in either the steam pressed or extruded pelleted form. Artificial diets are currently being developed for the tuna industry to replace the whole fish feeds (pilchards) presently used. This shift in feed type is significant in improving the feed conversion ratio, growth and reducing the potential environmental impacts of wet feeds. Environmental monitoring programs incorporating water quality, algal concentration and benthic invertebrate sampling have been established in many of the aquaculture industry sectors to minimise impacts and conflicts with other users. Practises such as site fallowing and rotation, reduced densities and more efficient distribution of feed pellets have been incorporated into many farm management procedures, developed in part by the grower wishing to optimise the production of a product and in part by government coastal or inland water management policy.

As feeds and feeding costs account for 30-70% of the operating costs on fish and crustacean farms, research on methods to reduce these costs has been a major focus. Identification of the nutritional requirements of new species being researched, fish meal replacement, feed distribution on the farm and identification of animal feeding behaviour have been targeted. Specifically formulated pellets may be manufactured once the nutritional requirements of "new" species have been identified. Fishmeal is a major source of protein in the formulated feeds. It is, however, expensive and is becoming increasingly more difficult to obtain (Lewis, 1995). In addition, it is considered a potential vector of disease introductions into Australia (Humphrey, 1995). Trials concentrating on salmon, silver perch and barramundi have identified meat meal, lupin meal and wheat gluten meal as the most promising protein replacement products. A significant quantity of pelleted formulations and the development of technologies which can better feed the fish and record the feeding patterns in the cage.

Feed distribution technology

Adaptive feeding system

The Adaptive feeding system (Figure 1) developed by Aquasmart Pty. Ltd. was used to automatically control feed delivery, storing this information to allow the description of the feeding patterns of three important aquaculture species. The system utilised an underwater sensor in combination with a 'feedback' algorithm, to self regulate the rate of feed input based on the detection of small amounts of feed. This matched the actual rate of feed output to that ingested by the fish (Blyth et. al., 1993).

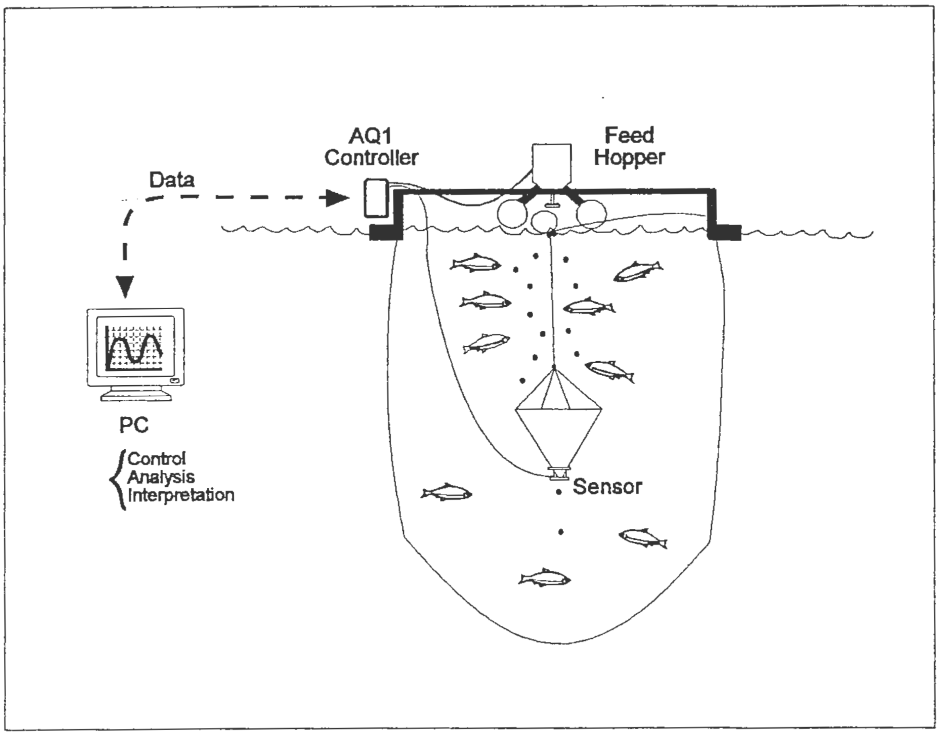

Figure 1. Schematic showing a typical configuration of the Adaptive feeding system in a sea cage.

Feeding Strategies

Feeding practise in aquaculture is often determined by the diurnal routine of farm staff, rather than the feeding preference of the species. Fish show patterns of activity that relate, to evolutionary adaptations for their environment and the behaviour of their prey (Forrester et al,. 1994, Thorpe and Cho, in press). In the wild, prey is often predictable in its distribution and habit, which will tend to reinforce predator activity patterns, although the ability of a predator to deviate from the general pattern will afford the greatest chance of successful foraging (Pitcher, 1986). When species are introduced to aquaculture, gradually the requirement to maintain wild habits diminishes, although broad patterns tend to remain (Thorpe and Cho, in press) and can be recognised when fish are fed to satiation. The Adaptive feeding system was used to identify these patterns, and deliver feed at the correct rate of ingestion during these feeding periods.

The most appropriate feeding period will depend on the species' feeding niche. Marine fish from the photic zone can be categorised into three groups, diurnal, nocturnal and crepuscular feeders (Potts, 1989). Diel cycles in activity and feeding are strongly associated to photoperiod, temperature and sudden changes in environmental conditions (Boujard and Leatherland, 1992a&b). Salmonids in the marine stage of their life cycle are typical diurnal feeders (Blaxter, 1980) and occasionally exhibit nocturnal behaviour as parr (Fraser et. al., 1993, Higgins and Talbot, 1985).

The focus of fish farmers is usually to grow fish as quickly as possible while maintaining the best feed conversion ratio, unless market forces dictate otherwise. Feeding the animal to satiation without waste will result in maximum growth, although there is debate as to whether this regime will produce the best feed conversion efficiency. Early work by Brett, 1979 and others using few individuals found maximum growth did not equate to optimum feed conversion efficiency while Talbot and Hole, 1994, support the theory that maximum ration will achieve maximum growth and optimum feed conversion efficiency. Initial data from a study in Scotland (Blyth et. al., unpub. data) appears to support this theory. Brett's work may have been influenced by the formation of hierarchies influencing behaviour and physiology (Abbott and Dill, 1989, Metcalfe et al. 1990, Talbot, 1993). Assuming the nutritional composition is appropriate, to achieve maximum growth, satiation feeding should be employed on a regular basis, which for most carnivores is daily. Restricting feed can result in the loss of growth (Blyth et. al., 1991).

One key area, where the most significant gains can be made is in the temporal and spatial distribution of feed (Blyth et, al., 1993, Brannas and Alanara, 1993). Starvation regimes or simply poor distribution on a daily basis may lead to under feeding, stress a proportion of the stock and result in a higher incidence of disease. Overfeeding will result in waste. Following are some examples of feeding patterns for several species, cold/temperate and tropical waters, showing the differences in feeding rhythms and the improvement in production performance gained by feeding to satiation. The Adaptive Feeding system was used to control and map feeding patterns (Figures 2,4,5) of the following species.

Atlantic salmon: *Salmo salar*

The life cycle of Atlantic salmon is well documented (Thorpe, 1988). In this study salmon were grown in polar circle cages (circumference 65m), at stocking densities increasing from 4-10kgm-3. Salmon were fed a steam pressed diet containing 18% oil over the period of the study. In late 1995 higher energy extruded diets started to be used widely in the Tasmanian salmonid industry.

Feeding Patterns
Figure 2 displays quite clearly the feeding pattern of Atlantic salmon in Tasmania in 1993/94. Salmon were introduced as spring smolt in 1993 at 60gms and grown through to harvest (6.4kg) in December 1994. No harvesting occurred on this cage prior to the December harvest. The Adaptive feeding system was introduced to the fish in November 1993. Juvenile salmon (700gms) in summer tended to feed throughout the day in small meals with a significant meal just after dawn (Table 1, Figure 2), a similar pattern was also observed on young Atlantic salmon (150-600gms) in Scotland (Blyth et.al., unpub. data). By the end of summer, as fish reached 2kg, feeding shifted to more pronounced morning and evening feed, with several secondary peaks during the day. By early autumn, another meal developed in mid morning and this pattern carried through winter, finally diminishing in spring. This surge in feed intake of Atlantic salmon in autumn has been reported in Scotland (Kadri, 1995) and been linked to early onset of gonad development and muscle/body store deposition. However, Scottish salmon during winter, unlike Tasmanian fish, experience shorter day length and lower water temperatures, resulting in one meal per day taken on average (Smith et al., 1993,). Tasmanian salmon mature after one sea winter which appears to be due to a combination of the genetic line, photoperiod and water temperature.

The three feeding peaks from autumn to spring may represent fish groups differentiated by size or hierarchical factors. Subordinates in the group may take a greater proportion of their daily intake in the second meal. The second meal could be implicated in producing a low coefficient of variation for weight at harvest (15.6%). Winter temperatures in 1994 of 11°C in combination with a winter solstice day length of 10 hours (twilight included) provided good conditions for high feed intake, as reflected by the third meal. By late spring feeding still occurred in the morning and evening but became increasingly spread throughout the day. It is interesting to note another small meal 'budding' from the second meal of the day in winter and shifting gradually later into the day, before merging with the evening meal in late spring. This may represent a third sub-group of fish within the main group and raises the possibility of several categories of dominance/subordination. Fish tags recording, depth, light, temperature and activity, with a clock, would be one method of studying this effect in sea cages. Such tags are already being used on southern bluefin tuna, *Thunnus macoyii,* in Australia, to record long term movements and behaviour (Zelcon Pty. Ltd., CSIRO)

Intake increased dramatically in spring as fish prepared body reserves for maturation, a phenomenon noted by others (Kadri, 1995). By summer feeding occurred in two distinct meals, early morning and late in the day. Anorexia, as noted by Kadri, 1995 for maturing Scottish salmon in summer was not found in this study as fish were starved then harvested in December, possibly too early to notice this effect. High summer water temperatures at certain sites, places this species on the edge of its optimal temperature range (18°C+) in Tasmania (Cameron, 1989).

Further data from 1995 shows circa annual variation possibly due to changes in environmental conditions and/or cage size effects (Blyth and Purser, unpub. data).

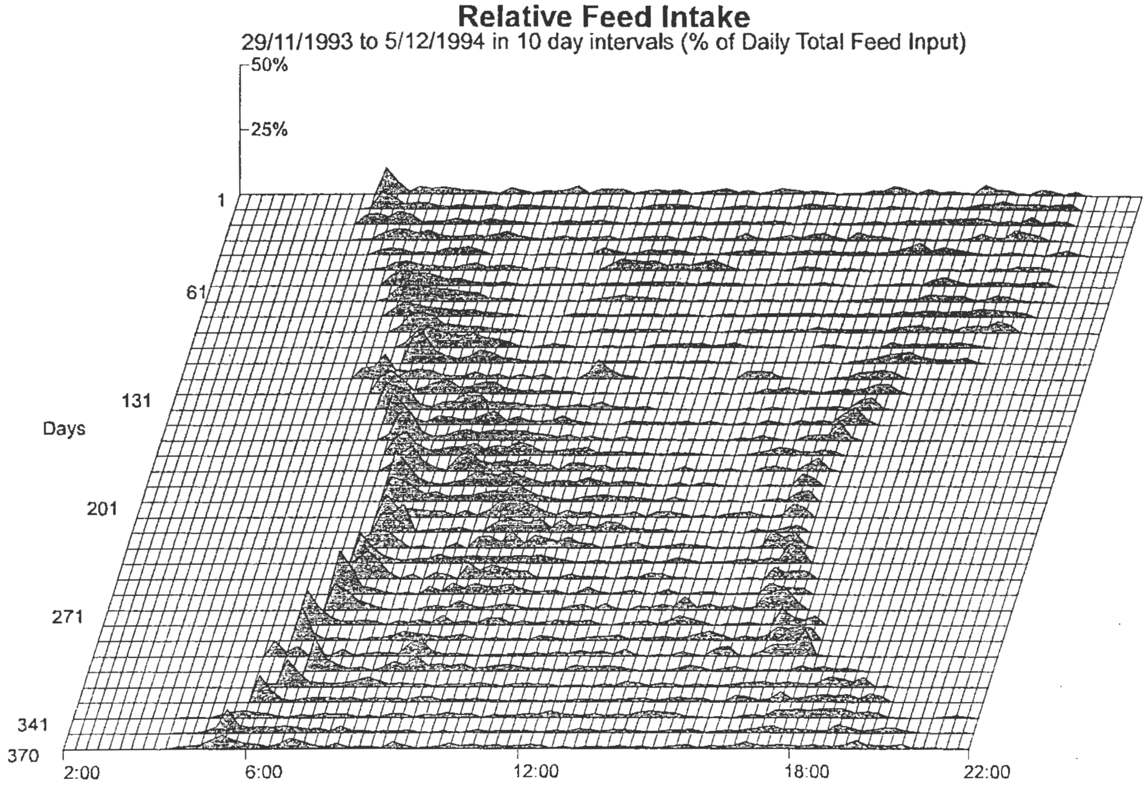

Figure 2. The relative feed intake of Atlantic salmon (500-6400gms) in Tasmania, Australia, expressed as a percentage of total grouped (10 day intervals) daily intake. Note: uncorrected for daylight saving.

Production performance

The growth of Atlantic salmon has steadily improved over time on this farm (Figure 3). Feeding practice prior to introduction of the Adaptive feeding system involved the use of automatic feeders in combination with hand feeding and almost constant surface observation of the fish. Feeding occurred continually throughout day light hours for juveniles in spring and summer, graduating to meal feeding for larger fish. Feed manufacturer tables were not used, as the strategy employed was one of daily feeding to satiation, ie; until no feeding activity was observed. Historical records provided an indicator of expected daily ration. Adaptive feeding systems were deployed broadly onto the farm in the summer of 1993, when a divergence in growth rate occurred. Results from trials in Scotland are showing similar trends (Blyth et. al., unpub. data.) Fish maintained this difference through to harvest. The growth of salmon 94' was greater than previous years, due to optimisation of system parameters and improvements in husbandry practice. The cumulative feed conversion ratio in 1993 ranged from 1.4-1.6:1 in 1993 (low energy steam pellet 18-20%), a 5% increase on the previous year. Corrections made to the data set based on calibration of the equipment has improved this value by elimination of sample or test outputs of feed (unpub. data). The introduction of a higher energy extruded feed in 1995 and further system settings optimisation has seen further gains in FCR.

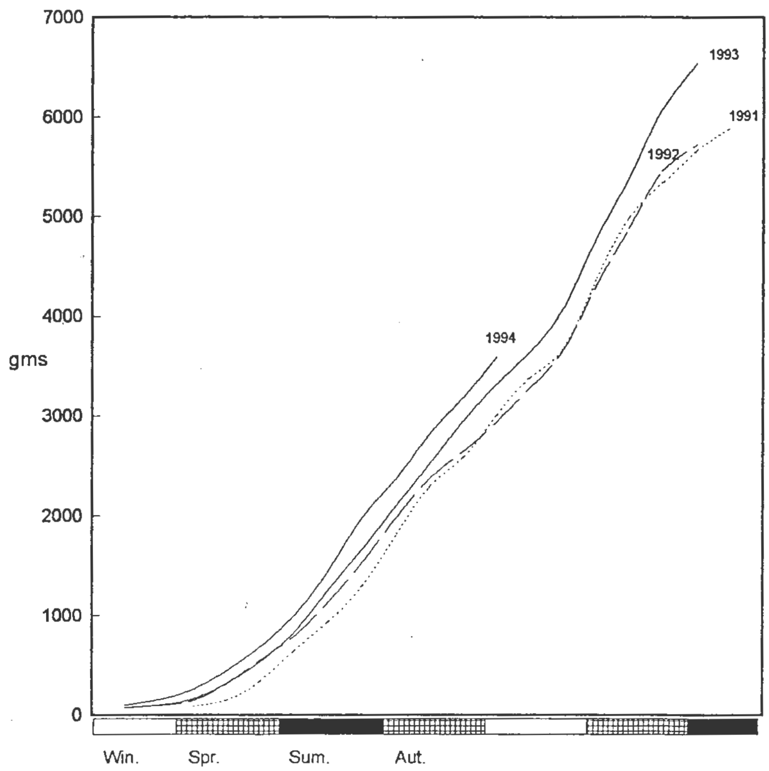

Figure 2. Average monthly weight versus year for smolt intake (1991-1994), from Huon Aquaculture Co, Tasmania, Australia.

Chinook salmon: *Oncorrhynchus tshawytscha*

Research conducted in New Zealand on Stewart Island and Marlborough Sounds has identified the feeding rhythms of Chinook salmon at various stages of their life cycle. Extracts of this data are presented in figure 4a,b&c. Chinook salmon enter marine cages in New Zealand as 20gms smolts in May and in the following year from October to December are harvested 3.5-4kg. Juvenile salmon exhibit multiple daily feeding peaks in spring (Figure 4a, Table 1), in the Marlborough sounds. In the colder waters of Stewart Island autumn patterns are characterised by 1-2 meals per day (figure 4b, Table 1) and by winter this reduced to one main feeding period per day. This is in contrast to Tasmania where higher winter temperatures and longer day length create the patterns discussed.

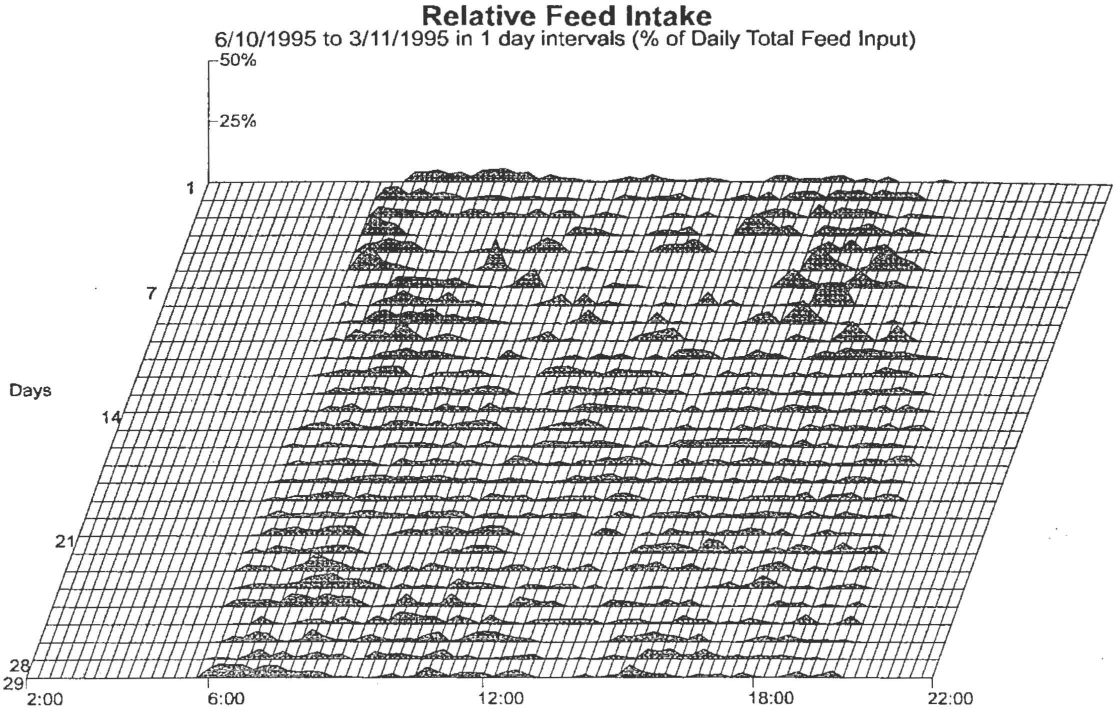

Figure 4a. The relative feed intake of Chinook salmon (160-360gms) in spring, expressed as a percentage of the total daily feed intake. From Marlborough Sounds, New Zealand.

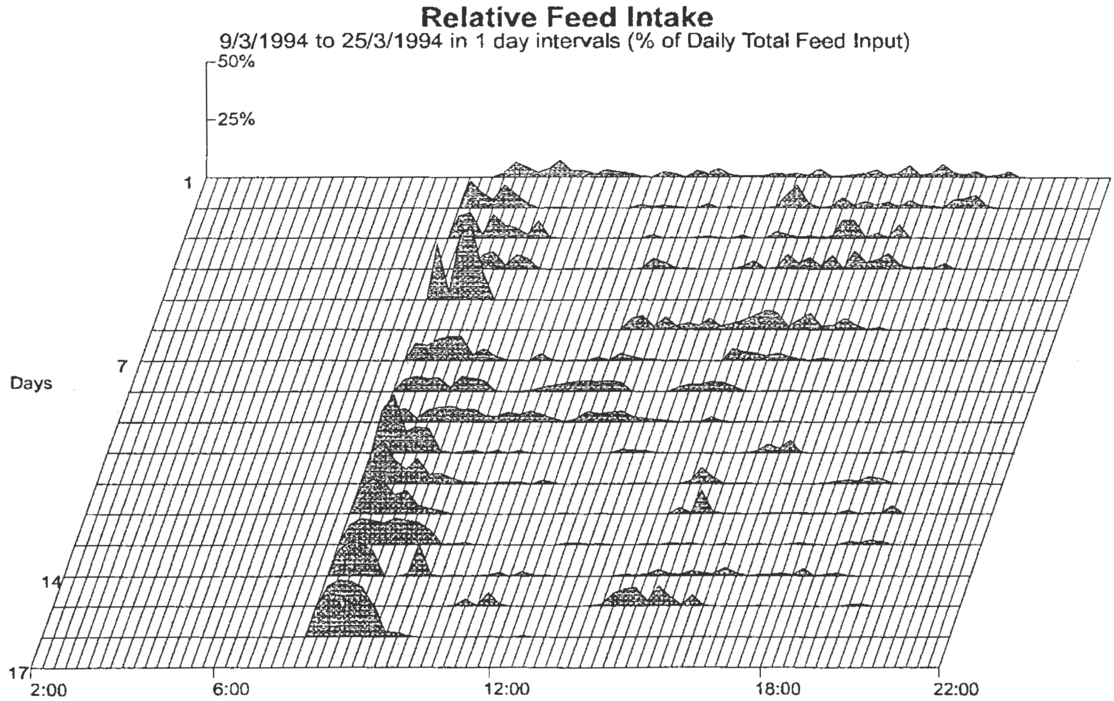

Figure 4b. The relative feed intake of Chinook salmon (1500-2200gms) in autumn, expressed as a percentage of the total daily feed intake. From Stewart Is., New Zealand.

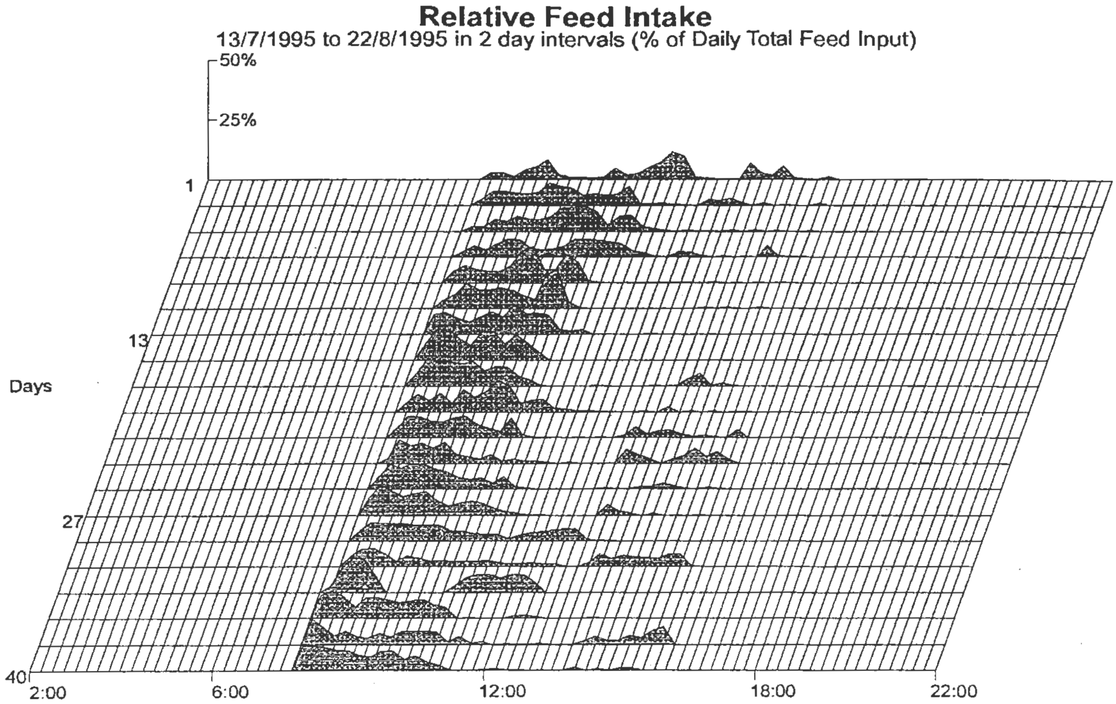

Figure 4c. The relative feed intake of Chinook salmon (2200-2600gms) in winter, expressed as a percentage of the total daily feed intake. From Stewart Is., New Zealand.

Barramundi (tropical sea bass): *Lates calcarifer*

Barramundi is a tropical species distributed widely through out the Indo-West Pacific region. The feeding behaviour of barramundi in is an area of research that has received little attention. Early research on this catadromous and protandrous hermaphroditic species has concentrated on other biological aspects (Grey, 1986) with few studies on the diel feeding time preference of the species (Barlow, et al., 1993).

Barramundi in Australia spawn in river mouths with salinities of 28+‰ (Tucker et al.,1988), the young will spend 3-4 years up stream in freshwater, reaching 2.6-4.2kg before returning as mature males to spawn. They will remain in this region until 7-12kg, then revert to female, continue to spawn, while inhabiting the tidal reaches of the estuary (Grey, 1986). Aquacultured barramundi in Australia are typically grown in cages and ponds in both marine and freshwater to plate size (500gms), although grow-out is moving to larger fish (2-3kg).

The study was carried near Darwin in the Northern Territory on a farm that produces 100 tonnes p.a.. The Adaptive feeding system controlled two automatic feed dispensers, on a 0.8 hectare pond (average depth of 1.7m). A vibrator motor with limited spatial distribution was used with the underwater sensor positioned below one feed distributor. The pond was stocked with 10,000-15,000 barramundi estimated at the start of the trial to weigh between 1-3kg. Semi floating, extruded barramundi diet (6&8mm diam.) was used in the experiment (Aquafeed P/L).

Feeding Patterns

Barramundi during late winter (dry season) fed in the afternoon through dusk and into the evening (Figure 5). Reports from cage farmers indicated that feed is presented during daylight hours in meals. During winter when temperatures reach 20°C, fish are fed once per day on alternate days to satiation. This is increased to 2-3 feeds per day, every day, during summer (25°C+), with the majority consumed at dawn and dusk. Meals can take 30-60 minutes (G. Doyle pers. comm.). Fry (18mm+) after transformation from a zooplanktivore to lurking predator, are visual feeders, taking food over the day, with a peak at dusk and can also feed under moonlight but not in total darkness (Barlow et. al., 1993).The feeding period recorded by the Adaptive feeder in the pond study was arguably long compared to the normal meal time reported in cages. Poor spatial distribution (point source delivery) may have contributed to this effect. Also as feeding on the farm historically occurred between 1000-1900 hours, with automatic vibrator feeders delivering approximately 10 pellets per second for ten minutes every hour, there is a possibility that this regime has had a residual effect. Optimal temporal and spatial distribution of feed are key factors in improving production efficiency (Kadri 1995, Thomassen and Lekang,1993)

Barramundi have well developed senses to allow successful foraging in turbid estuarine conditions and in freshwater rivers that can fluctuate from clear (dry season) to highly turbid (monsoon). They feed opportunistically on mainly fish and crustaceans (Penaieds) (Barlow, pers. comm).

Predatory species often show a degree of opportunism, and can transform from diurnal to crepuscular and then nocturnal feeding (Potts, 1989). Barramundi appear to display this ability. A decrease in temperature has been implicated as a switch from diurnal to nocturnal feeding in salmon parr in freshwater (Fraser et. a., 1993), raising interesting questions for barramundi. Circatidal influences (Johannes, 1981) could also determine the feeding pattern of a species that spends a large proportion of its adult life in tidally influenced mangrove estuaries. This factor may be important in ponds that are tidally flushed or in sea cages situated in tidally influenced areas, but was not a factor in this study, as water was released into the pond via a reservoir.

Future research should study the effect of diurnal compared to nocturnal feeding, and the effect of better spatial feed distribution on performance. The effect of water temperature, turbidity and salinity on diel feeding patterns would also be an area worth studying.

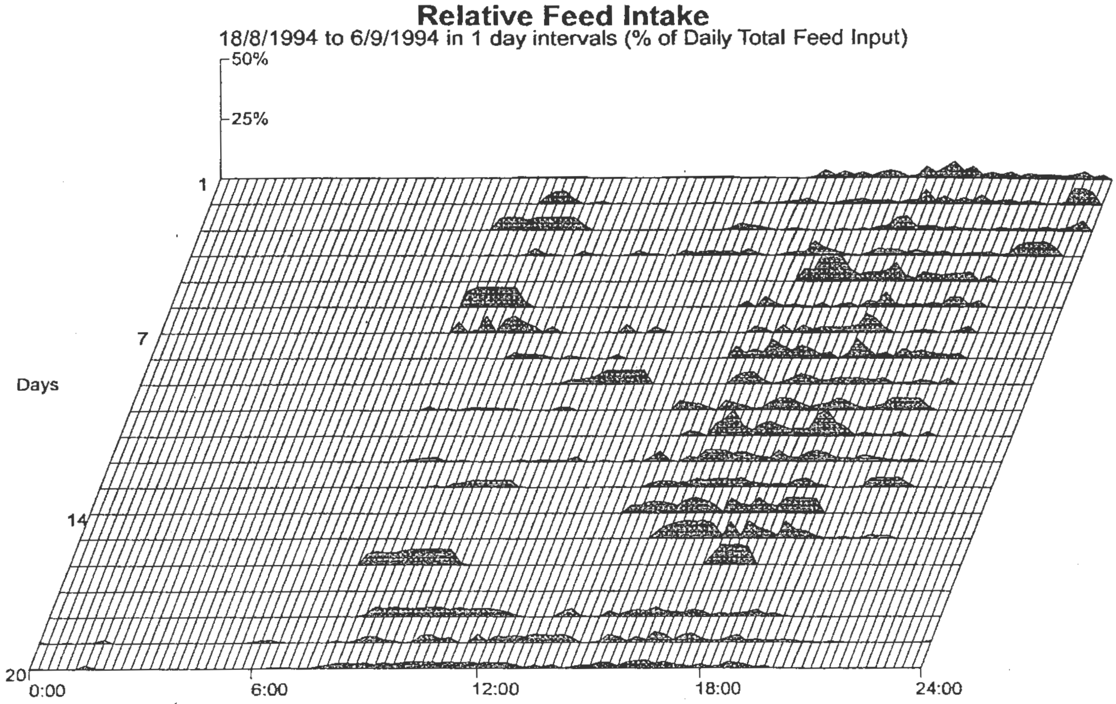

Figure 5. The relative feed intake of Barramundi (1000-3000gms) in the dry season, expressed as a percentage of the total daily feed intake. From Darwin, Northern Territory, Australia.

Application to Japanese species

Preliminary work on the suitability of the Adaptive feeding technology to yellow tail (*Seriola quinqueradiata*), is encouraging. The wild traits exhibited by this species in culture will undoubtedly subside over time as hatchery reared animals replace wild caught juveniles. Red sea bream (*Pagrus major*) also shows potential to be grown with the system (pers. obsv.). Advances in diet formulation and pellet type (Watanabe et. al., 1991), and the use of extruded feeds will see significant improvements in the grow out of these species.

Conclusion

The introduction of feeding technology, improved husbandry practice, larger grow out units and extruded feed, is ensuring rational, staged growth of finfish aquaculture in Australia. As fish meal becomes scarcer (Lewis,1995) it is important that a globally responsible attitude is taken to this resource and alternatives are introduced, to ensure the long term viability of aquaculture, fisheries and our natural environment.

The relationship of 'natural' feeding patterns to production performance is often under estimated and is area where major advances can be achieved.

Summary

Table 1. Table showing the number of meals per day in relation to season, water temperature, fish size and location. *S. salar* and *O. tshawytscha* were introduced as normal spring smolts.

Species	**Location**	**Fish size (gms)**	**Season**	**Temperature (°C)**	**Meals per day**
S.salar	T	60-700	spring	12.1	6+
	T	700-2000	summer	17.3	3+
	T	2000-3200	autumn	15.4	3
	T	3200-4600	winter	11.1	2-3
	T	4600-6400	spring/sum	12.2	2-3
O.tshawytscha	MS	160-360	spring	13.6	6+
	SI	1500-2200	autumn	13.2	2
	SI	2200-2600	winter	7.9	1
	SI	2600+	spring	8.9	1
L.calcarifer	NT	1000-3000	mid dry	24-27	1-2

T=Tasmania (42°S 147°E), MS=Marlborough Sounds, New Zealand (41°S175°E) SI=Stewart Island, New Zealand (47°S168°E), NT=Northern Territory, Darwin (11° S131°E). Mid-dry season = July-August

Acknowledgments

We thank the Australian Fisheries Research and Development Corporation (FRDC), Huon Atlantic Salmon Co., Regal Salmon Ltd., Barramundi Farms NT. and Northern Territory Department of Primary Industries, Aquaculture Centre for their support. Special thanks is extended to Peter Bender and Andrew Campbell for their assistance and good advice.

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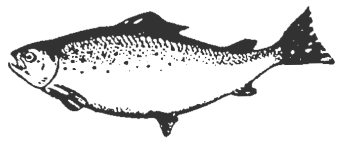
Salmon Speak



with Dr John Purser

"Smart" feeding systems

As the feed costs on salmon sea farms can commonly approach 40-50% of the production costs, it is important to optimise factors such as feed composition, form, storage, delivery, distribution to fish and utilisation by the fish in an attempt to minimise this cost component. Obviously, this is a very diverse field and developments have occurred across the board in recent years.

The development of extruded pellets has followed their extensive use overseas resulting in a better form quality, reduced dust, improved digestibility and the ability to incorporate higher fat levels. The long-term result should be a lower FCR, improving feed utilisation efficiency.

The production of pellets in bulk bags has improved handling efficiency and reduced pellet damage. It meant that boats had to be fitted with bulk feed containers and equipment modified to handle feed delivery to cages.

Traditionally, feed has been distributed to fish by hand or preset automatic feeder systems. Hand-feeding is very labour-intensive but does allow observation of fish behaviour. As cages became larger automatic feeders became less efficient: a number were needed per cage, capital and maintenance costs increased and servicing became more labour-intensive as was their continual adjusting to reduce wastage. As a consequence some farms converted to air-blown and water-cannon systems; with feed being delivered directly to cages from service vessels. Although these are active delivery systems there is no facility to measure feed waste.

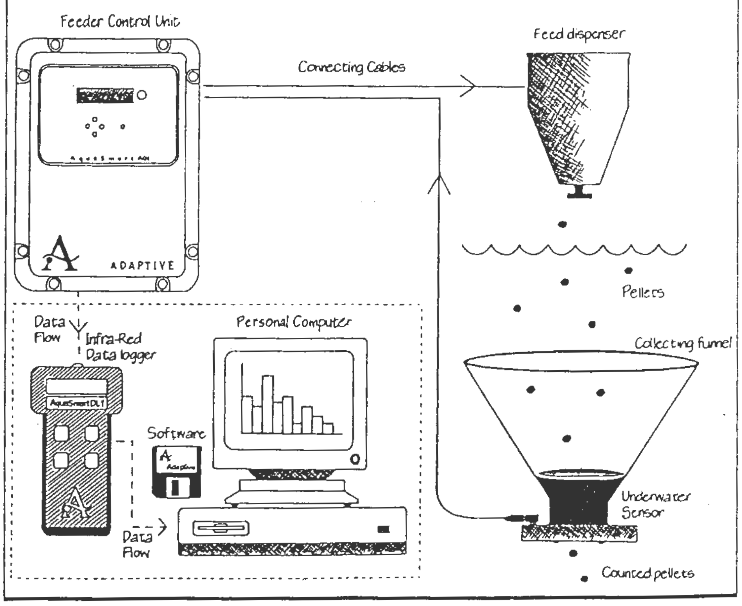
Aquasmart (Hobart, Tasmania) has developed some interesting technology which can be used as a tool to measure this pellet waste.

The Aquasmart Pellet Sensor uses an underwater collecting funnel and accompanying sensor to monitor excess pellets setting off a visual signal on the cage. This apparatus gives the operator of the feeder, underwater "eyes" enabling him confidently to cease feed delivery, knowing that the fish have stopped feeding. Obviously, this has the potential of delivering adequate meal sizes, it reduces waste and can also be used to train new personnel to better understand feeding patterns. The sensor removes a lot of the guess-work in feed distribution; more cages can therefore be serviced more efficiently in the same time period.

In addition to the sensor system, Aquasmart also produces a more comprehensive system, the adaptive feeding system, which controls feed delivery on the basis of monitored feed waste. This system is similar to the sensor but also includes computer software which "decides" how to match feed delivery from the autofeeder with preferred feeding times by the fish. The configuration of the system is shown in the schematic diagram (Figure 1). The fish therefore are capable of being fed exactly when they desire it rather than when a feeding operator has time to deliver it. Theoretically, it is a better feeding regime but this is being assessed against a discrete meal regime at present.

Although I have not contributed to the development or the commercialisation of this technology I have been involved in a research program which has used the equipment as a "tool" to monitor salmon feeding behaviour. This study has been supported by FRDC, Huon Atlantic Salmon, Saltas, Aquasmart and the University of Tasmania. The hardware and the feeding behaviour detection techniques used in this study are of international significance and have attracted attention from operators in many fish culture regions and research institutions worldwide. A few feed detection systems have been developed overseas but they do not have the capability to record the amount or type of information as the adaptive feeder. For this reason it is not only a means of reducing waste, improving FCR and improving growth but it has been shown to be a very useful research tool in recording feeding rhythms in fish stocks. Figure 2 demonstrates the type of information that can

Figure 1: Schematic diagram of adaptive feeder



be extracted from the collected data; the peaks indicate periods of feed intake. These vary both diurnally and seasonally but do indicate regular general feeding patterns. At present the research program is attempting to correlate feed intake with specific environmental factors such as temperature, light, day length, oxygen, weather and atmospheric pressure.

Although this technology was originally developed in Tasmania for use on salmon seacages, it has been tested in sea bass cages in Malta, chinook salmon cages in New Zealand, Atlantic salmon cages in Scotland, trout and coho salmon pens in Chile and barramundi ponds in the Northern Territory. A version will also be tested in a tank environment in the near future.

If you are worried about the feeding efficiency of your system and would like to perhaps know more about the feeding preferences of your fish leading to a potential improvement in the FCR and growth, then it may pay to look into it further. For enquiries contact Mr John Russell on (002) 718112.

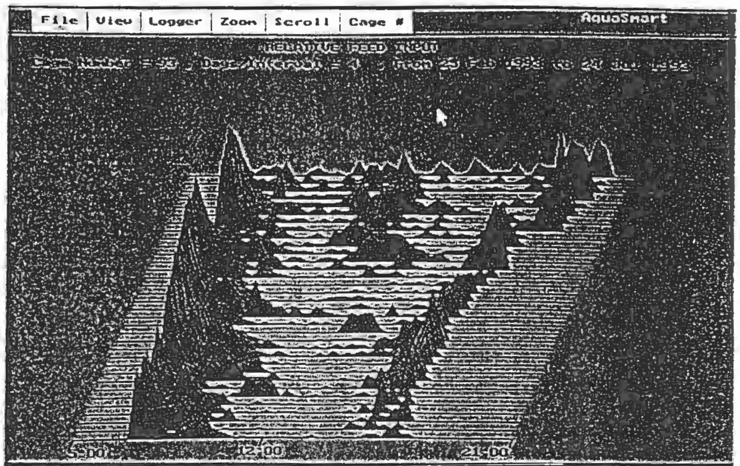


Figure 2: Feeding rhythms of seacage salmon between February and July 1993

DISCOUNT BOOKS

PLEASE NOTE NEW PRICES (from November '94)

Plankton Culture Manual
Covers Microalgae, rotifers, copepods ciliates, *Artemia* and *Daphnia*. Au$40 (add $2.50 airmail*)

Id Manual for Microalgae used in Aquaculture
Easy to follow guide to microalgae, contaminants and counting techniques. Au$40 (add $2.50 airmail*)

Nutritional Strategies & Aquaculture Waste
1st International Symposium on Nutritional Strategies in Management of Aquaculture Waste. 21 review papers. Au$60 (add $5.00 airmail*)

Seafood Handbook
A comprehensive buying guide for the Food Service Industry. Au$25 (add $2.50 airmail*)

Post Graduate Foundation in Veterinary Science
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No. 182: Finfish Workshop. Au$45
No. 128: Finfish Diseases. Au$49
No. 117: Invertebrates in Aquaculture. Au$43
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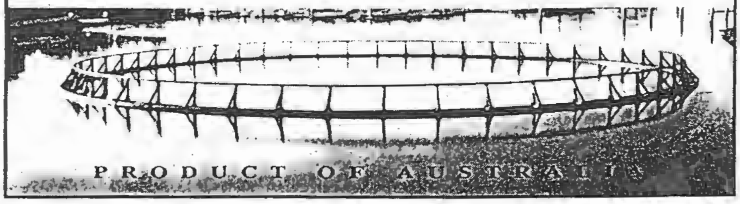
*Full payment must accompany order or an invoice fee of Au$10 will apply. Overseas orders add Au$10 for airmail for each book. O/seas cheques must be in $Aus drawn on Australian bank or a Au$10 surcharge will apply. Bankcard, Mastercard and Visa orders - supply full card number, expiry date and signature - add $A5 for Credit Card Service Charge. Send payment to DOSAQUA, PO Box 243, Mowbray, Tas 7248, Australia. Fax: (003) 347-007 or IDD fax: + 61 03 347-007.


New Plastic stanchions (Patent pending)



Atlantic salmon feeding behaviour research

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ABSTRACT

Environmental monitoring equipment was set up to continuously monitor water temperature, salinity, light, wind speed and direction, tide height, current and barometric pressure. This information will be related to feed intake. Long term feeding rhythms will be established for Atlantic salmon. Preliminary work shows that there is a predominant trend in young salmon (approx.< 1 kg) during late summer to display significant early morning and late evening feeding peaks as well as feeding in small bouts over the middle of the day. Larger salmon (1-2 kg) during autumn display a more pronounced three feeding peak pattern, depicted by a significant morning feed, post midday feed and late evening feed. By late autumn when salmon were about 2 kg the post midday feed tended to disintegrate and by winter a typical feeding rhythm of a protracted morning feed and a late evening peak was evident.

GENERAL AIMS

The following experiments were designed to study in detail, daily and seasonal feeding patterns of sea caged salmon utilising the 'Adaptive Feedback system'. It is intended to develop a robust model to predict feeding patterns of Atlantic salmon in relation to abiotic and biotic environmental factors and certain farm procedural factors. Feed intake as determined by the system will also be compared to absolute feed input to measure the accuracy of the system.

EXPERIMENTAL METHODS

The following list details the parameters measured and the factors expected to affect behaviour.

Response variables

a. feed rhythms (feed intake per 15 minutes, time between feeding bouts, duration of feeding bout, amount taken per bout, amount taken per day

b. swimming speed (body length per second)

Measured abiotic and biotic factors affecting behaviour

a. Environmental measurements taken daily

Light, temperature, salinity, oxygen, water clarity (secchi depth), wind speed, wind direction, wave height, barometric pressure, tide height, current speed, cloud cover

b. Predictable environmental measurements

Lunar phase, day length

c. Predator disturbance

Dolphins, seals, birds

d. Other

Algal bloom monitoring, disease

e. Controllable procedural effects

Auditory and Visual disturbance
- net changing
- cage visitation by boat (fish checking)
- diving mortality/stock checks
- daily filling of food hoppers

Experiment 1

Daily and seasonal feeding patterns in relation to environmental factors

Protocol

Selected cages around the farm will be utilised in this experiment. These cages will be grouped by year class and size. Adaptive feeders are used on each cage to determine the feeding pattern of the fish. Environmental data will be collected with the view to multiple regress against feed intake.

PARAMETER	SAMPLING RATE
Light	(at 1m, 5m and surface ref.) every 1 minute
Temperature	(at 1m, 5m and atmospheric) every 15 minutes
Salinity	(at 1m and 5m) every 15 minutes
Oxygen	(at 1m and 5m) every 60 minutes
Water clarity	(secchi depth, metres)
Wind speed	(every 15 minutes)
Wind direction	(every 15 minutes)
Wave height	(3 times per day)
Barometric pressure	(3 times per day)
Tide height	(every 15 minutes)
Current speed	(at 3 metres, every 1 minute)
Cloud cover	(3 times per day)

Other notes

Time hoppers filled
Other disturbance (predators)
Mortality
Diving
Net change

Sampling schedule

Feed intake Versus (a-d)
Starting July 94 continuously until Dec 1994

Analysis

Daily effects
Seasonal effects
Utilise multi-variate analysis to model environmental effects on feeding behaviour

Experiment 2
Swimming speed Versus season (a-d), fish size, % feed intake, time of day, during feeding and after feeding, temperature and light

Sampling schedule

Aug 94	3 day sampling period
Sep 94	"------"-----"------"-----"
Oct 94	"------"-----"------"-----"
Nov 94	"------"-----"------"-----"
Dec 94	"------"-----"------"-----"

Protocol

Video entire day then select 3 periods (non feeding) 0800,1200,1400, and measure fish speed.

Analysis

Anova

Experiment 3
Effect of disturbance (e) on feed intake

This experiment is designed to test the effect of audible/visual disturbance on salmon feeding behaviour.

Protocol

Utilise four cages of salmon

Sampling schedule

End of Aug 94 for 2 days.

Day 1 No disturbances on any cages (except fill hopper at 1200)

Day 2 Disturb cages every hour by approaching in vessel, and securing to the cage for 1 minute and repeating for all cages, note time.

An underwater hydrophone with recorder will record sounds on day 1 and day 2. Sound will be quantified in db.

Analysis

The effect of sound/visual disturbance on feed intake will be monitored.
Use regression analysis

Experiment 4
The absolute waste from the adaptive feeder when feeding to satiation

Protocol

A single underwater pellet collector will be placed under a representative cage for 1 day to monitor total waste feed from the adaptive feeder. 9 mm pellets will be used for this experiment.

Sampling schedule

Nov 94

Experiment 5
Trends in general production performance and farm seasonal feeding profiles

Long term feeding pattern data, total daily feed intake data and performance data of 30 cages fed using the adaptive feeding system will be collated over the entire production season.

Analysis

This is a descriptive analysis to show the season and size variations in feeding rhythms and will be presented graphically.

METHODS AND PRELIMINARY RESULTS

Information from a cage of salmon (1992-1993) utilising the Adaptive feeder was compiled and analysed.

Performance

Feeding patterns of 4,251 salmon grown under the control of the adaptive feeder system (25.2.93-24.7.93) in a 60m circumference polar circle cage are displayed in Figure 1. These fish were introduced into the sea as pre-smolts in the 1992 intake and introduced to the site on 2.11.92 (15,640 salmon at average weight of 154 gms and biomass of 2.41 tonnes). On the 24.1.93 this group of fish were split three ways. The group concerned had an average weight at this time of 850 gms (biomass of 3.61 tonnes). The cumulative FCR up to 2.11.93 was 1.05. The group of 4,251 salmon were then grown through to 25.7.93 at which point the cage was harvested. On 20.6.93 salmon had an average weight of 2.524 kg and a cumulative FCR of 1.34. The Adaptive feeding system during this period was set to target high growth through feeding to satiation. Wastage was kept to a minimum as depicted by a low cumulative FCR.

Feeding Patterns

The data presented in Figure 1 shows the relative feed input (Total spin time per 15 minute, in 4 day averaged days, z axis). The data is a time series from 25th February 1993 (background) to most recent, 24th July 1993 (foreground). Each grid line down the page (y axis) represents the accumulated average of 4 days of data. The x axis is divided into 15 minute time intervals. Both graphs show the same data from different aspects.

The predominant trend apparent from the graphs is that young salmon (approx. 1-1.5 kg) during late summer display significant early morning and late evening feeding peaks as well as feeding in small bouts over the middle of the day. As the fish grew and water temperature, day length and light levels decrease into autumn the salmon display a more pronounced three feeding peak pattern. These peaks are depicted by a significant morning feed, post midday feed and late evening feed. By mid April the post midday feed tended to disintegrate and by winter a typical feeding rhythm of a protracted morning feed and a late evening peak was evident.

Daily feeding efficiency

The daily changes in feeding efficiency index (no. pellets per spin time) can be seen on Figure 2. The feeding efficiency is generally better at the commencement of feeding and deteriorates at the end of a feeding bout. This pattern is repeated for the main feeding bouts of the day. During March and April 1993 there was significant feeding after midday in the early afternoon. The feeding efficiency during this period was good. By mid April feeding efficiency in the middle of the day deteriorated when a significant morning feed had occurred. The Adaptive feeder during these periods was characteristically in sleeping state.

ACKNOWLEDGEMENTS

The author wishes to thank the FRDC, University of Tasmania (Aquaculture), Aquasmart Pty. Ltd. and Huon Atlantic Salmon Pty. Ltd. for financial and technical support. Thanks is also extended to SALTAS Pty. Ltd. for the loan of underwater video equipment.

Figure 1. Showing the relative feed input (spin time of feeder motor) from 25th February to 24th July 1993. Each vertical grid is the average of 4 days of data. All points are relative to the largest value.

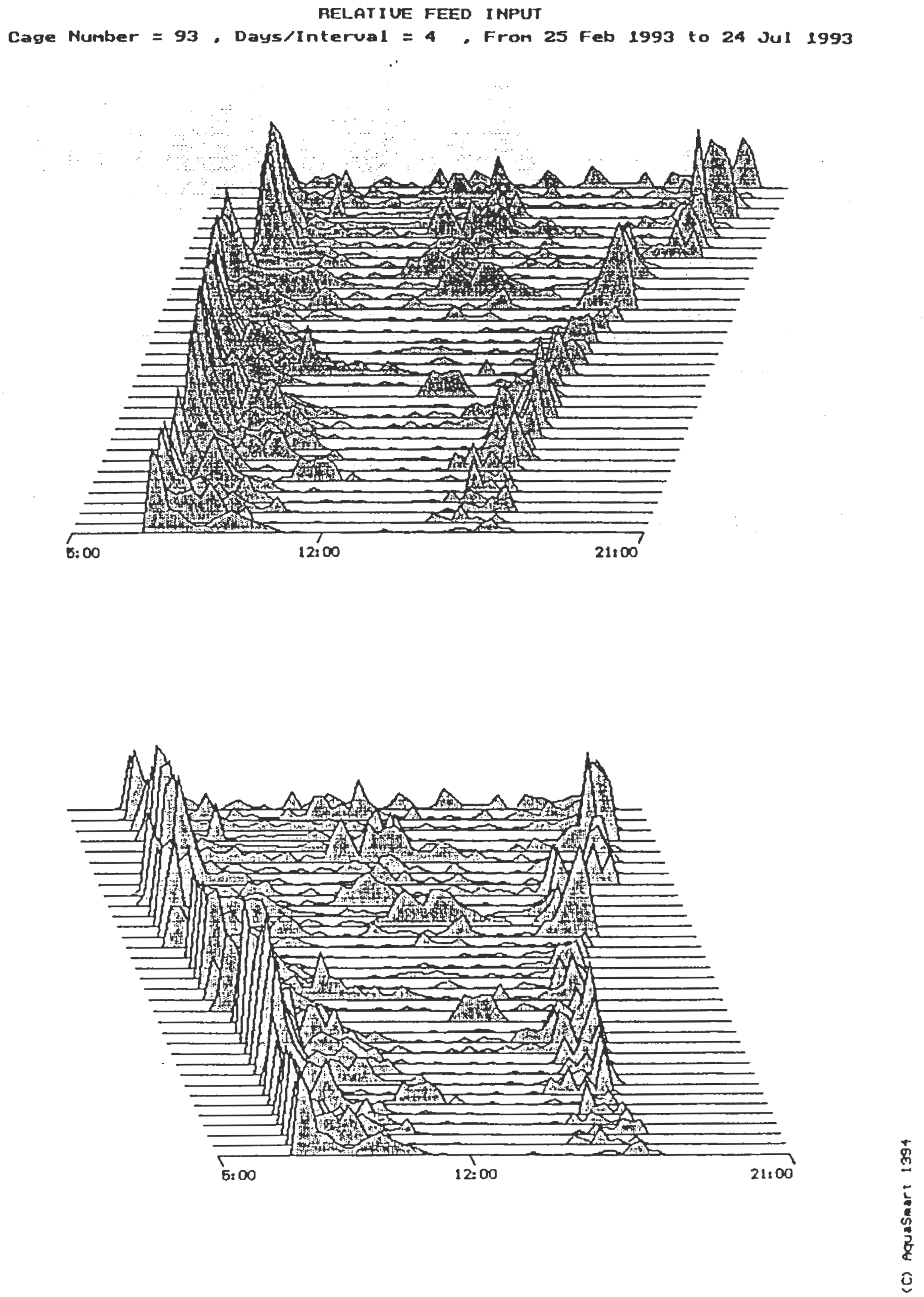

Figure 2. Feeding efficiency index. The feeding efficiency colour key is denoted by 4 shades of colour. The efficiency is calculated by the number of pellets per spin time. These values are scaled to the highest value and grouped into one of four categories, the best efficiency being black through to pale grey.