MODELING, IDENTIFICATION AND CONTROL, 1986, VOL. 7, NO. 4, 209–218
doi:10.4173/mic.1986.4.5

Monitoring biological and environmental parameters in aquaculture

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Keywords: *Aquaculture; monitoring system; data acquisition; behavioural sciences; stress control; signal processing; sensors.*

This paper describes a system for monitoring the behaviour of salmon in culture in relation to environmental factors and different rearing conditions. The main objective of this work is to minimize the stress level of the fish by optimizing critical factors in order to avoid disease and increase growth and fish quality.

Two generations of salmon are investigated under normal rearing conditions in sea water at the Austevoll Aquaculture station. The distribution, behaviour and physiological condition of the fish are studied by methods such as underwater biotelemetry, standard acoustic methods, underwater TV observations and blood sample analyses.

Environmental factors such as temperature, salinity, oxygen, current, tide, meteorological data and light level are continuously monitored. Several of these parameters are measured by different types of sensors for calibration and testing purposes. The sensors are interfaced to a HP-1000 computer. Special process monitoring and control software gives trend and historical analyses of stored data.

1. Background

A biological organism constantly interacts with its environment. A certain variation of the critical environmental factors is tolerated but beyond that range, mortality will increase. This also applies to farmed animals, although they are often both originally chosen and further selected for their wide tolerance limits. Variations in environmental conditions are especially crucial for water-living organisms as fish, with a constant interaction with the surrounding medium.

Rearing salmonid fish in net pens is a growing industry in Norway. There are, however, increasing problems with disease and pollution. Restrictions on the volume of the cages have resulted in a trend towards the use of higher fish densities. Overstocking could lead to unacceptable values of environmental factors and social stress due to interactions between the closely packed individuals (see Fagerlund, McBride and Stone, 1981; Fernø and Holm, 1986).

In order to study the interaction between the fish and its environment, a system simultaneously monitoring environmental and biological parameters is required.

Received 15 January 1987.

This paper was presented at the IFAC Symposium on Automation and Dataprocessing in Aquaculture, Trondheim, Norway, 18–20 August 1986.

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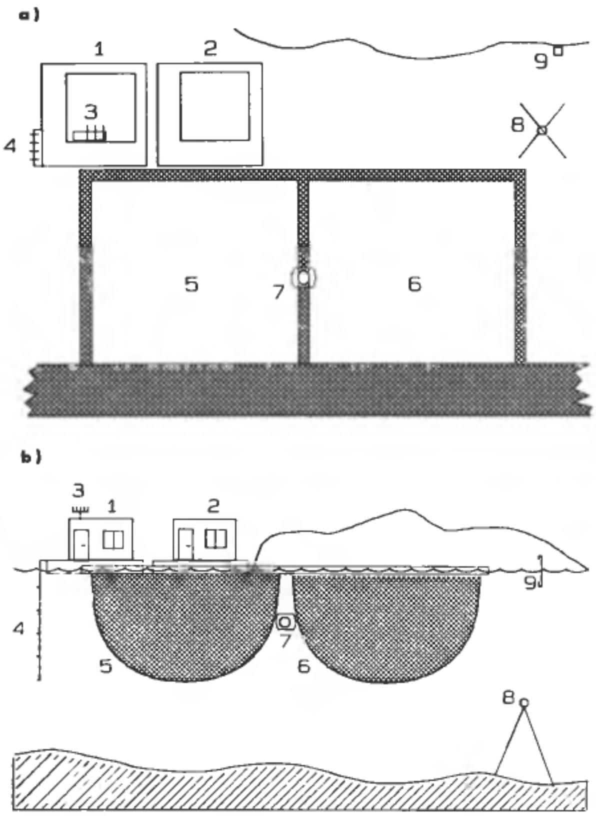

Figure 1. General experimental arrangement including some of the sensors. (*a*) Top view, (*b*) Side view 1, 2 = Rafts (laboratory and office) 3 = Meteorological sensors, 4 = Temperature sensors, 5, 6 = Fish pens, 7 = Underwater television cameras, 8 = Current sensor, 9 = Tide sensor. Size of fish pens: 12 × 12 × 5 m.

With such a system, the relationship between environmental factors and the behaviour and physiology of the fish could be described, with the ultimate goal of characterizing the behaviour typical for an optimal situation with rapid growth. Early warning signals of approaching critical values or of the initiation of disease could be identified. Moreover, a better understanding of the factors regulating food intake could lead to modification of feeding regimes giving higher utilization of food. Finally, establishing the relation between the environmental conditions and fish behaviour and physiology from a baseline study constitutes an important background knowledge when evaluating results from any systematic experiment in a fluctuating natural environment.

This paper describes a system monitoring a large number of environmental and biological parameters from normal rearing conditions of salmon in sea water as well as some preliminary experiments with the system.

2. General description

Figure 1(*a*) and (*b*) and 2 show the general experimental arrangement. The studies are conducted at the Austevoll Aquaculture station on two generations of salmon in two standard fish pens. Two housing rafts are moored close to the fish pens and used as instrument laboratory and office facilities. The rafts are supplied with electricity (220 V AC), telephone and fresh water.

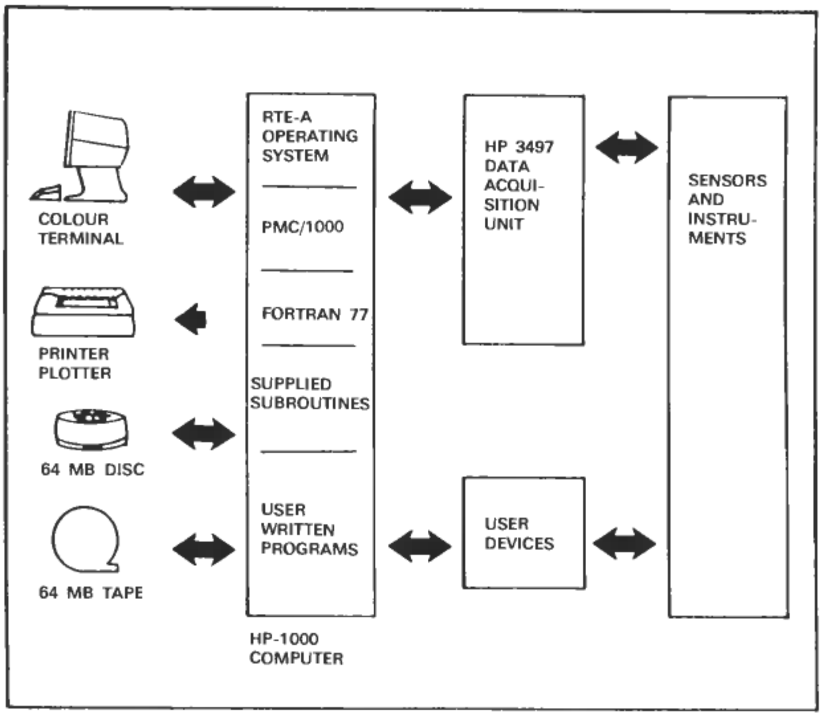

Figure 2. Computer and data acquisition system.

3. Environmental parameters—instrumentation

3.1. Introduction

In fish culture, some environmental factors (as temperature) are known to have a great influence on behaviour and growth, whereas the importance of other factors are more uncertain. The aim of this study was to monitor all presumably critical environmental factors. For several parameters, more than one type of sensor is used. In this way, the reliability of the system is improved. This also gives information about the accuracy of the sensors, and how often a certain sensor has to be calibrated, several of the sensors were not originally constructed for use in sea water. For calibration purposes, analyses of sea water is made in the laboratory.

3.2. Temperature

Two types of sensors, thermistors and P_t-100 elements, are used to measure temperature. The thermistors (type FENWAL GB32JM19) were moulded with polyurethane into a cable and have high sensitivity (0·05°C), although good linearization is difficult to achieve. The P_t-100 sensor consists of a P_t-element and a preamplifier giving a 4–20 mA linear signal. This sensor gives good linearization but the sensitivity is lower. The temperature is measured with thermistors at the surface and at depths of 2·5 and 5 m, while the P_t-100 sensors measure at 1 m and 4 m depth.

3.3. Salinity

Salinity is measured by four different sensors. Two of these (Aanderaa and Bergen Nautic) are inductive cells, based on two toroidal cores making up a seacoupled inductive system. Another sensor (Great Lakes) consists of two electrodes with an alternating current between them proportional to the conductivity of the water. The fourth sensor (Conducta) is based on four electrodes. Salinity is measured close to the surface (fresh water fluctuations) and at 2 m depth.

3.4 pH

The pH sensors (Great Lakes and Conducta) are based on standard principles with one measuring and one reference electrode with the potential proportional to the pH. The sensors were placed at the surface.

3.5. Oxygen

Most available oxygen sensors have not previously been tested in sea water over a long period of time. Two sensors (Syland and Conducta) are active cells based on the Clark principle while another sensor (Rexnord) consists of a passive cell with a lead anode, platinum cathode and a teflon membrane immersed in an electrolyte. Since the sensors consume oxygen, they are supplied with an agitator to give the necessary flow over the sensor. Oxygen is measured at 3 m depth where it will give the most representative value.

3.6. Current

The current velocity and direction is measured with an ultrasonic current meter (Sensordata) placed at 3 m depth. This sensor has a considerably higher sensitivity (1 mm/s) than traditional current meters based on the rotor principle, and algal growth has no negative influence.

3.7. Water level

The tidal variations are recorded with a conductance pole, for which the conductance changes with the water level.

3.8. Meteorological data

An Aanderaa weather station gives meteorological data. This station consists of sensors for temperature, barometric pressure, wind velocity and direction and amount of rain in addition to a logging device.

3.9. Light

Surface light level is measured by a photometric sensor (Photodyne, range 10E-3 to 1E 6 Lux). A sensor consisting of a photomultiplicator tube (Product of Research, sensitivity 10E-6 Lux) is used to measure the light underwater.

3.11. Feeding routines and food waste

Time of feeding and the type and quantity of food are recorded. Food waste is monitored by an acoustic system with two high-frequency (200 kHz) acoustic transducers.

3.12. Preliminary experiences

Except for minor initial problems with a few sensors (leakage, mechanical defects), the sensory equipment has so far functioned satisfactorily. However, some sensors gave incorrect values also after calibration, which demonstrates the necessity of regular recalibration and the use of different sensors for the same parameter. This must also be considered for use of sensors under standard rearing conditions.

4. Biological parameters—instrumentation

4.1. Visual observation of fish behaviour

Visual observations are essential in any behaviour study and can give valuable information both at the individual and group level. The various behaviour patterns of individual fish were recorded in different situations. In addition, the general situation in the fish pen was characterized into different categories.

Two underwater television cameras are mounted to a pan and tilt unit in a way that allows two net pens to be observed by rotating the unit. One camera is a light sensitive (0·005 Lux) silicon tube camera (Osprey OE 1321) and the other is a less sensitive (35 Lux) colour camera (Osprey OE 1336). By choosing the camera according to the prevailing amount of light, a reasonable image quality is obtained in all surface light levels above 50 Lux.

Fish behaviour is video-taped at fixed time intervals. The tapes are later analysed and the frequency of the behaviour patterns saved in the computor. Automatic image-processing has been evaluated, but the development of an acoustic system has so far been given priority.

4.2. Fish distribution and density

Fish density is the most prominent parameter investigated in Norwegian aquaculture today. This is partly due to the use of volume as a production licence criterion, and partly to the fact that high densities give lower investments per unit of product. This strongly motivates the individual farmer to keep stocking densities as high as possible. However, high densities also raise many questions concerning chronic and acute stress, and the effects on general health conditions and growth in the fish stocks.

In this context, it will be of great importance to know the distribution of the fish stock within the production unit. The distribution patterns reveal how well the total volume is utilized, give estimates of actual densities and also yield general information on fish behaviour in relation to environmental conditions (light level, temperature, algae blooms, etc.).

A system for observing distribution, consisting of a matrix of hydro-acoustic transducers under the fish pen, is under development. The echo signals are preprocessed and fed into the computer for further processing and presentation. The echo abundance will be integrated in steps of 1 m or less from the bottom of the pen to the surface.

4.3. Jumping activity

Salmon in net pens often jump. A preliminary jump count from two pens showed that salmon in its first and second year of life in the sea jumped an average of 12·3 and 2·3 times per fish per day (based on a total of 140 5-min observations from 23rd of October 1985 to 6th of February 1986). There have been several explanations for the jumping activity, ranging from parasite removal to training for the river rapids. Ecologically, it is bound to have a function due to the energy expenditure involved.

The swimbladder is the principal hydrostatic organ in salmonids and buoyancy is regulated by filling and emptying the swimbladder through the pharyngeal duct. Salmon deprived of access to the surface have a high swimming activity, loss of weight and increased mortality (Huse, unpublished observations).

Behaviour studies showed that surfacing fish trailed air bubbles from the mouth when diving after the jump. Air bubbles from non-surfacing fish were also frequently observed in the pen. There is therefore reason to believe that the jumping activity is related to buoyancy regulation. It is also known that scared farm fish release air and dive to the bottom of the pen, implying that jumping can be related to stress due to frequent buoyancy adjustment requirements.

The jumping activity is recorded continuously by an infrared sensor covering a 60° sector of the fish pen just above sea level.

4.4. Heart rate

The heart rate gives some information both about activity level and stress level of the fish. Although there is no simple relationship between heart-beat frequency and swimming activity, as most variation lies within the stroke volume, there is some correlation between heart rate and oxygen consumption (Priede and Tytler, 1977). An increase in heart rate in connection with acute stress has also been observed in fish (Priede, 1978). In addition, the heart beat is inhibited in response to a wide variety of external stimuli (Priede and Young, 1977). The relationship between the stimulus and the response may give information about the physiological state of the fish. The heart rate is monitored by acoustic tags operated into the body cavity with the electrode placed near the heart (Holand, 1975). The acoustic signals are received by a hydrophone, transformed to digital signals and further transmitted to a counter card in the front-end processor.

4.5. Fish physiology

Knowledge of the physiological state of the fish is important when understanding the connection between the immediate behaviour of the fish and the result on long-term processes as growth. Stress hormones, (catecholamines and corticosteroids) are of special importance (Donaldson, 1981). Blood samples of the fish for hormone analyses are taken at regular time intervals.

5. Data acquisition and processing

5.1. Introduction

Measuring behavioural, environmental and physiological parameters over a long period of time makes certain demands on the data acquisition system. Because of the great variety of sensors, the interfacing has to be easy and flexible. The data acquisition system must have a fairly large storage capacity and also provide continuous graphic and alphanumeric display of the input data, as well as easy retrieval and presentation of historical data. Easy configuration of standard setup and programming facilities for non-standard applications were required.

Three different solutions were discussed. The data acquisition system could range from non-intelligent dataloggers to sophisticated computer-based systems. In our case, three typical classes of equipment appeared: dataloggers, PC's and minicomputer based instrumentation. The choice of equipment was based on several criteria:

5.2. Interfacing of sensors and instruments

All three systems give good possibilities in connecting the most common sensors. Intelligent instruments may need more sophisticated solutions than a passive datalogger can supply. The number of input points that can be processed varies in all categories.

Many instruments are supplied with standard data interfaces. The system should therefore have the two standard interfaces IEEE-488 (GPIB) and RS-232. This is available in all categories, but more sophisticated systems usually give the user more flexibility in connecting intelligent instruments.

5.3. Multitasking

This feature was needed for several reasons. There was a need for programming and data analysis on the system concurrently with the logging and monitoring process. Some tasks also needed to be programmed independently from the general system, for example using the standard interfaces for special purposes. This was a strong argument for choosing a minicomputer based system.

5.4. Real-time alphanumeric and graphics output

On both PC and minicomputer based equipment, feasible alphanumeric and graphic presentation of input parameters in real time is available. Output of point values, graphic trend analyses and overview pictures are supplied on most computer-based systems. Dataloggers have more restricted possibilities in this respect.

5.5. Configuration and programming effort

The danger of underestimating time and effort in program development is always present. To avoid any delays in the system's implementation, it had to be as close to a turnkey system as possible. Configuration and changes of sensors and processes had to be easy.

5.6. Data storage and backup, history retrieval and presentation

In this baseline study, data are saved continuously over long periods of time. To be able to recall data systematically, it was therefore urgent that sufficient storage capacity with a suitable backup medium, was available. Routines for data storing and retrieval had to be included. Graphic presentation of historical data, with

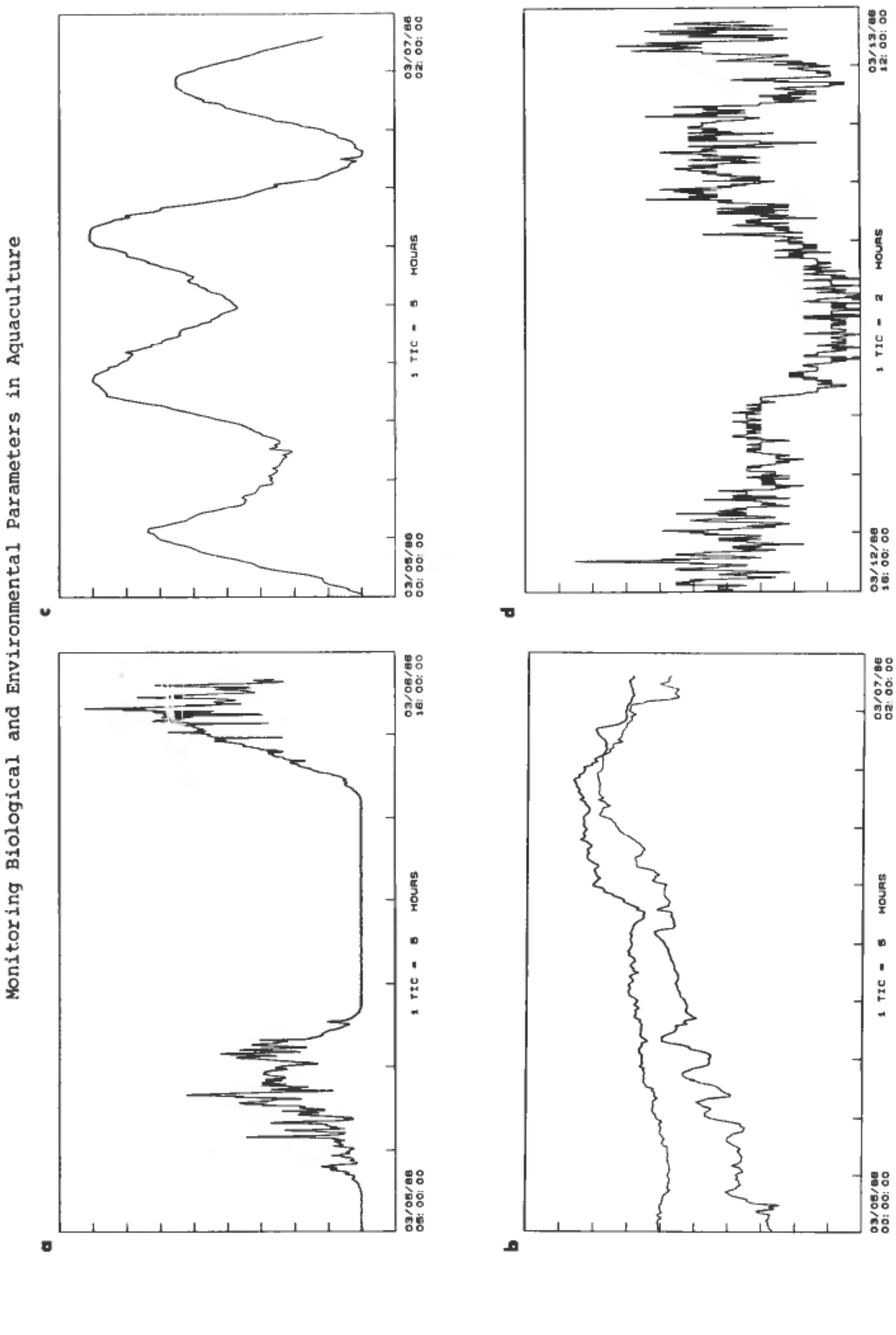

Figure 3. Examples of data presentation for different parameters. (*a*) Surface light, (*b*) Temperature, 0 m/5 m, (*c*) Tidal variation, (*d*) Wind velocity.

adjustable scaling and time intervals, would be preferrable. Historical data should be available to programs written by the user, for statistical analyses etc.

The equipment chosen was an HP-1000 minicomputer with an HP3497A front-end processor. The system fulfilled all of the previously mentioned requirements in addition to having some extra advantages. A software package (PMC/1000) for monitoring and controlling processes made configuration of a monitoring system simple. Front-end points and blocks for treating the input data, i.e. computation-, trend-, alarm- and control blocks, are given names. Further configuration is a matter of linking points and block names together, and assigning values to parameters of the blocks. There are provisions for interfacing with devices other than HP3497A, and to write routines other than those provided by PMC/1000.

5.5. *Preliminary experiences*

The system now functions reasonably well and provides a powerful tool to describe dynamic processes in aquaculture units. A clear representation of changes in the environmental conditions is achieved, (see Fig. 3).

The PMC/1000 software has been updated once since the implementation in September, 1985. The new version has been quite reliable, but some bugs still remain. Some problems with use of historical data files have existed, but this will be fixed in the next software revision. The front-end processor has some features that could have been utilized by the software, but it has been without importance to this project.

Another constraint of the system up till now is continuously recording a sufficiently large number of biological parameters. The environmental parameters are generally automatically logged into HP-1000. Of the biological events, only the jumping activity and the heart rate of a restricted number of fish can be logged directly and the video analysis only gives information from short sample periods. This restricts the total description of the interaction between the fish and its environment. The development of an acoustic system with automatic logging will improve the situation. Use of acoustic tags giving information about the position and swimming activity of the fish is also considered.

Acknowledgments

We would like to express our thanks to Norsk Hydro A/S for financial support and to the following suppliers of sensory equipment, who have kindly supported the project with the different sensors on a loan basis: Sigurd Sørum A/S, Endress & Hausser, Bergen Nautic, Thorolf Gregersen and Aanderaa Instruments.

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