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**A. Bergheim, M. Gausen (OSV), A. Næss (OSV),
J. Ravndal (EWOS), P. M. Hølland (EWOS), P. Krogedal
(EWOS), V. Crampton (EWOS) & Å. Molversmyr**

Hydrographical monitoring emphasising dissolved oxygen at EWOS Innovation Oltesvik 2003

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Preface

The sampling program in 2003 represents a follow-up of the collaboration between OxSeaVision – EWOS Innovation – Rogaland Research established in 2001. RF-Rogaland Research is engaged to manage and conduct several projects aimed to contribute to optimise the OxSeaVision (OSV) concept for injection of oxygen in salmonid cages.

At the site in Oltesvik, the following EWOS employees have played a vital role in collecting data, inspecting measuring equipment, daily management, etc:
Bjørg Bjelland, Arne Oltedal and Kjetil Frafjord.

Besides, Drs. Viv Crampton and Paul Williams, managers at EWOS Innovation, are important decision makers, especially in the planning process.

Åge Molversmyr, senior researcher at RF, has been involved in the sampling and processing of hydrographical data.

The project is financially supported jointly by EWOS Innovation and The Research Board of Norway (NFR) through the SkatteFUNN program.

Troels G. Jacobsen, research director at RF, has quality ensured the report.

This report is based on a huge amount of hydrographical and biological data which can be provided from RF by request.

Stavanger / Bergen, 20 March 2004

Asbjørn Bergheim, project leader

Contents

Summary

This report describes monitoring of hydrographic conditions and salmon performance at EWOS Innovation Oltesvik in 2003. During the period March – October, dissolved oxygen (DO) and other linked parameters were continuously monitored outside and within cages stocked with salmon of 1 – 4 kg transferred to sea as smolt in spring 2002. The fish stock was badly influenced by high temperature and occasionally low DO concentrations in September – October 2002.

From 11 June until start starvation in mid-October, three cages were added oxygen. DO concentrations, fish growth and feed utilisation were compared between cages added oxygen and reference cages (two cages without oxygen addition). Besides, feed consumption was measured on an hourly – daily basis in all five cages and these results will be presented in another report.

Typical episodes of rapidly reduced DO concentration and increased salinity at 3 – 5 m depth were observed several times due to estuarine circulation. Such DO drops are normally lasting for some hours or a few days and seem not to hamper the appetite and growth of the fish if the episodes do not occur frequently.

Compared to the previous year, 2002, the temperature last year was moderate with levels above 20 °C at 3 – 5 m depth only lasting for a few days in mid-August.

Frequently reduce DO concentrations below 80 % of saturation outside the cages were not observed before the second half of August. Oxygen was injected at 80 – 85 % of saturation (set-point) and the DO level was increased on average 5 – 10 % of saturation in August – October and the frequency of concentrations below set-point was strongly reduced.

In the oxygenated cages, the fish stocks proved an increased growth rate of around 10 % compared with the reference cages without oxygen addition. At slaughtering, the improved growth resulted in ca. 280 g higher average weight. The better growth amounts to ca. 5.5 tonnes higher biomass at slaughtering in a cage stocked 20,000 fish. At the existing price level, the increased biomass represented ca. 120,000 NOK higher revenue per cage, while the costs of the totally added oxygen came to ca. 20,000 NOK per cage. No calculations have been made on other costs such as capital equipment, rental of equipment or extra management time.

Further improvements are needed and episodic over-supply and strong DO super-saturation should be eliminated. Since 2002, the control of the oxygen addition has however been clearly improved.

1 Introduction

Little data are available describing hydrographical conditions on salmon cage localities. Besides, monitored hydrographical conditions on one cage locality can not indiscriminately be transferred to another locality. At most fish farms, such monitoring is confined to daily measuring of temperature, while some farmers also conduct supplementary measuring of salinity. Oxygen meters are rather difficult to maintain and calibrate, and thus dissolved oxygen (DO) data are often unreliable. Consequently, the existing hydrographical data at the major part of the fish farms are current temperature on one or a few spots, sporadic salinity data and more supplementary data of temperature, salinity and DO carried out by the regular veterinary.

Several farmers are however getting more aware of the risk of unfavourable conditions in the cages (e.g. low DO at high temperature and reduced water exchange). There is a growing interest for purchasing equipment for expanded monitoring of environmental parameters (Storebø, Aanderaa Ltd, personnel communication).

At The Norwegian Institute of Marine Research, a new and unique tool to answer question about environmental and husbandry influences on fish welfare has been established. The 'Cage-environment laboratory' has a basic set-up of six 15 m deep cages where behavioural and environmental screening can be carried out with high resolution in time and space in all cages. This includes vertical profiles of oxygen-levels, temperature, salinity, light, pH, and turbidity controlled by programmable winches, as well as vertical water current profilers. Swimming behaviour (speed, depth, fish density, group structure) and physiological parameters of both individuals and groups are monitored simultaneously by a range of different methods. Recently, a project on the effect of fish density and biomass on environmental factors and production parameters was conducted, but data analysis is not yet completed (Jon-Erik Juell, personnel communication).

Centre for Aquaculture Competence AS (CAC) has recently established an advanced cage based research facility in site Langavik in Ryfylke (Tor André Giskegjerde, personnel communication). The environmental conditions are continuously recorded by sensors for temperature, salinity, light intensity, dissolved oxygen and current velocity. Besides, the climatic conditions are recorded in a local weather station. The site is further equipped with 30 cameras (both submerged and above the surface).

Former monitoring of hydrographical parameters both at EWOS Innovation's cage sites Oltesvik and Grotnes is reported by Bergheim *et al.* (2001, 2003) and Crampton *et al.* (2003). These sites are situated in a typically stratified fjord with a brackish water layer at the surface (15 – 25 ppt salinity) and deeper layers with higher salinity (> 30 ppt salinity). Continuous monitoring in the fairly unstable layer at 3 – 5 m depth often indicates rapid changes in salinity and temperature. Consequently, dissolved oxygen (DO) fluctuates considerably, especially at distinct up-welling episodes of high-saline water low in oxygen.

In late summer – early autumn, the risk of critical DO concentrations in salmonid cages at high temperature (> 15 °C), high fish density and low current velocity is cresting. During the extremely warm period in August – September 2002, an early morning DO deficit *outside* the cages in Oltesvik as low as 50% of saturation at about 20 °C was measured, i.e. 3 – 4 mg DO/L. Diurnal fluctuations between 100 and 50% of saturation were monitored until mid-October. As a result, the salmon smolt stocked in spring (2002) suffered from high mortality (e.g. 5000 dead smolt in one week) and significantly reduced growth.

In the same period (18 – 28 September 2002), low DO concentrations were monitored in salmon cages at Farm Lingalaks situated in Hardangerfjord SE of Bergen (Bergheim *et al.* 2003). Oxygen injection by an OxSeaVision NetOx unit effectively increased the within-cage DO saturation from below 60% to above 100% of saturation. Injection of oxygen in salmon cages (NetOx) exposed to critical DO drops in British Columbia 6 – 16 October 2002) increased the average DO level by ca. 10%. The supply of oxygen was insufficient due to limited number of oxygen cylinders at the site. Nevertheless, the oxygen injection obviously increased the fish's appetite compared to in cages with no injection.

Reduced DO concentration lasting for a certain time strongly affects the growth and feed utilisation in salmonids (Pedersen, 1987). This was demonstrated in a study conducted at EWOS Innovation Dirdal in spring 2002: even at low temperature (8 - 9°C), growth rate and feed utilisation in adult salmon were significantly reduced at DO saturation < 65% compared with DO saturation > 80% (Bergheim *et al.* 2002). Another DO deficit test is planned at higher temperature in a new facility in Dirdal.

This report describes hydrographical monitoring at EWOS Innovation Oltesvik from March until October 2003. The monitoring includes temperature, salinity, DO and current outside the cages and monitoring of DO and temperature within cages with or without oxygen injection.

Since June 2003, similar monitoring has taken place in salmon cages at EWOS Lønningdal (project manager: Per Krogedal). The approach of the on-going projects in Oltesvik and Lønningdal is the same (effects of DO injection by the NetOx system) and the findings will be jointly assessed in a future summary report.

1.1 Justification

The objectives of this year's sampling were the following:

- To obtain more consistent data of the fluctuation of temperature, salinity, flow velocity and ambient DO on cage sites, especially in late summer – early fall
- To document the effects of oxygen injection on DO concentration and on fish production in cages
- To assess the relation between appetite of the fish stock and the cage environment, emphasising DO

2 Material and methods

2.1 Measuring equipment

The following equipment was used:

Aanderaa sampler:

Model RCM 9 Mk II. The instrument combines RCM Doppler Current Sensors and sensors for Temperature, Conductivity, Pressure and Oxygen measurements. The current is measured in the area from 0.4 to 2.2 m from the instrument which minimises the effect of marine fouling and local turbulence. This unit was used for continuous monitoring outside the cages.

The instrument records data internally in a removable and reusable solid-state Data Storage Unit (DSU 2990). A built-in quartz clock triggers the measuring cycle at regular, programmable intervals. A basic sensor configuration is:

Ch. 1	Reference (a control and identification reading)
Ch. 2	Current speed (range: 0 - 300 cm/s, accuracy: 1 % of reading)
Ch. 3	Current direction (accuracy: ± 5 - 7.5°)
Ch. 4	Temperature (range: - 2.7 – 32.9 °C, accuracy: ± 0.05°)
Ch. 5	Conductivity (range: 0 –74 mS/cm, accuracy: 0.2-0.8 % of range)
Ch. 6	Pressure (range: 0 – 700 kPa, accuracy: ± 0.1 % of range)
Ch. 7	Turbidity (not connected at sampling)
Ch. 8	Oxygen (range: 0 – 20 mg/L, accuracy: ± 0.8 mg/L)

Stored data is read by connecting the DSU 2990 via a reader unit (DSU Reader 2995) to a computer. For further reading, see the Operating Manual from Aanderaa Instruments (www. aanderaa.com).

WTW Network

A profibus network from WTW was installed for monitoring of DO, temperature and salinity within and outside cages. Totally, 10 sensors were connected to the system: six sensors combining DO and temperature and four sensors combining salinity and temperature.

DO:	range 0 – 600 % of saturation, accuracy 1 %
Salinity:	range 0 – 70 ppt
Temperature:	range 0 – 50 °C, accuracy ± 0.2 °C

The probes were connected to the profibus network through a 20 m cable and junction boxes.

Data were logged in the junction cabinet of the profibus network. This was also connected to a PC through the PLC system. When the system is running, the operator has full control of real values from the sensors on his desk top.

All DO probes (model: TriOxmatic 700 IQ) were calibrated and cleaned following the provided procedures on a weekly – biweekly basis. Occasionally, DO probe problems caused lost data, e.g. in Cage 4 where no data were collected throughout July.

2.2 Measuring program

2.2.1 Hydrography

Dissolved oxygen (DO) was monitored at 3-5 m depth in the centre of five cages, and on one site outside the cages at the same depth (reference, between Cage 8 and 9, Fig. 1). Salinity was measured at four different depths outside Cages 4 and 5 (Fig. 1). Within the cages, the sampling interval was 30 min while salinity (1, 3, 7 and 14 m depth) was monitored every 15 min.

The Aanderaa sampler, not marked in Figure 1, was placed outside Cage 9 and 10 at 4 meter depth. Sampling frequency: 30 min.

Due to technical problems, such as logging errors, measuring results are periodically lacking.

Total sampling program:

Location/system	**Parameters**
Outside cages:	
Aanderaa sampler	Temperature, Salinity, DO, current velocity and direction
WTW (reference locality)	Temperature and DO
WTW (vertical profile)	Temperature and salinity
Within cages:	
WTW (Cage 4, 5, 8, 9, 10)	Temperature and DO

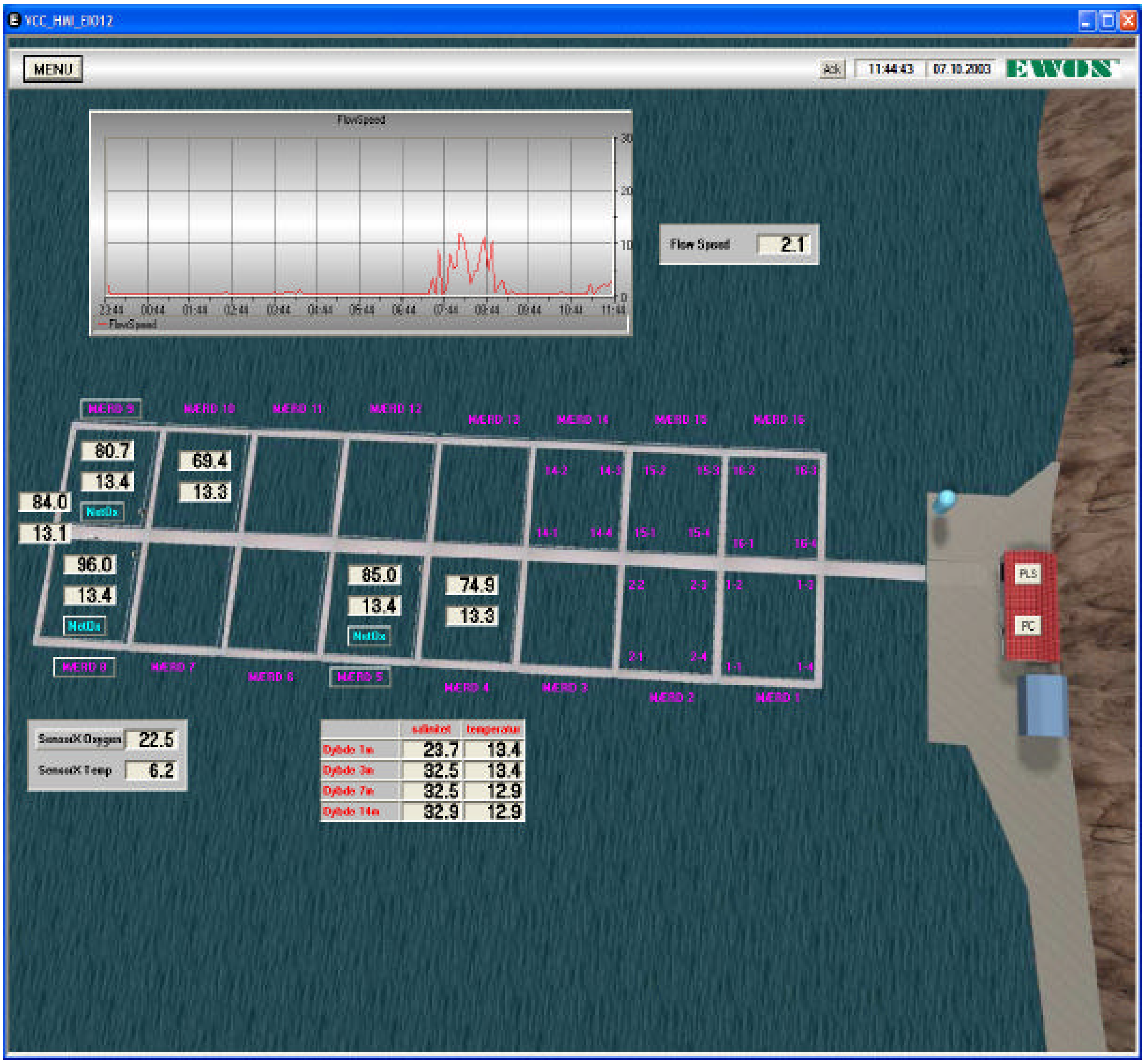


Figure 1. EWOS Innovation Oltesvik with 16 cages (15 x 15 m). Oxygen injection by NetOx in Cage No. 5, 8 & 9. Readings on PC at 11:43 am, 7 October 2003.
WTW Network for monitoring of DO and temperature within Cage No. 4, 5, 8, 9 & 10 (DO: 69.4-96.0 % of saturation, temperature: 13.3-13.4 °C) and outside cages (DO: 84.0 % of saturation, temperature: 13.1 °C).
Monitoring of salinity and temperature (WTW) at four depths outside Cage No. 4 and 5 (1, 3, 7 & 14 m, salinity: 23.7-32.9 ppt, temperature: 12.9-13.4 °C). Flow speed (graph at the top) monitored at 3 m depth

2.2.2 Oxygen injection

For oxygen injection into fish cages at reduced oxygen saturation, a system developed at the company OxSeaVision was used. This patented system, NetOx, was installed in three cages (Cage 5, 8 and 9) at a depth of 5 or 8 m. The system consists of about 80 m of special hoses per cage (perforated with 2 400 holes per m), dispersing oxygen into the sea water. The oxygenation system was connected to and controlled by the same profibus network as the sensors for monitoring of DO, salinity and temperature. When the DO concentration in the cage drops below the preset level (i.e. 80 – 85% of saturation), a regulator valve will open for oxygen addition. In other words, the oxygen addition is individual for each cage.

The rate of the oxygen supply to the specific cage can be read on a meter and is continuously logged.

Addition of oxygen was initiated on 11 June and continued until 17 October. Due to problems with power supply (stormy weather), etc., the injection was occasionally off. Power failure also caused uncontrolled oxygen supply a couple of times (e.g. 29-30 June). Such technical errors were however repaired during a few hours or days.

To ensure better control of oxygen dosage and logging of oxygen concentrations, improved power supply and network cable from ashore to the cages are needed.

2.2.3 Fish stock

A total number of 184,000 Atlantic salmon smolt, breed line NLA, was produced at EWOS Innovation Dirdal and put into sea at Oltesvik on 29 April 2002. The average weight at stocking was 82 g. On 19 November 2002, the fish stock was distributed in seven cages and the average weight was 655 g. Five of these cages were then selected for the present trial (Cage No. 4, 5, 8, 9 and 10, Figure 1). The cages were square-shaped, 15 x 15 m, and 20 m deep.

At start monitoring of oxygen, the average size of the fish was lower than usual after 10 months in sea. A very high temperature and low and fluctuating oxygen concentrations in August – September 2002 resulted in low growth and enhanced mortality.

The fish size was estimated by measurement of 200 random sampled fish from each cage a couple of times in spring 2003. Fish was crowded in the cage and lifted with a landing net to a tank for anaesthetizing. After individual weighing (± 5 g) and fork length monitoring (± 0.5 cm), the fish was released in the cage. The weight sampling on 2 June was basis for the estimated growth and feed utilisation until harvest in the five cages.

On 27 August, the fish size was estimated by the use of an AkvaSensor Vicass (Video Image capturing and Sizing System). The validity results achieved fluctuated from one cage to another due to technical problems and thus the results are not used for further calculations of fish growth.

In early June, before starting the oxygen injection in the cages, the biomass and average fish size in the cages were the following (Table 1):

Table 1. Biomass, average fish size and density in five cages at EWOS Innovation Oltesvik on 2 June 2003.

Criterion	**Cage 4**	**Cage 5**	**Cage 8**	**Cage 9**	**Cage 10**
Injection of oxygen	No	Yes	Yes	Yes	No
No. of fish	20,682	15,741	18,609	19,042	21,636
Average weight, g	1, 707	1,757	1,698	1,898	1,729
Biomass, tons	34.3	27.7	31.6	36.1	37.4
Density, kg/cu. m	9.2	7.2	8.3	9.4	9.8

2.2.4 Calculations

Specific growth rate:

SGR (%/day) = $[(\text{Ln } W_2 - \text{Ln } W_1)/(t_2 - t_1)] \times 100\%$, where W_2 and W_1 are mean weights at end and start, respectively. $t_2 - t_1$: number of days from start till end of trial.

Feed conversion ratio:

FCR (kg/kg gain) = S F/($B_2 - B_1$), where S F is total feed quantity supplied (period: $t_2 - t_1$) and B_2 and B_1 are total biomass at end and start, respectively

Further calculations (weight samplings: mean weights, variations, CF, etc) can be provided by request.

3 Results

3.1 Hydrography

The hydrographical conditions outside the fish cages from December 2002 until mid-October are presented in Table 1. Besides, the conditions during March – October are presented in Figures (Figs. 2, 4a & b, 6, 7, 10 and 11).

Due to estuarine circulation and up-welling of high-saline deeper water, several episodes of sudden DO drops from saturation level down to 25 – 60% of saturation were observed outside the cages (for example 10 – 14 April, 24 June, 12 July). Despite episodic drops, the average DO concentration outside the cages remained above saturation level from March till end of August (Table 1). In September – October, the average DO saturation was 85 – 90 %.

The temperature at 5 m depth peaked during the period 8 – 18 August with 19 – 20.4 °C, but then steeply dropped. Temperature changes of 6-7 °C within a few hours are not uncommon in brackish water fjords.

In spring, the DO concentrations in the cages were mainly about saturation level and remained above 80 % until late June at increasing temperature (Figs. 3 and 5). The DO levels in the cages were infrequently below the set-point of the oxygen injection (80 – 85% of saturation) till the end of July and thus only minor differences in DO levels between cages were observed in this period (Fig. 8). A DO drop below 50% of saturation in Cage 9 lasting for several days (18 – 21 July) was apparently not compensated for by oxygen injection (probe error?).

The situation throughout August was characterised by moderate short-lasting DO drops in Cage 4 and 10, without oxygen supply, and strongly fluctuating and temporarily DO super-saturation in the oxygen injected cages, nos. 5, 8 and 9 (Fig. 9). The frequent over-supply of oxygen was partly due to reduced control of the system during the summer holiday.

Any clear indications of higher DO concentrations because of oxygen injection were not observed before week no. 34 – 36 (Table 3, Figs. 12 and 13). Until harvest, the average DO concentrations were increased by 5 – 10% in the oxygen added cages. The frequency of DO concentrations below set-point for oxygen addition (80-85%) was significantly reduced in Cage 9 compared to in Cage 10 (Fig. 13).

During 28 September, DO concentrations in Cage 9 and 10 are presented together with the measured oxygen quantity injected in Cage 9 (Fig. 14). The major supply (ca. 8 kg oxygen per 30 min) took place between 5 - 12 am coinciding with reduced DO concentration level in Cage 10 (55 – 75 % of saturation). Another peak oxygen supply occurred in the afternoon at about 9 pm when another DO drop was observed in the parallel cage without oxygen supply. Throughout the day, a clear covariance was found between oxygen supply and DO concentration. The DO concentration was reduced 10 – 30 % of saturation by the fish stock from outside (Reference) to inside Cage 10.

Irregular current conditions, varying position of the fish stock in the cage, etc complicate an estimate of the needed oxygen supply to increase the DO level in the cages, i.e. by 5% (Figure 14). In Cage 9, an injection of 16 kg oxygen per hour seemed to increase the DO concentration from 55 – 65% of saturation to about the set-point level (85% of saturation).

Table 2. Hydrographic monitoring at 5 m depth outside fish cages, EWOS Innovation Oltesvik, December 2002 – October 2003. 24 February – 22 March: sampler off for maintenance and repair. Monitoring frequency: 30 minutes.

Period	**Temperature, °C**		**Salinity, ppt**		**DO, % of saturation**		**Current velocity, cm/s**		**No. of monitoring**
	Mean	**Percentile (90 – 10 %)**	**Mean**	**Percentile (90 – 10 %)**	**Mean**	**Percentile (90 – 10 %)**	**Mean**	**Percentile (90 – 10 %)**	
17 December 02 – 24 February 03	5.43	7.71 – 4.01	32.2	33.7 – 31.0	-	-*	2.54	4.69 – 0.88	3311
22 March – 22 May	6.14	7.15 – 4.75	31.4	32.4 – 29.9	118.1	133.4 – 104.3	2.59	4.40 – 0.88	2827
22 May – 3 July	10.5	13.1 – 7.51	29.2	31.2 – 26.4	107.5	124.0 – 89.2	2.32	4.11 – 0.88	2016
3 July – 7 August	15.4	18.8 – 11.4	29.3	30.7 – 28.0	102.4	117.8 – 85.0	2.27	4.00 – 0.88	1298
7 – 28 August	17.2	20.0 – 10.1	29.7	32.1 – 28.1	105.5	123.9 – 81.0	2.15	3.81 – 0.59	624
28 August – 19 September	14.1	16.1 – 11.1	30.7	32.1 – 29.0	89.8	105.3 – 76.0	2.10	3.81 – 0.88	1438
20 September – 17 October	14.1	15.9 – 12.5	29.6	31.5 – 27.1	85.6	97.9 – 73.8	2.04	3.52 – 0.59	1342

*: measuring error

Table 3. Monitoring of dissolved oxygen in five cages and outside cages (Reference) at EWOS Innovation Grotnes 9 August – 17 October 2003. Sampling depth: 3 m. Monitoring frequency: 30 sec. Unit: % of saturation

Period	**Cage 4 (without O_2 injection)**		**Cage 5 (with O_2 injection)**		**Cage 8 (with O_2 injection)**		**Cage 9 (with O_2 injection)**		**Cage 10 (without O2 injection)**		**Reference (outside cages)**	
	Mean	**90 – 10% percentile**	**Mean**	**90 – 10% percentile**	**Mean**	**90 – 10% percentile**	**Mean**	**90 – 10% percentile**	**Mean**	**90 – 10% percentile**	**Mean**	**90 – 10% percentile**
9 - 15.08	108	114-101	96	101-90	95	101-89	100	106-92	85	90-79	102	107-96
16 - 22.08	93	99-87	91	99-83	89	98-82	88	100-77	85	98-70	98	108-91
23 – 29.08	92	98-84	92	100-83	88	95-80	89	98-78	89	96-79	100	109-85
30.08 - 5.09	87	95-79	87	93-81	86	92-81	88	97-81	83	93-75	90	99-81
6 – 12.09	89	95-82	94	102-86	90	96-83	88	97-82	82	91-75	95	100-86
13 – 19.09	85	89-79	92	101-84	85	92-78	82	87-74	77	84-69	92	100-85
20 – 26.09	81	85-76	86	92-81	85	95-75	76	86-68	70	79-62	91	99-82
27.09 – 3.10	80	86-73	86	93-78	89	105-77	83	93-75	72	80-62	87	98-77
4 – 10.10	82	90-74	88	98-78	94	113-79	84	94-76	78	90-69	87	98-77
11 – 17.10	83	92-76	83	91-77	82	91-75	79	88-70	79	90-70	88	98-80

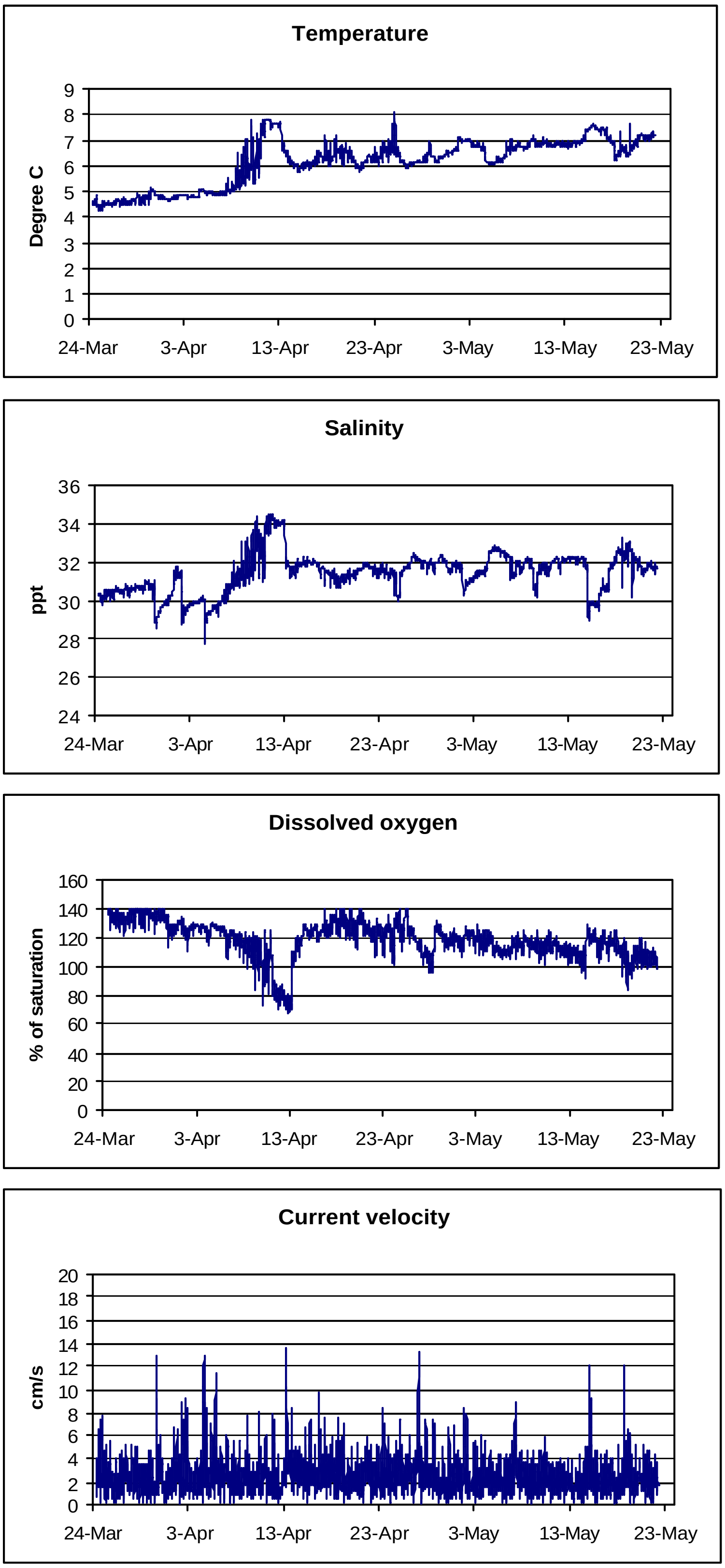


Figure 2. Hydrographic monitoring at 5 m depth outside fish cages, EWOS Innovation Oltesvik 24 March – 22 May 2003. Monitoring frequency: 30 minutes

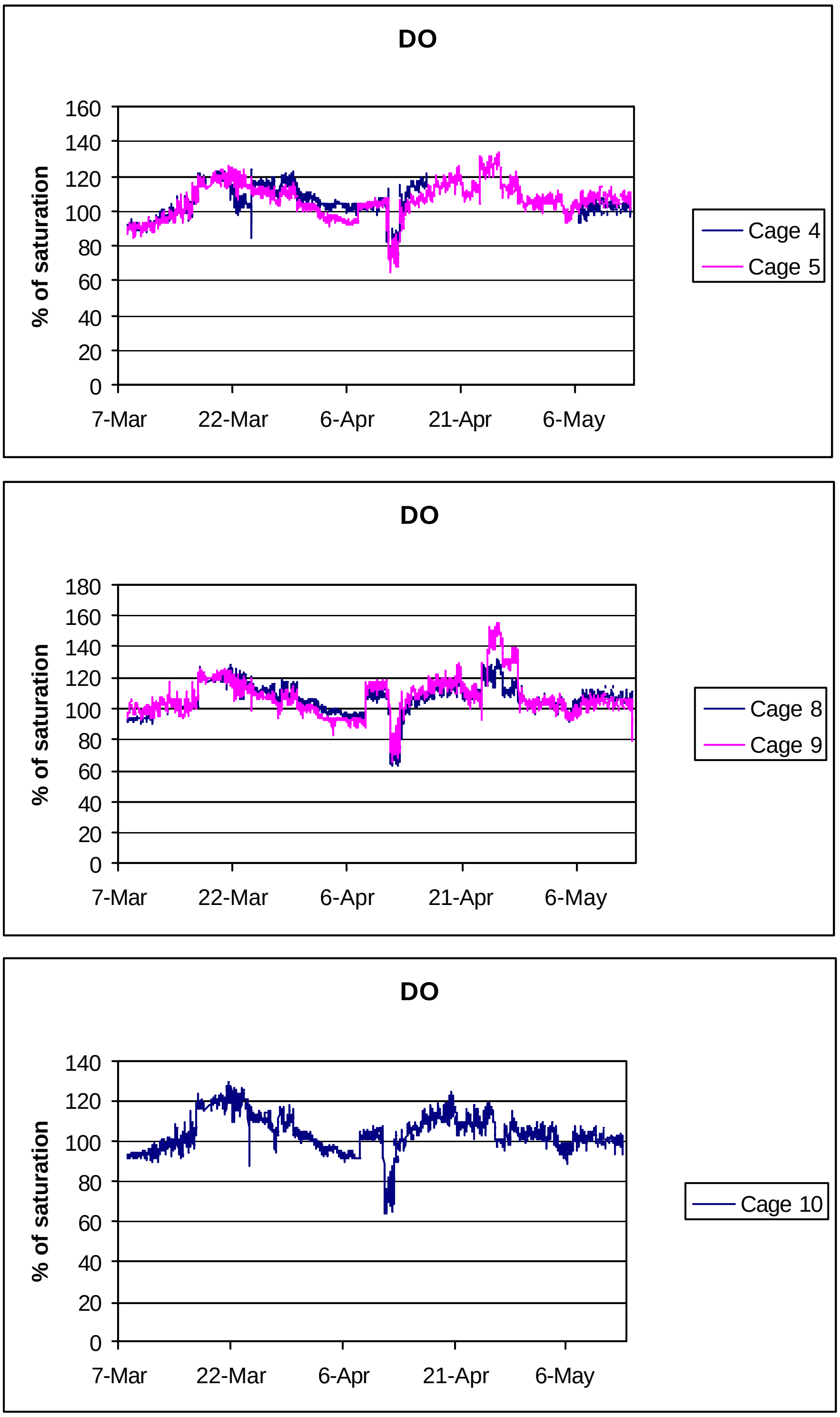


Figure 3. Dissolved oxygen in five cages at 3 m depth, EWOS Innovation Oltesvik, 8 March – 13 May 2003

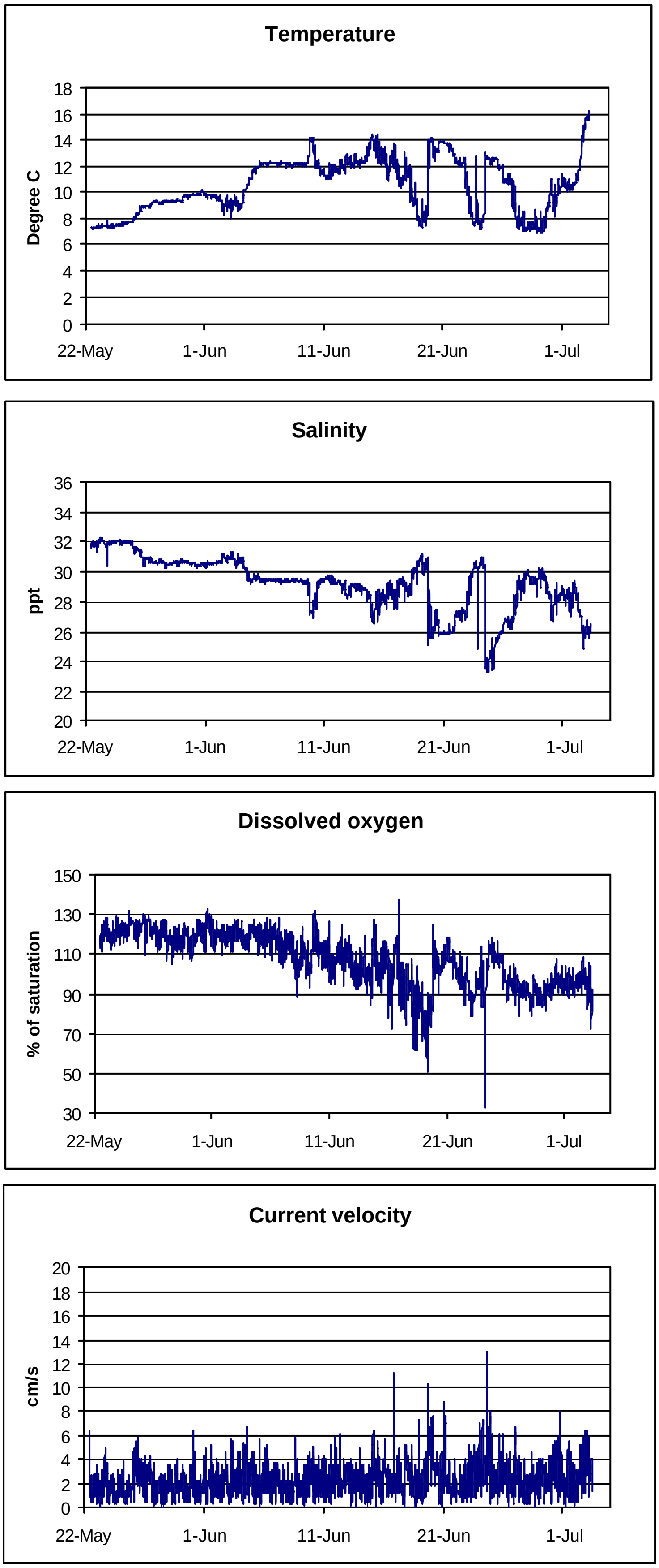
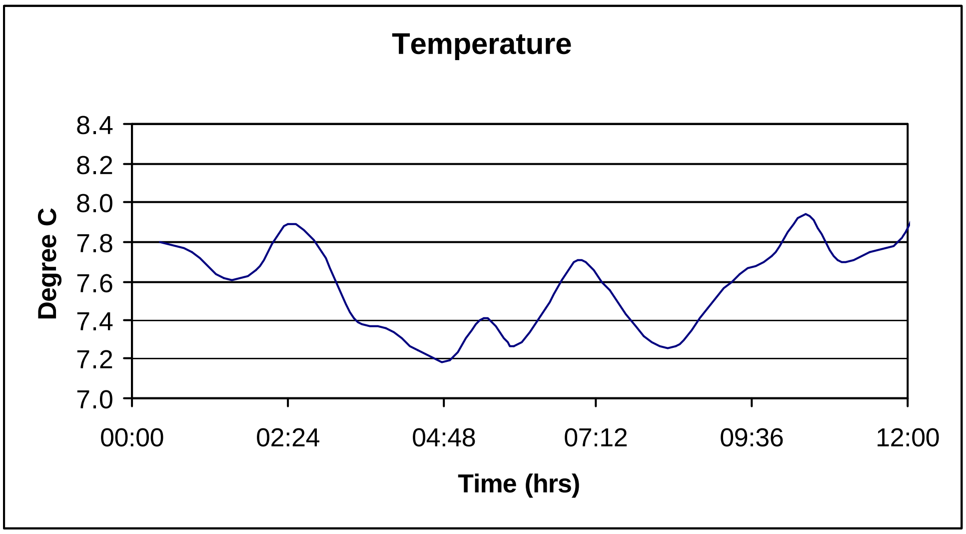
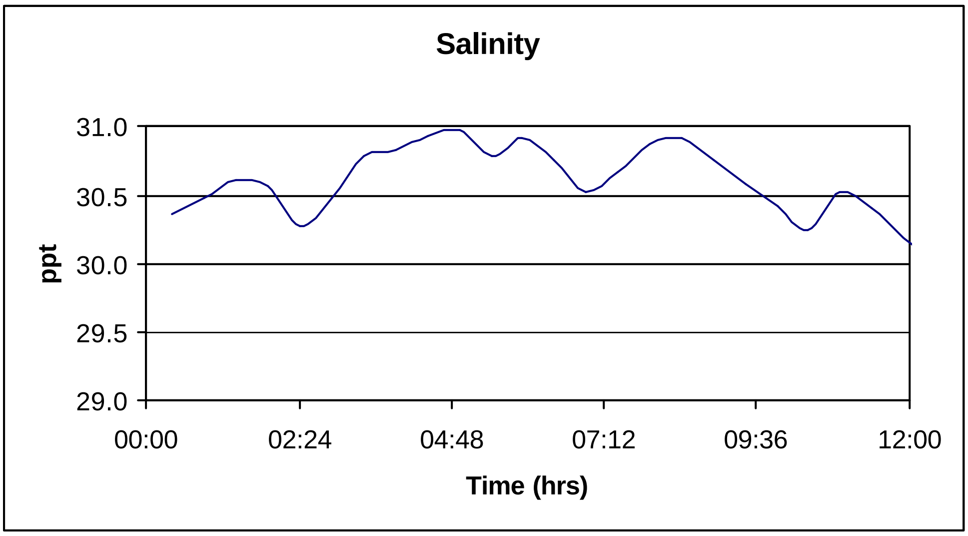


Figure 4a . Hydrographic monitoring at 5 m depth outside fish cages, EWOS Innovation Oltesvik 22 May – 3 July 2003. Monitoring frequency: 30 minutes





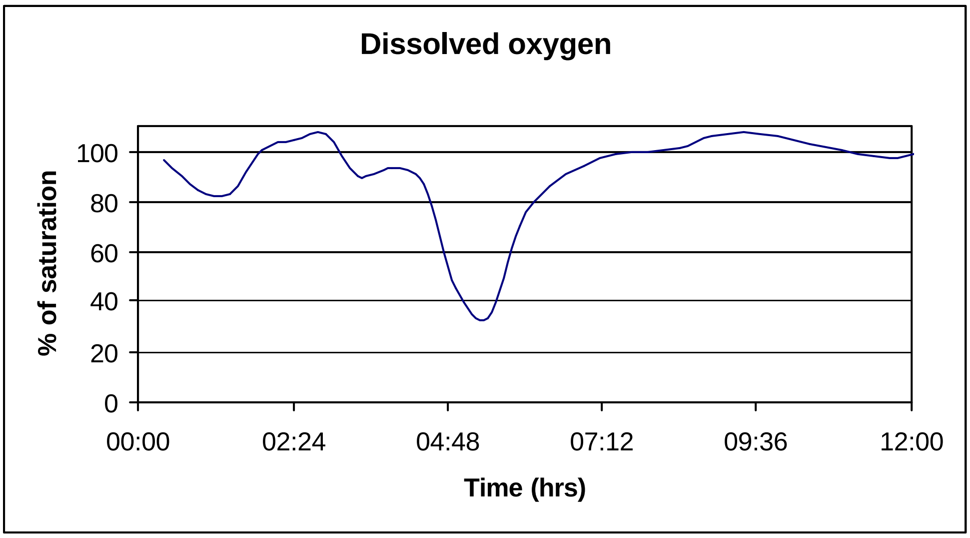


Figure 4b. Episodic dissolved oxygen drop at 5 m depth outside fish cages, EWOS Innovation Oltesvik, 24 June 0 – 12 am. Sampling frequency: 30 minutes

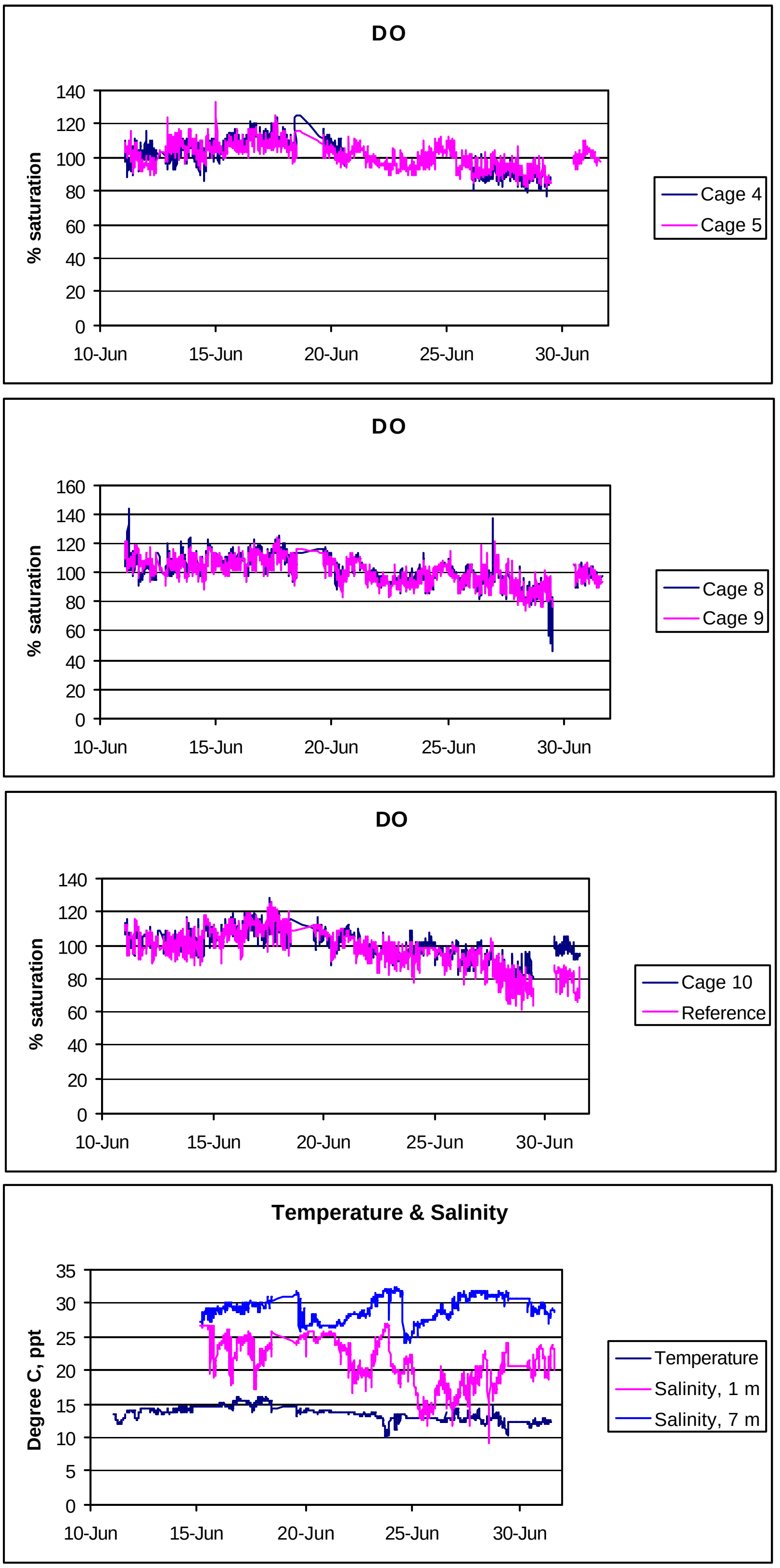


Figure 5. Dissolved oxygen in five cages at 3 m depth, EWOS Innovation Oltesvik 11 June – 1 July 2003. Reference: Outside cages (4 m depth). Temperature (1 m depth) and salinity (1 & 7 m depth)

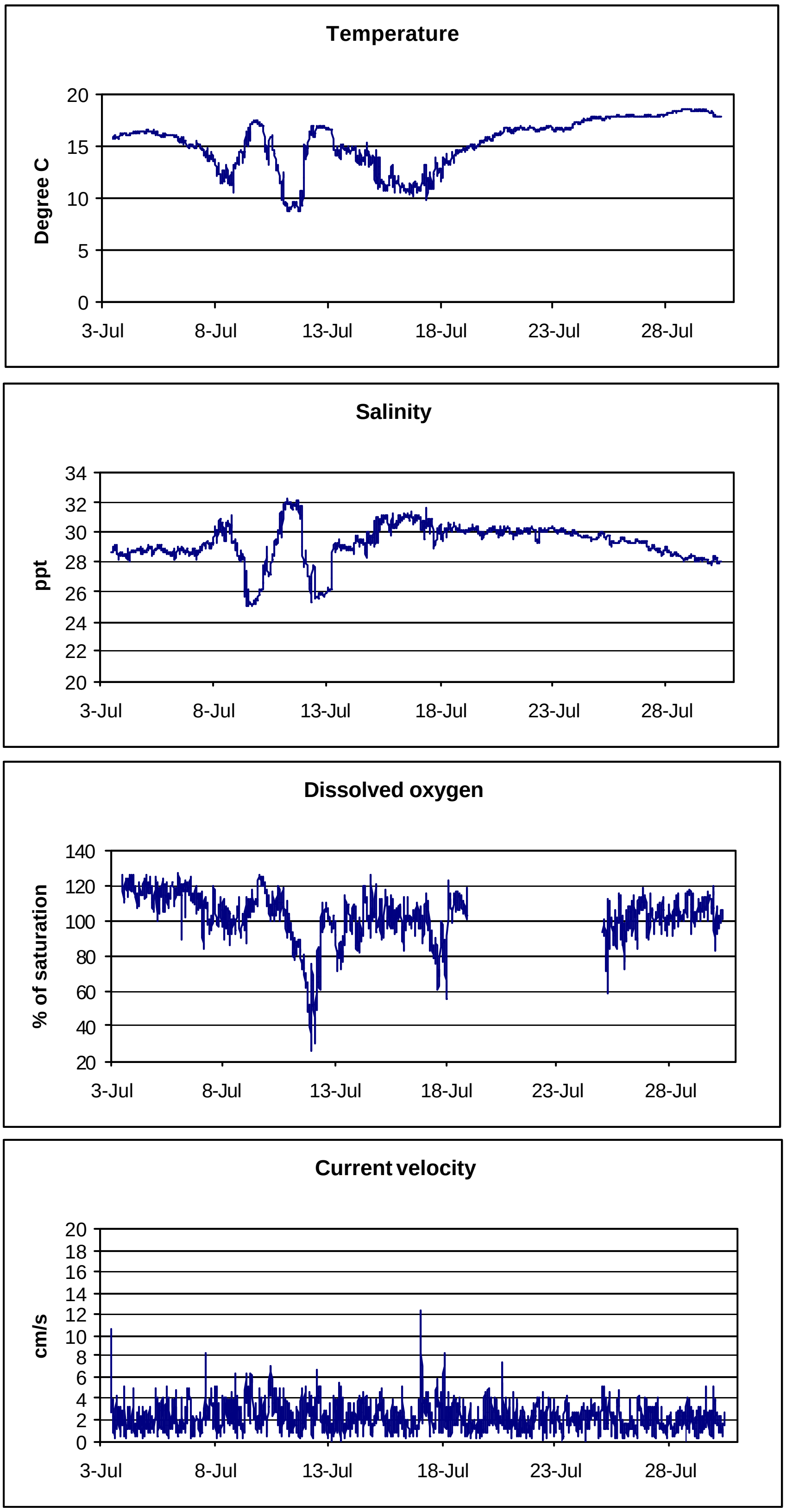


Figure 6. Hydrographic monitoring at 5 m depth outside fish cages, EWOS Innovation Oltesvik 3 – 30 July 2003. Monitoring frequency: 30 minutes

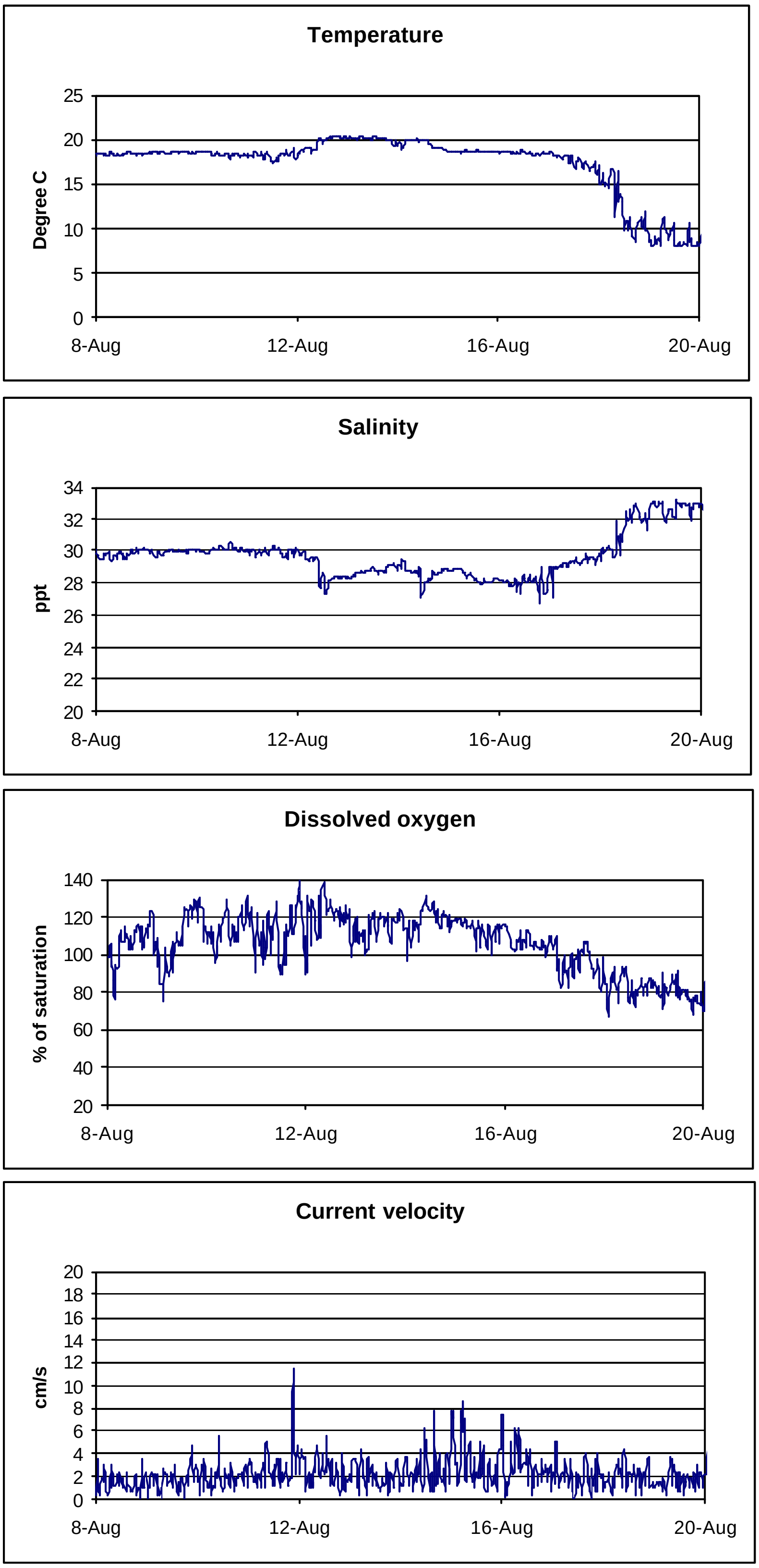
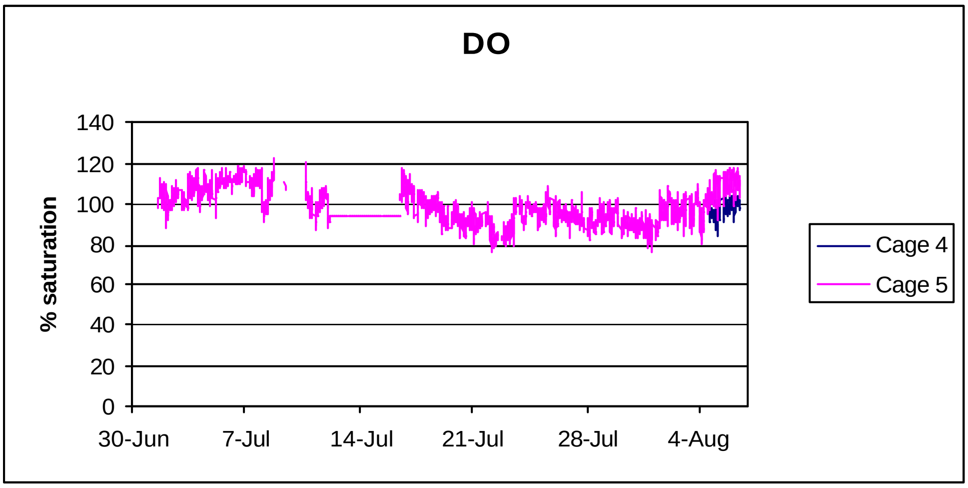
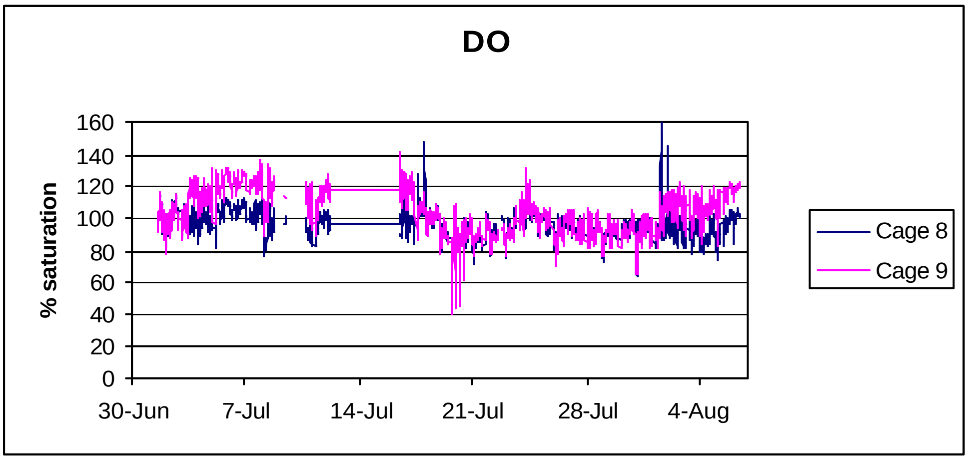


Figure 7. Hydrographic monitoring at 5 m depth outside fish cages, EWOS Innovation Oltesvik 7 – 20 August 2003. Monitoring frequency: 30 minutes





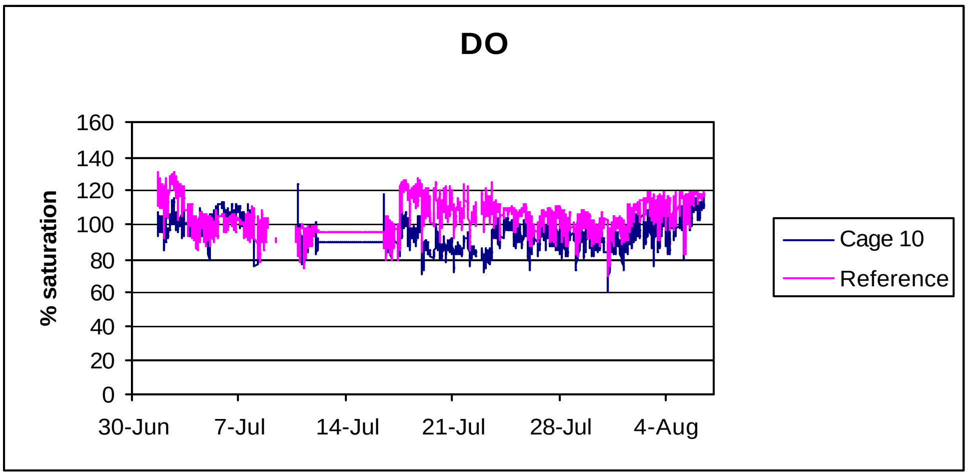


Figure 8. Dissolved oxygen in five cages at 3 m depth, EWOS Innovation Oltesvik 1 July – 6 August 2003. Reference: Outside cages (4 m depth).
No monitoring: 11 – 16 July

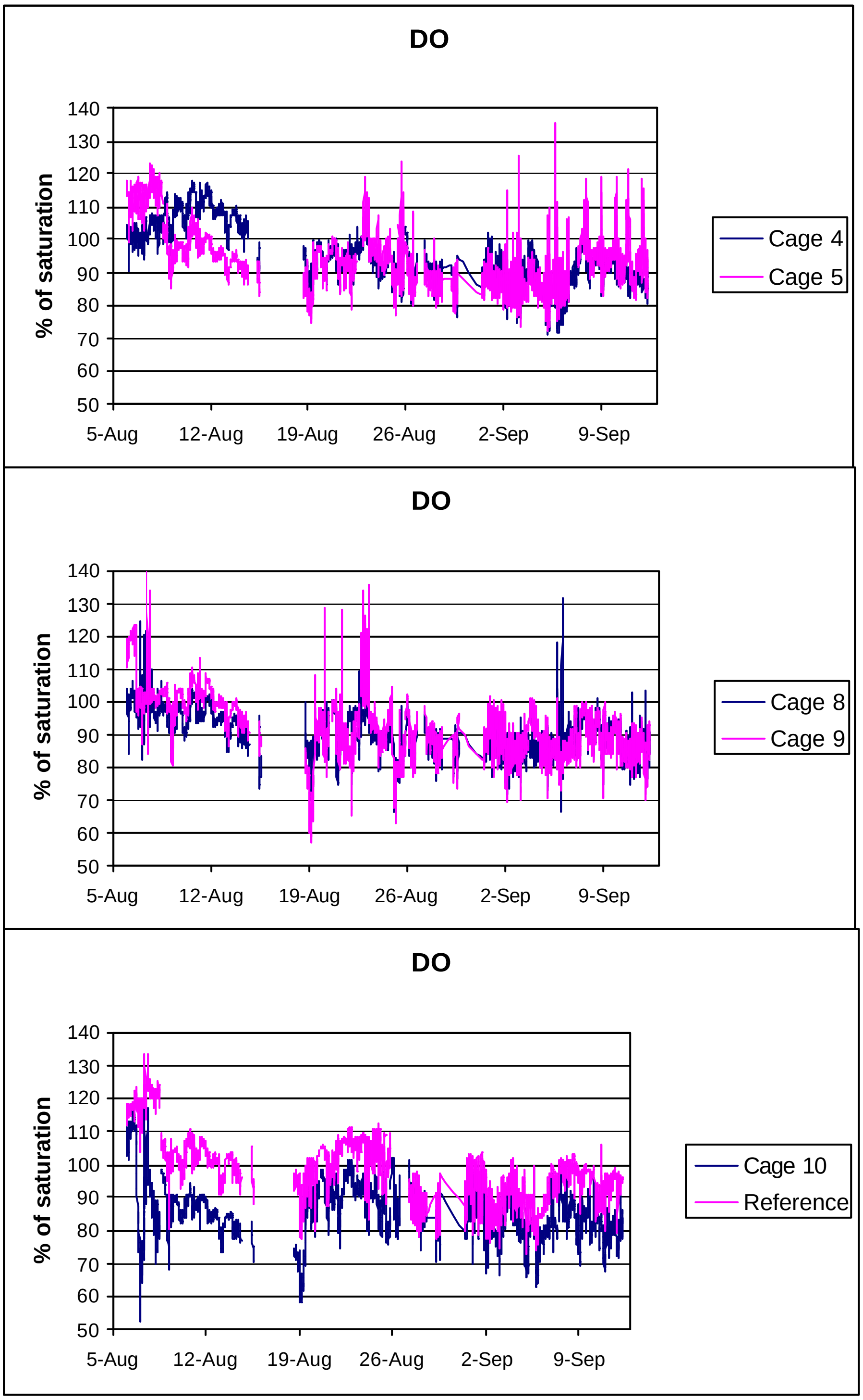


Figure 9. Dissolved oxygen in five cages at 3 m depth, EWOS Innovation Oltesvik 6 August – 12 September 2003. Reference: Outside cages (4 m depth). No monitoring: 15 – 18 August

Cages 5, 8 & 9: oxygen injection

Cages 4 & 10: no oxygen injection

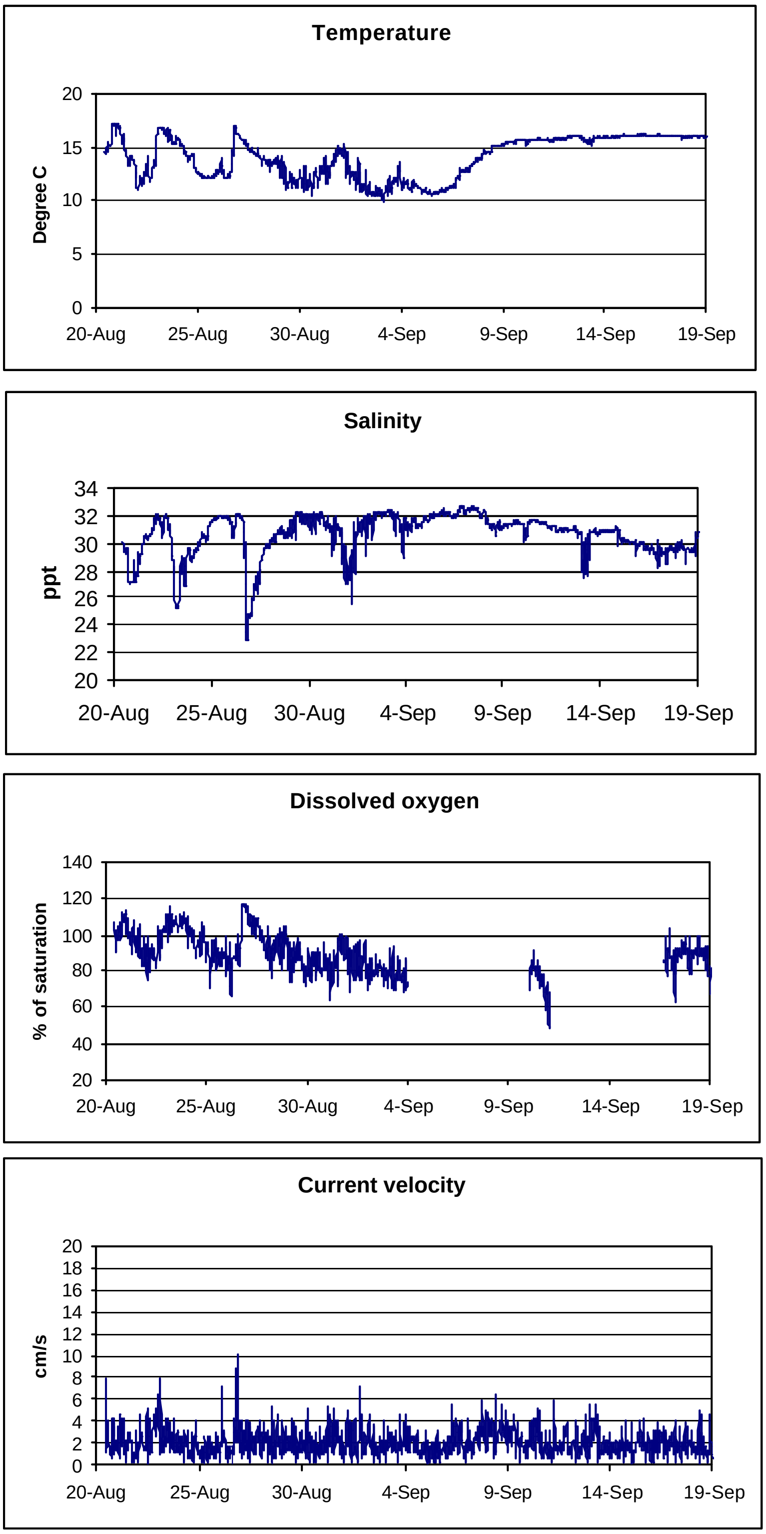


Figure 10. Hydrographic monitoring at 5 m depth outside fish cages, EWOS Innovation Oltesvik 20 August – 19 September 2003. Monitoring frequency: 30 minutes. DO probe error: 4 – 16 September

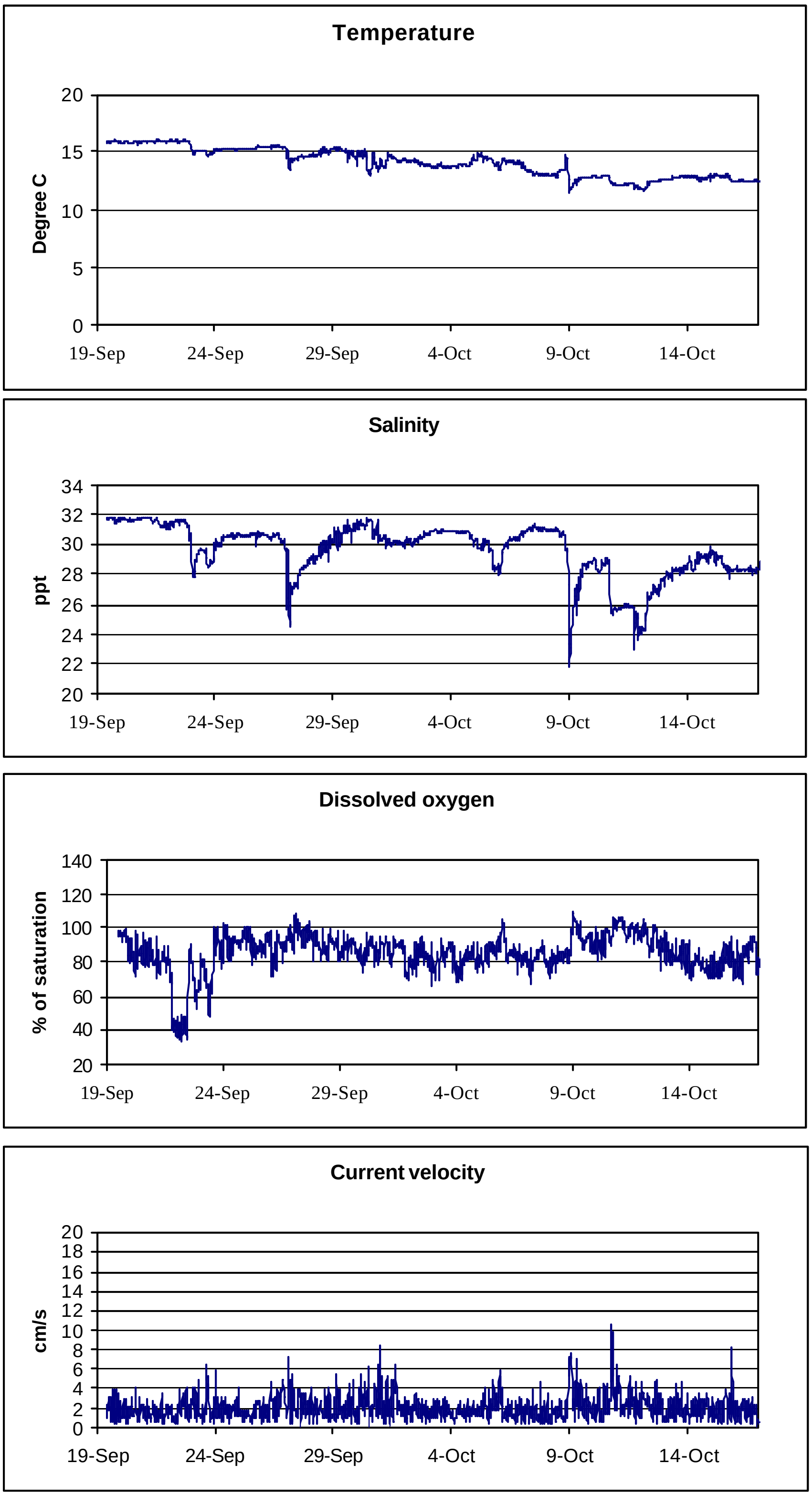


Figure 11. Hydrographic monitoring at 5 m depth outside fish cages, EWOS Innovation Oltesvik 20 September –17 October 2003. Monitoring frequency: 30 minutes.

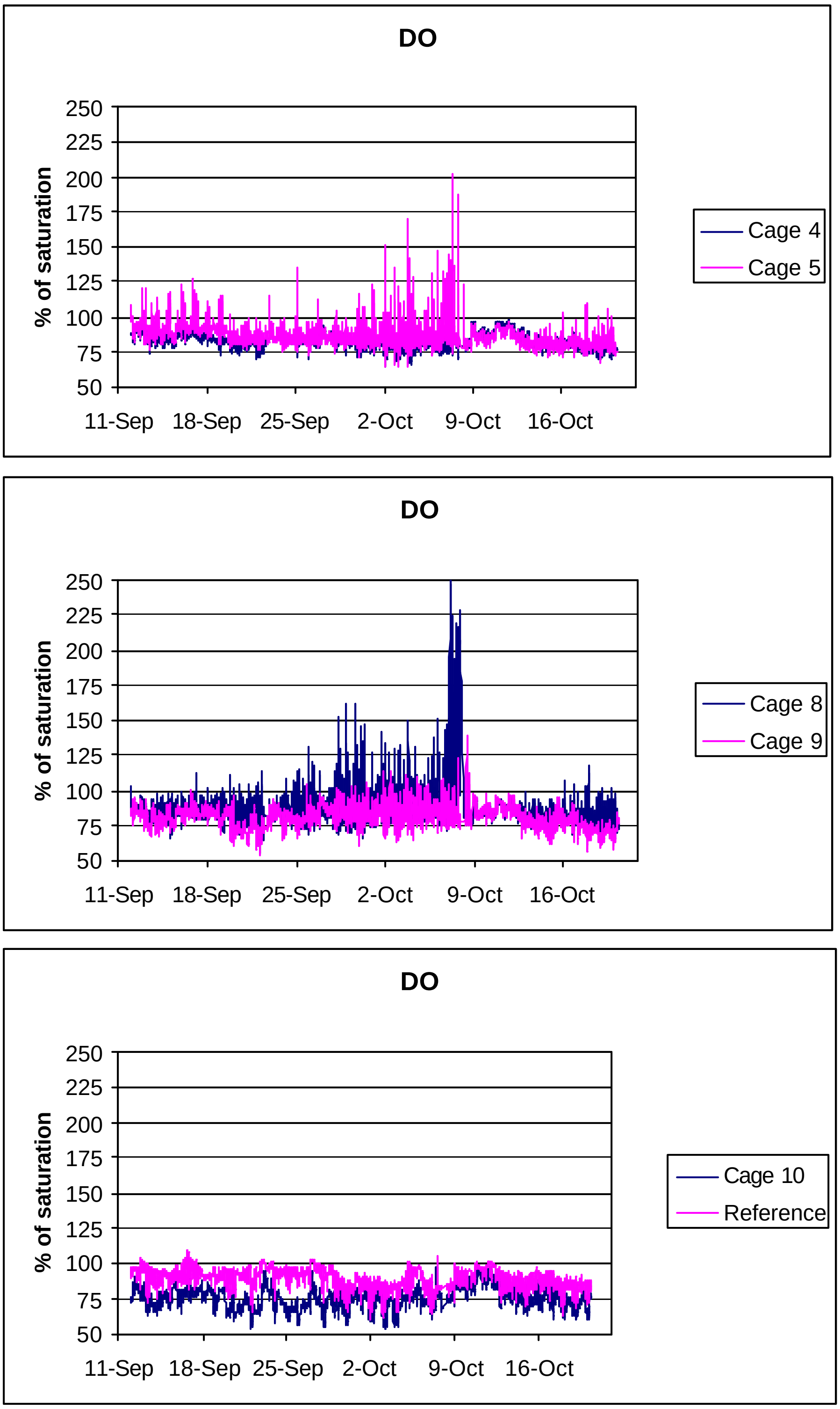
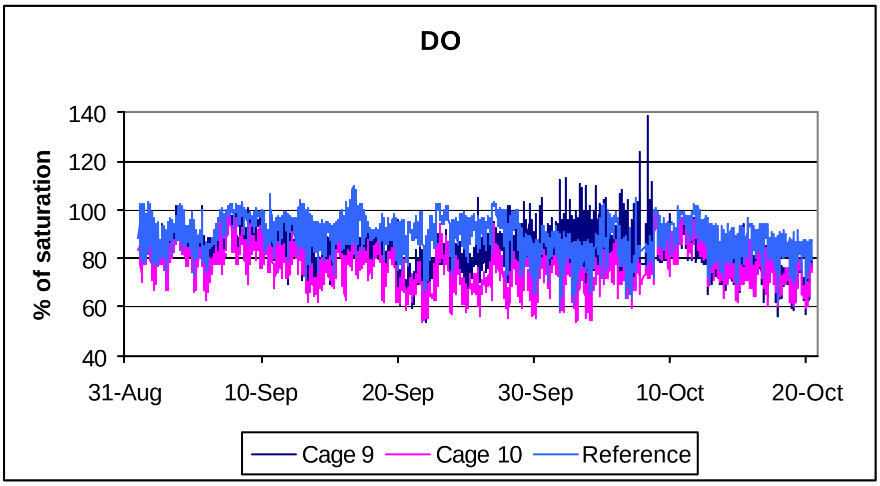


Figure 12. Dissolved oxygen in five cages at 3 m depth, EWOS Innovation Oltesvik 12 September – 20 October 2003. Reference: Outside cages (4 m depth).

Cages 5, 8 & 9: oxygen injection
Cages 4 & 10: no oxygen injection



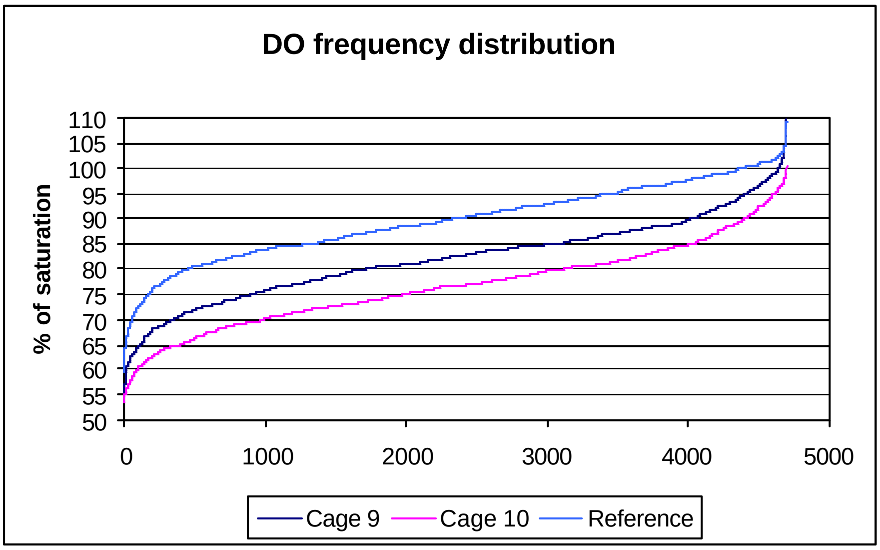
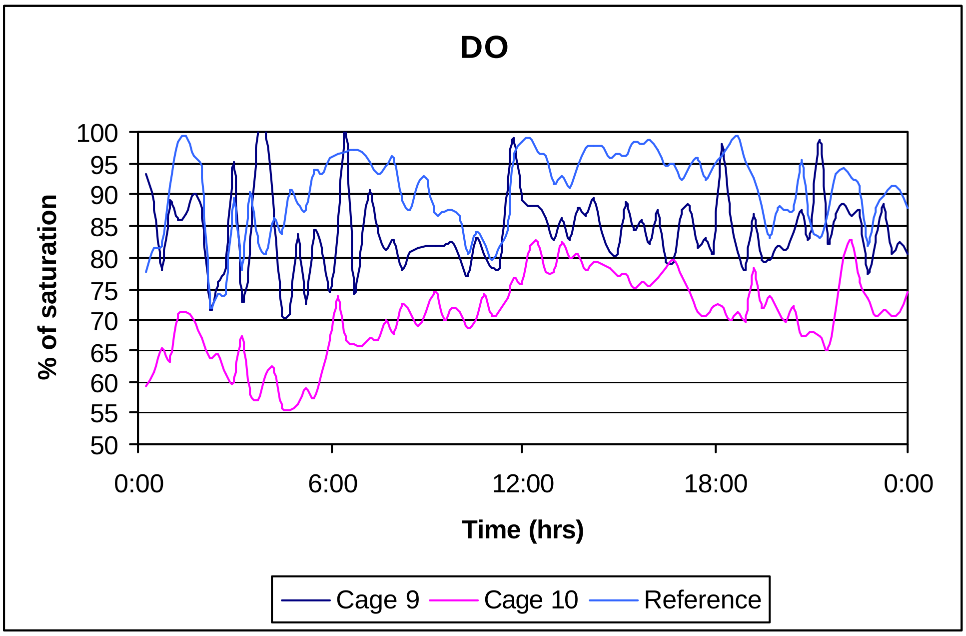


Figure 13. Dissolved oxygen in Cages 9 and 10 at 3 m depth EWOS Innovation Oltesvik 1 September – 20 October 2003.

Cage 9: Oxygen addition (set-points: 80 & 85% of saturation)
Cage 10: no oxygen additions
Reference: outside cages at 4 m depth



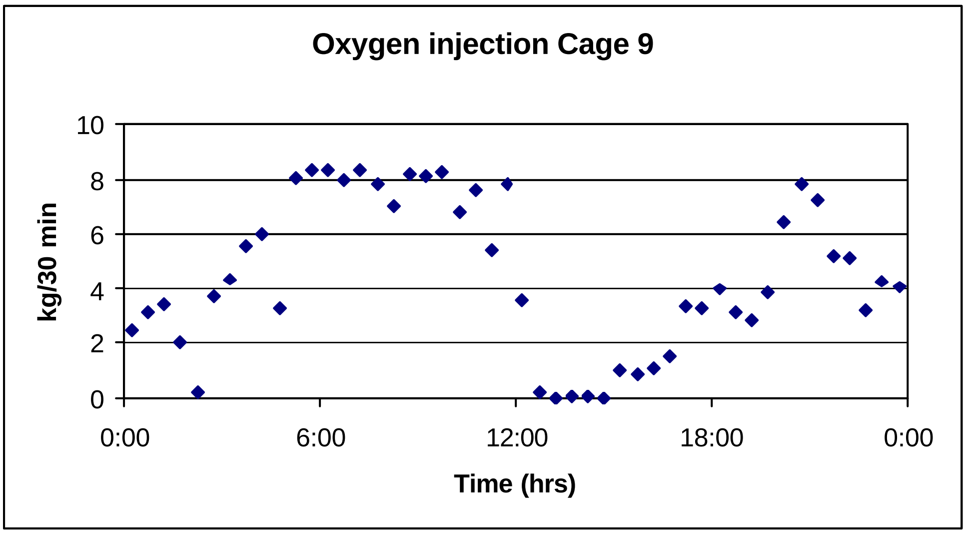


Figure 14. Dissolved oxygen in Cages 9, 10 and outside the cages (reference) at 3 m depth, EWOS Innovation Oltesvik 28 September 2003.

Cage 9: Oxygen addition as kg/30 min (set-point for addition: 85% of saturation)
Cage 10: no oxygen additions
Reference: outside cages at 4 m depth

3.2 Fish performance

Growth, mortality and feed utilisation of the fish stocks in the cages during summer until harvest are presented in Table 4. The rest of the fish affected by the critical period in September – October 2002 gradually died or were removed during April – May (2 – 5 %) before the weight sampling on 2 June. Consequently, the observed mortality in summer – autumn 2003 was considered to be little influenced by the critical situation the year before.

During the period June – start of starvation in October, the period influenced by oxygen addition of three cages, an improved growth rate was estimated for oxygen added cages compared to cages not added oxygen (Table 4a,b). On average, the growth rate (SGR) was 0.58 %/day in Cages 5, 8 and 9, and 0.50 %/day in Cages 4 and 10, not added oxygen. The feed utilisation, FCR, was slightly improved in the oxygen added cages, from 1.27 in the cages without oxygen supply to 1.20 in the cages supplied oxygen. Compared to the cages without oxygen addition, the mortality from June till harvest was reduced by ca. 50 fish per cage in the oxygen added cages (represented 0.6% of the total stock). However, the mortality losses fluctuated considerably among cages.

Statistical testing indicates that the average weight of the fish was similar at the start of the trial but differences were clear both in the variance of SGR and in weight gain ($p < 0.1$). This indicates that the fish growth was more uniform between cages added oxygen and/or that it was generally higher compared with not oxygenated cages.

The improved growth in the oxygen added cages amounted to around 280 g higher average weight at slaughtering. In a cage stocked with 20,000 fish, the improved growth represents ca. 5.5 tonnes higher biomass at harvest.

At slaughtering, the superior quality rate of the involved cages was 75 – 85 %, while discarded fish due to maturation amounted to 5 – 14 % (Table 5). No obvious link between slaughter quality and cages with/without oxygen addition was observed.

Fish sampling of Cage 5, as an example, is shown in Figure 16. The samplings on 1 April and 2 June were based on individual weighing of 200 fish, while the sampling on 27 August was based on usage of video monitoring (AkvaSensor Vicass) of 160 fish. The size distribution, in terms of coefficient of variation, was 37.7 % on 1 April, 51.3 % on 2 June and 33.6 % on 27 August. Due to different sampling procedures and small sample size, it is impossible to assess whether these variations reflect the real size distribution of the whole fish stock. The video based sampling on 27 August is not used as basis for calculations of growth.

Table 4 a. Growth (SGR), mortality and feed utilisation (FCR) in five cages at EWOS Innovation Oltesvik during the period 2 June 2003 – Harvest (135 – 149 days).

Harvest: time for start of starvation (15 – 29 October 2003)

Criteria	**Cage 4**	**Cage 5**	**Cage 8**	**Cage 9**	**Cage 10**	**No O_2 addition** **Cage 4+10**	**O_2 addition** **Cage 5+8+9**
Fish number:							
Start	20,682	15,741	18,609	19,042	21,636	42,318	53,392
Harvest	20,378	15,671	18,519	18,632	21,219	41,597	52,822
Dead	304	70	90	410	417	721	570
Mortality, %	1.5	0.4	0.5	2.2	1.9	1.7	1.1
Average weight, g:							
Start	1,744	1,774	1,707	1,666	1,658	1,700	1,712
Harvest	3,692	3,945	3,816	3,703	3,345	3,516	3,814
Weight gain, g	1,948	2,171	2,109	2,037	1,687	1,816	2,102
SGR, %/day	0.54	0.59	0.59	0.56	0.47	0.50	0.58
FCR, kg/kg	1.22	1.26	1.10	1.24	1.32	1.27	1.20

Table 4 b. Statistical testing

Parameter	**p-value using Levene's test of homogeneity of variance**	**p-value using independent samples t-test for equality of means**
Start number	.154	.093
Harvested number	.129	.090
Mortality, number	.156	.334
Mortality, %	.107	.450
Initial average weight (g)	.849	.795
Average weight gain (g)	.165	.151
Harvest average weight(g)	.054	.078
SGR (% per day)	.015	.259
FCR (kg/kg)	.517	.419

Note: Levene's test for equality of variance was applied and the t-test used assumed equal variances except for SGR where the unequal variances were assumed.

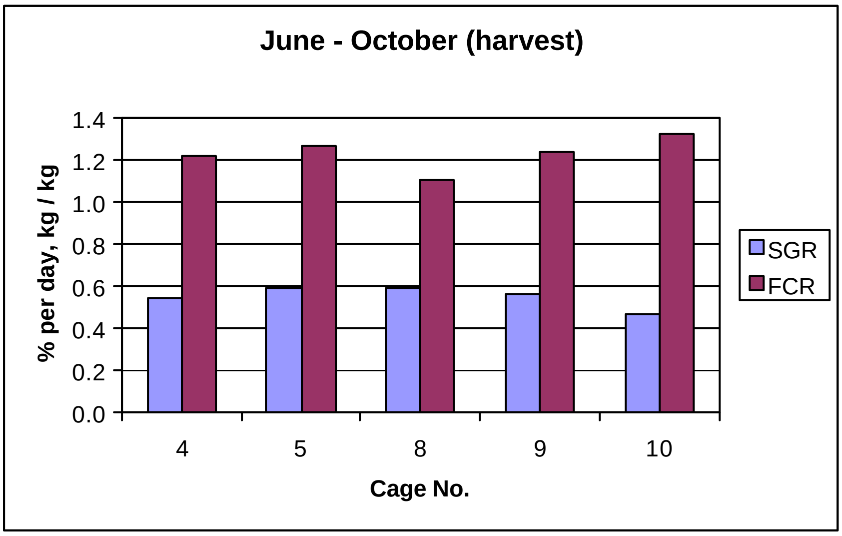


Figure 15. Specific growth rate (SGR, %/day) and feed utilisation rate (SGR, %/day), 2 June - start of starvation (15 – 29 October), EWOS Innovation Oltesvik 2003

Cages 5, 8 & 9: oxygen injection
Cages 4 & 10: no oxygen injection

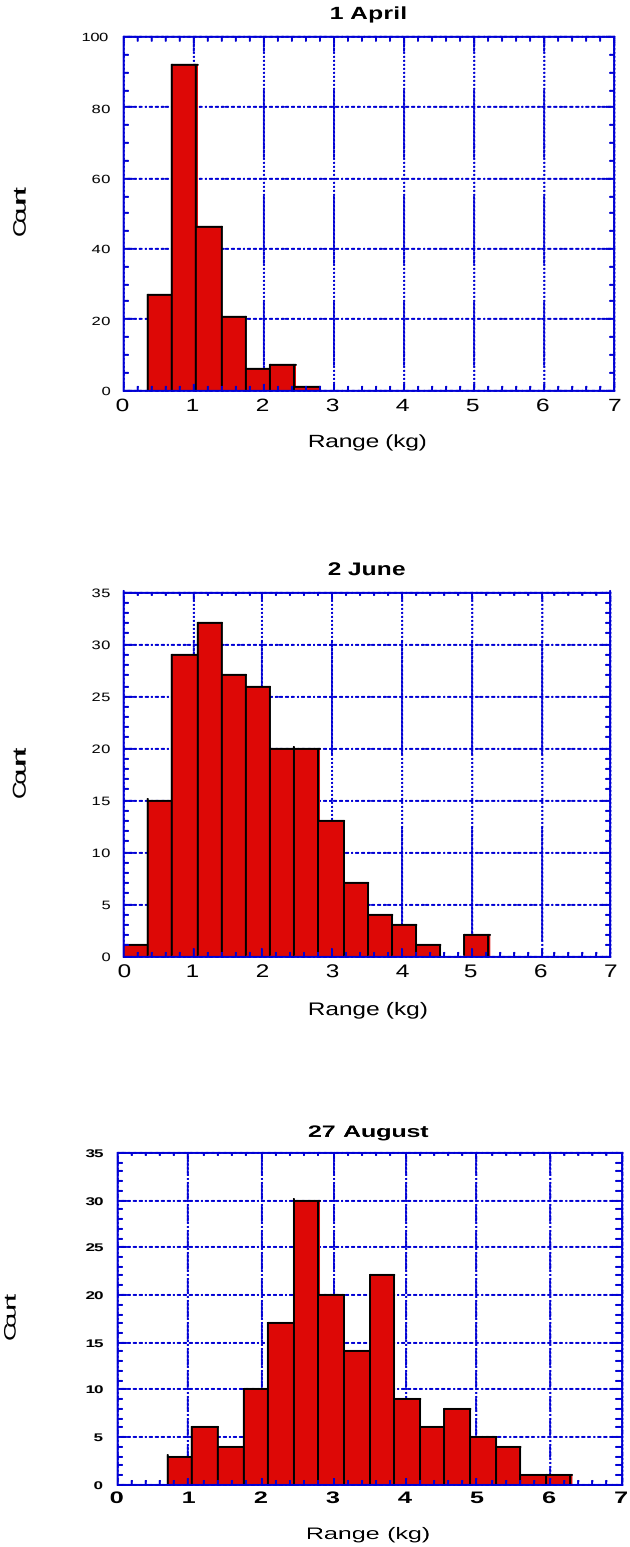


Figure 16. Individual weight distribution based on sampling of Cage 5, EWOS Innovation Oltesvik on 1 April, 2 June and 27 August 2003.

Sample size: N = 200 on 1.04 & 2.06, 160 on 27.08

Table 5. Quality distribution of the fish stocks in the five involved cages, EWOS Innovation Oltesvik October – November 2003. Unit: %

Quality class	**Cage 4 (no O_2)**	**Cage 5 (O_2 added)**	**Cage 8 (O_2 added)**	**Cage 9 (O_2 added)**	**Cage 10 (no O_2)**
Superior	79.8	85.5	76.4	83.8	85.1
Ordinary	9.2	5.9	7.7	2.9	2.8
Production	3.9	3.4	2.3	2.7	2.0
Discarded/mature	7.2	5.2	13.6	10.6	10.0

4 Discussion

The temperature curve during summer – autumn 2003 in Oltesvik reflected conditions not deviating much from expected “normal” conditions. Temperatures at 5 m were above 18 °C for only 2 – 3 weeks and the peak of 18 – 20 ºC was maintained for only 2 – 3 days. The ongoing warm and sunny weather in August – September in 2002 was quite different characterised by 18 – 20 °C lasting for about 6 weeks after 1 August (Bergheim *et al.* 2003).

In the period April – June, the DO concentration was above 100 % of saturation outside the cages. DO super-saturation in the phototropic zone is quite common in Norwegian fjords at this time of the year due to the major algal bloom (K. Tangen, personnel communication). Levels as high as 150 % of saturation in the daytime can frequently be observed during this period.

Due to estuarine circulation, several episodes of DO drops from saturation level to below 50 % of saturation were observed. Such situations typically last for a few days at 3 – 5 m depth and occur irregularly from April till late autumn. Based on continuous monitoring of appetite/feed supply in all involved cages, such short-lasting episodes normally do not seem to hamper the fish growth much. The connection between daily appetite and environmental conditions will however be assessed in a later report.

No negative effects on growth and feed utilisation were expected from May till mid-August as only short and moderate DO concentration drops were observed outside and inside the cages. Both on reference sites and in cages without oxygen addition, DO concentrations below 5 mg/L (< 60 % of saturation) were only occasionally measured. It is known that continuous low DO levels will affect the performance of salmon even at lower temperature (Bergheim *et al.* 2002) but the influence of fluctuating DO concentrations at higher temperature is not well understood (Forsberg & Bergheim, 1996).

Episodic DO super-saturation occasionally occurred, e.g. during the period 6 – 9 October when a saturation level above 200% was reached in a couple of cages, due to oxygen dosage control problems. Recently reported results indicate that DO super-saturation (400% of saturation) resulted in hyperoxia, i.e. respiratory acidosis, in salmon smolt in freshwater (Brauner et al. 2000). On-going studies demonstrate harmful physiologic effects in salmon parr prior to smoltification of long-lasting DO concentrations of 130 – 140% of saturation in freshwater, i.e. reduced growth, oxidative stress and increased susceptibility of the disease IPN (Torstein Kristensen, personnel communication). Similar studies have not been conducted for adult salmon in seawater.

The control of oxygen addition below a fixed DO concentration (set-point) has obviously been improved since 2002. In oxygen added cages, the DO level was increased on average 5 – 10 % of saturation in August – October and the frequency of DO levels below the set-point was strongly reduced. Further improvements are however needed both to remove completely very low oxygen levels and to prevent episodic over-supply which results in strong DO super-saturation.

During the period of oxygen addition, June – October, the fish stocks in the oxygenated cages demonstrated an increased growth of ca. 10 % compared with the reference cages not supplied oxygen. The average weight at slaughtering was ca. 280 g higher in oxygen added vs. not oxygen added cages. This improved growth amounts to ca. 5.5 tonnes higher biomass at harvest in a cage stocked 20,000 fish or ca. 120,000 NOK higher revenue at the existing price level. The extra costs of the total added oxygen quantity June – October 2003 amounted to ca. 20,000 NOK per cage. No calculations have been made on other costs such as capital equipment, rental of equipment or extra management time.

5 Conclusions

- The seawater temperature in summer – autumn 2003 was close to normal and levels above 18 – 19 °C only occurred a few days
- Despite moderate temperature and dissolved oxygen (DO) deficit in the cages, a positive effect of oxygen addition during June – October was observed
- Improved growth and slightly reduced feed consumption (FCR) in oxygen added cages seemed to justify the extra costs
- The fish stock tested had been exposed to critical conditions in autumn 2002 (extremely high temperature, low DO) and suffered high mortality prior to test
- Adjustments have improved the use and control of the oxygen injection equipment
- More R&D activity is still needed to optimise the oxygenation technology

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