The Impact of Fish Cages on Water Quality in One Fish Farm in Croatia

G. Jelic Mrcelic, M. Sliskovic

Abstract**—**In Croatia, the majority of cultured marine fish species are reared in net cages. The intensive production of the fish in net cages may generate the considerable amount of bio waste and change water quality especially in enclosed and semi-enclosed coastal areas. The aim of this paper is to assess the potential impact of sea bass (*Dicentrarchus labrax* L.) cage farm on water quality. The weak relationship between food supply and water quality parameters (nutrient content and phytoplankton biomass) was found, but significant changes in oxygen saturation was observed in the cages during the warmer period of a year especially in the morning (occasionally it dropped below 70 %). Despite of, satisfactory results of water quality parameters, it is necessary to establish comprehensive monitoring process, especially to include quality assessment of fouling communities.

Keywords—Mariculture, monitoring, fish cages, water quality parameters.

I. Introduction

INTENSIVE fish farming by its nature grows many fish in a confined area which produces considerable amounts of nutrient waste in dissolved form – i.e. ammonia and urea – and in particulate form – i.e. uneaten food and faces [1]. These wastes are usually discharged to the surrounding environment which acts as an effective agent of dilution and dispersion. However, each form of waste can have an impact on the environment, in the form of nutrient enrichment effects or direct and indirect toxicity effects at a lethal and sublethal level, which may alter the nature or ecology of the local system [2]. The reared fish also has demand for the oxygen and can lead to low oxygen content in the rearing location [3]. In good water conditions, high content of nutrients, especially phosphorus and nitrogen compounds, will stimulate primary production and can lead to phytoplankton blooming especially during the summer, when the temperature rises [4]. The degradation of excessive phytoplankton biomass can lead to further oxygen content reduction and nutrients content increase in water. These environmental impacts must be maintained at a minimum and within acceptable limits. The basics tool is data generation process from which decisions on the environmental management may be reached, i.e. monitoring. Monitoring may look at many topics and levels including the scale of impacts, general ecological change, and implementation of acceptable limits or acceptable zones of effect over a defined timeframe [2]. The aim of this paper is to evaluate the impact of fish cages on water quality and to find out the possibilities to reduce negative impact of the fish farming on farming location. The temperatures, oxygen content in the cages and out of the cages at different depth, at different time and at different distance from the cages were measured. The content of nutrients, added food, horizontal and vertical profile of chlorophyll a was analysed. The correlation between temperature, food supply, nutrients content, oxygen content, and primary production at given time and space scale were obtained.

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II. Materials and Methods

The fish farm is located on one of the islands in the central coast of Croatia. The bay is about 1 800m long with the maximum width of 714m and the maximum depth of 37m. It is relatively shallow and sheltered bay, well protected from dominating winds (NE and SW). Sediments are predominately sandy with some isolated muddy zones (below the cages). Currents are predominant tidily driven to NW. The shape of the bay enables good dynamics of water masses and hence good oxygen supply.

Pilot scale production started in 1981 and from 1983 industrial scale production varied from 150 to 250 tones per year. The main farmed species is the sea bass (*Dicentrarchus labrax* L.), which represents 90% of produced population. The fish was reared in rectangular cages (10m * 10m * 5m) of 500m^3. In 1994 four platforms were moved closed to the entrance of the bay to obtain better rearing conditions for yearly fish. The depth below the cages varied from 15 m to 30 m. From June 15th 1994 till December 1995 fish production was 231 tones with a food consumption of 521 tones. The phosphorus and nitrogen load estimation was based on the food containing 0.9% phosphorus and 7.2% nitrogen with an average food coefficient (gain/feed) of 2.3%. Final stocking density in the cages was 12 kg/m^3. Total mortality was 30% over 565 days. Salinity was stable and ranged from 36 ppt to 27.5 ppt. The temperature ranged from 10˚C in the winter to 23˚C in the summer. The vertical amplitudes (from the surface up to 10m depth) fluctuate from 0.2˚C in the autumn to 1.3˚C in the spring. Daily differences in surface waters were from 0.1˚C in September to 0.8˚C in May [5].

Standard oceanographic methods for N and P analyses were used [6]. Dissolved oxygen concentration (DO) and temperature by using YSI dissolved oxygen-temperature meter and salinity was recorded daily by an optical refractometer. Standard fluorescence method with an acidification step to estimate the concentration of chlorophyll a was used [7].

III. Results

Table 1 shows the records of total feed, temperature and total fish biomass for the first and the last year (the fourth year) of the monitoring. Total food supply rose as the temperature growth for both years. The minimum values of the temperature and total food supply were recorded in March, and the maximum values of the temperature and total food supply were recorded in August. Total food supply was lower in the last year than in the first year, probably due to lower fish biomass. We could only guess because the data of total fish biomass were missing for the first year.

TABLE I
TOTAL FOOD SUPPLY, THE TEMPERATURE AND TOTAL FISH BIOMASS IN THE FIRST AND THE LAST YEAR OF MONITORING

	The First year		The Last year		
	Food supply (t)	T (˚c)	Total fish biomass (t)	Food supply (t)	T (˚c)
January	21	12.7	93	25	12.7
February	39	11.5	102	22	11.5
March	12	10.8	107	12	10.8
April	27	13.0	111	13	13.0
May	40.5	16.3	117	27	16.3
June	62.5	19.7	127	27	19.7
July	83.3	21.8	145	51	21.8
August	96.3	22.1	167	53	23.0
September	73	20.3	190	60	20.3
October	60	19.6	207	39	19.6
November	67.7	17.5	222	29	17.5
December	37.4	15.2	231	19	15.2

Table 2. gives the average monthly oxygen saturation from April to September for the last year of the monitoring. The oxygen saturation was measured in the cages and at the 10 m out of from the cages, every day at 09.00 am at the surface waters (0.5 m depth). Dissolved oxygen decreased from June and reached its minimum during September in the cages and out of the cages. Better oxygen saturation was recorded out of the cages. The difference between oxygen saturation in the cages and out of the cages was the highest in August. Low saturation during the summer (lower than 80 %) had no influence on farmed fish.

TABLE II
THE AVERAGE OXYGEN SATURATION IN FISH CAGES AND OUT OF THE CAGES (AT DISTANCE OF 10 M) IN THE LAST YEAR OF THE MONITORING

OXYGEN SATURATION (%)		
MONTH	IN THE CAGE	OUT THE CAGE
April	97.0	100.8
May	94.1	98.5
June	86.1	96.5
July	78.2	95.3
August	82.9	94.8
September	75.5	94.5

Table 3 shows daily fluctuation of oxygen content (the saturation) in the cages and out of them, at various depths (0m, 5m, 10m) at different time (every three hours started from 7.00 am till 8.00 pm) during the day (June 7th in the last year of the monitoring). The lowest values were recorded early in the morning at all depths - oxygen saturation occasionally dropped below 75 % (7.00 am in the cages). This problem was associated with high summer temperature. The maximum of oxygen saturation was recorded at 4.00 pm. The table also shows the difference between oxygen saturation in the cages and out of them. The oxygen saturation rose with the depth and reached its maximum at 10 m (with exception at 4.00 pm).

TABLE III
DAILY FLUCTUATION OF OXYGEN (JUNE 7TH IN THE LAST YEAR OF THE MONITORING) AT THREE VARIOUS DEPTH

	OXYGEN SATURATION (%)									
	7 am		10 am		1 pm		4 pm		8 pm	
	Cage	Out	Cage	Out	Cage	Out	Cage	Out	Cage	Out
0 m	74	89.1	80.4	100.9	88.8	94.3	105	105	90.6	87.9
5 m	99.6	99.1	115.1	125.8	93.5	99.0	103.2	104	88.8	98.5
10 m	-	105.1	-	127.3	-	109.6	-	101.8	-	104.1

Table 4 shows horizontal profile of oxygen saturation. The samples were collected at five sites at various distances from cages at 4.00 pm on June 6th in the last year of the monitoring. The lowest oxygen saturation was recorded in the cages near the surface. Good oxygen saturation at all depths was recorded at other sites. The decrease of oxygen saturation was limited to less than 100 m from the cages. The oxygen saturation rose with the depth in the cages.

TABLE IV
OXYGEN SATURATION IN THE WATER IN FIVE SITES (JUNE 6TH IN THE LAST YEAR OF THE MONITORING).

OXYGEN SATURATION (%)					
Depth	Control site S3	Cages S1	100m from cages S2	300m from cages S4	700m from cages S5
0 m	102.1	88.8	109	106.8	106.7
5 m	110	93.5	115.5	116.2	106
10 m	109.6	109.6	116.2	112.9	105.9
15 m	109.2	-	-	114.1	-

Table 5. gives nutrient content in water from 29 July in the first year to 20 July in the third year. The samples were taken in two sites (S1 – the site of cages and S3 - control station at the entrance of the bay), at the depth of 3m and at the depth of 10 m. In the site S1 minimum concentration of phosphates was recorded at 3m depth in the warmer period of year (June and July) what corresponded to maximum food supply to the fish and maximum nutrient loading in the environment throughout uneaten food and feces.

High nutrient concentrations were also recorded in August and September when fish biomass in the cages is was the largest. Similar situation was recorded in S3. According to Croatian regulations (N. N. 2/08/84) maximum allowed phosphates concentration is: 0.025 mg/l (for I and II category of coastal sea). That value was exceeded three times in S1 and four times in S3. Nitrate concentrations were low for both depths and for both sites; those concentrations were below maximum allowed concentrations (1 mg/l). In the both sites nitrite concentration was below maximum allowed concentration for I and II category of coastal sea (0.01 mg/l); maximum concentration was found on February 17th in the fourth year of monitoring in S3. In the great majority of the samples the nitrites were not found.

TABLE V
NUTRIENT CONCENTRATION IN THE WATER IN S1 AND S3 AT 3M AND 10M DEPTH FROM JULY 29TH IN THE FIRST YEAR OF MONITORING TO JULY 20TH IN THE FOURTH YEAR OF MONITORING

Year	**Date**	**PHOSPHATES**				**NITRATES**			
		S1		**S3**		**S1**		**S3**	
		3m	**10m**	**3m**	**10m**	**3m**	**10m**	**3m**	**10m**
1St	**29/07**	0.016	0.016	0.018	0.010	0.024	0.028	0.025	0.027
	27/08	0.014	0.023	0.015	0.013	0.038	0.022	0.018	0.024
	28/09	0.016	0.014	0.018	0.015	0.002	0.004	0.004	0.006
	29/10	0.012	0.008	0.012	0.018	0.017	0.017	0.015	0.017
	26/11	0.012	0.011	0.015	0.007	0.050	0.050	0.031	0.035
	22/12	0.012	0.011	0.009	0.006	0.040	0.048	0.039	0.039
2nd	**24/02**	0.012	0.010	0.010	0.008	0.010	0.009	0.011	0.011
	05/04	0.010	0.014	0.014	0.012	0.023	0.024	0.024	0.022
	29/04	0.011	0.018	0.013	0.013	0.011	0.010	0.012	0.012
	02/06	0.014	0.014	0.024	0.022	0.014	0.013	0.013	0.011
	30/06	0.015	0.017	0.020	0.017	0.013	0.012	0.012	0.013
	29/07	0.020	0.026	0.024	0.128	0.010	0.012	0.010	0.015
	26/08	0.011	0.029	0.014	0.011	0.011	0.091	0.010	0.010
	29/09	0.013	0.017	0.016	0.015	0.022	0.017	0.010	0.012
	27/10	0.014	0.012	-	-	0.021	0.014	-	-
	17/11	0.020	0.016	-	-	0.013	0.027	-	-
	14/12	0.015	0.020	-	-	0.019	0.020	-	-
3rd	**17/02**	0.008	0.014	0.012	0.008	0.013	0.012	0.012	0.013
	21/03	0.014	0.023	0.016	0.016	0.009	0.008	0.008	0.007
	26/04	0.018	0.024	0.030	0.027	0.006	0.006	0.009	0.006
	17/05	0.011	0.021	0.015	0.019	0.015	0.014	0.011	0.011
	28/06	0.051	0.050	0.026	0.029	0.004	0.004	0.003	0.010
	20/07	0.022	0.031	0.015	0.015	0.008	0.008	0.007	0.006

Chlorophyll a content (mg/m^3) from May to July in the last year of monitoring at sampling station S1 (the cages) is given in Table 6. The phytoplankton biomass slightly increased from May, but till July it was still below 1 mg/m^3. The chlorophyll a content increased from the bottom to the surface. *Skeletonema costatum* and *Chaetoceros compressus* were dominant species (90 %) in summer chlorophyll.

TABLE VI
CHLOROPHYLL A IN S1 FROM MAY TO JULY IN THE LAST YEAR OF MONITORING

CHLOROPHYLL A (mg/m^3)			
Depth	**May**	**June**	**July**
0m	0.30	0.59	0.95
5m	0.28	0.42	0.76
10m	0.24	0.37	0.59
Bottom	-	0.25	0.40

The results of chlorophyll a in three different sampling sites (S2 – 100 m from the cages; S3 – control site; S5 – 700 m from the cages) and at three different depths (0m, 5m, 10m, the bottom) are given in Table 7. The samples were taken at 13.00 on June 6th in the last year of monitoring. The highest values were recorded at the surface and the lowest at the bottom. The lowest values were recorded in site S3.

TABLE VII
CHLOROPHYLL A (MG/M^3) IN THREE DIFFERENT SAMPLING SITES AND AT THREE DIFFERENT DEPTHS ON JUNE 6TH IN THE LAST YEAR OF MONITORING.

CHLOROPHYLL A CONTENT (mg/m^3)			
Depth	**100 m from cages S2**	**Control site S3**	**700 m from cages S5**
0m	0.59	0.28	0.66
5m	0.42	0.39	0.48
10m	0.37	0.34	0.51
Bottom	0.25	0.14	-

IV. DISCUSSION

Significant correlation between temperature and total food supply were found. No correlation between total food supply and nutrient concentration were found. Despite of large percent of P and N compounds in food and low factor of food conversion, slightly higher values of phosphates were occasionally recorded. These high values were recorded both in the cages and on control station.

Normally good oxygen saturation dropped below critical values from June to September. This scenario took place especially in the cages early in the morning. The depletion of oxygen was associated with high summer temperatures and high food loading during summer period. The highest values of oxygen saturation were recorded in the afternoon. Morning depletion of the oxygen in the summer was caused by rapid fish consumption of oxygen over the night and reduced water exchange. It was also noticed that low oxygen saturation is associated with heavily net fouling.

Vertical distribution of the oxygen showed greater fluctuation of oxygen near the surface than near the bottom. These fluctuations were more obvious as the temperature rose. The low oxygen content in the cages was caused by fish consumption of oxygen. In the morning, differences between the oxygen values in the cages and out of them were greater due to the fish feeding (deterioration of uneaten food and metabolic products). Minimum oxygen saturation was 74 % at the surface (7.00 am) what could be critical for fish. Oxygen saturation can decrease even more, especially during the summer, due to high temperatures and poor water dynamics. In further monitoring it will be necessary to measure oxygen early in the morning. If any critical situation is noticed adequate measurements must be taken (to reduce feeding or even to stop feeding during the morning and to feed fish mostly during the afternoon).

Horizontal profile of oxygen saturation in the bay depends mostly on the currents. The movement of water masses is caused by tides and possible general direction of the currents is clockwise. The influence of the cages is restricted on small radius of only a few meters from the cages. Horizontal influence of the cages is vertically confined only on the depth of the cages (5 m).

According to production records and estimated load per ton of the fish produced, it was assumed that the total load of nutrients was 3.8 t/y of phosphorus and 29.3 t/y of nitrogen. Good exchange of water between the bay and the main basin throughout a year caused good dispersion of nutrients load. The highest nutrients concentrations were recorded in warmer part of a year what is directly related to increased food supply from June to September (during optimal summer temperatures – above 20°C). No clear relationship between nutrient supply and concentration of phosphorus and nitrogen components in the water was found. There were no significant differences in the concentrations of phosphate in water column as well as between the cages and control station. The same situation is noticed for nitrate and nitrite.

The phytoplankton community was diverse and consisted mostly of diatom and partly of dinoflagellates, what is typical for Middle Adriatic coastal waters [8]. We found out that phytoplankton chlorophyll increases were associated with adequate nutrient loading increases, what was in accordance with theories of the relationship between nutrient loading and primary production in shallow and sheltered aquatic system. Some authors [9], [10] were not able to confirm such clear relationship nutrient levels-primary production while others [11] thought that nutrient enrichment would stimulate phytoplankton growth only when the particular nutrient was limiting factor of phytoplankton growth. Due to relatively low primary production and great variety of phytoplankton community conclusion that monitored location was not threat by fish farming operations can be made. Oxygen saturation, nutrient loading, phytoplankton growth…, also proved that surrounding waters of fish farm in of monitored location were not much depressed by farming operations. Despite of high nutrient loading during long farm history, the studied location did not show any signs of eutrophication. Good condition of the bay could result from the bottom morphology and high flushing rate, which prevented accumulation of nutrients. But many of potential problems could be avoided by increased attention in the next years. Most probably such monitoring programs should include chemical measurements of enrichment as well as studies on temporal variability of macrobenthos and fouling communities. If the problems emerge negative impacts can be reduced by proper selection of cage micro-location (off-shore or semi off-shore) and by adaptation of rearing processes to new situation in the bay (optimization of feed regime, optimization of stock density in the cages, adoption of total fish production to the biocapacity of the bay, etc.)

V. Conclusion

1. Significant correlation between temperature and total food supply were found.
2. No correlation between total food supply and nutrient concentration were found.
3. Despite of large percent of P and N compounds in food and low factor of food conversion, slightly higher values of phosphates were occasionally recorded.
4. Normally good oxygen saturation dropped below critical values from June to September.
5. The phytoplankton community is typical for Middle Adriatic coastal waters (diverse and consisted mostly of diatom and partly of dinoflagellates).
6. Due to relatively low primary production and great variety of phytoplankton community conclusion that monitored location was not threat by fish farming operations can be made.

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