ECASA Study Site Report

Site name
DALMAR - Pakoštane

Country
CROATIA

ECASA Partners
Partner 15. Ruđer Bošković Institute (RBI)

Authors

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Non Technical Summary

During the summer of 2006, Sea Bass and Sea Bream fish farm located near Pakoštane, Croatia was visited twice in order to complete fieldwork program within ECASA project. Main purpose of this program, beside evaluation of various environmental state indicators, was to assess the performance of KK3D deposition model. Visits to the study site were carried out on 30 June – 8 July and 23 – 28 July 2006. Fish farm at study site is being operated by Dalmar Ltd. from 1999. At present, total production is approximately 400 tons/year.

Initial yield of fish at study site was below 50 tons/year. After two years in operation, Dalmar's management decided to increase production to the present level. Such expansion is not possible without a detailed Environmental Impact Assessment (EIA) study. Study was completed in 2001 and site was declared as suitable for intensive aquaculture. In particular, (i) currents are strong enough to maintain optimal water quality in the net pens at all stages of production, (ii) local topography provides sufficient protection from waves and wind, (iii) surrounding waters are not polluted and (iv) moderate increase of nutrient sources in the area isn't likely to cause deterioration of regional water quality.

During the field campaign we collected samples of the water column and sediment. Most of the indicators of environmental impact reveal the state of the environment at one particular moment in time. Analysis suggests that these indicators are not reliable for assessment of impact. Probable cause is the timing of sampling – one cannot expect to capture unfavorable conditions with samples taken instantaneously. Some indicators, however, integrate the effect of fish farm on the environment during several days. These indicators seem to produce distinguishable results when placed near fish farm in comparison with the reference station.

We used data from sediment trap deployment to test the predictive capability of KK3D model. KK3D was designed to be used within EIA studies before production of fish begins. Comparison of model output with observed data suggests that model slightly underestimates deposition of particulate organic matter on the bottom. Performance does not deteriorate over the whole range of observed values.

0 Contents

1 Introduction to the aquaculture operation

1.1 Introductory background statement

- Study site is being operated by Dalmar Ltd., headquartered in Pakoštane, Croatia. The farm has been in operation since 1999, when the first concession was issued by Zadar County. It produces sea bream and sea bass. Yearly production is 400 tons.
- ECASA contributors: RBI (Ruđer Bošković Institute) and Dalmar Ltd. with subcontractors: Diiv Ltd., Oikon Ltd. and Department of Public Health Zadar. Additional help was provided by Dror Angel (Recanati Institute for Maritime Studies).
- Dates of visits: 30.06. – 08.07.2006 and 23.07 – 28.07.2006
- Major information source: Environmental Impact Assessment Study made by Hydrographic Institute in 2001 on behalf of Dalmar Ltd. [5]
- Difficulties encountered: loss of several samples, slow sample analysis
- Limitation of this report: incomplete data analysis

1.2 Summary statement of key site specific environmental issues

Area around Dalmar study site is sparsely populated and fish farm is away from any major waterway. Also, area is not particularly interesting to tourists, meaning that anthropogenic impacts are minimal. Sea water is not polluted. Five other aquaculture facilities are present within 5 miles radius.

Farm site is 12 km away from the national park Kornati, but no negative side effects of fish farming have been recorded at such distance. The EIA study contains prediction in increase of nitrogen concentrations by 1.7% once farm sets production to 400 tons/year (assumed mean current was 6.0 cm/s, daily water exchange was $23 \cdot 10^6$ m^3, excretion of nitrogen totaled 255 kg/day and area used in calculations was 4375 m^2).

Posidonia oceanica which attracts many other species, was not found in the concession zone, although dense meadows exist nearby. *Posidonia* is very sensitive to deposition of organic matter and quickly deteriorates if fish farm is located above. Among marine mammals only bottled-nose dolphins sometimes come in the vicinity of farm. No problems occurred so far.

1.3 Information of farmer's environmental strategy

Environmental Impact Assessment (EIA) study was made in 2001 when production was increased form 50 tons to 400 tons/year. In the study, legally binding Environmental Management System is prescribed. The Ministry of Environmental Protection and Physical Planning is responsible for controlling the enforcement and execution of the farm environmental management system.

2 Site specific regulatory and management background

2.1 The regulatory status of proposed location with respect to fish farming developments

The Dalmar site is situated in the area designated for aquaculture activity. The first concession was issued in 1999 for a period of 4 years. In 2005 concession was prolonged for another 10 years.

To obtain an operating license for aquaculture in Croatia, investor must go step-by-step through the following procedure:

1. A letter of intent is prepared for the county office of maritime affairs. In the letter investor states his intention to open an aquaculture at a location designated for fish farming by a local physical plan.
2. If the total production is higher than 50 tons/year it is necessary to make an EIA study.
3. County issues a location permit and opens public tender for concession.
4. After obtaining concession from the county, Ministry of Agriculture, Forestry and Water Management issues a license to the investor.

However, the regulations which govern planning and zoning of aquaculture, as well as concession–obtaining legislation, are rather complex. They are thoroughly described in [2]. Concessions can only be obtained if the site is designated for fish farming activity in the county physical plan. Physical plans are brought by County assemblies and have to be in compliance with Strategy of physical planning of Croatia and the Program of physical planning of Croatia (OG 5/99). Some counties have precise zoning for specific species, especially Zadar County, where Dalmar site is situated.

To issue the concession for operating an aquaculture, planned activity must be in accord with the laws from different areas of concern including: **maritime affairs** – Act on Maritime Estate and Sea Port (OG 158/03), Ordinance on the procedure of issuing of the concession for usage of a section of maritime estate (OG 23/04, 101/04), **environmental issues** – Environment Protection Act (OG 82/94, 128/99), Regulation on Environmental Impact Assessment (OG 59/00), location and construction planning and other **physical planning issues** – Act on Physical Planning (OG 30/94, 68/98, 61/00, 32/02), **marine aquaculture regulations** – Marine Fisheries Act (OG 46/97), **veterinary issues** – Veterinary Act (OG 70/97), **food production** – Food Law (OG 23/03) and **others** – Nature Protection Act (OG 162/03), Regulation on suitability of a section of marine estate for marine aquaculture (OG 8/99, 56/02), Ordinance on water classification (OG 77/98), Water Act (OG 107/95).

2.2 Site description

The Dalmar study site is positioned in Zadar County, near Pakoštane (Figure 1).

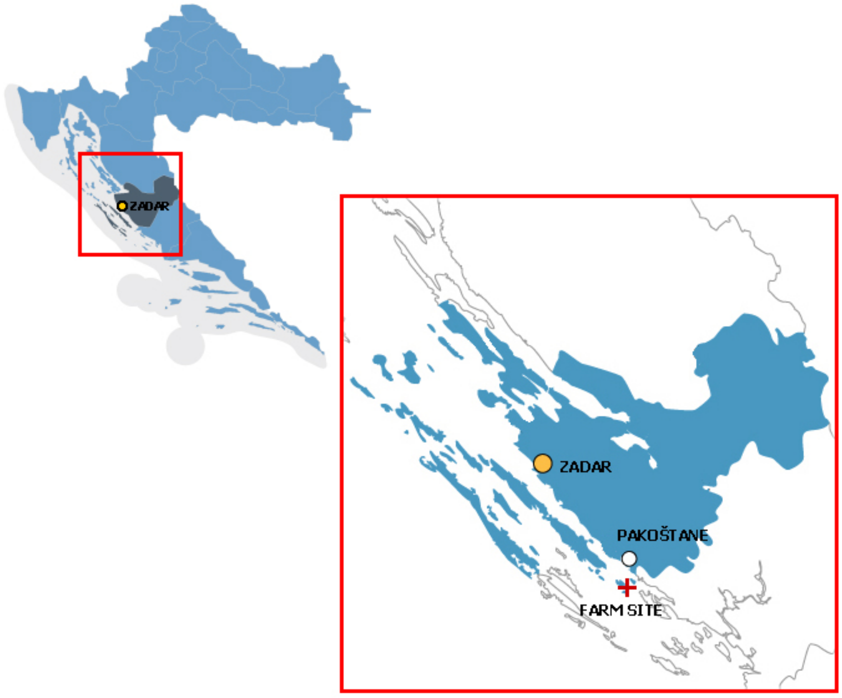


Figure 1. Location of the Dalmar study site in the Zadar county.

Zone B

Dalmar's net pens are located southeast of island Vrgada, in-between islands Školjić Veli, Školjić Mali, Oblik and Murvenjak. (Figure 2). Due to positive physical attributes, this area is designated for aquaculture activity within Zadar County physical plan. The site is partially exposed to open sea. Local topography provides natural protection from high waves and strong winds. However, water exchange remains sufficient at all times. The sea depth ranges between 15 and 30 m. The Regulation on suitability of a section of marine estate for marine aquaculture (OG 8/99, 56/02) defines a minimum set of suitability criteria for fish production. According to the EIA study, Dalmar site satisfies all conditions stipulated by the Regulation (Table 1).

Table 1. Values of parameters and their marks according to the Regulation.

CRITERIA	STATUS	VALUE
EXPOSURE TO OPEN SEA	good	Partial
WAVES	good	1 – 3 m
DEPTH	average	15 –30 m
CURRENTS	average	5 – 20 cm/s
POLLUTION	good	minimal
MAX TEMPERATURE	average	24 – 27 ˚C
MIN TEMPERATURE	average	10 ˚C
SALINITY – AVERAGE	good	15 – 24
– VARIATIONS	good	5 – 10
BOTTOM CONFIGURATION	good	Sand/pebble
TROPHIC STATUS	average	Mesotrophic
FOULING	average	Moderate
PREDATORS	average	Rare

The farm site is situated away from the main waterways and it is not close to inhabited area.

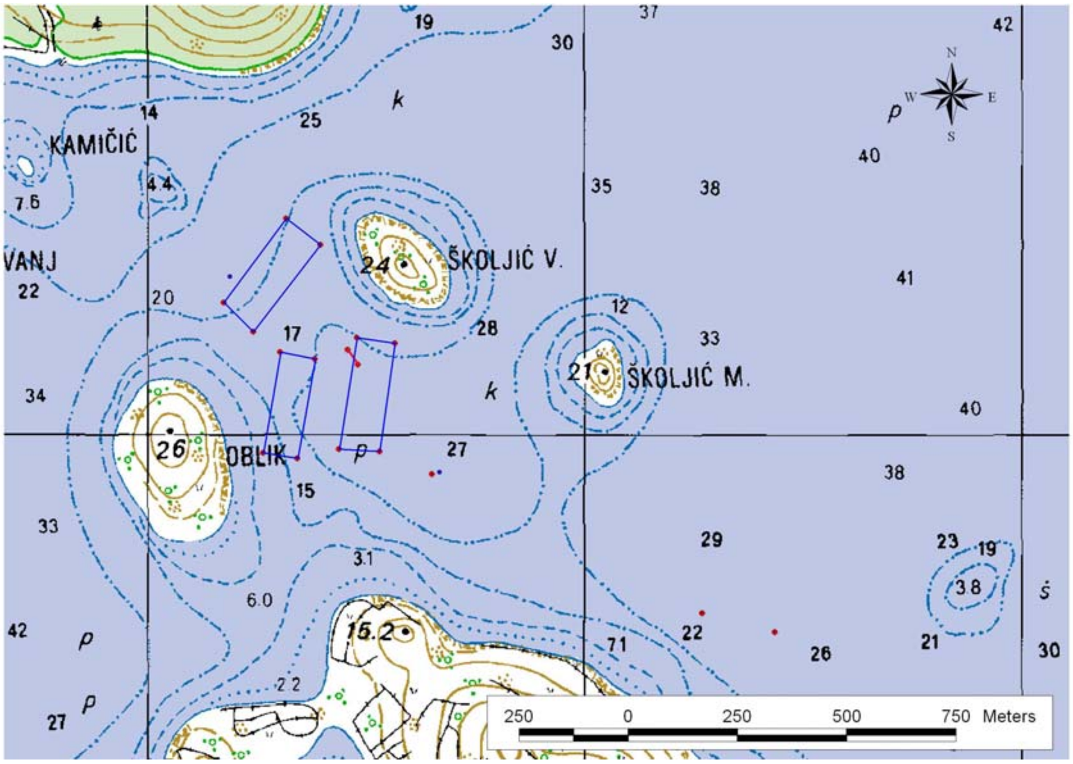


Figure 2. Zone B, Dalmar study site with location of three cage groups.

<u>Zone C</u>

Zone C is a broader area around study site in which impact of a single farm is negligible; however, synergy of impacts from all fish farms in the area could lead to deterioration of regional water quality. In Croatia, the limit for aquaculture sites and their zoning are laid down on the County level. Zadar County has made a thorough physical plan incorporating spatial, physical, biological and chemical characteristics of sites together with socioeconomic status of specific area. Zones inappropriate for aquaculture were eliminated. The physical plan was based on [8]. The complete spatial plan of Zadar County together with current aquaculture sites and zones of anticipated aquaculture activity is shown in Figure 3.

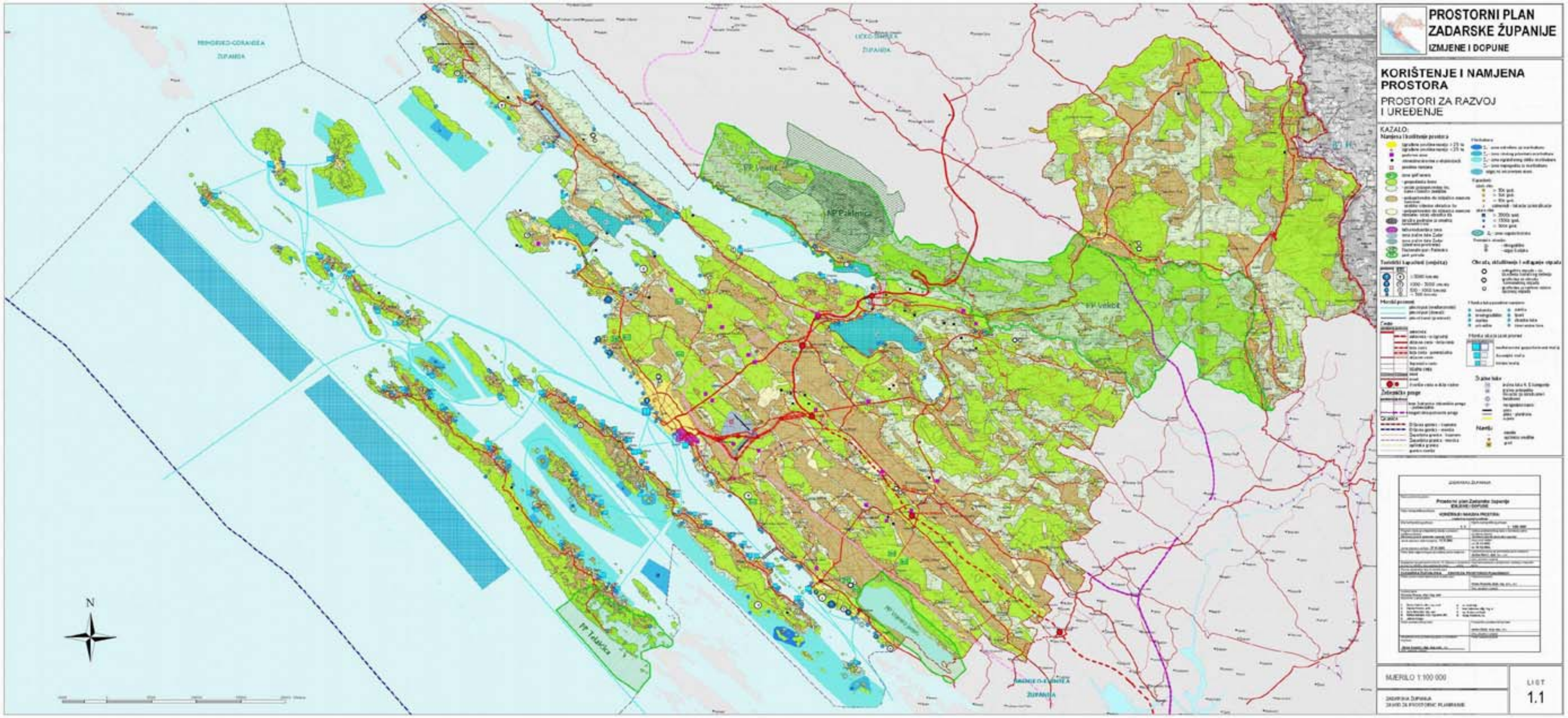


Figure 3. Spatial plan of the Zadar County. The figure was taken from [4].

2.3 Detailed description of the farm

The sea bream/sea bass farm has been in operation since 1999 when the first concession was issued for a period of 4 years. In 2005 concession was prolonged for another 10 years. The concession area has the total of 98,137 m^2. The company produced less than 50 tons for the first two years, later increasing its production to 400 tons/year. The process of expansion was accompanied by making an EIA study in 2001. (In Croatia, farms producing less than 50 tons/year are not obliged to make an EIA study). The plantation of juveniles was 450,000 individuals in 1999, increasing the number to 1,500,000 individuals. Production of sea bream reaches up to 40% of the total production.

The farm has 34 net pens. There are three shore bases – (i) on the Island Školjić Veli, (ii) warehouse near the land port (Pakoštane) and (iii) company headquarters with factory situated 1 km away from the land port. Island Školjić Veli is uninhabited, but adapted to serve the farm's operational needs. It has a dock for operating boats and semi enclosed warehouse for feed storage with workshop, electricity generator and fish net laundry. Also, built on the Island is a building for employees. It consists of kitchen with dinning room and two bedrooms. Sanitary facility with toilette and shower is also available. Since there is no water well on the island, the water is brought with transport boats, together with feed and groceries. The warehouse situated on land in Pakošane is used for several company's aquacultures (Kurba mala, Balabra Vela and Velo Žalo) and it plays an important role in overall logistics. The third shore base, company headquarters, is also situated in Pakoštane, but further away from the port, on the main road. It consists of temporary food storage, mechanical workhouse, administrative building, laboratory, social facilities with kitchen, dinning room, dressing room, sanitary facilities and energy block. Also, there is a factory for sorting and packing the fish for market.

All employees are local. There are 12 people employed to work directly on site related jobs (project manager, manager, 6 feeders, diver, administrative worker and truck driver). However, since the company has other sites in operation, the number of employees is much higher and includes: factory workers, administration and several workers deployed at different sites according to needs, for example during yields, while changing nets, etc.

Waste on the site is collected in several different containers, and transported on land for disposal, where it is categorized and documented. After preparation, waste is transported by a competent body. Organic wastes mostly consisting of dead fish and spoiled feed are treated according to the law (Veterinary law OG 70/97 and Ordinance of conditions for waste management OG123/97) using one of the following procedures: a) burring in the animal holes, b) transportation to the animal feed processing factory, c) treating the fish with acid, then neutralizing and using as a fertilizer or d) burning in specialized waste incineration facility.

2.4 Proposed management strategy: biomass, medicines, chemicals, cycle, feed inputs, growth measurements

Yearly production at the site is 400 tons. The rearing cycle starts in April/May by plantation of new juveniles. After they reach 10 g, they are transferred in new pens where they are farmed to consumption size (330 g). It takes about 15 to 24 months to complete the cycle. While changing the nets, fish are relocated to other pens. Their density is kept at 12 – 15 kg/m^3.

Juveniles are imported from Italy and France, with known genetic origin (to avoid inbreeding). Minimum required weight of juveniles is 5 g with at least 95% functional bladder. All juveniles are vaccinated. They are planted in the April/May with abundance of 7 kg/m^3. Juveniles are fed *ad libitum* 8 to 10 times a day with protein-rich starters. Expected food conversion ratio is 1 (i.e. kg of dry feed utilized for 1 kg of wet weight gain). After they reach 10 grams in weight, the number of daily meals decreases gradually.

The feed for older fish is used in form of extruded pellets with protein content of 40 – 52%, mostly of animal origin. The fish is fed once or twice a day. The amount of feed depends on the current stage of fish, and it varies from 6.5 to 13.1 kg of feed per day per tone of fish. The average is around 7.6 kg/day/ton. The expected food conversion ratio is around 2.5.

Anticipated organic loading on the seafloor is above 40 gC/m^2/day.

The data for added chemicals and medicines used are not available.

Table 2. Summary of rearing cycle and feed input.

Maximum production (t/yr)	400
Sea depth (m)	40
Juvenile/hatch mass (g)	5
Number of juvenile fish	1,500,000
Time of juveniles' plantation (month)	IV, V
Fish density in nets (kg/m3)	12 – 15
Average fish mass at the end (g)	330
Duration of an production cycle (months)	15-24
Survival rate (%)	80
Food convertion rate (FCR)	2.5

2.5 Physical farm logistics

Net pens are arranged in 3 groups (Figure 4). The first group consist of 14 pens with sea bass sized from 80 – 100 g up to consumer size. The second group consist also of 14 pens with sea bream of the same size as sea bass in the first group. The last, third group, consist of 6 pens. Four of those pens have juveniles of sea bass/sea bream, and the other two have wild mature sea bass and sea bream fishes, intended to be used for hatchery in the future.

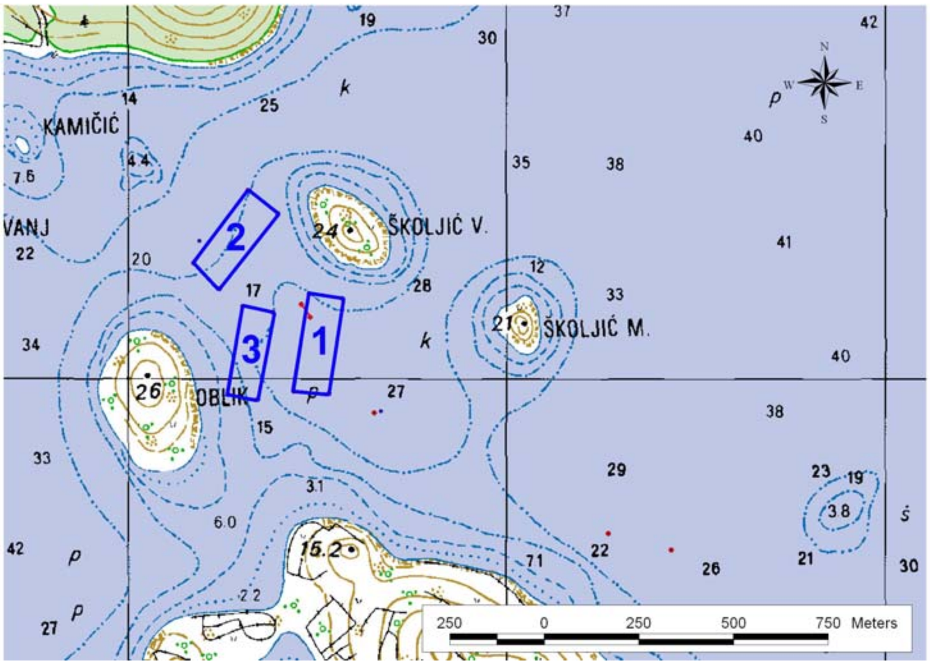


Figure 4. Location of three groups of net pens.

All net pens are made from polyethylene tubing. For juvenile sea bass pens are 12 m in diameter and 19 m for older fish. The pens for sea bream are larger, 16 m in diameter for juveniles and 22 m for older fish. Nets are made from polyethylene or polypropylene and reach 10 to 15 m depth.

The site has three bottom mooring networks, each sized 175 x 50 m with the capacity for 14 pens.

The site is located between five islands and is neither on the international or national waterway. However, some tourist and domicile boats pass through that area, so anticipatory lighting is positioned on the outer band of net pen groups to avoid accidents.

2.6 Production and Processing

When fish reaches consumer size it is removed from net pens into iced containers on the company's fishing boat. The fish is transported onshore to Pakoštane, situated nearby. There the stock is slaughtered, processed and packed for the market. Most of the yield is exported to Italy.

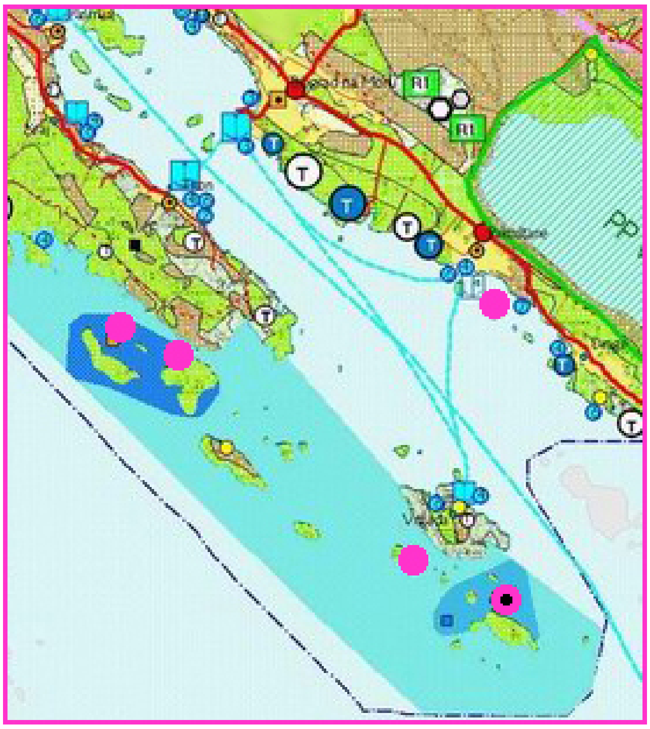
There are no air-borne emissions from the farm.

The company considers building an incinerating facility, but presently the waste is disposed and treated according to the current Croatian law (as described in chapter 2.3).

3 Description of the site and quantification of effects on the environment – existing information only, not collected by ECASA.

3.1 Land use, landscape and visual quality

The farm has been in operation since 1999. Yields from 2002 are 400 tons/year (up to 40% is sea bream). First concession has been given for the period of 4 years, and after the first agreement expired it has been prolonged to another 10 years. The total area under concession is 98,137 m^2.



Pink dots denote other mariculture sites within 5 miles. The Dalmar site is marked by pink – black dot.

The figure has been cropped from the spatial plan of the Zadar County <www.mzopu.hr>.

Figure 5. Other fish farms situated near Dalmar study site.

Area near Dalmar's farm is designated as the zone suitable for aquaculture activity and in the radius of 5 nautical miles there are 5 other aquaculture facilities. The companies (Cenmar, Adria – Oktopus, Limbora, Uroda and Jadran tuna) are mostly located around island Košara.

The whole area has characteristics that are appropriate for aquaculture activity in terms of depth, current speed and protection from strong winds and waves.

The site is located further away from inhabited areas and tourist zones. Also, the site is not located on the main waterways. The nearest small residential area is 2.5 km away, with total population of 242 according to census in 2001 [7].

The reduction of visual pollution is achieved by using dark color for fish pen construction.

<u>Marine protected areas</u>

In Zadar county there are two marine protected sites: Nature park Telašćica (25 km away) and a nature protected area located at the NW part of Dugi otok (> 50 km away). In the neighboring county, Šibensko-Kninska, there is a National Park Kornati. The proximity from the farm to that marine protected area is about 12 km.

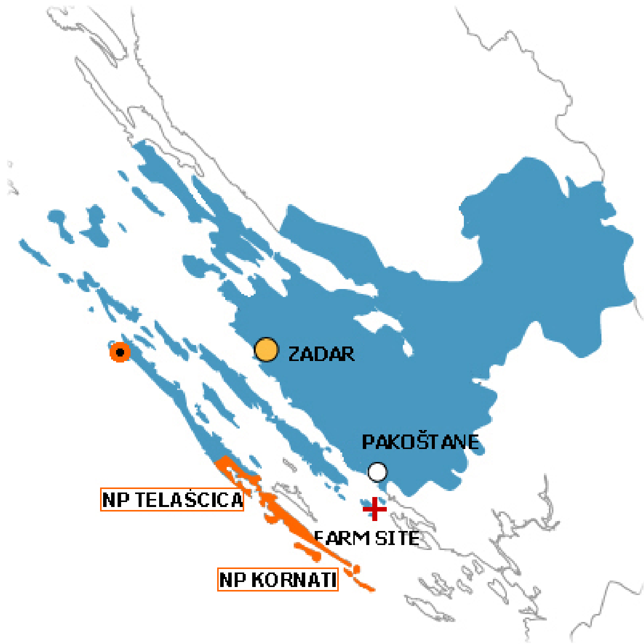


Figure 6. Location of protected areas closest to the Dalmar study site.

3.2 Hydrography and water quality

The EIA study report contains the analysis of current measurements made in the period from 20.03. – 18.04.2000. During ECASA experiments currents were measured at the same location again. The data and complete analysis of the second measurement can be found in appendix B. However, here we present a summary of data and analysis from the EIA study report.

The maximum current speed was 37 cm/s in the surface layer (2 m) and 25 cm/s in the bottom layer (20 m). Mean current speed was 8.6 cm/s (2 m) and 2.5 cm/s (20m), respectively. The residual current had the WNW direction in the surface layer and N in the bottom layer. The factor of stability was very high both for surface layer (79%) and bottom layer (52.5%) – the flow has small angular variability, especially in the surface layer.

Table 3. Summary of current measurement at Dalmar study site.

	Surface layer	Bottom layer
Layer depth	2	20
Maximal current speed (cm/s)	37.5	25
Mean current speed (cm/s)	8.6	2.5
Minimal current speed (cm/s)	1.0	1.0
Standard deviation	7.0	2.8
Residual vectors (cm s^{-1}/deg)	6.77/291	1.33/352
Factor of stability (%)	79	52.5

Currents in NW direction (39%) and W direction (28%) dominate in the surface layer. The dominant direction of bottom currents is NE (39%). In the surface layer 5% of current attain or exceed 25 cm/s, mostly in NW direction. Bottom layer has the maximum current speed of 25 cm/s. The mean bottom current is about 3.5 times smaller than the surface current.

Water quality

EIA study report contains water quality analysis preformed while farm was producing less then 50 tons fish/year. The data are shown in the Table 3.

Table 4. Values of water quality indicators while aquaculture produced 50 t/year.

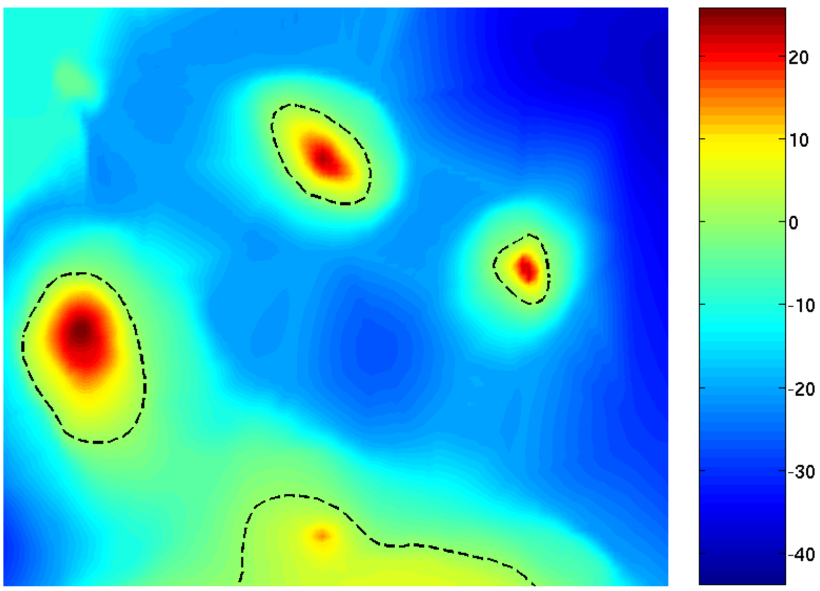
Depth (m)	pH	O_2 (%)	NO_2 (mmol/m^3)	NO_3 (mmol/m^3)	NH_4 (mmol/m^3)	SiO_4 (mmol/m^3)	PO_4 (mmol/m^3)
0	8.25	94.5	0.048	0.152	2.324	0.267	0.000
5	8.25	92.4	0.041	0.013	1.400	0.288	0.000
10	8.26	97.4	0.039	0.109	1.270	0.319	0.000
20	8.25	96.9	0.049	0.101	1.215	0.329	0.000

The EIA study report contains prediction in increase of nitrogen concentrations by 1.7% once farm sets production to 400 tons/year. For calculation they used 6.0 cm/s as the mean current speed, daily water exchange of $23 \cdot 10^6$ m^3 and the excretion of nitrogen of 255 kg/day for 400 tons/year production. The total size of area used in calculations was 4375 m^2.

3.2 Bathymetry, geology and habitats

Bathymetry

Bathymetry near Dalmar's fish farm is fairly complex (Figure 7). Four small islands (Školjić Veli, Školjić Mali, Oblik, Murvenjak) and one larger island (Vrgada) are situated nearby. Depth immediately below the fish pens ranges between 15 and 30 m. Water level is strongly affected by tides, but this is not reflected in current velocities (Appendix B). We assume that tidal constituents are distorted by various bathymetric features. Thus bathymetry determines the dispersion of nutrients and other chemicals from the fish farm. It also protects the fish farm from strong winds and high waves.



- Dashed lines: Mean water level
- Colors: Depth or height above mean water level in meters

Figure 7. Bathymetry in the immediate vicinity of fish farm.

Geology

The following paragraph has been translated from EIA study report [5].

The Island of Balabru, the Island of Kurba Mala and the Island of Vrgada are all made of Upper Cretaceous carbonate rocks (Mamužić and Nedela-Devide, 1968). These Upper Cretaceous deposits are composed of limestones in alternation with dolomites in lower section and limestones with marly limestone inclusions in the upper section. Senonian deposits are characterized by numerous rudist limestones.

Inside the investigated area, at the sea-land contact, carbonate beds enters into the sea overlaid by recent marine sediments. The marine sediments are mostly made of half-rounded gravels. Flat and steep segments can be noted since the relatively inclined sea bed do not immerse uniformly towards the deep sea.

The shallow sea bed is mostly overgrown by brown algae, while deeper sea bed is overlaid by *Posidonia* meadows.

At the investigated location of the Island of Vrgada, the basic rock and recent sediments were identified at the sea bed. The basic rock is made of thick-bedded light-gray rudist limestones that extend towards the deep sea. The bare rocky sea bed is visible down to 1.5 m (approximately 10 m far from the coastline). Due to the very shallow sea, the coastal zone does not extend far from the coastline. The deeper sea bed is covered by coarse-grained sand which turns into the fine-grained sand and deeper to silty sand towards the off-shore. Shallower sea bed mostly lack vegetation cover enabling the mobilization of sand sediments under the storm waves. Deeper sea bed is covered by *Posidonia* meadows.

Habitats have been mapped in the EIA study report. Since the site is located between three islands there are habitats that corresponds to habitats related with depth and presence/occurence of seawater. These are presented below.

Supralittoral (supratidal zone): The coast is rocky, steep, and the supralittoral step is 3 m long. All characteristic species are found, such as *Littorina neritoides*, *Ligia italica* and *Chthmalus depressus*.

Littoral (intertidal zone): The coast is rocky, and the seabed has same steepness as in supralittoral. On the upper part of littoral there are many endolitic Cyanobacteriae and animals *Patella coerulea* and *Chthamalus stellatus*. On the lower part of littoral one finds *Actinia equina*, *Monodonta turbinata* and *Chthamalus stelatus*. The algae from genus *Litophyllum* are also present but in smaller abundance.

Sublittoral (subtidal zone): The seabed is rocky, and its steepness is the same as in the intertidal zone up to 3 m, and later it decreases. From the 3 to 11m of depth the seabed is rocky, but it has several patches of sediment. Below the level of lowest low tide, biodiversity is very high. Present are mostly algae *Cystoseira* and *Laurentia* and many sedentary cnidarians, gastropods, shells, crustaceans and fishes. The communities of algae have high abundance and they cover existing rocks completely. From the 1 to 6 m depth (on some places up to the depth of 8 m) there is a community of intertidal photophylic algae. Deeper, as sediment patches appear, algae abundance decreases. Very often there are habitats of sponge *Aplysina aerophoba*. From the depth of 11 m onward, community of *Posidonia oceanica* is dominant. It decreases its abundance with depth and from 20 m onward one finds none. Hence, *Posidonia oceanica* has not been found in the concession area. On the area without *Posidonia* there are many tali of red algae mostly from *Vidalia colubilis*. Below the cages the benthos is degraded. Up to 10% of seabed area there is a bacterial cover, similar to the one found on other fish farms. Another 10% has patches of bacterial cover, but the buried animals are still alive.

Authors of this text, taken from EIA study, report that this is the smallest impact seen so far on the sea bream farms.

Further to the south of the net pens, benthos is undisturbed and habitats are similar to the transition between intertidal and subtidal standard Adriatic habitats.

The complete list of species found near and in the concession area – which corresponds to zone B in ECASA terminology is:

Actinia cari Delle Chiaje
Actinia equina (Linnaeus)
Alicia mirabilis (Johnson)
Amphiroa rigida Lamouroux
Anadyomene stellata (Wulfen) C. Agardh
Anchinoe tenacior Topsent
Anemonia sulcata (Pennant)
Antedon mediterranea (Lamarck)
Aphrodita aculeata Linnaeus
Aplysina aerophoba (Schmidt)
Arbacia lixula (Linnaeus)
Arca noe Linnaeus
Ascidia sp.
Astropecten aurantiacus (Linnaeus)
Atherina sp.
Balanophyllia europaea (Risso)
Bispira volutacornis (Montagu)
Bittium reticulatum (da Costa)
Bonelia viridis Rolando
Boops boops (Linnaeus)
Caryophyllia inornata (Duncan)
Caryophylliasmithi (Stok-Brod.)
Cerithium vulgatum (Bruguiere)
Chlamys varia (Linnaeus)
Chromis chromis (Linnaeus)
Chthamalus stellatus (Poli)
Cladophora sp.
Clanculus sp.
Cliona celata (Grant)
Cliona viridis (Schmidt)
Conger conger (Linnaeus)
Coris julis (Linnaeus)
Coscinasterias tenuispina (Lamarck)
Cystoseira sp.
Dentex dentex (Linnaeus)
Diplodus annularis (Linnaeus)
Diplodus puntazzo (Cetti)
Diplodus sargus (Linnaeus)
Diplodus vulgaris (Geoffroy Saint-Hilaire)
Echinaster sepositus (Gray)
Eriphia verrucosa (Forskal)
Eunice aphroditois (Pallas)
Eupolymnia nebulosa (Montagu)
Flabellia petiolata (Turra) Nizamuddin
Galathea squamifera (Leach)
Gastrochaena (Rocellaria) dubia (Pennant)
Gelidium latifolium (Greville) Thuret et Bornet
Gobbius cruentatus Gmelin
Gobius bucchichii Steindachner
Gobius niger Linnaeus
Halimeda tuna (Ellis et Solander) Lamouroux
Haliotis lamellosa Lamarck
Hippocampus guttulatus Cuvier
Holothuria sp.
Holothuria tubulosa Gmelin

Inachus sp.
Jania rubens (Linnaeus)) Lamouroux
Labrus merula Linnaeus
Laurencia obtusa (Hudson) Lamouroux
Ligia italica Fabricius
Lima lima (Linnaeus)
Lithophaga litophaga (Linnaeus)
Lithotamnium fruticulosum (Kützing) Foslie
Macropodia longirostris (Fabricius)
Maia sp.
Maia verrucosa Milne Edwards
Mantellum sp..
Marthasterias glacialis (Linnaeus)
Microcosmus sp.
Modiolus barbatus (Linnaeus)
Monodonta turbinata (Born)
Murex trunculus (Linnaeus)
Myxicola infundibulum (Renier)
Oblada melanura (Linnaeus)
Octopus vulgaris Cuvier
Ophioderma longicaudum (Retzius)
Ophiothrix fragilis (Abildgaard)
Ozaena moschata (Lamarck)
Pachygrapsus marmoratus (Fabricius)
Padina pavonica (Linnaeus) Thivy
Paguristes oculatus (Fabricius)
Pagurus sp.
Palaemon elegans Risso
Parablennius rouxi (Cocco)
Paracentrotus lividus (Lamarck)
Patella caerulea Linnaeus
Petricola lithophaga (Retzius)
Petrosia ficiformis Poiret
Peysonnelia rubra (Greville) J. Agardh
Peysonnelia squamaria (Gmelin) Decaisme
Pilumnus hirtellus (Linnaeus)
Pisidai longicornis(Linnaeus)
Pomatoceros triqueter (Linnaeus)
Porcellana platycheles (Pennant)
Posidonia oceanica (Linnaeus) Delile
Protula sp.
Pseudochama gryphina (Lamarck)
Rissoa sp.
Sabella spallanzani (Viviani)
Sarpa salpa (Linnaeus)
Schizobrachiella sanguinea (Norman)
Sepia officinalis Linnaeus
Serpula vermicularis (Linnaeus)
Serranus (Serranellus) cabrilla (Linnaeus)
Serranus (Serranellus) hepatus (Linnaeus)
Serranus (Serranellus) scriba (Linnaeus)
Sparus auratus (Linnaeus)
Sphaerechinus granularis (Lamarck)
Spicara (Maena) maena (Linnaeus)
Spicara (Maena) smaris (Linnaeus)

Spirorbis sp.
Spondyliosoma (Cantharus) cantharus (Linnaeus)
Spondylus gaederopus Linnaeus
Sydnium sp.
Symphodus (Crenilabrus) melanocerus (Risso)
Symphodus (Crenilabrus) roissalii (Risso)
Symphodus (Symphodus) rostratus (Bloch)
Tethya aurantium (Pallas)
Tethya citrina (Sara & Melone)
Tripterygion tripteronotus (Risso)
Vidalia volubilis (Linnaeus) J.Agardh
Wrangelia penicillata C.Agardh
Xantho poressa (Olivi)
Xantho sp.
Zosterisessor (Gobbius) ophiocephalus (Pallas)

3.3 Benthos and sediments

EIA study report contains results of granulometry analysis. The sediment is characterized as silted sand. The sample was described as gray fine to rough granulated dusted sand with shellfish fragments. It has consisted of 6% of gravel (>2000µm), 60% sand (64-2000 µm), 21% silt (2-64 µm) and 13% clay (<2 µm)[5]

Even though the EIA study report prescribes yearly obligatory monitoring of sediment chemistry, including redox potential, organic carbon and total nitrogen, no initial values are presented therein.

Protected species: *Posidonia oceanica*, in the zone B, however, outside concession area.

3.4 Marine mammals; seals, cetaceans, otters

In Croatia all marine mammals are protected by law. Bottle-nosed dolphin schools sometimes pass in the vicinity of the concession area; however there is no record of embroilment to the nets.

3.5 Birds

Bird species: seagulls and cormorants. There are no rare species in the area. Several nesting sites exist nearby, but neither scattering nor scaring of the birds is preformed. To avoid interactions between birds and reared fish for preventing parasite transmission, two management measures are performed: keeping the pens platforms clean without any food leftovers and covering pens by nets.

3.6 Fisheries and wild fish populations

Local fishery is active outside the concession area. Wild fish gathers around the farm in order to grab uneaten feed pellets. Fishing inside the concession area is allowed only to the farm employees in terms of their "additional family fishery" licenses (for personal use only).

No recapture of escapes is preformed, but efficient prevention is maintained. Regular inspection by divers is performed. Found holes are mended until the nets are changed and repaired completely.

There is a regulation that describes minimum distances between actively utilized objects, in order to prevent aquaculture from self-contamination and disease transition. The proscribed minimum distances are:

- 2 km between two larger aquaculture facilities,

- 1 km between shellfish farm and hotel,
- 0.8 km between shellfish farm and inhabited area,
- 0.8 km between fish farm and birds/mammal colonies.

3.7 Noise

All activities take place during the day (feeding, fishing, diver's inspection and delivery of feed). During the night-time two guards look after the facility. They are situated on the uninhabited island nearby. The nearest residential area is approximately 2.5 km away. During daytime, service boats are the origin of noise, but the level of noise produced by boat engines is in accordance with law.

3.8 Transport

Deliveries of feed, materials and supplies for employees occur on a regular basis by company's boat. Workers on the farm are local residents and are transported to the site from the port in Pakoštane (8 km away) by boats. Roads on land are within Croatian standards. There are three shore bases – one on the site's nearest Island, warehouse in nearest land port (Pakoštane) and the company headquarters with factory situated 1 km away from Pakoštane.

3.9 Socio-economic impact

Currently Dalmar Ltd. is the 14th largest exporter in the Zadar County. In the beginning, 12 people were hired (project manager, manager, 6 feeders, diver, administrative worker and truck driver). As the number of sites operated by Dalmar increases, more local people are being employed. All employees are local residents.

Other benefits to the local community:
- facilities are situated on low priced and economically undeveloped marine area,
- concession money, plus 0.33% of company's one year earnings,
- better offer for tourists (high quality fish),
- attraction of experts and information exchange.

4 Results of ECASA field studies: Indicators and Models applied and evaluated

4.1 Background to field program

The first phase of field program started on 30 June 2006. All samples were taken around a single net pen from group 1 (Figure 4) filled with 19 tons of Sea Bass. Water column was sampled at two stations: 4 m from the net pen and at the reference station. On each station triplicates were collected just below the surface, at 12 m depth and 0.5 m above bottom. Sediment samples at 0 m, 4 m, 12 m, 20 m and the reference station were also taken in triplicates. To test the KK3D model [3], sediment traps were deployed below the center of the net pen and at distances of 8 m, 12 m, 20 m and 40 m. Two trap designs were used: short (diameter: 8 cm, height: 20 cm) and long (diameter: 8 cm, height: 50 cm). Long sediment traps were in accordance with the recommendation that the ratio between height and diameter should be 5:1. Short traps were used to quantify the resuspension. Approximately, 30% less faecal material was present in short sediment traps compared to the long traps.

Sontek ADP was deployed on 04 July 2006 at 18:34, to measure currents near the fish farm. Current meter was located at 43° 50' 15" N, 15° 30' 49" E. 13 days of useful data were recorded and the complete analysis of this record is given in Appendix B.

Upon collection, all samples were taken to the Department of public health in Zadar for analysis. Samples were given over on 06 and 07 July 2006. Analysis was completed on 15 August 2006.

Work on the study site was done by a team of five people: two scientists from RBI (Jasminka Klanjšček and Marko Jusup), two divers (Donat Petricioli and Hrvoje Čižmek) and one assistant (Srećko Trajbar) (all from D.I.I.V. Ltd.). Operations were performed from a 4.5 m long rubber boat equipped with Yamaha 25 hp engine.

The first phase of the field program finished on 07 July 2006. The second phase started on 23 July and lasted until 28 July 2006. During the second phase bioassay samples were collected at four stations (0 m, 25 m, 50 m and reference). Additional help was provided by Dror Angel (Recanati Institute for Maritime Studies). Bioassay samples were analyzed at RBI, Department for physical chemistry, Laboratory for analytical chemistry. Analysis was completed on 14 December 2006.

4.2 Sampling methods and materials, analytical methods.

Table 5. Sediment sampling methods, material and analytical methods.

Sample	Sampling method	Sampling material	Analytical method
Sediment traps	Sediment traps were deployed for 43 hours at four stations (0 m, 8 m, 12 m, 20 m, 40 m and reference)	▪ Plastic tubes: Long (h = 50 cm) Short (h = 20 cm) ▪ Rope ▪ Buoys ▪ Anchors	Samples were filtered over Whatmann GCF filters, dried (24 h at 60 °C), weighted, homogenized and stored at 4 °C for subsequent CHN analysis
Meiofauna	Triplicate cores taken at each station	Plastic corers d = 3.3 cm	Analysis incomplete
Surface sediment	Triplicate cores taken at each station	Plastic corers	Samples were dried (24 h at 60 °C), homogenized and stored at 4 °C for further analysis

Table 6. Water column sampling methods, materials and analytical methods.

Sample	Sampling method	Sampling material	Analytical method
T	Vertical profile measured by CTD probe	Idronaut Ocean Seven	N/A
S	Vertical profile measured by CTD probe	Idronaut Ocean Seven	N/A
TSS	Sampled at 3 depths with Niskin sampler	Niskin sampler	Samples were filtered (0.45 µm pores), dried at 105 °C and weighted
DO	Sampled at 3 depths with Niskin sampler	Niskin sampler	Winkler's method
NH_4^+	Sampled at 3 depths with Niskin sampler	Niskin sampler	Spectrophotometric phenolate method (after Ivancic and Deggobis)
NO_2^-	Sampled at 3 depths with Niskin sampler	Niskin sampler	Spectrophotometry after treatment with sulphanilic acid
NO_3^-	Sampled at 3 depths with Niskin sampler	Niskin sampler	Spectrophotometry after reduction with Cd column (after Morris and Riley)
TN	Sampled at 3 depths with Niskin sampler	Niskin sampler	Oxidation of organic and inorganic nitrogen compounds by combustion to nitric oxide. Oxidation (ozone) to electronicaly excited nitrogen dioxide. Quantification by chemiluminescence detection (Shimadzu TOC-V_{CPH}-TNM analyzer).
TP	Sampled at 3 depths with Niskin sampler	Niskin sampler	UV/VIS spectrophotometer (Shimadzu UV-2401)
PO_4^{3-}	Sampled at 3 depths with Niskin sampler	Niskin sampler	Spectrophotometry with molybdate acid (after Koroleff)
SiO_2	Sampled at 3 depths with Niskin sampler	Niskin sampler	Spectrophotometry with molybdate (after Koroleff)
TOC	Sampled at 3 depths with Niskin sampler	Niskin sampler	Oxydation of organic carbon to CO2 by high temperature combustion. Carbon dioxide is detected with non-dispersive infrared spectrometry (NDIR) detector (Shimadzu TOC-V_{CPH}-TNM analyzer).
Chl a	Sampled at 3 depths with Niskin sampler	Niskin sampler	Fluorimetry

Table 7. Bioassay sampling methods, materials and analytical methods.

Sample	Sampling method	Sampling material	Analytical method
Chl a	Filtered (through 25 µm sieve) and unfiltered water from the control station was poured into dialysis bags and placed for five days into seawater at four stations (0 m, 25 m, 50 m and reference)	▪ 25 µm mesh sieve or plankton net ▪ Dialysis membrane ▪ Plastic coated metal wire ▪ Nylon mesh bags ▪ Metal plate ▪ Rope ▪ Weights (100g) ▪ Buoys ▪ Anchors	200 ml or 250 ml of water was filtered through Whatmann GF/F filters. The quantity of pigments was determined by reversed-phase HPLC technique using UV-Vis detector (440 nm).
CHN	Filtered (through 25 µm sieve) and unfiltered water from the control station was poured into dialysis bags and placed for five days into seawater at four stations (0 m, 25 m, 50 m and reference)	▪ 25 µm mesh sieve or plankton net ▪ Dialysis membrane ▪ Plastic coated metal wire ▪ Nylon mesh bags ▪ Metal plate ▪ Rope ▪ Weights (100g) ▪ Buoys ▪ Anchors	250 ml of water was filtered through Whatmann GF/F filters. The ratio C:H:N was determined by Perkin Elmer series 2 CHNS/O 2400 analyzer.

4.3 Models used and their parameterization

Primary goal of field program conducted at Pakoštane was to gather data for evaluation of KK3D model performance. To that end sediment traps were deployed for 43 h. Flux of solid waste was determined at the depth of 23 m.

KK3D model is based on the possibility to breakdown the sea current velocity into two parts: 1) slowly varying component due to tidal, thermohaline and wind forcing, and 2) random component related to turbulence that quickly changes in time. Former part is responsible for displacement of waste material from the source (advection) while the latter part causes the dispersion (turbulent diffusion). Therefore, it is tempting to adopt the semi-empirical approach (Monin and Yaglom, 1971) and model the transport of any passive tracer emitted from an aquaculture by using the advection/diffusion equation:

$$\frac{\partial C}{\partial t} + v_i(\mathbf{x},t)\frac{\partial C}{\partial x_i} = \frac{\partial}{\partial x_i}\left(K_{ij}(\mathbf{x},t)\frac{\partial C}{\partial x_j}\right), \qquad (1)$$

where C is the tracer concentration, v_i, $i = 1, 2, 3$ are current velocities and K_{ij}, $i, j = 1, 2, 3$ are eddy diffusivity coefficients. This is an Eulerian approach and we can replace it by a Lagrangian technique called Random Displacement Model (RDM) which is consistent with equation (2) (Rodean, 1996). However, in order to predict the distribution of particulate organic material on the seabed we must calculate the paths of heavy particles and not the passive tracer. According to Wilson (2000), RDM easily resolves this problem by superimposing to it the particle settling velocity v_z. Thus, the position of a particle in RDM is given by the stochastic differential equations:

$$\mathrm{d}x_i = \left(v_i(\mathbf{x},t) + v_z\delta_{i3} + \frac{\partial K_{ij}(\mathbf{x},t)}{\partial x_j} \right)\mathrm{d}t + \sqrt{2K_{ij}(\mathbf{x},t)}\mathrm{d}W_j \ , \qquad (2)$$

where $\mathrm{d}W_i$, i = 1, 2, 3 are standard Wiener processes. Sedimentation pattern is expressed in the form of solid waste flux (g DW/m^2/day).

Wilson (2000) classifies RDM as a "zeroth-order" LSM thereby noting its main weakness; if $x_i(t)$ is treated as Markovian random variable, the model cannot be valid close to the source, that is for travel times shorter than the velocity correlation timescale. The more advanced, "first-order" LSM, called Langevin Equation Models (LEM), have been used extensively in atmospheric research owing much of their popularity to analytical description of turbulence properties in the surface boundary layer. For example, Kurbanmuradov and Sabelfeld (2000) have shown how a number of simplifying assumptions lead to unique selection of three-dimensional LEM for turbulent diffusion in the atmosphere. This turns out to be an impossible task in oceanographic application (Brickman and Smith, 2002) where turbulent quantities are provided by circulation models with incorporated appropriate closure scheme (e.g. Warner et al., 2005). Furthermore, there is a problem of the so-called trajectory crossing. Initially the heavy-particle position will coincide with the position of some fluid element. As the time passes, particle drifts away from the fluid element because of its settling rate, leaving the eddy in which correlation with initial velocity still exists. Therefore, it is suggested to reduce the heavy-particle correlation timescale with respect to the fluid element timescale (e.g. Wilson, 2000), but this is a heuristic approach. There is also a possibility that due to finite inertia, heavy-particle is unable to follow rapid velocity fluctuations, resulting in a different velocity variance compared to the fluid element. Our objective was to construct a model that is usable in many different locations prior to installation of an aquaculture. In such situations, at best, measured current profiles are available as input data. So to avoid unnecessary complexities and account for dispersion, one must impose reasonable assumptions about joint moments of concentration and velocity fluctuations. The simplest and widely used example is the eddy diffusion hypothesis:

$$\overline{v_i^{\prime} C^{\prime}} = K_{ij}\frac{\partial C}{\partial v_j} . \qquad (3)$$

Particle tracking model described above requires two types of input data:
1. Measured current record from a representative location, and
2. Rectangular grid containing bottom topography.

Grid cell resolution is arbitrary and depends only on available data from a location of interest. Cromey et al. (2002a) used the resolution of 10 m or 25 m depending on the size of the sedimentation pattern and in realistic application one can hardly expect higher precision due to instrument limitations.

To start particle tracking we also need the magnitude of settling velocity v_z. The velocity is chosen randomly for each particle from the species dependent distribution (Magill et al., 2006). Approximate solutions to equations (2) are obtained by means of the Euler-Maruyama method or, as Kloeden and Platen (1992) put it, an Ito-Taylor scheme of strong order 0.5:

$$x_i(t+\Delta t) = x_i(t) + \left(v_i(\mathbf{x},t) + v_z\delta_{i3} + \frac{\partial K_{ij}(\mathbf{x},t)}{\partial x_j} \right)\Delta t + \sqrt{2K_{ij}(\mathbf{x},t)\Delta t}\,\eta_j \ . \qquad (4)$$

Here Δt is the time-step and $\eta_j \in N(0,1)$.

In the atmospheric surface boundary layer, it is convenient to choose coordinate axes so that the x_1-axis coincides with the direction of the mean wind velocity. Then, the crosswind velocity fluctuations are symmetrical with respect to the planes x_1=0 and x_3=0, and we have $\overline{v_1'v_2'} = 0$ and $\overline{v_2'v_3'} = 0$. In addition, since the Ox_1, Ox_2 and Ox_3 are clearly the preferred axes of the flow they are often considered as principal axes of the diffusivity tensor. Within the sea, the direction of the mean flow can change with depth making the above reasoning inapplicable. However, Monin and Yaglom (1971) note that "all qualitative predictions of semi-empirical diffusion theory can hardly depend on the presence or absence of terms with coefficients K_{13} and K_{31}" (authors considered the inclusion of these terms into equation (1)). Accordingly, our model includes only diagonal elements of the diffusivity tensor. Besides, these coefficients are depth dependent to account for the existence of surface and bottom boundary layers. Their mean values correspond to the values observed in Scottish inshore waters ($\overline{K_{11}} = \overline{K_{22}} = 0.1\ \mathrm{m}^2/\mathrm{s}$, $\overline{K_{33}} = 0.001\ \mathrm{m}^2/\mathrm{s}$) and used for modeling by Gillibrand et al. (2002) and Cromey et al. (2002a). Thus, based on published results, we expect that the key properties of sedimentation pattern such as its shape and size, the location of maximum loading, etc. can be estimated with acceptable accuracy.

Initial particle position in x_1Ox_2 plane is chosen randomly from a non-uniform distribution assuming that the fish usually swims around the center of the net pen. The net pen diameter was set to 19 m for the validation run. Let us note that fixing the starting position (for example, to the net pen center) does not affect the sedimentation pattern at all in sufficiently deep water. In such conditions, the deposition area is much larger than the net pen area and the exact initial position of the particle is hardly relevant. However, in shallow water, fixing the starting position can result in under-prediction of sedimentation pattern size. The model is far more sensitive to the choice of initial vertical coordinate x_3 because dispersion is depth dependent, i.e. deposition area increases rather quickly with depth. Since there is observational evidence that defecation occurs near the surface immediately after feeding, we have chosen x_3=-10 m for all particles. The number of tracked particles in each simulation was set to $2 \cdot 10^5$ since no changes in results occurred with higher values. Output data is passed to a visualization module, which produces contour plots revealing details of predicted sedimentation pattern. Unless we simulate exceedingly large number of sample paths, the stochastic nature of employed algorithm will cause appearance of small patches in final images. Clearly, these patches are insignificant as they disappear with large number of tracked particles.

In the present validation study, dispersion is simulated over 1-week period, but that value can easily be changed in order to meet specific requirements. For example, sometimes it is useful to predict dispersion when strong currents towards the shore dominate the aquaculture area.

4.4 Results

Tables of bulk data are located in appendix A. Results indicate that:

1. impact of aquacultures on the water column cannot be determined by instantaneous sampling. None of the indicators that were taken by Niskin sampler are significantly higher near the net pen in comparison with the reference station. However, bioassay results suggest that aquaculture contributes to eutrophication due to release of dissolved nutrients.
2. Flux of solid waste on the seabed is relatively high and suggests that the sediment is anoxic (at least occasionally). This expectation was confirmed by the presence of dense layers of *Beggiatoa* bacteria. We also tested an innovative and simple method for determination of oxic layer depth. Unfortunately, our equipment at the reference station

was ripped out of the sediment and for that reason we omit detailed discussion of results. Valid samples were obtained in the vicinity of net pens at stations 0 m, 8 m, 12 m, 20 m and 40 m and they are consistent with anoxic conditions in the sediment.

One of the main goals of fieldwork program at Dalmar study site was validation of KK3D model. Schematic representation of model prediction is shown in Figure 8. Maximum predicted benthic loading is 46.3 g DW/m^2/day, located approximately 6 m westward from the net pen center (denoted by a blue circle). Flux quickly decreases with increasing distance from the outer rim of the net pen. 40 m away benthic loading is indistinguishable from normal background sedimentation.

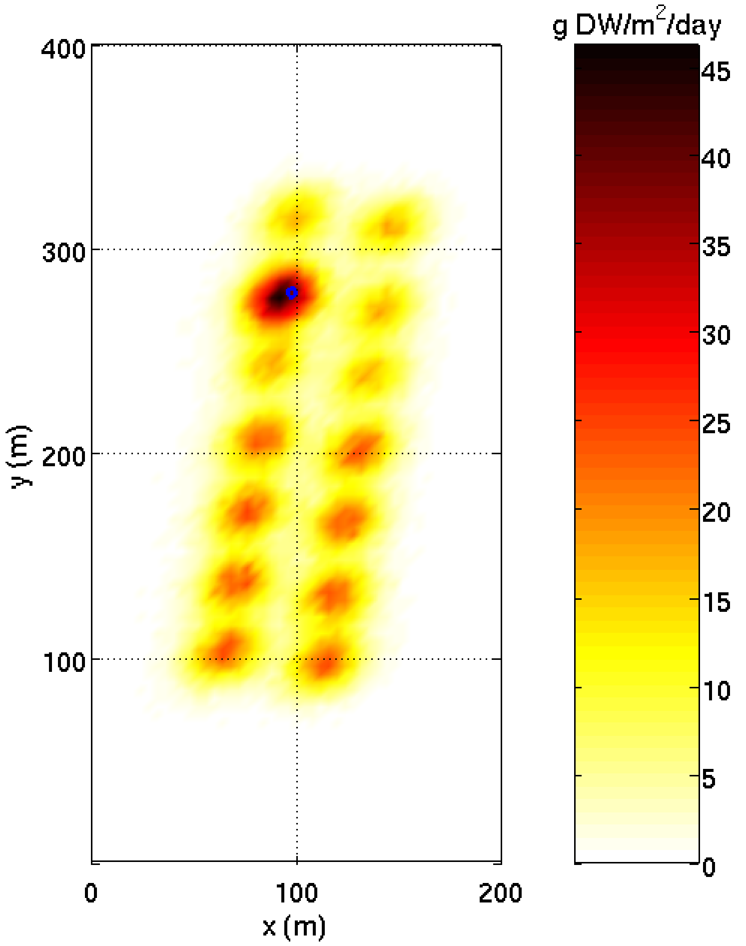


Figure 8. Prediction of dry weight deposition by the KK3D model.

4.5 Evaluation of indicator performance

From all measured indicators we single out the performance of solid waste flux on the bottom and bioassay. The former is related to the state of sediment and can be used to test the performance of deposition models (for details please refer to section 4.6). The latter clearly detects contribution of aquaculture to eutrophication of nearby seawater.

In general, all indicators proposed in ECASA project can be divided into two groups:

1. indicators which represent the state of the environment at one moment in time (obtained by instantaneous sampling).
2. indicators which sum (integrate) the state of the environment over a certain time period.

Fieldwork done at Dalmar study site suggests that the first group of indicators is unreliable for determination of environmental impact of aquacultures. This could be offset by obtaining a time series of measured values. The problem with such a procedure is dramatic increase in costs. Thus, we should turn to indicators from the second group, especially when sampling protocols are relatively simple and inexpensive.

4.6 Evaluation of model performance

Comparison of measured and predicted values is given in table 5. Linear regression analysis of model performance is displayed in the figure 5. Slope coefficient k = 1.02 means that the model operates well over the whole range of observed values. Intercept l = 2.58 g DW/m^2/day signifies that the model consistently underestimates the observations. Overall accuracy, determined by combining all data, is ±50% which is in accordance with previously published results [1].

Table 8. A comparison of model prediction and measurement.

Station	Model prediction (g DW/m^2/day)	Measurement (g DW/m^2/day)
0 m	41.0	53.0
8 m	30.6	34.5
12 m	24.7	12.3
20 m	9.6	13.4
40 m	1.1	9.1

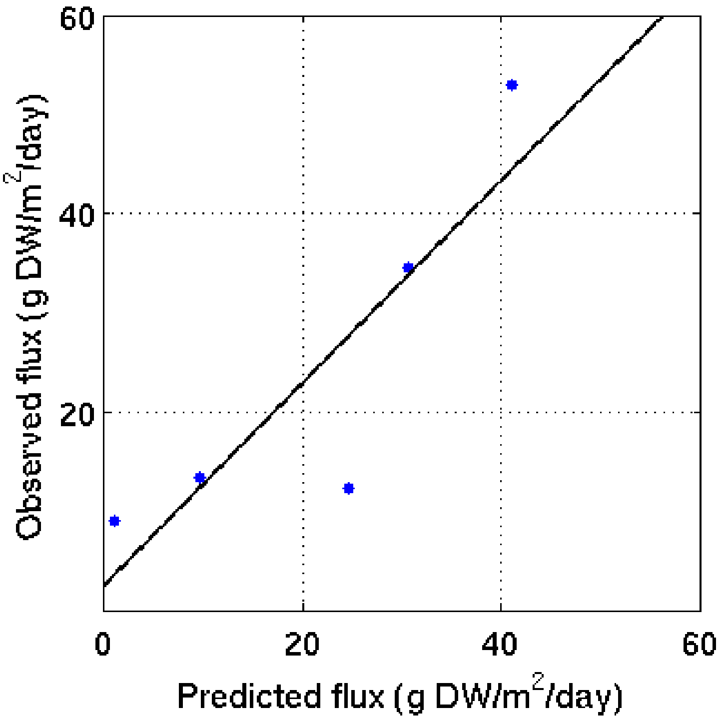


Figure 9. Predicted versus observed dry weight deposition.

4.7. Site specific conclusions

At zone A scale, KK3D model predicts relatively high flux of solid waste on the bottom. Measurements confirm this prediction. Conditions in the sediment are anoxic, at least occasionally, which is implied by dense layers of *Beggiatoa* bacteria present at the seawater-sediment interface. Impact is traceable up to 40 m from the net pens and possibly extends further away. However, healthy communities of *Posidonia oceanica* are present within 200 m from the net pens. Since *Posidonia* is extremely sensitive to organic loading of seabed, we conclude that the impact of fish farm on the bottom is localized and occurs at a distance smaller than 200 m.

At zone B scale, measurements of dissolved nutrient concentration or chlorophyll-a did not show elevated values near the fish farm. On the contrary, values of chlorophyll-a obtained through bioassay clearly indicate that fish farm contributes to eutrophication.

At zone C scale there are no effects attributable to fish farming. Perhaps when number of fish farms increases, deterioration of regional water quality will become observable.

Dalmar's fish farm is located in sparsely populated area and thus minimally interferes with tourism. There are no conflicts with owners of luxury apartments or hotels. The farm mostly employs people from nearby coastal towns or islands. Latter is considered especially positive, since employment prevents young people from leaving their home on island in search of job opportunities.

Current fish farming practice is sustainable from at least three points of view:

1. Although sediment beneath fish farm is anoxic, sufficient depth and flushing minimize the threat to cultured fish, i.e. degassed harmful substances like hydrogen sulfide will not enter into the net pens.
2. Water quality within net pens is kept at optimal levels at all times due to appropriate farming practice and flushing.
3. Regional water quality is presently unaffected by aquacultures and their contribution to eutrophication is negligible.

Prospects for development of aquaculture in Zadar County are excellent. Study of utilization and protection of coastal waters was made before the spatial plan has been adopted. This study defined zones suitable for future development of fish farming activities. Conclusions of the study entered into the spatial plan of Zadar County.

5 Acknowledgements

We would like to thank Dalmar’s Ltd. management for allowing access to the EIA study of their aquaculture. Dr. Dror Angel from Recanati Institute for Maritime Studies, Israel provided vital help during the bioassay study.

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Appendix A: Tables of bulk data

Water column

Station: 4 m, surface		Temperature: 20.4 °C Salinity: 38.02		
Indicators	Unit	Result 1	Result 2	Result 3
TSS	mg/l	< 0.5	-	-
DO	mg O_2/l	6.90	7.00	6.86
Saturation	%	93.75	95.11	93.21
NH_4^+	mg N/l	< 0.001	0.002	0.001
NO_2^-	mg N/l	< 0.001	< 0.001	< 0.001
NO_3^-	mg N/l	0.009	0.008	0.008
TN	mg N/l	0.121	0.125	0.131
TP	mg P/l	0.002	0.002	0.001
PO_4^{3-}	mg P/l	0.001	0.001	0.001
SiO_2	mg SiO_2/l	0.039	0.039	0.039
TOC	mg/l	0.887	0.877	0.915
Chl a	µg/l	0.25	-	-

Station: 4 m, depth 12 m		Temperature: 16.6 °C Salinity: 37.92		
Indicators	Unit	Result 1	Result 2	Result 3
TSS	mg/l	< 0.5	-	-
DO	mg O_2/l	7.75	9.46	7.62
Saturation	%	98.10	119.75	96.45
NH_4^+	mg N/l	< 0.001	< 0.001	< 0.001
NO_2^-	mg N/l	< 0.001	< 0.001	< 0.001
NO_3^-	mg N/l	0.006	0.006	0.005
TN	mg N/l	0.058	0.061	0.052
TP	mg P/l	0.002	0.002	0.002
PO_4^{3-}	mg P/l	< 0.001	< 0.001	< 0.001
SiO_2	mg SiO_2/l	0.072	0.066	0.072
TOC	mg/l	0.846	0.790	0.811
Chl a	µg/l	0.16	-	-

Station: 4 m, bottom		Temperature: 15.1 °C Salinity: 38.06		
Indicators	Unit	Result 1	Result 2	Result 3
TSS	mg/l	1.0	-	-
DO	mg O_2/l	7.77	7.76	7.71
Saturation	%	95.69	95.57	94.95
NH_4^+	mg N/l	< 0.001	< 0.001	< 0.001
NO_2^-	mg N/l	< 0.001	< 0.001	< 0.001
NO_3^-	mg N/l	0.008	0.007	0.006
TN	mg N/l	0.067	0.061	0.059
TP	mg P/l	0.002	0.002	0.002
PO_4^{3-}	mg P/l	0.001	0.001	0.001
SiO_2	mg SiO_2/l	0.084	0.079	0.084
TOC	mg/l	0.729	0.708	0.726
Chl a	µg/l	0.18	-	-

Station: Reference, surface		Temperature: 20.56 °C Salinity: 37.75		
Indicators	Unit	Result 1	Result 2	Result 3
TSS	mg/l	< 0.5	-	-
DO	mg O_2/l	7.42	7.07	7.15
Saturation	%	100.95	96.19	97.28
NH_4^+	mg N/l	< 0.001	< 0.001	< 0.001
NO_2^-	mg N/l	< 0.001	< 0.001	< 0.001
NO_3^-	mg N/l	0.010	0.007	0.008
TN	mg N/l	0.083	0.088	0.087
TP	mg P/l	< 0.001	< 0.001	< 0.001
PO_4^{3-}	mg P/l	< 0.001	< 0.001	< 0.001
SiO_2	mg SiO_2/l	0.041	0.036	0.038
TOC	mg/l	0.878	0.889	0.890
Chl a	µg/l	0.12	-	-

Station: Reference, depth 12 m		Temperature: 17.91 °C Salinity: 37.70		
Indicators	Units	Result 1	Result 2	Result 3
TSS	mg/l	< 0.5	-	-
DO	mg O_2/l	7.72	7.94	7.67
Saturation	%	100.13	102.98	99.48
NH_4^+	mg N/l	< 0.001	< 0.001	< 0.001
NO_2^-	mg N/l	< 0.001	< 0.001	< 0.001
NO_3^-	mg N/l	0.006	0.007	0.006
TN	mg N/l	0.049	0.059	0.062
TP	mg P/l	< 0.001	< 0.001	< 0.001
PO_4^{3-}	mg P/l	< 0.001	< 0.001	< 0.001
SiO_2	mg SiO_2/l	0.072	0.069	0.072
TOC	mg/l	0.745	0.732	0.740
Chl a	µg/l	0.14	-	-

Station: Reference, bottom		Temperature: 15.40 °C Salinity: 38.03		
Indicators	Unit	Result 1	Result 2	Result 3
TSS	mg/l	< 0.5	-	-
DO	mg O_2/l	7.24	7.72	7.75
Saturation	%	89.60	95.54	95.91
NH_4^+	mg N/l	< 0.001	< 0.001	< 0.001
NO_2^-	mg N/l	< 0.001	< 0.001	< 0.001
NO_3^-	mg N/l	0.007	0.007	0.007
TN	mg N/l	0.054	0.065	0.056
TP	mg P/l	< 0.001	< 0.001	< 0.001
PO_4^{3-}	mg P/l	< 0.001	< 0.001	< 0.001
SiO_2	mg SiO_2/l	0.074	0.077	0.082
TOC	mg/l	0.734	0.737	0.773
Chl a	µg/l	0.10	-	-

Sediment

Dissolved oxygen concentration 10 cm above sediment							
Station	Temp. (°C)	Salinity	Indicators	Unit	Result 1	Result 2	Result 3
0 m	15.10	38.06	DO	mg/l	7.95	8.08	8.09
				%	97.85	99.45	99.58
4 m	15.10	38.06	DO	mg/l	7.70	7.79	8.20
				%	94.77	95.88	100.92
12 m	15.10	38.06	DO	mg/l	-	9.20	8.27
				%	-	113.23	101.78
20 m	15.10	38.06	DO	mg/l	7.64	7.56	7.56
				%	94.03	93.05	93.05
40 m	15.43	38.05	DO	mg/l	7.50	7.38	7.36
				%	92.82	91.34	91.09
Ref.	15.40	38.04	DO	mg/l	7.64	7.71	8.44
				%	94.03	94.89	103.88

Sediment trap model validation study					
Station	Indicators	Unit	Result 1	Result 2	Result 3
0 m, depth 12 m	Solid waste	g DW/m^2/day	19.64	19.19	19.42
0 m, depth 23 m	Solid waste	g DW/m^2/day	55.24	54.30	49.33
8 m, depth 23 m	Solid waste	g DW/m^2/day	34.00	34.92	-
12 m, depth 23 m	Solid waste	g DW/m^2/day	15.28	9.33	12.33
20 m, depth 23 m	Solid waste	g DW/m^2/day	15.30	13.46	11.44
40 m, depth 23 m	Solid waste	g DW/m^2/day	-	9.25	8.90
Ref., depth 23 m	Solid waste	g DW/m^2/day	1.60	1.24	1.38

Station: 0 m				
Indicators	Unit	Result 1	Result 2	Result 3
TOC	mg TOC/g	3.12	3.72	5.52
TN	mg TN/g	0.65	0.65	0.81
TP	mg TP/g	2.8	2.72	2.49

Station: 4 m				
Indicators	Unit	Result 1	Result 2	Result 3
TOC	mg TOC/g	3.21	3.28	3.20
TN	mg TN/g	0.55	0.47	0.57
TP	mg TP/g	1.95	1.90	1.90

Station: 12 m				
Indicators	Unit	Result 1	Result 2	Result 3
TOC	mg TOC/g	3.61	3.42	3.32
TN	mg TN/g	0.46	0.46	0.42
TP	mg TP/g	1.68	1.64	0.85

Station: 20 m				
Indicators	Unit	Result 1	Result 2	Result 3
TOC	mg TOC/g	2.26	2.62	3.00
TN	mg TN/g	0.39	0.33	0.36
TP	mg TP/g	0.79	0.82	0.81

Station: 40 m				
Indicators	Unit	Result 1	Result 2	Result 3
TOC	mg TOC/g	3.26	2.28	1.99
TN	mg TN/g	0.40	0.41	0.32
TP	mg TP/g	0.80	0.80	0.76

Station: Ref.				
Indicators	Unit	Result 1	Result 2	Result 3
TOC	mg TOC/g	7.46	7.43	7.35
TN	mg TN/g	0.87	0.88	0.94
TP	mg TP/g	0.37	0.41	0.34

Bioassay

Station: 0 m			Time: end			
(F)iltered/ (Un)filtered	Indicators	Unit	Result 1	Result 2	Result 3	Result 4
F	Chl a	µg/l	7.838	3.705	3.200	4.136
F	CHN sample mass	mg	2.094	2.548	1.906	1.928
F	C	%	0.56	0.57	0.38	0.50
F	H	%	0.61	0.57	0.38	0.37
F	N	%	0.13	0.10	0.05	0.10
F	Inorganic part	%	94.67	94.45	94.85	94.66
Un	Chl a	µg/l	6.883	7.874	5.040	4.365
Un	CHN sample mass	mg	2.096	2.154	2.094	2.076
Un	C	%	0.48	0.44	0.57	0.46
Un	H	%	0.58	0.36	0.28	0.24
Un	N	%	0.10	0.09	0.10	0.11
Un	Inorganic part	%	94.02	94.18	93.85	94.53

Station: 25 m			Time: end			
(F)iltered/ (Un)filtered	Indicators	Unit	Result 1	Result 2	Result 3	Result 4
F	Chl a	µg/l	8.127	5.429	5.140	6.981
F	CHN sample mass	mg	1.968	2.194	1.954	2.006
F	C	%	0.67	0.67	1.36	0.77
F	H	%	0.49	0.62	0.67	0.40
F	N	%	0.15	0.16	0.16	0.13
F	Inorganic part	%	93.61	94.78	94.59	94.65
Un	Chl a	µg/l	4.460	6.630	6.087	5.596
Un	CHN sample mass	mg	2.116	2.174	2.118	1.986
Un	C	%	0.47	0.53	0.79	0.63
Un	H	%	0.24	0.51	0.34	0.28
Un	N	%	0.10	0.12	0.12	0.12
Un	Inorganic part	%	94.72	94.99	94.75	94.91

Station: 50 m			Time: end			
(F)iltered/ (Un)filtered	Indicators	Unit	Result 1	Result 2	Result 3	Result 4
F	Chl a	µg/l	5.305	5.602	4.646	5.820
F	CHN sample mass	mg	2.240	2.346	2.106	2.066
F	C	%	0.45	0.89	0.76	1.27
F	H	%	0.58	0.41	0.53	0.40
F	N	%	0.11	0.14	0.15	0.13
F	Inorganic part	%	94.62	94.54	95.01	94.55
Un	Chl a	µg/l	5.388	4.673	5.494	7.131
Un	CHN sample mass	mg	2.172	2.120	2.076	2.128
Un	C	%	0.61	0.60	0.39	0.54
Un	H	%	0.29	0.20	0.59	0.42
Un	N	%	0.09	0.09	0.08	0.12
Un	Inorganic part	%	94.76	95.44	95.38	94.59

Station: Reference			Time: end			
(F)iltered/ (Un)filtered	Indicators	Unit	Result 1	Result 2	Result 3	Result 4
F	Chl a	µg/l	2.689	1.519	1.757	1.532
F	CHN sample mass	mg	2.092	2.128	2.152	1.912
F	C	%	0.40	0.36	0.40	0.96
F	H	%	0.52	0.29	0.21	0.23
F	N	%	0.09	0.08	0.09	0.11
F	Inorganic part	%	94.86	95.70	94.85	94.98
Un	Chl a	µg/l	5.354	5.886	3.267	3.906
Un	CHN sample mass	mg	2.100	-	2.144	2.176
Un	C	%	0.56	-	0.50	0.41
Un	H	%	0.29	-	0.26	0.26
Un	N	%	0.12	-	0.09	0.07
Un	Inorganic part	%	94.98	-	95.13	94.81

Station: -			Time: 0				
(F)iltered/ (Un)filtered/ (B)lank	Indicators	Unit	Result 1	Result 2	Result 3	Result 4	Result 5
F	Chl a	µg/l	0.182	0.129	0.246	0.127	0.063
F	CHN sample mass	mg	2.114	1.922	2.062	1.988	2.096
F	C	%	0.14	0.37	0.17	0.12	0.11
F	H	%	0.54	0.38	0.34	0.64	0.37
F	N	%	0	0	0	0	0
F	Inorganic part	%	94.33	94.81	95.44	93.63	95.31
Un	Chl a	µg/l	0.171	0.342	0.303	0.310	0.250
Un	CHN sample mass	mg	2.158	1.978	2.132	2.002	2.182
Un	C	%	0.21	0.12	0.18	0.12	0.11
Un	H	%	0.58	0.38	0.35	0.28	0.27
Un	N	%	0	0	0	0	0
Un	Inorganic part	%	94.64	94.64	92.98	95.78	94.11
B	Chl a	µg/l	-	-	-	-	-
B	CHN sample mass	mg	2.096	2.032	2.148	2.102	1.956
B	C	%	0.09	0.09	0.06	0.07	0.28
B	H	%	0.40	0.20	0.13	0.13	0.11
B	N	%	0	0	0	0	0
B	Inorganic part	%	99.06	98.75	98.54	98.60	98.76

Appendix B: Analysis of ADP current measurement

During the fieldwork at Dalmar study site, Sontek 500 kHz ADP probe with three transducers was deployed in order to measure the time series of current velocity. The probe was located at 43° 50' 15" N, 15° 30' 49" E, nearly 200 m from the net pens (Figure 10). Current velocity was sampled along a vertical profile, at points 2 m apart. This resolution is normally used with 500 kHz ADP units, when seawater is relatively shallow (less than 60 – 70 m). On Dalmar site, current meter was placed at depth of 23 m. Valid velocity samples were obtained within a depth range from 21.6 m (ADP's blanking distance prevents measurement approximately 1.5 m from the transducers) up to 5.9 m (waves and sidelobe energy qualify measurements closer to the surface as unreliable). In total, ADP was deployed slightly less than 14 days.

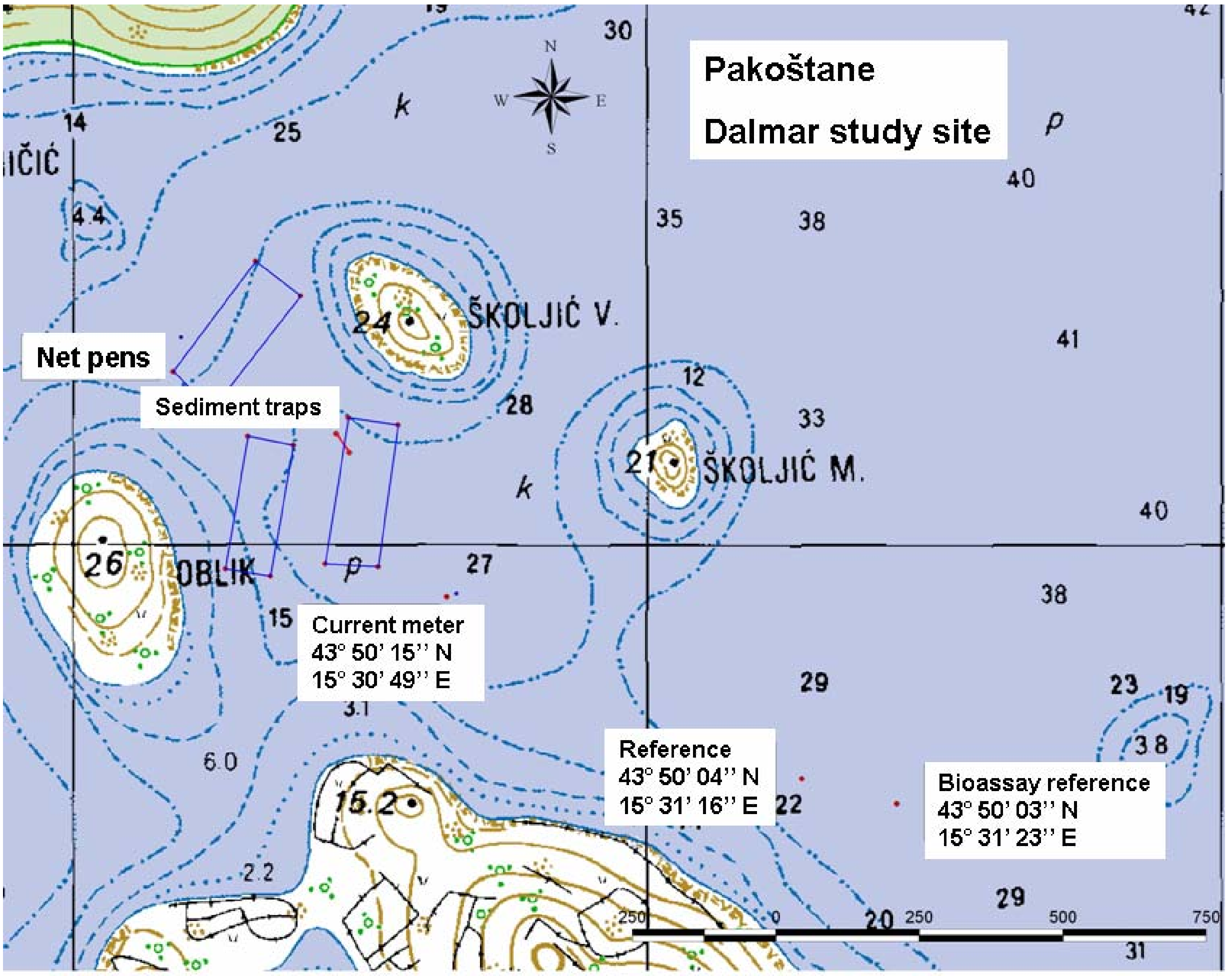

Figure 10. Overview of Dalmar study site.

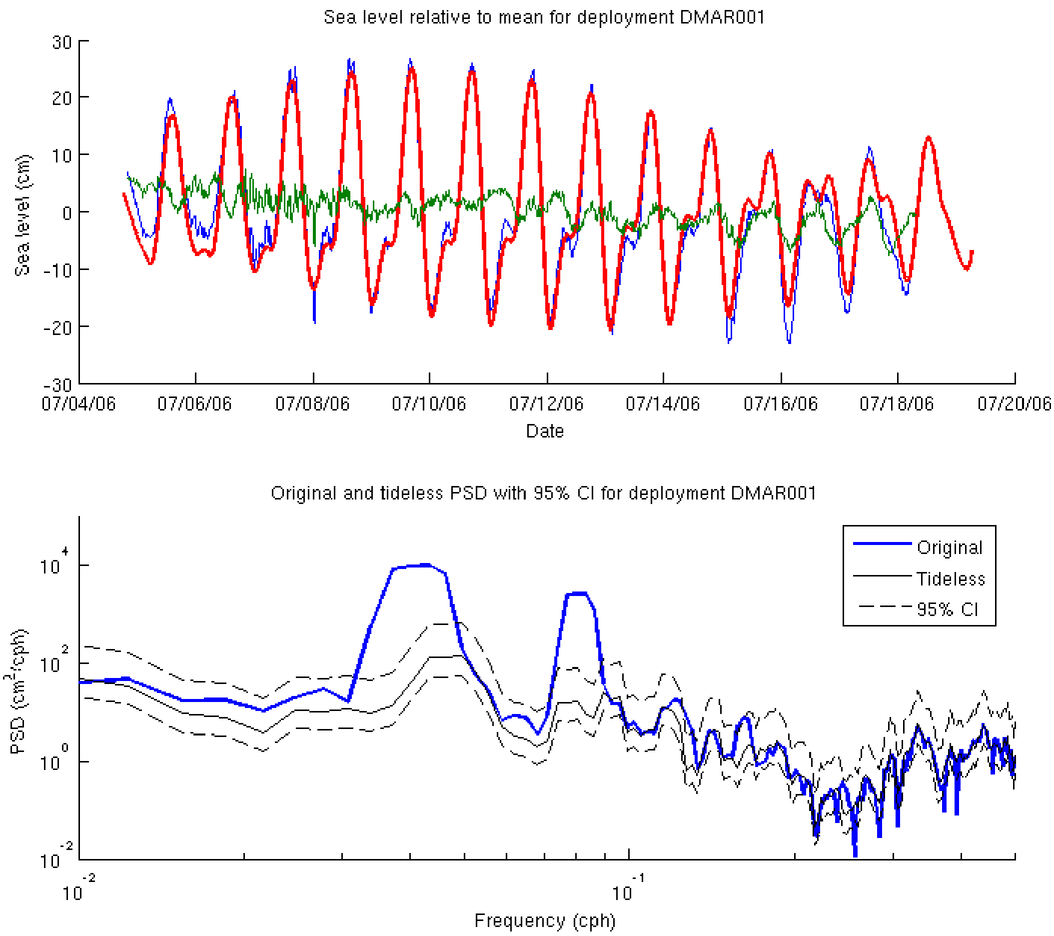

Figure 11. Upper panel: Comparison of observed (blue) and synthesized (red) sea level after tidal analysis. Lower panel: Spectral analysis of sea level prior to (blue) and after (black) removal of tidal energy.

ADP probe is equipped with pressure sensor to record information on sea level oscillations. Figure 11 shows that the sea level is almost entirely determined by tidal activity. In the Adriatic main diurnal constituents are K1 and O1, while main semi-diurnal constituents are M2 and S2. At the study site these four constituents make up for more than 90% of tidal energy. Their parameters are displayed in Table 9. Sound to Noise Ratio (SNR) roughly corresponds to significance of each tidal constituent. One can observe that the sea level is dominated by K1 diurnal and M2 semi-diurnal constituent. According to these findings one would also expect that currents are also strongly dominated by tidal activity. However, this is not the case, at least not directly, as we shall explain later.

Table 9. Parameters of four main tidal constituents at Dalmar study site.

Tidal constituent	Frequency (h^{-1})	Amplitude (cm/s)	Amp. error (cm/s)	Phase (°)	Phase error (°)	SNR
O1	0.0387307	3.8726	1.096	55.10	16.69	12
K1	0.0417807	11.9748	1.235	75.08	5.81	94
M2	0.0805114	6.3785	0.643	168.45	6.43	98
S2	0.0833333	2.6806	0.608	194.33	14.98	19

In the surface and middle layer currents mostly flow toward W and NW (Figure 12) and current speed is the highest in these directions. Seawater in the bottom layer moves mostly toward W, SW and S, what again corresponds to direction of the highest current speed. However, flow in the bottom layer is generally slower than in the middle or surface layer.

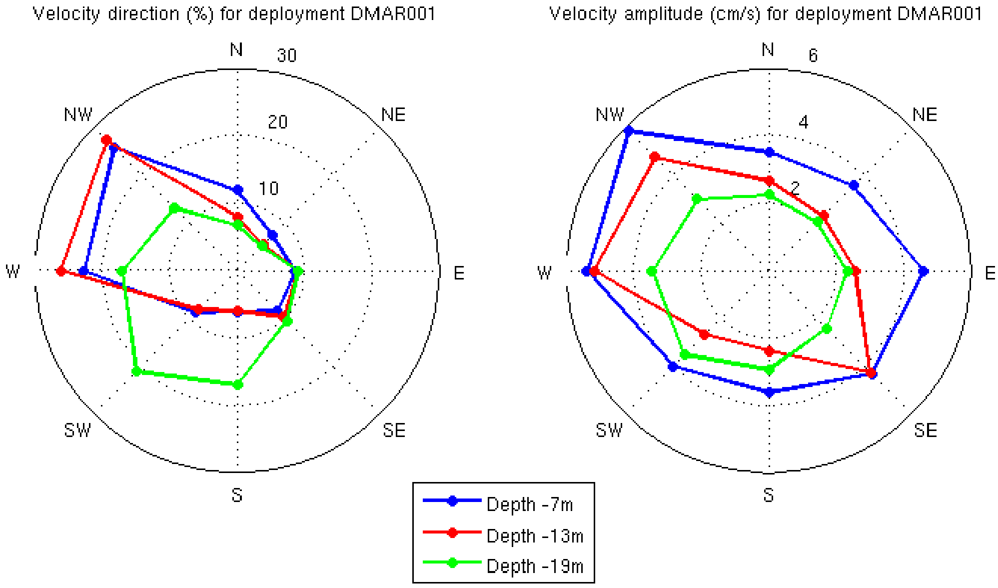

Figure 12. Left panel: Distribution of flow direction. Right panel: Distribution of current speed.

Profile of residual current is in accordance with described situation (Figure 13). Throughout most of the water column, long-term movement of seawater is directed toward NW. Only in the bottom layer, residual flow changes direction to SW. Residual current speed is contained within a range 0.8 – 2.5 cm/s (Table 10). Higher values were recorded in the surface layer and lower values in the bottom layer. The same stands for the maximum current speed which falls in the range between 11.5 and 21.2 cm/s. Obviously, only a small percentage of kinetic energy can be attributed to residual flow, which means that either tides or wind are responsible for hydrodynamics near the fish farm. Since wind blowing events during the summer are not sufficiently energetic nor persistent in the Adriatic, tides must be the only driving force. Thus, tidal constituents should be detectable in the current record, unless significant amount of energy is taken from the barotropic tides and converted into internal waves or topographic eddies. This conversion is caused by the complex bathymetry, which certainly is present in immediate vicinity of Dalmar's fish farm. Overall stability of the flow is relatively low in the bottom layer and increases toward the middle of the water column. Near the surface stability decreases again. Described profile reflects turbulent activity in the bottom and surface boundary layers.

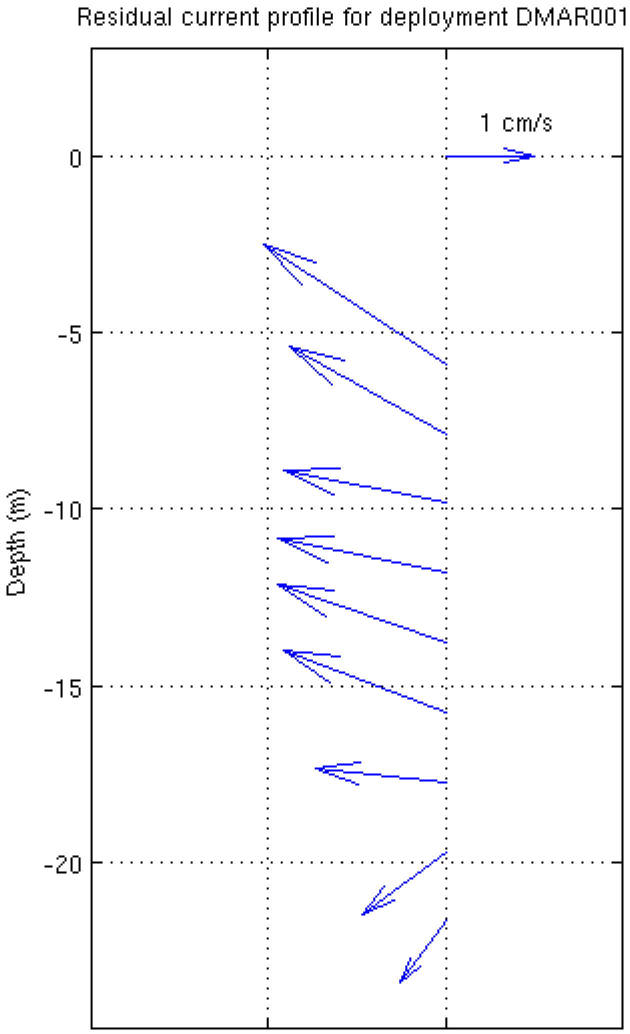

Figure 13. Residual current profile.

Table 10. Basic statistics of measured current record.

Depth	Residual current: Intensity/Direction	Minimum current speed	Average current speed	Maximum current speed	Standard deviation	Stability
m	cm s^{-1}/°	cm s^{-1}	cm s^{-1}	cm s^{-1}	cm s^{-1}	%
5.89	2.47/303.45	0.10	5.64	21.11	3.44	43.89
7.86	2.03/299.56	0.20	4.77	20.51	3.16	42.47
9.83	1.88/281.52	0.00	4.57	19.15	3.06	41.19
11.80	1.94/281.90	0.00	4.38	17.73	2.99	44.26
13.77	2.01/288.87	0.00	4.01	16.34	2.88	50.12
15.74	1.96/290.99	0.00	3.62	15.62	2.59	54.02
17.70	1.48/276.03	0.00	3.22	14.86	2.16	46.04
19.67	1.18/233.18	0.00	2.96	12.20	1.85	39.98
21.64	0.86/216.36	0.00	2.73	11.54	1.63	31.46

Classical tidal harmonic analysis reveals that recorded current velocities cannot be explained by tidal forcing. Maximally 25.6% of energy can be attributed to main tidal constituents and that occurs in the bottom layer (Figure 16). Middle layer owes 25.3% of its energy to main tidal constituents (Figure 15), while surface layer only 16.8% (Figure 14). As explained above, we assume that complex bathymetry distorts the effect of tidal forcing by creating internal waves or topographic eddies. More extensive measurements are required, to explain exactly the mechanism of this distortion. As a conclusion we qualify Dalmar study site as being mostly depositional.

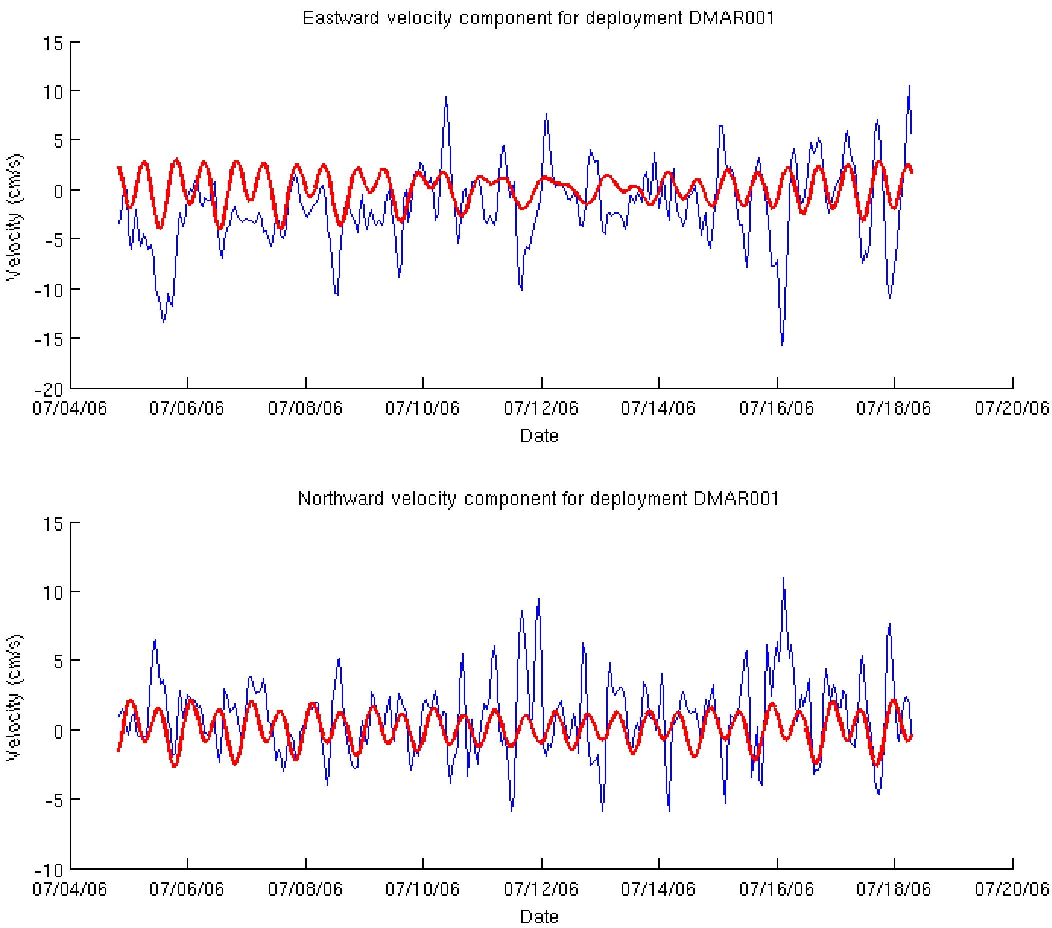

Figure 14. Comparison of measured (blue) and synthesized (red) current velocity at 7 m depth.

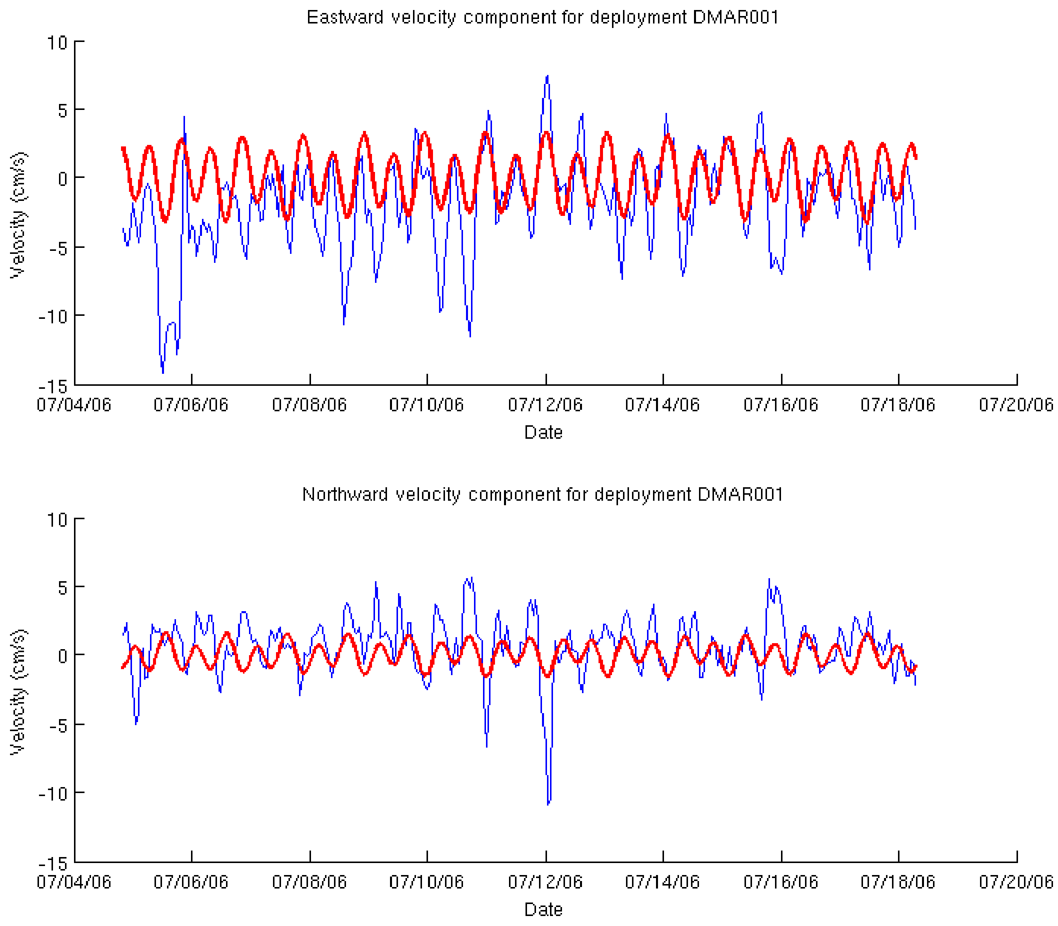

Figure 15. Comparison of measured (blue) and synthesized (red) current velocity at 13 m depth.

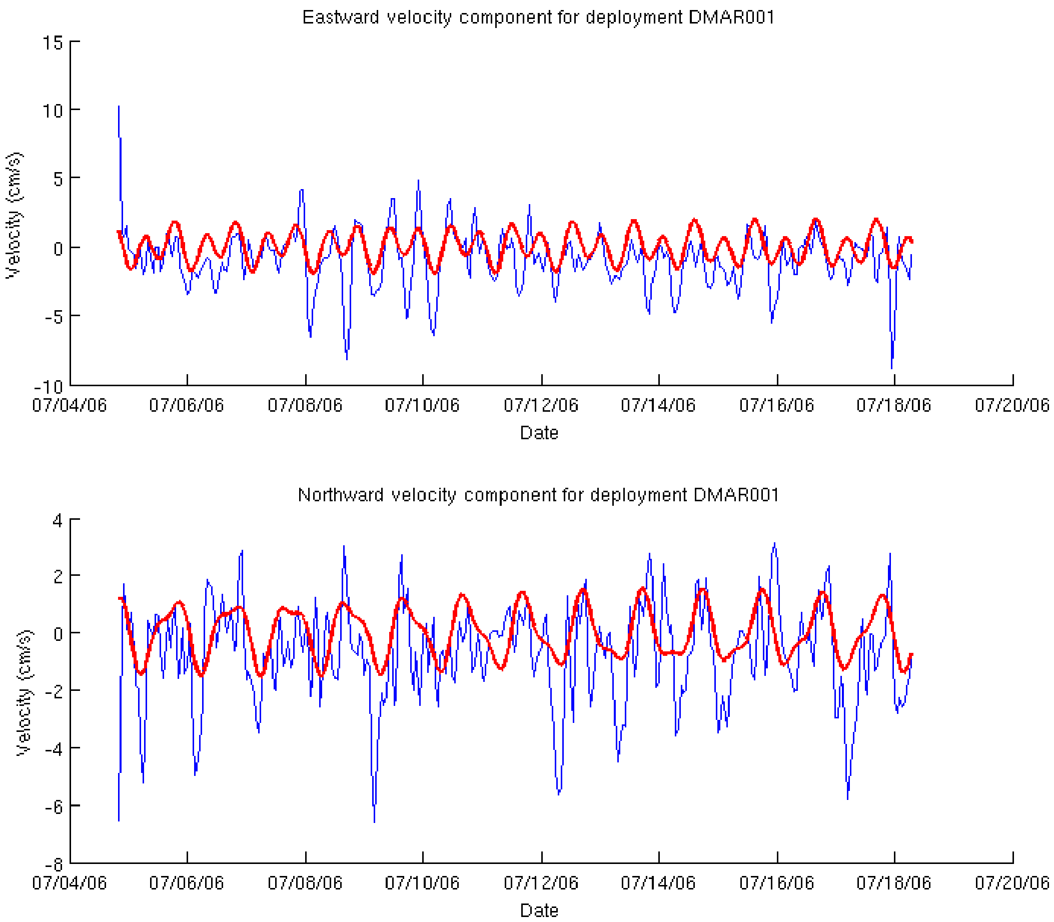

Figure 16. Comparison of measured (blue) and synthesized (red) current velocity at 19 m depth.

Appendix C: Diver's inspection of seabed

During the fieldwork on Dalmar study site, experienced diver (B.Sc. in biology) made inspection of seabed beneath the net pens. Results are given in Table 11.

Table 11. Results of diver's inspection of seabed beneath the net pens.

No.	Distance (m)	Depth (m)	Impact	Remark
1	200	19,5	V/N	Starting of posidonia bed degradation because of the next battery of net pens with fish (around 50 m from this point)
2	190	19,5	N	Dense posidonia, no visible impact or degradation of the "meadow"
3	180	19,9	N	Dense posidonia, no visible impact or degradation of the "meadow"
4	170	20,0	N	Dense posidonia, no visible impact or degradation of the "meadow"
5	160	20,0	N	Dense posidonia, no visible impact or degradation of the "meadow"
6	150	20,5	N	Dense posidonia, no visible impact or degradation of the "meadow"
7	140	21,2	N	Dense posidonia, almost no visible impact or degradation of the "meadow"
8	130	21,7	V/N	Dense posidonia, with visible impact and degradation of the "meadow" but less than 10 m before, almost "normal"
9	120	21,8	V/N	Dense posidonia, with visible impact and degradation of the "meadow" but less than 10 m before, impact less visible
10	110	22,0	V	Dense posidonia, with visible impact and degradation of the "meadow"
11	100	22,6	S	Dense posidonia, with visible impact and degradation of the "meadow, less than 20 % dead sprouts
12	90	23,1	S	First live posidonia sprouts, dead posidonia sprouts
13	80	23,3	S	First live polychaetes in tubes (sesile, multiyear), dead posidonia sprouts
14	70	23,6	S	More specimens of green algae *Codium bursa* (small specimens), dead posidonia sprouts
15	60	23,8	S	First alive specimen of green algae *Codium bursa* (small specimen), dead posidonia sprouts
16	50	24,0	S	First alive macroalgae (brown, small, nitaste with a lot of sediment on them), dead posidonia sprouts
17	40	24,3	S	One alive specimen of juvenile fan slell *Pinna nobilis*, one alive specimen of shell *Pecten jacobaeus* (small specimen),
18	30	24,4	S	No visible settled faeces pellets, no alive "native" macrobenthic organisms, dead posidonia sprouts
19	20	24,6	S	Tiny, green layer on the bottom is disapearingalmost no visible fish faeces, no alive "native" macrobenthic organisms
20	10	24,6	S	Tiny, green layer on the bottom (thicknes of layer less than od 1 mm, some settled fish faeces, no alive "native"
21	0	25,0	S	Sediment light brown (from this point to the end of the diving transect – not mentioned in other remarks).Tiny, green layer on the bottom (thicknes of layer more than 1 mm, probably diatoms or less probably unicellular green algae – sample not taken), no more mussel shells, settled fish faeces cover around 10% of bottom, no alive "native" macrobenthic organisms, dead posidonia sprouts
22	Pen centre	25,1	S	Sediment light grey, dead polychaetes in tubes (only degradated tubes), lot of black mussel shells (only few alive), few seastars *Marthasterias glacialis*, little areas with *Beggiatoa bacteria*, few specimens of gobbies *Gobius jozo*, lot of settled faeces (cover around 40% of seabed, thin layer), dead posidonia sprouts bearly visible (almost completely degradated)

S = significant
V = visible
N = none