Università Ca'Foscari Venezia

Scuola Dottorale di Ateneo
Graduate School

Dottorato di ricerca
in Scienze Ambientali
Ciclo XXIX
Anno di discussione 2017

Structure and functioning of the Northern Adriatic coastal ecosystem, within the context of the Marine Strategy Framework implementation

SETTORE SCIENTIFICO DISCIPLINARE DI AFFERENZA: BIO/07
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a nonno Giorgio e a mia figlia Carlotta Maria

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Introduction

The entering into force of the Madrid Protocol (2011) is of high relevance for the implementation of Integrated Coastal Zone Management (ICZM) approaches and tools as well as for adopting new approaches for the management of the sea. The Protocol promotes the adoption of the ecosystem approach in coastal planning and management, in order to ensure sustainable development (art. 6.c). Both the ICZM protocol and the Ecosystem Approach claim for the adoption of an integrated approach, operating across both natural and social systems, and between ecosystems. All this implies that management decisions should consider the local economic and social context and promoting the implementation of participatory forms of governance. The understanding of biophysical limits that constrain ecological process as well as spatial and temporal limits remains, however, the base for all management decisions.

Within this context, one of the main issues to be emphasized is the central role played by ecological system, which has to be perceived as the 'management unit', as also suggested by the Marine Strategy Framework Directive (MSFD). The directive recognizes, indeed, the importance to achieve good environmental status of the EU's marine waters by 2020 and to protect the natural resources upon which marine-related economic and social activities depend. Goods and services availability directly depends on the ecosystem health and its proper functioning. By applying this paradigm, management policies should move from a remediation perspective, which works on compensative and restoration measures related to already impacted situations, towards a precautionary approach, in which decisions and strategies anticipate negative possible events.

Coastal zone represents a crucial area for the implementation of environmental management because of their characteristics, such as:

- the concentration of many activities and the presence of different kinds of anthropogenic pressures;
- the high vulnerability to climate changes effects;
- the large biological diversity supported, including nursery areas for several marine species and wintering areas for birds;
- the provision of many goods and services, among the others renewable resources, particularly critical in terms of trade-off between ecological status and exploitation impacts.

Within this context, the Northern Adriatic Sea represents a sort of 'hotspot' due to its climatic peculiarities:

- in the context of global warming scenarios, this area can be regarded as extremely vulnerable; due to the local geographic features, the zone has been described as an area where Mediterranean climatic conditions are replaced by boreal ones, supporting the presence of ‘glacial relicts’;
- in the context of sea level rise scenarios, this portion could be extremely vulnerable, as it is one of the areas in the Mediterranean basin characterized by the highest tidal range;
- in relation to the exposure to global changes, this area, being a semi-enclosed basin, can be considered a sort of ‘cul de sac’ for endemic species.

As a matter of fact the Northern Adriatic Sea summarizes all different critical elements of a ‘typical’ coastal area, such:

- important trawling activity in the inshore area despite the recent prohibition by the EC Fishery Common Policy (PCP);
- presence of aquaculture activities (mussel farms), widely distributed along the coast;
- presence of small scale fisheries activities;
- seaside touristic pressures;
- extended seaport activities.

Among the pressures that drive the ecosystem functioning in the Northern Adriatic coastal area (within three miles from the coast), the project aims to investigate acquaculture and small scale fisheries activities. This would provide on one side a better understanding of major impact sources and on the other side an identification of the processes that need to be preserved/enhanced to maintain or also increase the resilience of the system.

At present time, offshore mussel culture farms (MCF) can be considered as one of the major driver affecting both the structure and functioning of the coastal area in the Northern Adriatic Sea. It represents an anti-trawling barrier, a possible factor affecting the system carrying capacity and the bentho-pelagic coupling, a potential source of impact on bottom sediments, furthermore, it functions as fish aggregating area. Moving from this, the project will assess the potential role of MCF in determining the functioning of the coastal ecosystem.

Moreover, small scale fisheries is the most exercised type of fishing in Italy (67%). Along West coast of NAS, these activities are practiced by 28% of the fishing fleet, being the second type of fishing after trawling.

The main working hypothesis is that an ecosystem in a good environmental status can support high quality of services supply (such as healthy benthic communities) and, due to the high resilience of the system, can tolerate a medium level of disturbance (such as fishing activities).

Within this context, the main objectives of the project are:

- moving from the description of the main ecological processes driving the structure and functioning of the West coast of the NAS, to assess the role played by MCF, both in terms of negative impacts and positive feedbacks;
- focalizing the attention on one of the main key factors presently affecting, but also structuring, the ecosystem in the NAS coastal area, in order to better understand the major drivers also in terms of opportunities to be managed;
- defining long term management objectives, indentifying the self-sustaining processes to be maintained or restored, in order to increase the system resilience and stimulate an adaptive management.

The study area is a mussel farm located in front of Sile river mouth and along the coastal zone between Caorle and Jesolo, on the West coast of the Northern Adriatic Sea; the analysis taken into the account the two main compartments (benthos and nekton), by applying different tools.

The obtained results are organized in 5 main chapters, regarding:

Benthic community structure and functioning. Mussel farming is a growing practice around the world. It was reported how high biomasses of farmed bivalves may play an important role in marine ecosystems (Dahlbäck and Gunnarson, 1981; Chamberlain *et al*., 2001; Christensen *et al*., 2003), affecting the system carrying capacity and the bentho-pelagic coupling (Tucker and Hargreaves, 2008) and acting as a potential source of impact on bottom sediments. At present, offshore mussel culture is a well developed activity along the coastal area of Northern Adriatic Sea with about 35 km^2 of 'exploited' area that provide 1/3 of total national production (Trevisiol, 2013). Despite the relevance at national scale of Northern Adriatic Sea mussel production, only few studies regarding the influence of biodeposition on benthic community were carried out (Brizzi *et al.*, 1995; Fabi *et al.*, 2009). Moving from this, a characterization of meiobenthos and macrozoobenthos communities in and out a mussel farm, with the aims of evaluating potential changes of mussel farm on this communities, was carried out. The analysis highlighted the relevance of the farm position to assess possible impacts on benthic fauna, roughing out the portions of sea near river mouth as particularly adapted for shellfish farming.

Biogeochimical cycles analysis. The mussel farm was used as a model to study changes in soft sediments geochemical processes along gradients of organic deposition, characteristic of coastal areas. Shellfish farming influences downward organic matter fluxes and sediment biogeochemistry through faeces and pseudofaeces production. Although recognized as a highly sustainable practice, extractive aquaculture is also expected to induce relevant changes in the biogeochemistry of intensively farmed coastal areas, due to the potentially relevant extension of the zones allocated to these activities. In this chapter, a set of combined mathematical modelling and field sampling efforts is presented. To describe biogeochemical fluxes towards the mussel farm and to predict the extent of the deposition area underneath the farm an integrated model was applied. The model framework includes an individual-based population dynamic model of the Mediterranean mussel coupled with a Lagrangian deposition model and a benthic model of early diagenesis. The work was articulated in 4 steps: 1) the predicted fluxes of organic carbon were compared with field data obtained from a short-term sediment trap experiment conducted in-situ; 2) based on the first model application, two stations were localized, for collecting sediment cores on which to carry out measurements including O2 and pH microprofiling, porosity, micro-porosity and pore waters, NH4, PO4, SO4, Fe2+, Alkalinity, and Dissolved Inorganic Carbon; 3) two distinct early diagenesis models were set-up, to reproduce observed field data in the sampled cores; 4) an integrated model was then used to extend the simulation over the entire farmed area, and to explore the response of the prediction to changes in water temperature.

Fish aggregating function. Mussel farms are three-dimensional structures that are off-limits to commercial and partially recreational fishing activities and that supports a diversified trophic chain; as a result, they could play an important ecological role as shelters and reproductive area for different fish species. Moving from this, a passive listening survey was conducted in the mussel farm in order to describe the use of the area by fish populations, using a soniferous species (the brown meagre, *Sciaena umbra*) as proxy. *Sciaena umbra* is a small, vocal sciaenid occurring along most of the Mediterranean coast, producing sounds for reproductive purposes. The recordings highlighted the presence of the brown meagre inside the mussel farm, while only few vocalizations were detected in the surrounding environments, suggesting that the area may work as reproductive area for breeding aggregations for this species. All this would be, therefore, used as a proxy to describe the role of mussel farms along the coast as fish attracting areas.

Emergy assessment. The extractive aquaculture, as the mussel farming, has many interactions with the surrounding environment, depleting resources and producing changes in the marine ecosystem. Moving from that, the detection of the environmental sustainability of mussel farm activities was carried out, using a comprehensive environmental accountability methodology like an emergy-based analysis. This approach allowed to consider under the same energetic language natural and anthropic inputs and is able to consider both natural and economic systems comparing their products. In this study, the renewable and non-renewable inflows of emergy used the in mussel farming and the related transformity have been quantified. The evaluation of indicators of environmental sustainability for this activity revealed a predominance of renewable inputs and their comparison with similar productive processes assessed that a mussel farm exploits natural renewable resources for its maintenance and needs low quantity of non-renewable emergy contribution to perform its activity. Transformity of mussels resulted quite efficient and comparable or lower than other shellfish farming activities.

Small scale fishery description. The small scale fishery represents, with the hydraulic dredging, the main exploitation activity in the Northern Adriatic coastal area and so one of the principal affecting ecological processes. Within this context, an analysis of the landings vulnerability and sustainability was carried out, aiming to define the basic characteristics of artisanal fishery along the Cavallino-Caorle coast, in terms of metièrs, fishing strategies and catches. On the basis of fishery data, the fishing effort, total catches per species and the discard incidence have been assessed. Considering official IREPA regional statistics, collected data showed that fishing effort and CPUE values were greater, and also indicated that the discard rate was lower than in other Adriatic areas. Regarding ecological effects, the application of two trophodynamic indicators suggested a sustainable situation, but scenarios of possible changes in environmental or in fishing effort conditions highlighted the proximity of the activity to the unsustainability threshold. All this suggested the need for an adequate management strategy to cope with possible future climate changes and fleet modifications.

From a general point of view, the five issues here considered allowed us to assess possible effects of one of the most spread exploitation activity (with the clam dredging and the artisanal fishery) along the west coast of Northern Adriatic Sea.

Three main compartments were taken into account: two ecological (benthos and nekton) and one socio-economic (Fig. 1).

The benthic compartment was analysed in the first two chapters ("Benthic community structure and functioning in relation to the presence of a mussel farm" and "Modeling mussel farm influence on sediment biogeochemistry"), within the context of the MSFD descriptor 6 – seafloor integrity. Obtained results can be discussed also in the light the ICSM art. 5 - Objectives of maritime spatial plans and integrated coastal management strategies - letter d: "*ensuring the preservation, protection and improvement of the environment as well as the prudent and rational use of natural resources…*".

The socio-economic compartment was examined inside the chapter 4 ("Emergy analysis of a mussel farm") and can be considered within the context of ICZM the art. 5 - Objectives of maritime spatial plans and integrated coastal management strategies - letter c: "*fostering the sustainable development and growth of the fisheries and aquaculture sector…*".

The nekton compartment was analyzed in the chapters 3 and 5 ("Passive Acoustic Monitoring as a tool for investigating the potential role of a mussel farms for fish aggregation in the Northern Adriatic Sea" and "The role of artisanal fishery in the

Northern Adriatic coastal area”) and results can be useful within the context of the MSFD descriptor 1 – Biodiversity and 3 - Commercial Fish and shellfish. These chaps, moreover, can be considered from the point of view of the ICZM art. 5 - Objectives of maritime spatial plans and integrated coastal management strategies - letter d: “*ensuring the preservation, protection and improvement of the environment as well as the prudent and rational use of natural resources*…” (chapter 3) and letter e: “*ensuring climate resilient coastal and marine*…” (chapter 5).

Finally, the general vision obtained can be useful for defining the “Specific minimum requirements for maritime spatial plans - When establishing maritime spatial plans Member States shall take into consideration, at least, the following activities: “*… (e) fishing areas; (f) sea farming sites*…” and - Specific minimum requirements for integrated coastal management strategies - When establishing integrated coastal management strategies, Member States shall take into consideration, at least, the following activities: “*… (d) fishing and aquaculture…*” as reported by the ICZM art 7 and 8, respectively.

For the first time, here a complete overview of the coastal mussel culture farming and its possible effects is given. Obtained results could be useful for planning an adaptive management strategy in the coastal area, focusing on the self-sustaining processes to increase the system resilience. If implemented, this strategy will be able to offer a real opportunity to cope with environmental and social changes, such as those related to climate variability, expected to be particularly strong in a sensitive area as the Northern Adriatic Sea.

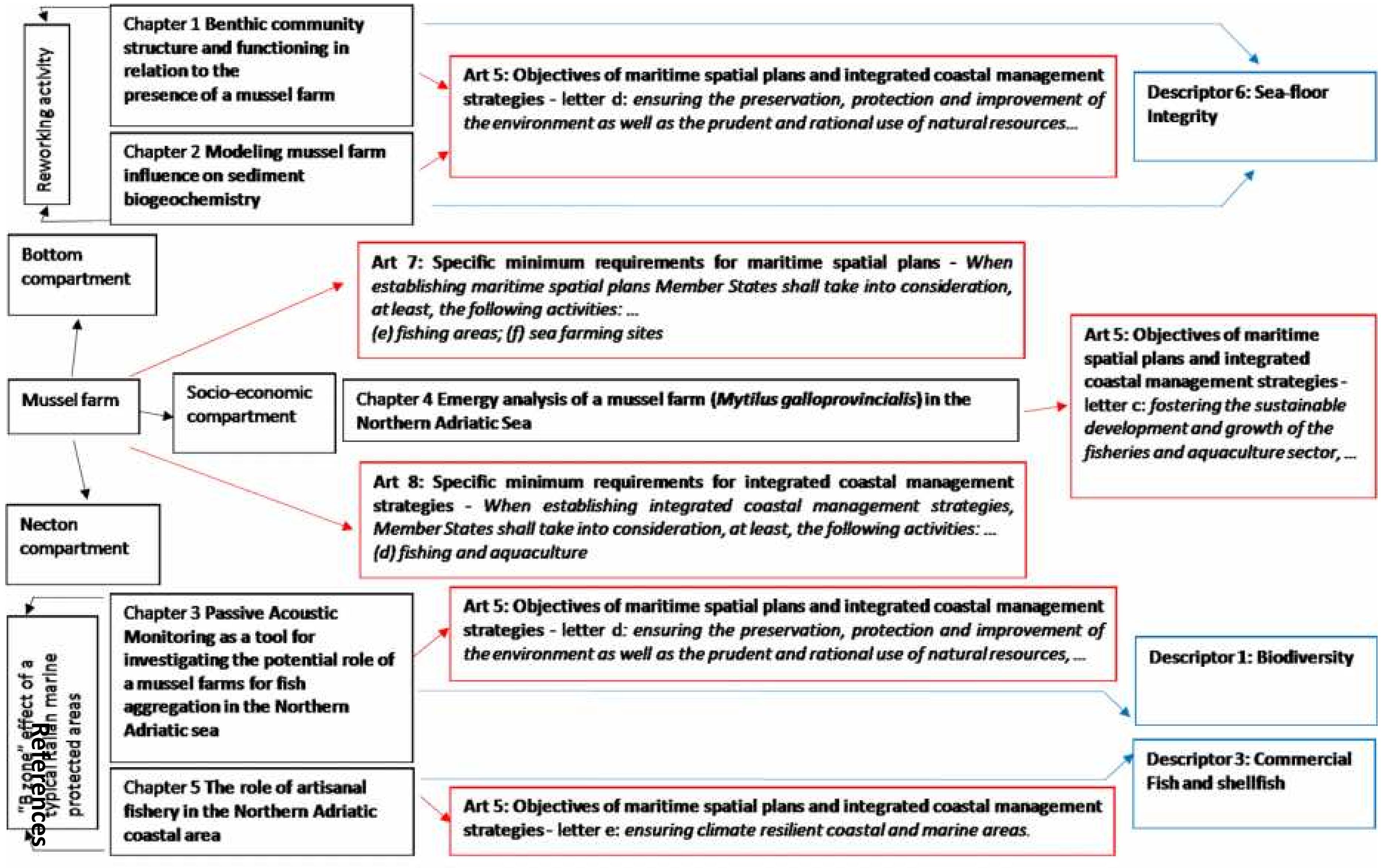

Figure 1: diagrammatic framework of thesis. In red, references to ICZM; in blue references to MSFD.

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Chapter 1

Benthic community structure and functioning in relation to the presence of a mussel farm.

1. Introduction

Aquaculture activities, particularly for bivalves such as mussels and oysters, showed a rapid expansion in many part of the world and are practised in several countries during last decades. Being a source of protein that do not require human intervention in terms of rearing (e.g. external feeding activities), these cultures appears more sustainable compared with marine sea-cage aquaculture (Naylor *et al*., 2000). Mussels are farmed in different ways (bouchot cultures, on-bottom cultures, raft cultures, longline cultures), by stocking suitable sites with juveniles and allowing them to grow for a period prior to harvest. However, high biomasses of farmed bivalves may play an important role in marine ecosystems (both in terms of biogeochemical cycles and benthic community structure) (Dahlbäck and Gunnarson, 1981; Chamberlain *et al*., 2001; Christensen *et al*., 2003), affecting the system carrying capacity and the bentho-pelagic coupling (Tucker and Hargreaves, 2008) and acting as a potential source of impact on bottom sediments.

Mussels are filter feeding molluscs that through special gills trap particulate material. These particles may be either ingested or ejected as pseudofaeces. True faeces and uningested pseudofaeces are dispersed inside and outside the farm depending on currents and water depth and accumulate on the seabed together with living and dead shells. Deposition of pseudofaeces and faeces by mussels may alter the organic profile of sediments and thus affect the diversity and abundance of benthic invertebrates. In the first stages of the enrichment process, a possible increase of the macrobenthic community abundance and diversity is expected (Person and Rosenberg, 1978). As the organic load increases, sediments become more and more anoxic and enriched with sulphides; at this stage, benthic community is dominated by sulphide-tolerant opportunistic deposit-feeder species and shows a very low diversity (Person and Rosenberg, 1978; Munday *et al*., 1992; Grant *et al*., 1995). Worldwide, many studies on mussel culture impacts on the bottom environment and macrobenthic communities have been carried out providing different results, ranging from no, or minimal negative effects, to those that describe positive and or negative changes. Many factors may contribute to these seemingly conflicting results because the type and the intensity of benthic effects depend on local features, including age and size of the farm, the reared, the farming density, hydrodynamic conditions and coasts morphology, which can considerably vary among sites (Aleffi *et al*., 2006; Fabi *et al*., 2009; Grant *et al*., 1995; Christensen *et al*., 2003; Callier *et al*., 2008; Callier *et al*., 2009; KLC Wong & O'Shea, 2011; Wilding and Nickell, 2013; Kraufvelin and Diaz, 2015). As well as the macrofauna, also the meiobenthic community have been analysed in relation to possible effects due to the mussel farms biodeposition (Grego *et al*., 2009; Mazzola *et al*., 1999; Mirto *et al*., 2000; Vezzulli *et al*., 2008).

At present, offshore mussel culture farm (MCF) is a well developed activity along the coastal area of Northern Adriatic Sea with about 35 km^2 of 'exploited' area that provide 1/3 of total national production (Trevisiol, 2013). Despite the relevance at national scale of Northern Adriatic Sea mussel production, only few studies regarding the influence of biodeposition on benthic community were carried out (Brizzi *et al*., 1995; Fabi *et al*., 2009).

Moving from this, the meio and macrozoobenthic community within a farm located in the proximity of the Sile river mouth has been analysed. The main objectives of this work are:

- to detect possible differences in the benthic community, both in terms of structure and functioning, due to the presence of the mussel farm;
- to verify the possible relationships with organic carbon fluxes from the water column to sediments;
  to assess the global effects of the mussel farm on the benthic compartment within a context of the the MSF implementation.

2. Materials and methods

2.1 Study area

The study area is a mussel farm (*Mytilus galloprovincialis*) located 1.5 nautical miles off Cavallino – Treporti (West coast of the Northern Adriatic Sea) (Fig. 1). The farm was activated in 1990 and is in a shallow water area (max depth 15 m.) characterised by relict sands (Alfirević, 1981) and exposed to first and second quadrant winds. It is located leeward to two rivers (Piave and Sile), important sources of nutrient and organic matter inputs, which flow into the sea, respectively about 7 and 0,3 nm north. Due to the proximity to the coast, the predominant current is parallel to the coastline from north-east to south-west. The equipment of mussel farm consists of 20, 2000-m-long, long-lines that are kept in place by big buoys and anchors. The distance between each long-line is about 40 m. The mussels farm covers a total surface area of c.a. 2 km^2. Until 2010 the mussel farm produced about 2.100 tons of mussels per year. Actually, the farm production is estimatend in about 800 tons/y.

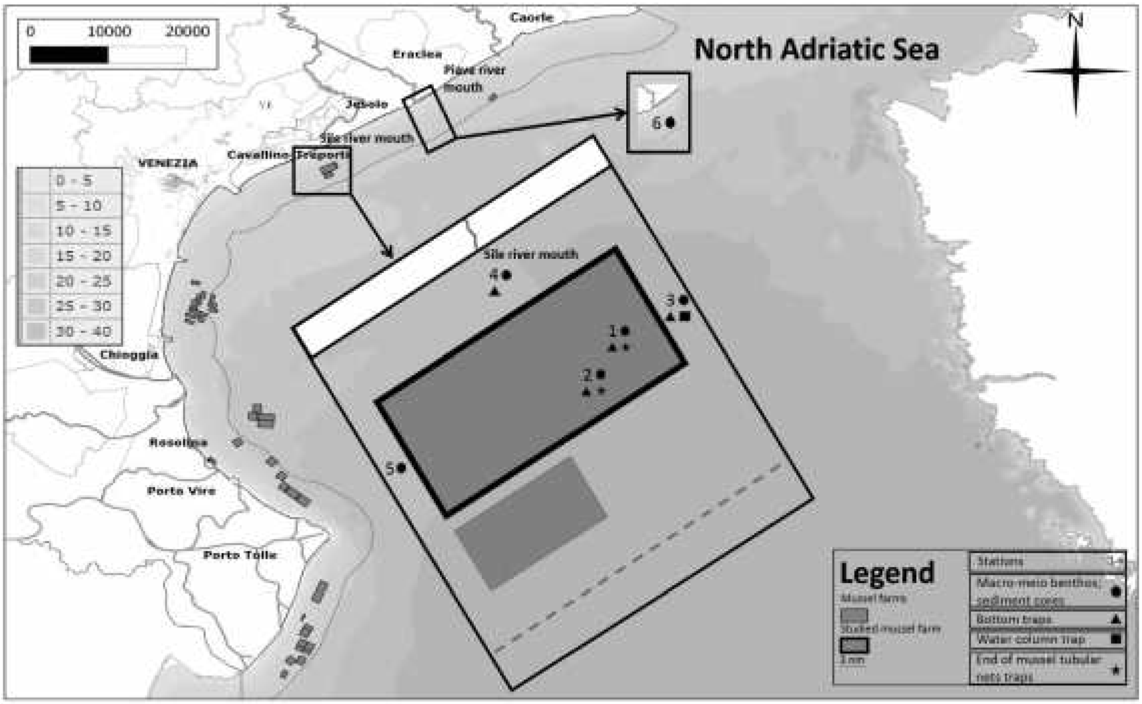

Figure 1: study area.

2.2 Acoustic mapping

In order to describe the seabed features in terms of sediment texture and presence of submerged 3D structures, in July 2014, a multibeam echo sounder (Reson SeaBat 7125, at 200-400 kHz MBES) survey was carried out, in collaboration with the CNR_IAMC (dr. Sara Innangi and dr. Renato Tonielli (for details see Innangi *et al.*, 2015).

2.3 Sampling scheme

In August 2014, both abiotic and biotic data were collected at 6 sites, 2 located inside the mussel farm (named 1 and 2); 2 outside of the farm (named 3 and 5, in the Northern and South-Western side, respectively); 2 in proximity of the Sile and Piave river mouths (named 4 and 6, respectively) (Fig.1).

2.3.1 Abiotic data

In each site, three sediment cores (7 cm of depth) were taken by scuba divers. Each core was placed in a refrigerated box (5°C) and, once in lab, frozen (-20°C) for particles size analysis.

Moreover, sediment traps were placed in four site (1, 2, 3 and 4) at different depths, in order to investigate the organic matter and the particulate organic carbon fluxes (Tab. 1). Sites 3 and 4 are considered reference points. All the traps were recovered after 48 hours and the water filtered on Whatmann GF/F filter that earlier were put in an oven at 500°C for 4 hours and pre-weighted. Each filter was placed in a refrigerated box (5°C) and, once in lab, frozen (-20°C) for the analysis.

Table 1: localization of the sediment traps.

	st1	st2	st3	st4
Bottom traps	X	X	X	X
Water column traps			X	
End of mussel tubular nets traps	X	X		

2.3.2 Biotic data

Meio and macrozoobenthos samples were collected, in each site. Meiobenthos was sampled manually by scuba divers using 1,8 cm^2 cores in three replicates. Each core was then fixed immediately in 5% buffered formaldehyde. Macrozoobenthos was sampled by means of a Van Veen grab (0,09 m^2) in three replicates per site; each replicate was sieved on a 0.5 mm mesh size and refrigerated (5°C). Once in laboratory, samples were frozen (-20°C).

2.4 Analysis data

2.4.1 Acoustic mapping

Multibeam ecosounder data were processed using SonarWiz 5 software; *slant range* corrections and a return signal amplification by means of AGC (*Automatic Gain Control*) algorithm were applied to data (for details see Innangi *et al*., 2015).

2.4.2 Abiotic data

Sediment cores were defrosted and sieved on a 1 mm mesh size, in order to remove pieces of shell that may interfere with analysis. Each core was then placed into a glass becker (volume 1 L) filled with freshwater, homogenized and decanted for one week. Finally, freshwater was eliminated and the particle size was evaluated using wet sediments with a laser diffraction particle size analyzer (Mastersizer Hydro).

Regarding sediment traps, each filter was defrosted and put in oven at 60°C for 48 hours and weighted. The suspended matter (SM) was calculated making the difference between the two filters weights. Concerning the organic carbon, the percentages were calculated by an elementary flash analyser EA 1112 series thermo electron corporation, in collaboration with Palermo University; after data were transformed in g $d^{-1}m^{-2}$.

2.4.3 Biotic data

2.4.3.1 Meiobenthos

Samples were sieved on a 0.063 mm mesh size and specimens extracted by triplicate differential floatation in colloidal silica (Ludox TM, density 1.15 g cm^{-3}). The surnatant, after the third extraction, was sieved again on a 0.063 mm mesh size, and finally storage with 5% buffered formaldehyde and three drops of Rose Bengal solution (1 g l^{-1}). After one week all individuals were counted and identified to the lower possible taxonomic level using a stereomicroscope with a magnification range from 5 –40, equipped with an ocular micrometer. For nematode and copepod, length and width of 20 individuals were recorded for the biomass estimate. First the body volume was calculated by comparing the morphology into geometric figure. Individual body weight was then determined as the product of biovolume and a specific gravity.

To describe the trophic structure of the nematode assemblage 60 nematodes were classified into four trophic groups according to the classification of Wieser (1953), based on the structure of the buccal cavity (selective deposit feeders, nonselective deposit feeders, epigrowth feeders and predators/omnivores). If more than 60 nematodes were present in a single sample, proportions starting from the classified ones were performed in order to assign a trophic group to all recorded specimens.

2.4.3.2 Macrozoobenthos

Samples were defrosted, coloured with a solution of Rose Bengal (1 g^{l-1}) and sorted by means of a dissecting stereoscope features a zoom range 6.7:1 zoom ratio along with a magnification range from 8X – 40X and identified to the lowest taxonomic level, usually species. Abundance, wet and dry biomass were calculated for each species. Molluscs biomass includes the weight of calcified structures. Species were also classified into trophic groups based on the literature (filter feeders (moff), detritus feeders (md), herbivores (mhd), predators (mop), and omnivores (momf)) (Fauchald and Jumars, 1979).

2.5 Indicators and statistical analysis

Benthic community data were standardized to m^2 and then processed using both univariate and multivariate analyses.

The univariate indicators evaluated for meio and macrozoobenthos community were abundance, total biomass, number of species (S), and Shannon-Wiener index (H').

Univariate indices were calculated using PRIMER v6.1.13 and STATISTICA 9 software package and compared by nested PERMANOVA, grouping sites by spatial localization (sites 1,2: IN; sites 3,5: OUT; sites 4,6: RIVER MOUTH). Also trophic groups' analysis was performed using this statistical approach, considering each trophic group separately.

About multivariate analyses, a similarity matrix was constructed using square root transformed data and the Bray-Curtis coefficient. Significant differences in the composition of species assemblages by sites was determined through permutational multivariate analysis of variance (PERMANOVA) using 9999 permutations to asses significance analysis was also performed among sites standardized density values. Data were presented graphically using multi-dimensional scaling (MDS) ordinations. All these analyses were performed using the PRIMER v6.1.13 software package.

To assess the ecological quality of the macrofaunal communities inside and outside the farm, the AZTI Marine Biotic Index (AMBI) (Borja *et al*.,2000) was applied.

The functioning of the macrozoobenthic community was assessed by using different methods: Potential Bioturbation, Trophic levels and biomass and abundance size spectra (this last analysis was performed for both meio- and macrozoobenthic communities).

The potential bioturbation (the biogenic mixing of sediment by benthic organisms) was estimated according to the method proposed by Solan *et al*., (2004):

$$BP_i = B_i^{0,5} M_i R_i$$

where BP_i, the per capita effect, takes into the account for three biological traits of species, known to influence sediment bioturbation (Pearson, 2001; Bremner *et al*., 2003a; Meysman *et al*., 2003): the mean body size (Bi, in grams); the propensity to move through the sedimentary matrix (M_i, defined as 1 = in a fixed tube; 2 = limited movement, sessile, but not in tube; 3 = slow movement through sediment; and 4 = free movement via burrow system); and the method of reworking sediments (R_i, 1 = epifauna that bioturbate at the sediment water interface; 2 = superficial modifiers, whose activities are restricted to the first 1e2 cm of the sediment profile; 3 = head-down/head-up feeders that actively transport sediment to/from the sediment surface; 4 = bio-diffusers whose activities result in a constant and random diffusive transport of particles over short distances; and 5 = regenerators that excavate holes, transferring sediment from depth to the surface). Per capita effect was then multiplied by the species abundance and obtained values summed across species in the sample to estimate the community-level bioturbation potential, BPc.

3. Results

3.1 Abiotic data

The mosaic resulting from the acoustic mapping showed a quite homogeneous seabed structure, mostly muddy, but in some areas most reflective material accumulation is revealed. Based on acoustic survey and underwater photos, it has been possible to create a map of the seabed that consists of four acoustic facies (Fig. 2):

1. Muddy: muddy bottom.
2. Muddy and mussels: bottom partially covered by mussel shell.
3. Mussels: abundant mussel shells accumulations.
4. Living mussels: accumulations of living mussels covering the bottom.

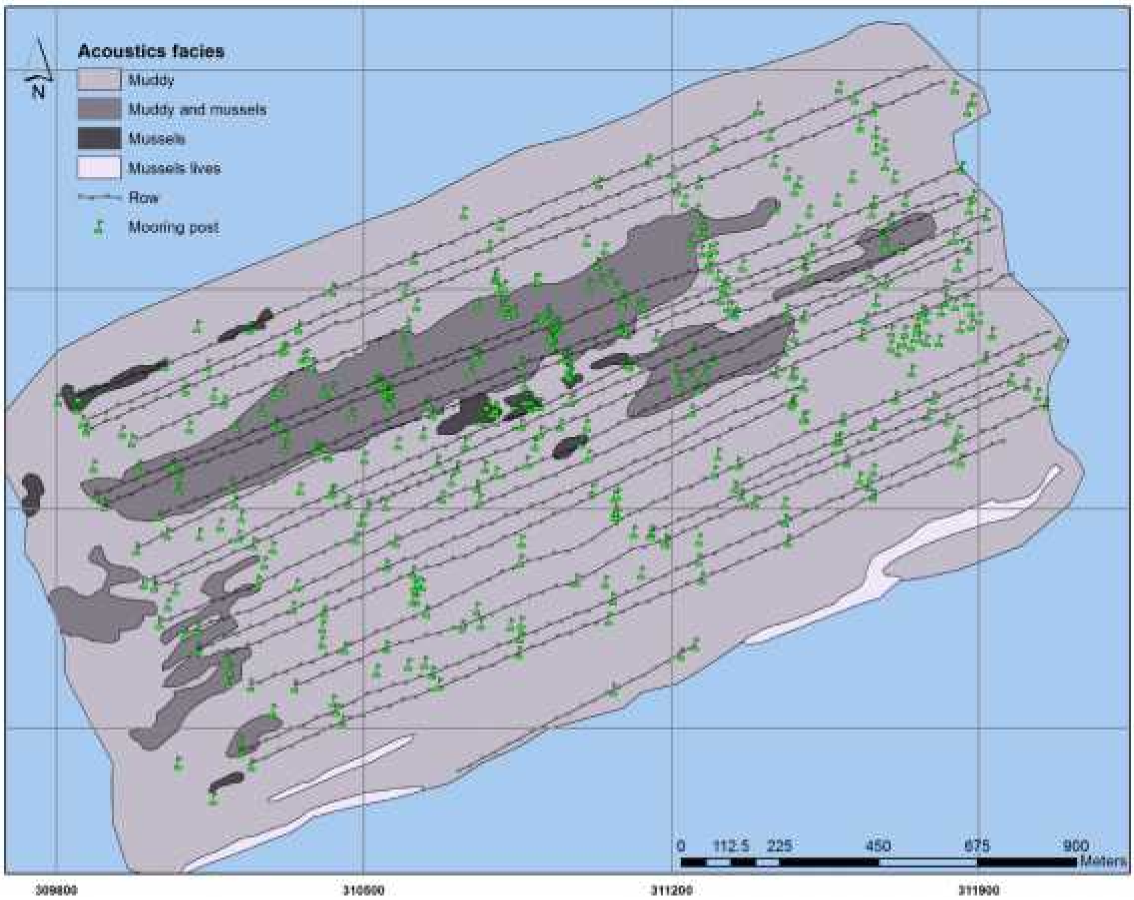

Figure 2: acoustic mosaic of the seabed mussel farm.

For what concern sediment cores analysis, in the majority of the samples (st5, 4, 1 and 2), the sediment was classified as "sandy mud" with percentage of sand and mud respectively, included between 11.9 - 25.5 and 88.1 - 74.5. In particular st1 and 2 show, respectively, mud percentages of 84 and 88,1; both values are very close to 90% that represent the threshold value that separate sandy (lower) from mud (higher). Two sites, 6 and 3, were classified as "mud" with percentage of sand and mud, respectively, included between 6 - 7.7 and 92.3 - 94 (Fig. 3).
The total suspended matter deposition and organic carbon fluxes showed the highest values at bottom level, inside the mussel farm (Tab. 2); whereas the lowest one at the

bottom level, outside the farm. The traps located in the water column, immediately below the mussel ropes, showed intermediate values. However, no statistical differences were detected among the sampling sites.

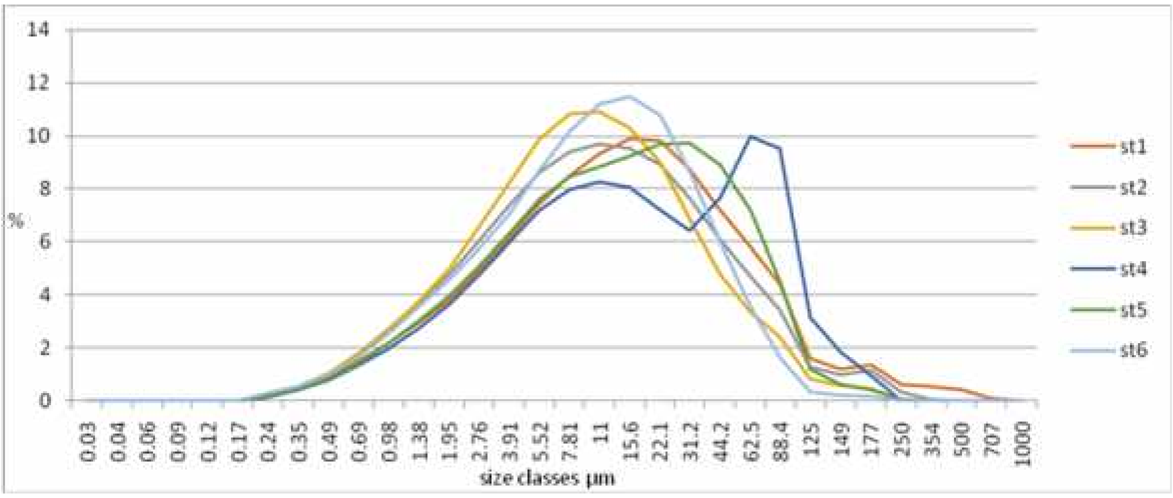

Figure 3: grain size distribution for each sampling site.

Table 2: suspended matter and particulate organic carbon fluxes in sampling sites.

Sites	Suspended matter (SM) fluxes ($g\ d^{-1}\ m^{-2}$)	Particulate organic carbon (POC) fluxes ($g\ d^{-1}\ m^{-2}$)
1	6.55	3.79
2	5.95	3.48
3	4.61	2.10
4	4.58	2.14
End of mussel tubular nets traps 1	4.42	3.41
End of mussel tubular nets traps 2	4.92	2.99
Water column trap	5.32	1.97

3.2 Biotic data

3.2.1 Meiobenthos

35 taxa have been detected, for a total of 1416 individuals analysed. In all the sites the meiobenthic community resulted to be dominated by Nematoda (ranging from 42 to 78 %, respectively st4 and st1) and Copepod (10 - 21% in st1 and st6 respectively).

The st4 resulted to be the richest in terms of species (together with st5) and total number of individuals, even if the Shannon index showed no significant differences among all the sites (Fig. 4). The only statistically differences were recorded in number of specimens between the st3 and st5 (p=0,001) and between st4 and st6 (p=0,001).

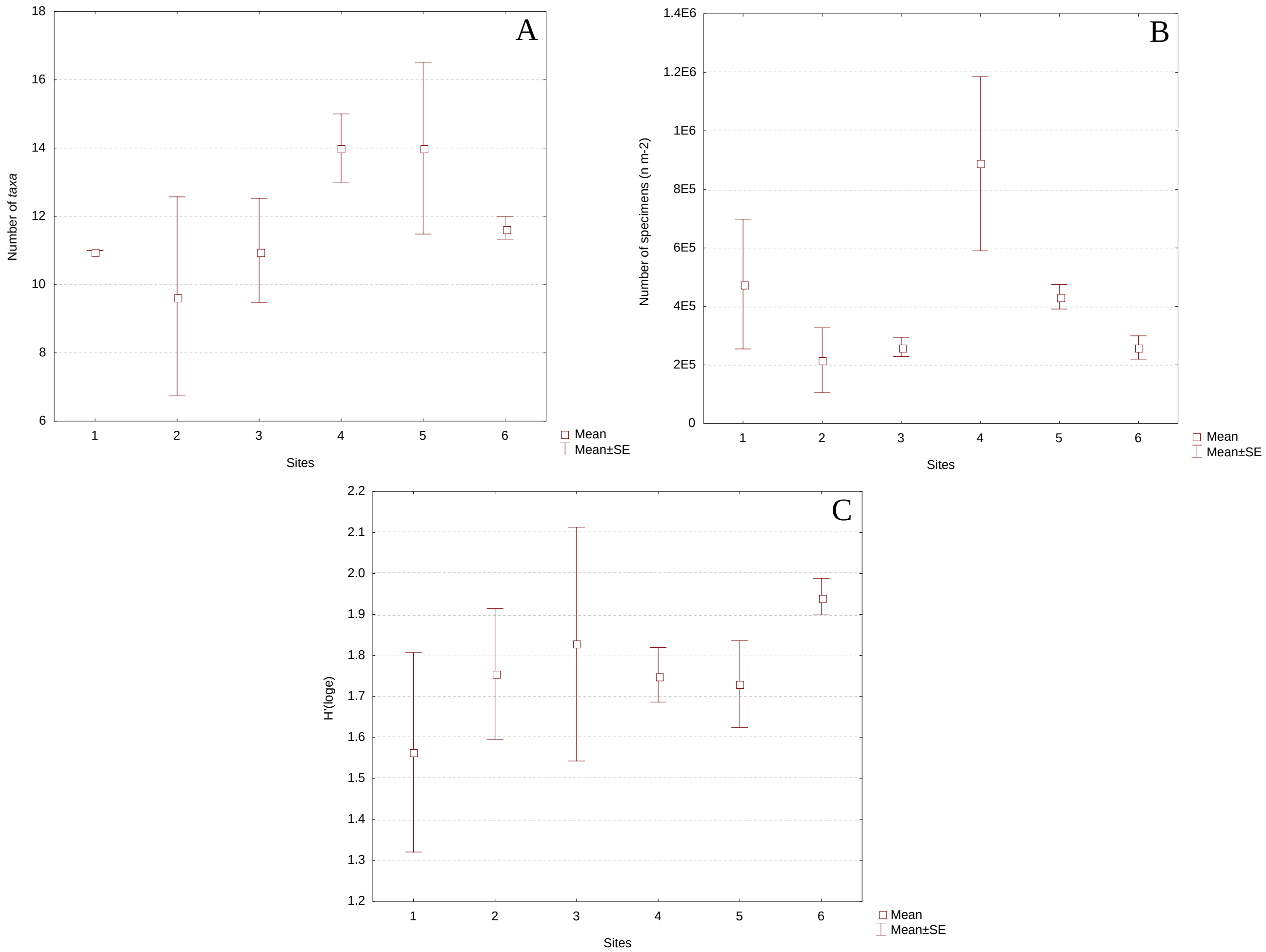

Figure 4: diversity indices for the meiofaunal community (mean ± s.e); A= Number of species, B= Number of individuals, C= Shannon-Wiener index.

The total biomass (nematode and copepod pooled), showed statistically significant differences among groups IN and OUT (p=0,007). (Fig. 5).

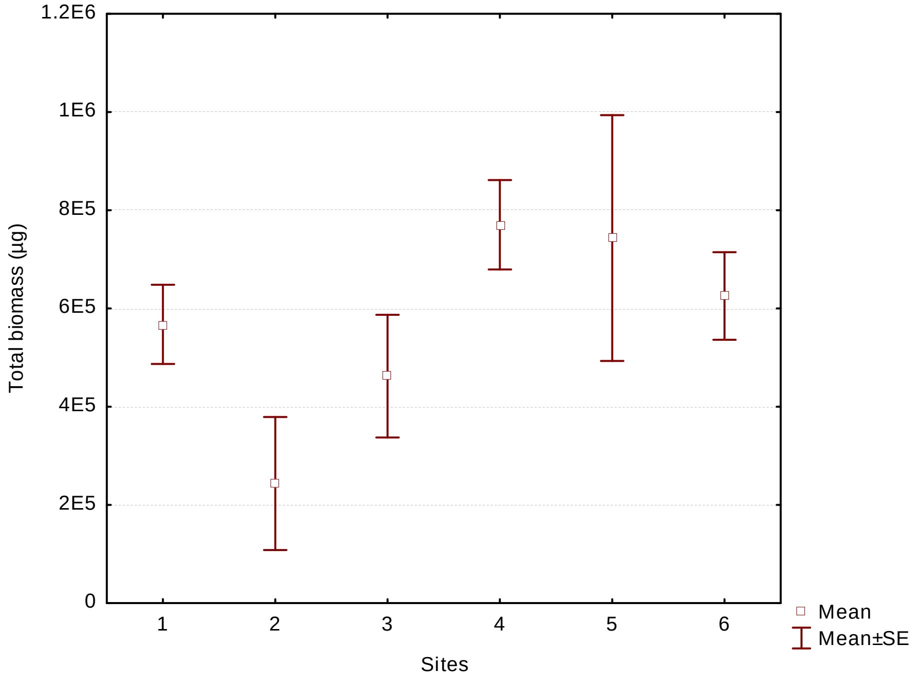

Figure 5: total biomass of meiofauna (mean ± s.e).

The trophic structure of the nematode assemblage showed that the selective deposit feeders (sdf) are the most abundant group in terms of abundance (Fig. 6A). Predator/omnivores (p), nonselective deposit feeders (nsdf) and epigrowth feeders (ep) groups are numerically very low. For biomass, there is not an evident predominance of a specific trophic groups in all sites, but nematode show different trophic assemblages in each sample site (Fig. 6B). Statistical analysis show significative differences both for abundance and for biomass data. In the first case nested PERMANOVA revealed differences for epigrowth feeders between OUT and RIVER (p=0,001) groups and between st4 and st6 (p=0,001). Concerning biomass, statistical differences were recorded for select deposit feeders, between st1 and st2 (p=0,001) and for epigrowth feeders both between groups (OUT–RIVER p=0,023; OUT–IN p=0,016) and sites (4-6 p=0,001).

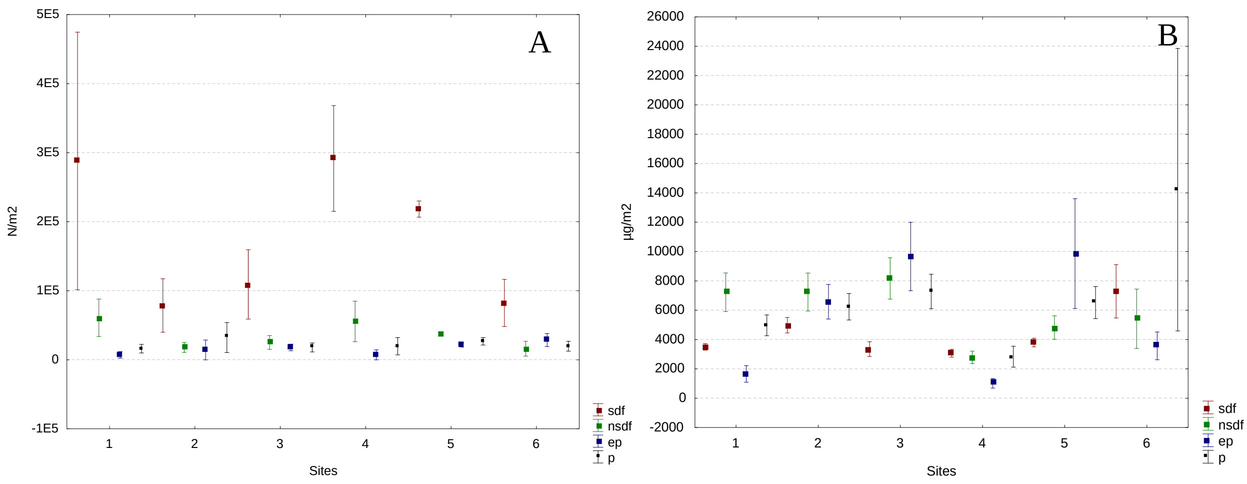

Figure 6: trophic structure of the Nematoda assemblage (A =abundance m^{-2}; B = biomass m^{-2}); sdf= select deposit feeders, nsdf= non selective deposit feeders, ep=epigrowth feeders, p=predators/omnivores (mean± se).

3.2.2 Macrozoobenthos

Macrozoobenthic community resulted to be composed by 145 taxa (56 molluscs, 54 polychaetes, 29 crustaceans, 8 echinoderms and other 4 minor groups; for the complete list of species see appendix 1). In three sites (1, 2 and 6) molluscs are the richest group in terms of species followed by polychaetes and crustaceans; in the other sites (3, 4 and 5) polychaetes dominate, followed by molluscs and, with the same values, by crustaceans and echinoderms. The highest number of species has been detected in st1, whereas the lowest in st3 (Fig. 7).

In general, sites inside the farm showed higher values than outside, for all the tested diversity indices (Fig. 7). In particular, the maximum value was always recorded in st1 and the minimum in st3 (Fig. 7) The results of the statistical test are reported in the table 3. IN sites group is always statistically different from others groups, while no evident trend is shown among the single sites. (Tab. 3).

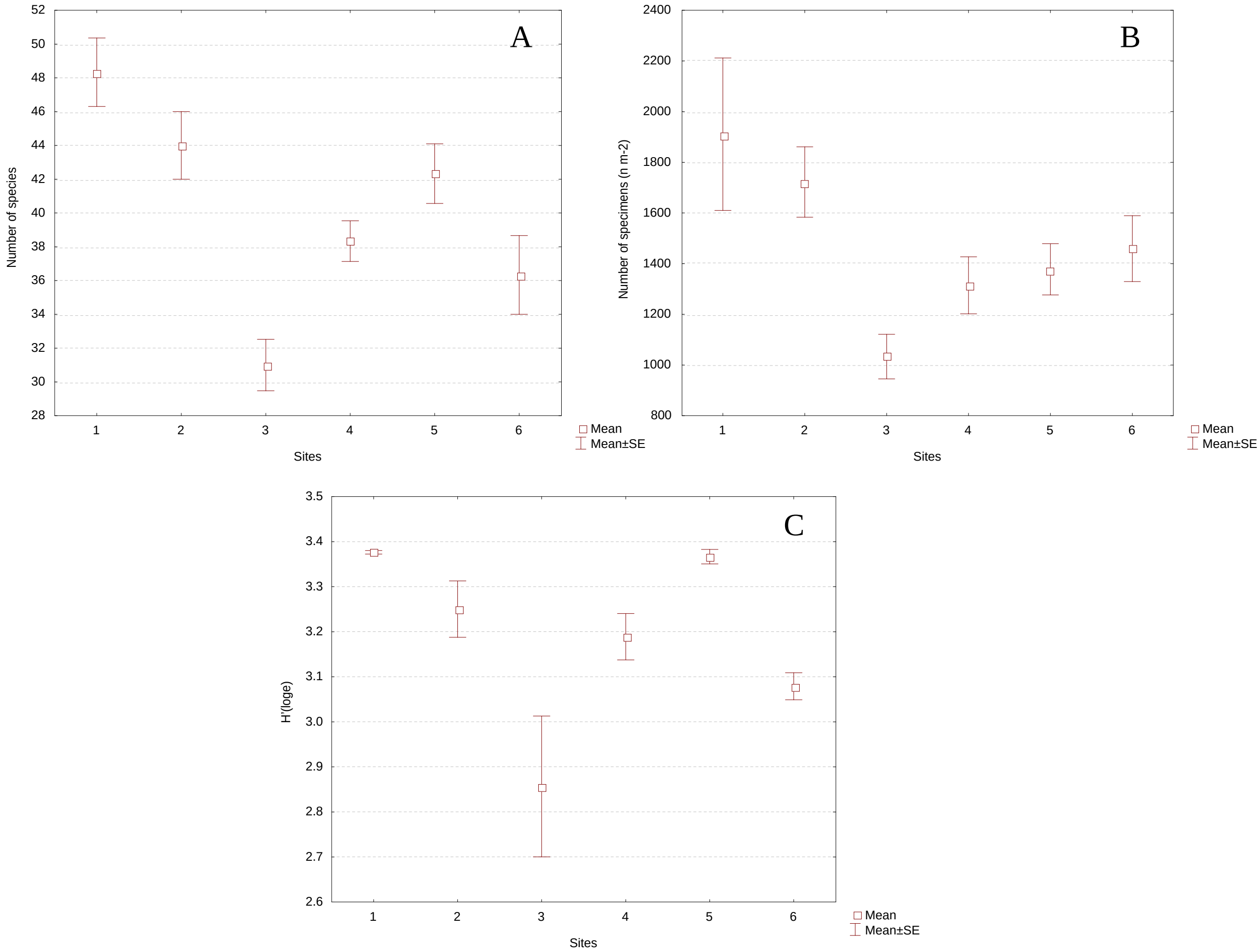

Figure 7: diversity indices for macrofaunal community (mean ± se). A= Number of species, B= number of individuals, C= Shannon-Wiener index.

Table 3: nested PERMANOVA results for the univariate indices (Number of species (S), Number of specimens (N), Shannon-Wiener index (H')) among the sample sites. Ns-not significant; * -significant (p<0,05).

	IN-OUT	IN-RIVER	OUT-RIVER	1-2	3-5	4-6
S	*	*	*	Ns	*	Ns
N	*	*	Ns	Ns	Ns	Ns
H'	*	*	Ns	*	*	Ns

In term of total biomass, nested PERMANOVA revealed significant differences among the three groups (p=0,001) and between st3 and st5 (p=0,001) and between st4 and st6 (p=0,001) The highest values have been recorded outside the farm in st4 and st5 (Fig. 8).

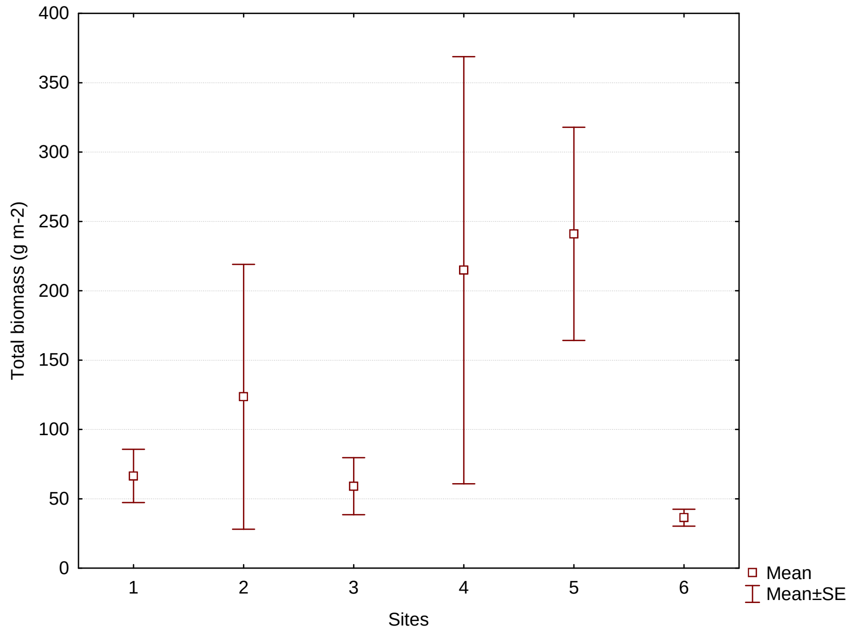

Figure 8: total biomass of macrofauna (mean ± s.e).

In terms of community structure, the MDS analysis revealed the presence of a group composed by the sites located inside the farm and st6, whereas the other sites are widespread (Fig. 9) this is confirmed by the PERMANOVA (F= 3.8215, P = 0.0001). This differences, however, seems to be due mainly to the presence of many rare taxa inside the farm (contributing for less than 3 % in terms of abundance and for less 10%, excluding the first species, regarding biomass).

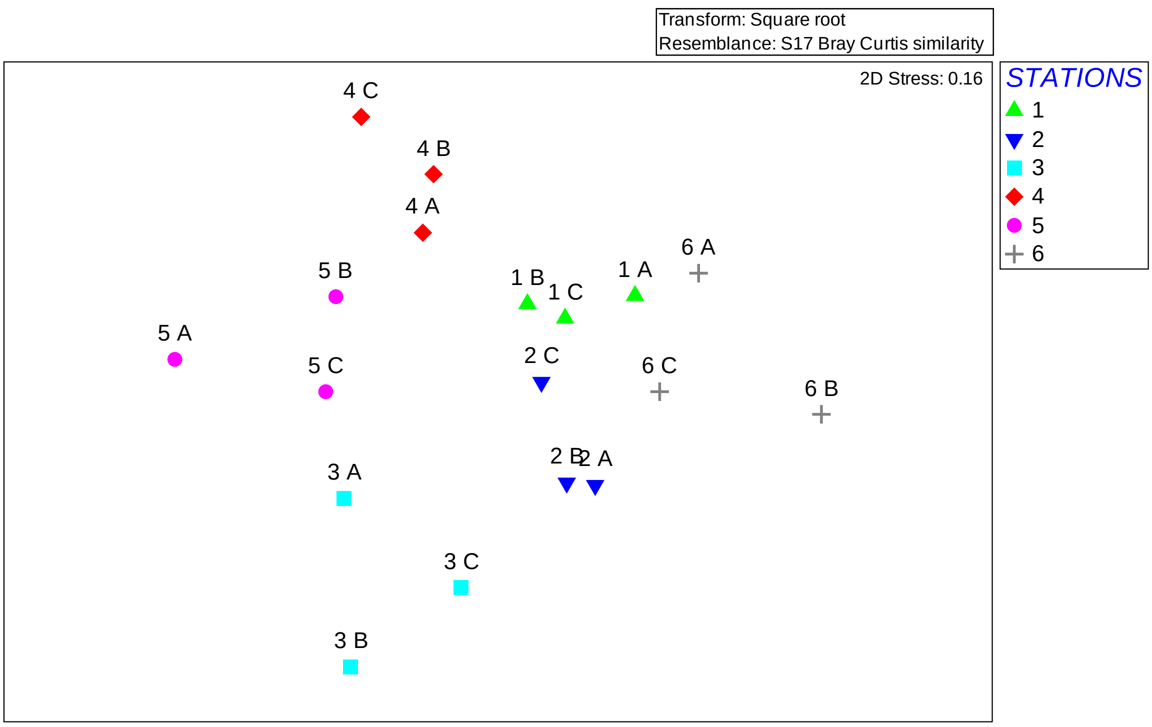

Figure 9: MDS for macrobenthic abundance for all replicates.

Regarding the trophic structure of the community, detritivorous species are the main group (both in terms of abundance and biomass) in all the sites (Fig. 10). For abundance, statistical analysis revealed differences for md (IN-OUT p=0,032; IN-RIVER p=0,03), moff (IN-RIVER p=0,028; st4-st6 p=0,001), momf (st3-st5 p=0,001) and mop (IN-OUT p=0,001; IN-RIVER p=0,001; st3-st5 p=0,001) trophic groups. For biomass, analysis show statistical differences for md (OUT-RIVER p=0,002; st3-st5 p=0,001; st4-st6 p=0,001), moff (st4-st6 p=0,001), momf (IN-RIVER p=0,001 statistical differences among the coupled sites have been detected for the biomass.

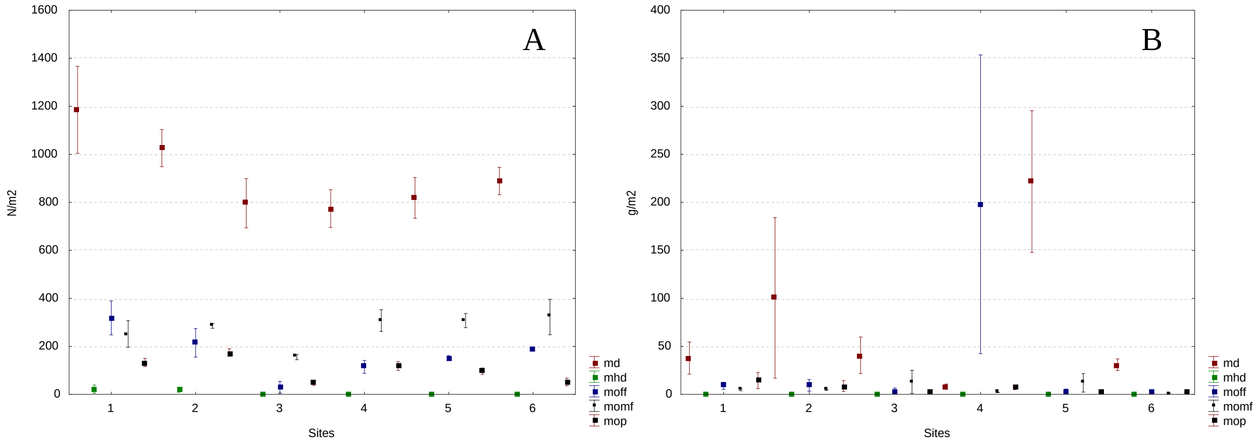

Figure 10: trophic structure of the macrobenthic community (A=abundance m-2; B=biomass); md= detritus feeders, mhd= herbivores, moff= filter feeders, momf= mixed feeders and mop= predators (mean±se).

Biogenic Mixing Index pattern is shown in figure 11. Sites 1, 2 and 5 present the highest values of potential reworking capability assessed at the level community. Statistically differences (p<0,05) were found among sites 5 and 3, 4, 6. Although sites 1 and 2, show medium values of the same magnitude of site 5, no statistically differences were observed probably due to the high standard errors.

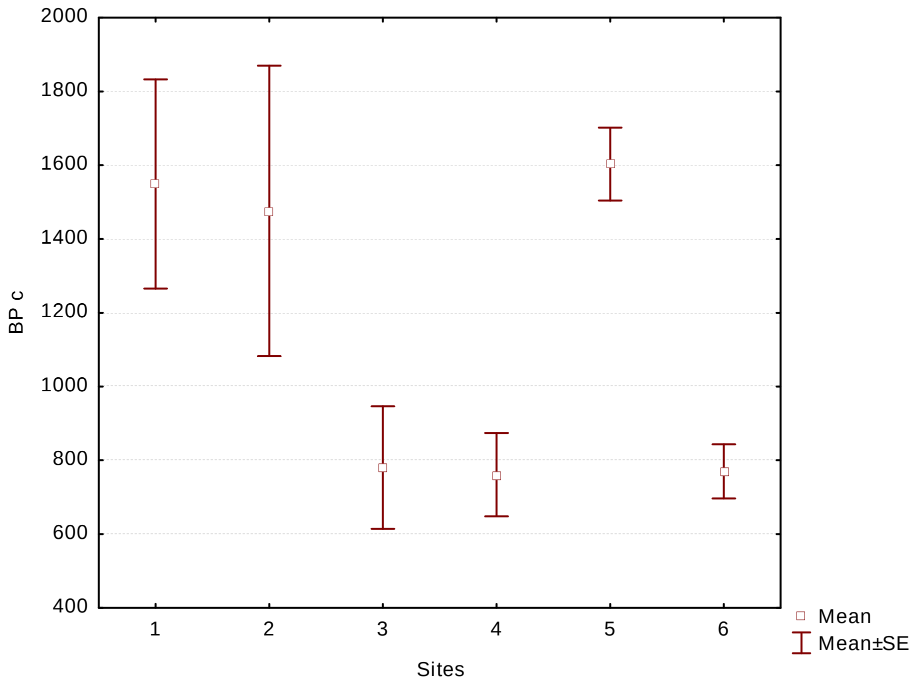

Figure 11: BPc pattern for macrofaunal community.

Finally, the application of the AMBI (Fig. 12), allowed us to classify all the sites in two groups: st1, 4 and 5 as undisturbed and st2, 3 and 4 as slightly disturbed.

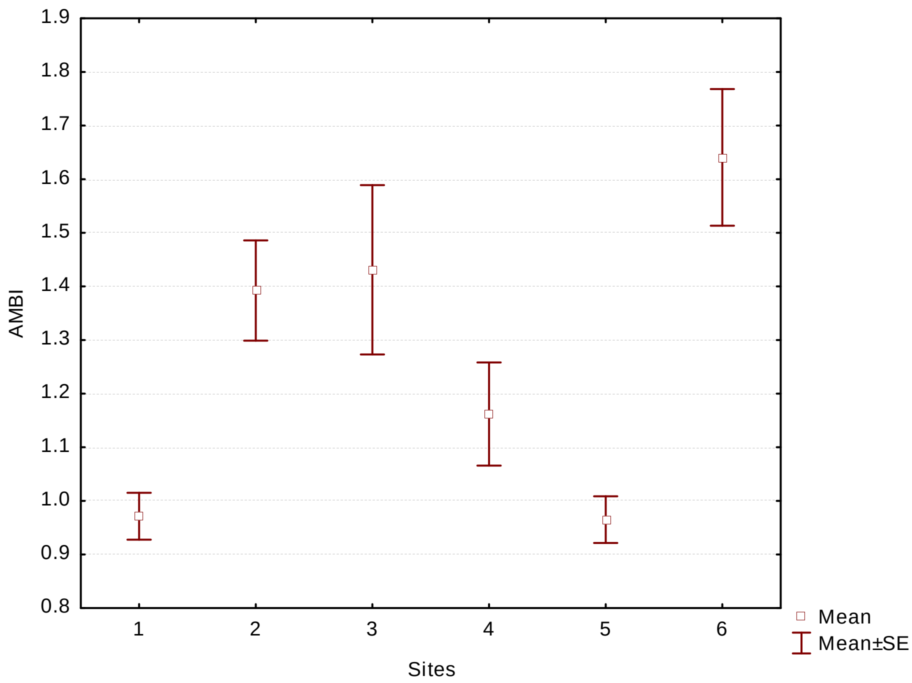

Figure 12: results obtained for the AMBI application.

4. Discussion

Several studies have been carried out to assess impact of shellfish farms (typically mussels and oysters) on the benthic community since the ’80s, across the world, but with contrasting results (Mattsson and Lindén, 1983; De Jong, 1994; Mirto *et al*., 2000; Chamberlain *et al*., 2001, Crawford *et al*., 2003; Hartstein and Rowden, 2004; Giles *et al*., 2006; Callier *et al*., 2008). Among the main factors influencing the benthic fauna in a mussel farm, the biodeposition and the creation of new habitat by the deploy of buoys, mooring posts and, by the accumulation of live and dead mussels on the bottom, have been recognized the most important ones.

Among the others, the organic enrichment due to the biodeposition activity may deeply affect benthic organisms. However, as the ‘behaviour’ of any type of contaminant released into the water column, it strongly depends on the hydrographical conditions, production and decay rates, being less impacting in areas with great water exchange (Midlen and Redding, 1998; Crawford *et al*., 2003).

The placement of hard substrates on the bottom, necessarily alters a typical soft bottom benthic community, giving the opportunity to hard bottom species to settle and to grow. This process, that typically interest only small portions of the farm (Tenore and González, 1976; Khalaman, 2001a, 2001b; LeBlanc *et al*., 2003b; Murray *et al*., 2007; Lutz-Collins, 2009a-b), may instead be more important considering also the fall-off of mussels and associated organisms from suspended structures (de Jong, 1994; Inglis and Gust, 2003; Leonard, 2004). Both the hard bottom species and the mussels and their associated fauna are expected to enhance the food available for benthic predators and scavengers, modifying the community structure. Many studies, indeed, have reported increased abundance and/or biomass of benthic predators under the mussel farms (Saranchova and Kulakovskii, 1982; Gerlotto *et al*., 2001; Miron *et al*., 2002).

In the present study, the acoustic mapping showed that seabed below the mussel farm is characterized by a homogeneous backdrop, mostly muddy, with the presence of some hard substrates (accumulations of living and dead mussels, the ropes on the seabed and concrete blocks). The sediment core analysis confirmed the results of multibeam echosounding for what concern the two sites located inside the mussel farm and showed that also two of the outside sites (4 and 5) share the same sediment texture; only the sites positioned in front of the Sile and Piave rivers mouth resulted to be characterized by a different grain size composition, with mud and sand in an almost equal percentage.

The suspended matter fluxes measured in the water column and at the bottom level, both inside and outside the mussel farm, showed values characterized by the same order of magnitude and no statistically differences among the sites have been recorded. In terms of vertical fluxes, this means that the sedimentation rates in the external sites and the sum of mussel biodeposition and sedimentation amounts calculated in the inner sites are quite similar. Moreover, also biodeposition rates obtained by the sediment traps placed at just below the mussel tubular nets showed no differences from the water column ones in the reference site.

Suspended matter fluxes measured at the bottom level inside and outside the mussel farm are one order of magnitude lower than literature data concerning both sedimentation (Puskaric *et al*., 1992; Matteucci and Frascari, 1997; Giani *et al*., 2001) and biodeposition rates (Jaramillo et *al*., 1992; Hatcher *et al*., 1994; Jovanovic *et al*., 2009; Alonso-Pérez *et al*., 2010) but are in accordance with data colected in 2004 inside the same mussel farm (mean 7,593 g d^{-1} m^{-2}) (Boldrin *et al*., 2006). While the difference in sedimentation fluxes may be attribute to the more long-lasting sampling periods, that include also stronger natural resuspension periods as winter months, more complex is the discussion about biodeposit data. Many authors reported as mussel farming increases suspended matter fluxes by the biodeposits production (Hatcher *et al*., 1994; Stenton-Dozey *et al*., 1999; Hartstein and Rowden, 2004; Callier *et al*., 2006). Biodeposit production and settlement rates, however, vary among mussel size and diet and are quite variable over short time scales (days) (Weise *et al*., 2009). Biodeposits produced by large body size mussels are in general quantitative lesser and have a higher settlement rate than smaller ones. Biodeposits are also affected by environmental factors, *in primis* local hydrodynamic conditions. A positive correlation between biodeposit dispersion, redistribution and current regime has been reported (Hartstein and Stevens, 2005; Giles, 2009), highlighting at same time the gaps in biodeposit knowledges. Most of available data on species-specific biodeposit production and sedimentation rate derived from laboratory experiments and are referred to one or a little group of individuals (Tenore and Dunstan, 1973; Chamberlain, 2002). Regarding biological functions, mussels inside a tubular net cannot be assimilated to a sum of individuals, as the interactions between mussels and the environment are scale-dependent (Smith *et al*., 2006; Stevens *et al*., 2008; Fréchette, 2010). For the Mediterranean mussel, laboratory experiments run on 22 specimens with size included between 54,72 and 89.6 mm, revealed a mean biodeposit sinking rate of 0,7 ± 0,3 cm/s (Barnes, 2006). Hydrodynamic conditions of the study area are those typical of the west coast of North Adriatic. A current parallel to the coastline (from NE to SW), tidal currents and strong winter winds from 1st and 2nd quarters are the most relevant environmental variables that affect water masses. Depending on these factors, in the mussel farm, the vertical fluxes are influenced mainly (80%) by bottom sediment resuspension and lateral transport processes (Boldrin *et al*., 2006). All this suggests that the mussel biodeposits only minimally interest sea bottom and that probably are scattered away by currents as also indicated in Alonso-Pérez *et al*., 2010. This is also confirmed by water column traps data that, inside the farm, give a direct measure of biodeposition. Comparing these data with bottom traps results is possible to see how mussel contribution nearly disappear before to reach sea bottom. Also regarding POC fluxes, no differences among sites were found. The observed carbon fluxes agree with the most recent data available for the study area (august 2004, water column, 2.69 g $m^{-2}d^{-1}$) and show the same order of magnitude recorded inside other mussel farms (Tenore *et al*., 1982; Alonso-Pérez *et al*., 2010). Such a situation, relative high POC concentrations in all sites both at bottom and in water column, may induce to think to some mechanisms that interest in the quite same way the entire study area. As suggested for the SM fluxes, also regarding POC concentrations, probably bottom sediment resuspension and lateral transport processes in a shallow water coastal area characterized by a high hydrological dynamism are the factors that mainly affect the carbon distribution in the study area (Boldrin *et al*., 2006).

Within the contest of a general homogeneity in the sediment texture and similar vertical fluxes in all the sites, the benthic fauna showed some differences among sites, mainly regarding macrobenthic components. These differences, both in terms of abundance and biomass, suggest the presence of a more diverse, but with lower biomass, community inside the mussel farm; notwithstanding these differences, however, the community composition recorded inside and outside resulted to be quite similar, as showed by the MDS results. This could be related to the presence of hard substrates, as live and dead mussels, that contributed to the establishment of a community which besides most soft bottom species, presents also some rare species that colonize the seabed mussel accumulations or that are attracted by food availability. These species from one hand contributes to the differences recorded in univariate indices values, but on the other are not enough to completely differentiate the community. These data indicate that the presence of farm itself is not a factor able to strongly affect the species assemblage, as also highlighted by other authors (Chamberlain, 2002; Crawford *et al*., 2003; Miron *et al*., 2005).

Both inside and outside mussel farm, meio and macrozoobenthic communities are dominated by detritivorous species highlighting as the entire study area is characterized by a high presence of organic matter. With reference to reworking activities, no significant differences have been detected between inside and outside the farm, even if the inside sites are characterized by higher mean and variance values.

All this indicates that the entire study area is affected by the same pressures of the environmental drivers, resulting in an almost uniform benthic community. According to some studies that evidence the importance of site-specific characteristics in understanding the magnitude of farm impact on benthic community (Hartstein and Rowden, 2004; Hartstein and Stevens, 2005; Alonso-Pérez *et al*., 2010), as mentioned above, the high hydrological dynamism of the area, due to currents and waves, added to the presence of two important rivers (Sile and Piave) and their suspended matter loads, are probably the main features modelling the ecological processes in the area. Acting at the same time, in the same way, inside and outside the mussel farm, the uninterrupted action of these environmental variables have developed an almost homogeneous meiobenthic community and a well defined macrobenthic fauna, dominated by anellids, molluscs and crustaceans, typical of a transitional environment. In such a context the disturbance induced by a 2 km^2 wide and 20 years old mussel farm resulted quite scarce.

5. Conclusions

The results of the present study are in accordance with findings by other authors such as Chamberlain *et al*., (2001) in Southwest Ireland (at site 1); Crawford *et al*., (2003), in Tasmania, Australia; da Costa and Nalesso, (2006) in Southeastern Brazil; Fabi *et al*.,

(2009) in Western Adriatic Sea, Italy), showing little or no differences in the benthic community between sites inside and outside the farm. The general pattern detected for the macrozoobenthic community, with higher number of individuals and species inside the farm, may be ascribed to slodged mussels on the seabed as reported also by Grant *et al*., (1995). The location of the mussel farm, inside the plum of Sile river (Bruno *et al*., 2006) in a typical transitional environment, and the exposure to strong longline current and winds play a fundamental role in the dynamics of the study area biotic and abiotic components. The importance of farm location and hydrological conditions in detecting the potential impact on the benthic biocenosis associated with mussel production (Hartstein and Rowden, 2004) is also confirmed with minimal impact at sites characterised by high hydrodynamic energy. Thus, the present study, as reported by other authors (Midlen and Redding, 1998; Chamberlain *et al*., 2001; Crawford *et al*., 2003) underline the relevance of mussel farm position to assess the possible impacts on benthic fauna, roughing out the portions of open sea near river mouth as particular adapted for mussel acquaculture. Finally, in present study SM and POC fluxes were recorded on only 48 h of sediment traps deploy and biotic samples were collected only during one season (summer); analysis for a longer period of time and data acquisition on N and P concentration both in the water column and sediments would be desirables, in order to better understand the biogeochemical cycles in the area, as far as to describe the seasonality of the benthic community structure in relation with the mussel farming cycle.

The results here reported are of considerable relevance within the context of the Intgrated Coastal Zone Management (ICZM) and Marine Strategy Framework Directive (MSFD). The low impact observed on the bentic compartment, indeed, well fits with the indication of the human development safeguarding habitat promoted by the ICZM approach and with the descriptor 6 (Sea-floor integrity) of MSFD.

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Appendix 1 – List of macrozoobenthos species and presence in the stations

Stations	**1**	**2**	**3**	**4**	**5**	**6**
Crustacea, Amphipoda						
Ampelisca diadema (Costa, 1853)	x	x	X	X	X	X
Ampelisca ledoyeri Bellan-Santini & Kaim-Malka, 1977	x			X	X	
Ampelisca sarsi Chevreux, 1888	x	x	X	X	X	X
Ampelisca sp.	x	x	X	X	X	X
Caprella sp.				X		
Leucothoe cfr. *richiardii* Lesson, 1865	x	x	X	X	X	X
Medicorophium annulatum (Chevreux, 1908)	x		X	X	X	X
Microdeutopus gryllotalpa Costa, 1853			X		X	
Microdeutopus sp.			X			
Phtisica marina Slabber, 1769			X		X	
Isaeidae ind.			X	X	X	X
Lysianassa sp.		x	X	X	X	
Amphipoda ind.				X		X
Crustacea, Cumacea						
Iphinoe cfr. *adriatica* Băcescu, 1988	x	x	X	X	X	
Diastylis rugosa Sars, 1865				X		
Cumacea ind.		x	X	X	X	X
Crustacea, Decapoda						
Brachynotus foresti Zariquiey Álvarez, 1968				X		
Gourretia denticulata (Lutze, 1937)			X		X	
Ilia nucleus (Linnaeus, 1758)		X				
Liocarcinus vernalis (Risso, 1816)				X		
Liocarcinus depurator (Linnaeus, 1758)					X	
Processa edulis edulis (Risso, 1816)	x		X		X	X
Upogebia pusilla (Petagna, 1792)		X				
Natantia ind.						X
Crustacea, Isopoda						
Aega sp.	x	x	X	X	X	
Eurydice cfr. *affinis*(Hansen, 1905)					X	
Eurydice sp.					X	
Gnathia sp.					X	
Crustacea, Tanaidacea						
Apseudopsis laitrellei Milne-Edwards, 1828	x	x	X	X	X	X
Pycnogonida						
Pycnogonida ind.				X		
Echinodermata, Echinoidea						
Ova canaliferus (Lamarck, 1816)		x			X	
Echinodermata, Holoturidea						
Leptopentacta elongata (Düben & Koren, 1846)	x	x	X	X	X	X
Oestergrenia thomsonii (Herapath, 1898)		x	X			X
Pseudothyone sp.(Panning, 1949)	x	x			X	
Echinodermata, Ophiuroidea						

Amphiura chiajei (Forbes, 1843)	x	x	X	X	X	X
Ophiothrix quinquemaculata (Delle Chiaje, 1828)				X		
Ophiura ophiura (Linnaeus, 1758)	X					
Echinodermata, Asteroidea						
Astropecten irregularis irregularis (Pennant, 1777)	x					X
Mollusca, Bivalvia						
Abra alba (W. Wood, 1802)	x	X				
Abra nitida (O.F. Müller, 1776)	x		X			X
Abra prismatica (Montagu, 1808)				X		
Abra tenuis (Montagu, 1803)						X
Arca noae Linnaeus, 1758				X		
Acanthocardia aculeata (Linnaeus, 1758)				X		
Acanthocardia deshayesii (Payraudeau, 1826)			X			
Acanthocardia paucicostata (G. B. Sowerby II, 1834)	x	x				X
Corbula gibba (Olivi, 1792)	x	x	X	X	X	X
Dosinia lupinus (Linnaeus, 1758)	x	x	X	X	X	X
Dosinia exolenta (linnaeus, 1758)	x	X				
Ensis minor (Chenu, 1843)	x	x	X	X	X	
Ennucula aegeensis(Forbes, 1844)	x	x				X
*Flexopecten glaber (*Linnaeus, 1758)	x			X	X	
Kurtiella bidentata (Montagu, 1803)	x	x	X	X	X	X
Litigiella glabra (P. Fischer in de Folin & Périer, 1873)	x		X			
Loripes lucinalis (Lamarck, 1818)	x	x			X	
Loripinus fragilis (Philippi, 1836)	x	x		X	X	X
Mytilus galloprovincialis Lamarck, 1819		X				
Musculus subpictus (Cantraine, 1835)				X	X	
Ostrea edulis Linnaeus, 1758				X		
Modiolus barbatus (Linnaeus, 1758)				X		
Musculus costulatus (risso, 1826)	x	X				
Nucula nucleus (Linnaeus, 1758)	x					X
Nuculana pella (Linnaeus, 1767)	x	x	X	X	X	
Pitar rudis (Poli, 1795)	x					X
Papillicardium papillosum (Poli, 1791)	X					
Solemya togata (Poli, 1791)	X					
Spisula subtruncata (da Costa 1778)	x	x				X
Solecurtus strigilatus (Linnaeus, 1758)						X
Striarca lactea (Linnaeus, 1758)	x	x				X
Tellina albicans Gmelin, 1791	x					X
Tellina distorta Poli, 1791	x	x	X	X		X
Tellina donacina Linnaeus 1758	x	x	X	X	X	
Tellina pulchella (Lamarck, 1818)			X			
Thracia phaseolina (Lamarck, 1818)	x	x				X
Bivalvia ind. 1				X	X	
Venerupis corrugata (Gmelin, 1791)	x	x			X	

Venus casina (Linnaeus, 1758)		x			X	X
Nucula sp.			X		X	X
Mollusca, Gastropoda						
Acteon tornatilis (Linnaeus, 1758)		X				
Aporrhais pespelecani (Linnaeus, 1758)	x	X				
Bolinus brandaris (Linnaeus, 1758)			X	X	X	
Calyptraea chinensis (Linnaeus, 1758)	X					
Cylichna cylindracea (Pennant, 1777)	x	x		X	X	X
Eulima glabra (da Costa, 1778)	x	x	X	X	X	X
Fusinus pulchellus (Philippi, 1840)	x	x				X
Nassarius cuvierii (Payraudeau, 1826)		X				
Nassarius incrassatus (Strøm, 1768)	x	x	X	X	X	X
Nassarius reticulatus (Linnaeus, 1758)			X		X	X
Odostomia sp. (Fleming, 1813)		x	X			X
Turitella turbona (Monterosato, 1877)	x	x				X
Tectonatica sagraiana (d'Orbigny, 1842)	x				X	X
Scaphander lignarius (Linnaeus, 1758)					X	
Mollusca, Scaphopoda						
Antalis inaequicostata (Dautzenberg, 1891)	x	x	X	X	X	X
Antalis vulgaris (da Costa, 1778)	x					
Sipunculida						
Phascolion strombus strombus (Montagu, 1804)	x	x		X	X	
Sipunculus nudus Linnaeus, 1766	x		X		X	X
Phoronida						
Phoronis muelleri (Selys-Lonchamps, 1903)		x	X	X	X	X
Annelida, Polychaeta, Eunicida						
Abyssoninoe hibernica (Mc Intosh, 1903)	x	x	X	X		
Aponuphis bilineata (Baird, 1870)	x	x		X	X	X
Diopatra neapolitana (Delle Chiaje, 1841)	x	x		X	X	
Eunice vittata (Delle Chiaje, 1828)	x	x	X	X	X	
Hilbigneris gracilis (Ehlers, 1868)	x	x	X	X	X	X
Annelida, Polychaeta, Phyllodocida						
Alitta succinea (Leuckart, 1847)						X
Glycera tridactyla (Schmarda, 1861)		x		X		
Glycera unicornis (Savigny in Lamarck, 1818)	x	x			X	X
Goniada maculata (Örsted, 1843)				X		
Malmgreniella lunulata (Delle Chiaje, 1828)	x	x	X	X	X	
Mysta picta (Quatrefages, 1866)					X	
Nephtys hombergii (Savigny in Lamarck, 1818)					X	
Nereis falsa (Quatrefages, 1866			X		X	
Phyllodoce lineata (Claparède, 1870)		x			X	X
Pilargis verrucosa (Saint-Joseph, 1899)	x				X	X
Sigambra tentaculata (Treadwell, 1941)				X		
Platynereis coccinea (Delle Chiaje, 1822)				X		
Hesionidae (Grube, 1850)					X	

Syllidae (Grube, 1850)					*X*	
Nephtys sp. (Cuvier,1817)	*x*	*x*	*X*			
Websterinereis glauca (Claparède, 1870)	*X*					
Annelida, Polychaeta, Sabellida						
Ditrupa arietina (O.F. Müller, 1776)	*x*	*x*			*X*	
Galathowenia oculata (Zachs, 1923)		*x*	*X*		*X*	*X*
Owenia fusiformis (Delle Chiaje, 1844*)*		*x*			*X*	*X*
Annelida, Polychaeta, Scolecida						
Euclymene oerstedi (Claparède, 1863)	*x*			*X*	*X*	
Euclymene santandarensis (Rioja, 1917)	*x*	*x*	*X*	*X*	*X*	
Heteromastus filiformis (Claparède, 1864)				*X*	*X*	
Levinsenia gracilis (Tauber, 1879)			*X*			*X*
Pseudoleiocapitella fauveli (Harmelin, 1964)	*x*	*x*	*X*	*X*	*X*	*X*
Aricidea (Acmira) sp. Hartley, 1981	*x*		*X*	*X*	*X*	*X*
Notomastus sp. 1		*x*	*X*			*X*
Aricia sp.	*x*			*X*		
Euclymene spp.						*X*
Annelida, Polychaeta, Spionida						
Magelona alleni (Wilson, 1958)	*x*				*X*	
Annelida, Polychaeta, Terebellida						
Amphicteis midas (Gosse, 1855)	*x*	*x*	*X*	*X*	*X*	*X*
Amphictene auricoma (O.F. Müller, 1776)	*x*	*x*	*X*		*X*	*X*
Eupolymnia nebulosa (Montagu, 1818)			*X*			
Melinna palmata (Grube, 1870)	*X*					
Sternaspis scutata (Ranzani, 1817)	*x*	*x*		*X*		*X*
Cirratulidae ind.			*X*		*X*	
Ampharetidae ind. (Malmgren, 1866)	*x*		*X*			
Pectinariidae ind.						*X*
Pectinaria belgica (Pallas, 1766)					*X*	
Lanice conchilega (Pallas, 1766)				*X*		
Lagis koreni (Malmgren, 1866)	*x*	*x*		*X*		*X*
Stylarioides sp. (Delle Chiaje, 1831)	*x*			*X*		
Terebellides stroemii (Sars, 1835)	*x*			*X*		
Trichobranchus glacialis (Malmgren, 1866)			*X*			

Appendix 2 – List of meiozoobenthos Taxa and presence in the stations (sdf= select deposit feeders, nsdf= non selective deposit feeders, ep=epigrowth feeders, p=predators/omnivores).

Stations	**1**	**2**	**3**	**4**	**5**	**6**
Nematoda (sdf)	X	X	X	X	X	X
Nematoda (nsdf)	X	X	X	X	X	X
Nematoda (ep)	X	X	X	X	X	X
Nematoda (p)	X	X	X	X	X	X
Copepoda	X	X	X	X	X	X
Bivalvia		X		X		
Gastropoda		X	X		X	
Amphipoda			X	X	X	X
Munna	X	X	X	X	X	X
Appendicularia					X	X
Pharaonidae	X	X	X	X	X	X
Syllidae	X	X	X	X	X	X
Capitellidae	X	X		X	X	X
Lumbrinereidae	X	X		X	X	X
Terebellidae				X	X	
Sabellidae	X	X	X	X	X	X
Nereidae				X	X	
Ostracoda					X	X
Eunicidae					X	X
Spionidae	X	X	X	X	X	X
Maldanidae	X				X	
Pilarcidae	X					
Kinorhyncha	X	X		X		
Sipunculida					X	X
Anisopoda (Apseudes spp.)	X				X	X
Nephthyidae	X	X	X	X	X	
Cumacea	X		X		X	
Caprellidira					X	
Isopoda				X	X	
Cossuridae	X	X	X			
Cladocera				X		
Larvae copepoda		X	X	X		
Aricidae				X		
Phillodocidae				X		
Cyrratulidae				X		

Chapter 2

Modeling mussel farm influence on sediment biogeochemistry

Manuscript in preparation

EGU Congress April 2016. 'Benthic processes and coastal aquaculture: merging models and field data at a local scale'. Poster. Geophysical Research Abstracts Vol.18, EGU2016-17177,2016.

Congresso S.It.E Società italiana di Ecologia,30 Agosto-2 Settembre 2016, Milano-Italia.1° Congresso Nazionale Congiunto SITE-UZI-SIB. 'Variability of organic matter deposition and degradation at a Mediterranean mussel farm'. Oral communication. Work in press on Congrees abstract book.

1. Introduction

Shellfish farming is regarded as an extractive aquaculture activity (Troell *et al*., 2009). However, the production of faeces and pseudofaeces leads to a net transfer of organic matter from the water column to the surface sediment (Tenore and Dunstan, 1973; Cranford *et al*., 2003). This process is expected to locally affect sediment biogeochemistry, benthic-pelagic coupling, and benthic community functioning. A range of studies peformed in the last 30 years reported on farm-induced changes in sedimentation rates (Callier *et al*., 2006), sulfate reduction (Dahlbäck and Gunnarson, 1981), NH4 and PO4 regeneration (Hatcher *et al*., 1994; Nizzoli *et al*., 2005), porewater nutrient concentration gradients (Mesnage *et al*., 2007), benthic community structure (Stenon-Dozey *et al*., 1999; Mirto *et al*., 2000; Christensen *et al*., 2003). More recently, the quantitative understanding of these processes received attention in relation to the role of bivalve mariculture in the CO2 cycle (see Filgueira *et al*., 2015 and references therein) and for the assessment of ecosystem services provided by these activities (McKindsey *et al*., 2011; Filgueira *et al*., 2015). Quantitatively understanding of mussel-induced alterations to benthic-pelagic coupling, is also relevant for assessing the role of shellfish farms in "shaping" the functioning of coastal food-webs, which effects at the ecosystem level can be driven by local habitat diversity (Brigolin *et al*., 2014). Knowledge of these processes in coastal ecosystems interested by mussel farming activities is relevant in order to attempt a sound planning of the marine space (Filgueira *et al*., 2007), and to promote sustainable marine aquaculture development (Sanchez-Jerez *et al*., 2016).

The influence of local hydrodynamics on organic matter deposition was the focus of different modelling studies: Hartstein and Stevens, (2005) applied a Lagrangian model in New Zealand, and Weise *et al*. (2009) proposed a similar approach. Based on these works it was possible to have a clearer mechanistic understanding of the relationship between the degree of deposition and the different farming conditions (in terms of local hydrodynamics and farm characteristics – depth; geometry). To our knowledge, less attention received the temporal variability of these fluxes, which is primarily associated to the different phases of the rearing cycle, and, ultimately to physiology of the farmed mussel. Faeces and pseudofaeces production rates are markedly dependent on water temperature and seston quantity and quality (Tenore and Dunstan, 1973), parameters which could present relevant variations at the annual time scale, in particular at those sites characterized by a fast growth out cycle, such as the Mediterranean sea. On the top of this, water temperature and particulate organic matter concentrations variability at the inter-annual time scale and long term trends of variation of these parameters are expected to have an influence on mussel growth performances. A question of relevance is how this variability affects deposition and, ultimately, sediment biogeochemistry. This aspect can be investigated by a combination of in-situ obsevations and early diagenesis models (Boudreau, 1996). However, the recent review by Paraska *et al*., (2015) highlighted that a limited number early diagenesis modeling studies in the past were focused on understanding the effects of human activity on benthic biogeochemistry, with only two studies considering aquaculture related issues (Dedieu *et al*., 2007; Brigolin *et al*., 2009).

In the present work, we used the modeling framework recently proposed by Brigolin *et al*., (2014), which allows to couple individual based population dynamic models of the farmed species with deposition and benthic biogeochemical (early diagenesis) models. The specific goal here, is to quantify mussel farm influence on the spatial and temporal variability of organic matter downward fluxes, and identify geochemical and ecological mechanisms explaining the observed changes in sediment pore-waters and solid phase characteristics. This allowed to obtain an estimation of the mussel farm influence on sediment biogeochemistry and benthic-pelagic coupling at the local scale.

A case study is selected from the North western Adriatic coast, were longline mussel farming is practices since the 90ies, and farmed mussels account for approximately 2/3 of the national Italian production (MiPAAF, 2014). This area is under the influence of freshwater inflows, which can act as a confounding factor when assessing mussel farm deposition (Rampazzo *et al*., 2013).

2. Materials and methods

The study was articulated in four steps:

1) a biogeochemical model was applied at the mussel farm, and an analysis of model uncertainty with respect to environmental forcings, water temperature and chlorophyll-a was performed;
2) two sediment trap experiments were carried out at the beginning and at the end of mussels rearing cycle, with the aim of validating model predictions;
3) sediment cores were collected at two stations, which were localized on the basis of model application, within a field campaign carried out in June 2015. Measurements included O2 microprofiling, porosity and micro-porosity, Total Organic Carbon, and pore waters NH4, PO4, SO4, Alkalinity, and Dissolved Inorganic Carbon;
4) two distinct early diagenesis models (EDM) were set-up, to reproduce observed field data in the sampled cores at the two stations.

This section will first provide a description of the study site, therefore focusing on methodological aspects related to the model adaptation for simulating mussel farm deposition, the sediment trap experiments, and the benthic biogeochemistry data acquisition, and the early diagenesis model application.

2.1 Study site and mussel farm description

The study was performed at a longline farm located approximately 1.5 nautical miles off-shore the city of Jesolo (Italy), in the North-Western Adriatic Sea (see Figure 1). The farm, which produces Mediterranean mussel (*Mytilus galloprovincialis*) covers an area of about 2 km^2 and has been operating since 1990 with an average annual production ranging between 600 and 800 tons $year^{-1}$ (mussel farmers pers. comm.). Mussels are grown on ropes approximately 4 m long, which are suspended on cables, and placed at depths between 2 and 4 m. Lines are positioned parallel to the coast, along the principal current direction (see Figure 1) at a distance of 40m between each other. Length of each line is approximately 2 km. Mussels are normally harvested within July-September, after a rearing cycle lasting a single year, during which they are re-socked 2-3 times (mussel farmers pers. comm.). The area is characterized by a flat bathymetry ranging between 13 and 15 m (Innangi *et al*., 2015). The farm is affected by the freshwater plume of the Sile river, which outlet is located at approximately 1.5 nm of distance from the SW edge of the farm (see Figure 1). The mean annual Sile river discharge in 2008-2009 was 10.9 m3 s-1, ranging between 5.2 m3 s-1 in March 2008, and 14.7 m3 s-1 in December 2009 (ARPAV, 2010).

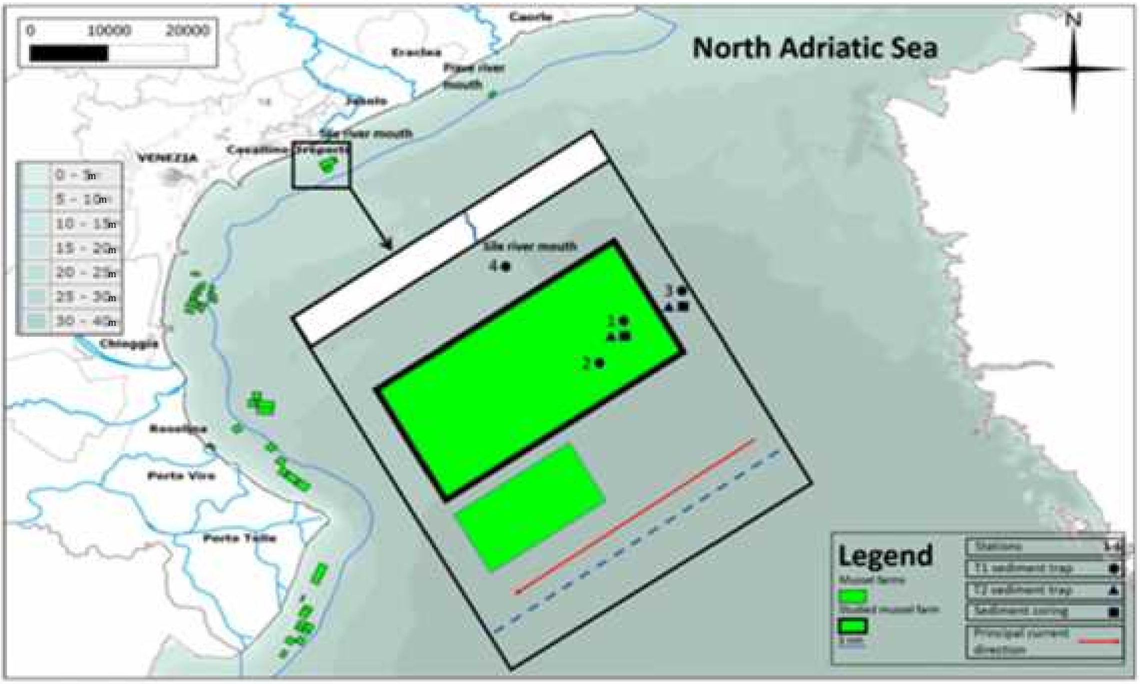

Figure 1: study site and stations sampled in this study.

2.2 Mussel farm biogeochemical model

For the purposes of this work, the integrated model FiCIM (Fish Cage Integrated Model), described by Brigolin *et al*., (2014) was adapted to simulate C, N and P biogeochemical cycles across shellfish farms. For a detailed description of the model, the reader should refer to the original publication, here we will focus on changes required to adapt the model to the simulation of mussel farms in the Northern Adriatic Sea. The model (see Figure 2) combines three generic modules, respectively accounting for: i) individual growth and dynamics of the farmed population; ii) organic particle tracking and deposition; iii) benthic degradation (early diagenesis). Mussel growth and population dynamics were estimated by means of the individual-based approach by Brigolin *et al*., (2009). Briefly, the individual model is capable to simulate physiological processes and their response to key environmental forcings, i.e. food availability and water temperature. This allows accounting for the daily energy intake, weight gain, and faeces and pseudofaeces production rate, which represents the input for the deposition module. A Monte-Carlo approach is used to upscale the model from the individual to the population (for details see Brigolin *et al.*, 2009). The individual-based growth model requires in input daily time series of chlorophyll-a, Particulate Organic Carbon, and sea water temperature.

Faeces and pseudofaeces deposition from mussel lines is simulated by means of a Lagrangian technique, consistent with the advection-diffusion equation (for details see Jusup *et al*., 2007). This model requires as input time series of water velocity and fluxes of faeces and pseudofaeces. The latter variables are provided by the individual-based population dynamic model, which assigns a different C, N and P content to each class of biodeposit. Integral fluxes associated with the metabolic activities of the entire farmed population are computed as described in Brigolin *et al*., (2014). 5000 particles are launched every day from each mussel line. A depth comprised between 1 and 7 m is assigned randomly. The output of this module is a daily map of downward fluxes of organic C, N and P reaching the sea bed (in g m-2 d-1). The complete set of parameters used in the deposition model, values and their references, are reported in Table A1 (Appendix). Settling velocities for mussel faeces and pseudofaeces were set to 1.0 ± 0.1 cm s^{-1} and 0.1 ± 0.01 cm s^{-1} (see Weise *et al*., 2009; Chamberlain, 2002). The settling velocity of each particle was randomly selected from a Gaussian distribution. The cage population and deposition modules were coupled by maintaining constant the input of faeces and pseudofaeces to the deposition model over the 24 h (see Brigolin *et al*., 2014).

The early diagenesis model (EDM) was developed by means of the Biogeochemical Reaction Network Simulator - BRNS - (Regnier *et al*., 2002b), through the Knowledge-Based Reactive Transport Model application (Aguilera *et al*., 2005). EDM integration with aquaculture deposition models have been described for Salmon farming in a Scottish sealoch by Brigolin *et al*., (2009). In the present application we used the EDM identified for the Northern Adriatic Sea by Brigolin *et al*., (2011). The model solves the diagenetic equations describing mass conservation for solids and dissolved species in a vertical sediment column - see Eqs. 1 and 2 in Table A2 (Appendix) (Berner, 1980; Boudreau, 1997). The advection term includes burial, compaction, and bioirrigation; the diffusion term includes molecular and ionic diffusion, as well as bioturbation. Organic matter oxidation is described by means of a multi-G model (Westrich and Berner, 1984), following the approach by Wang and Van Cappellen, (1996). Oxic and anoxic pathways of organic matter oxidation are included (see Eqs. 3 - 7 in Table A2). Secondary redox reactions and FeS precipitation (8-14 in Table A2) are also included. A fixed concentration was imposed at the upper boundary for all solutes, while a fixed flux was used for solids.

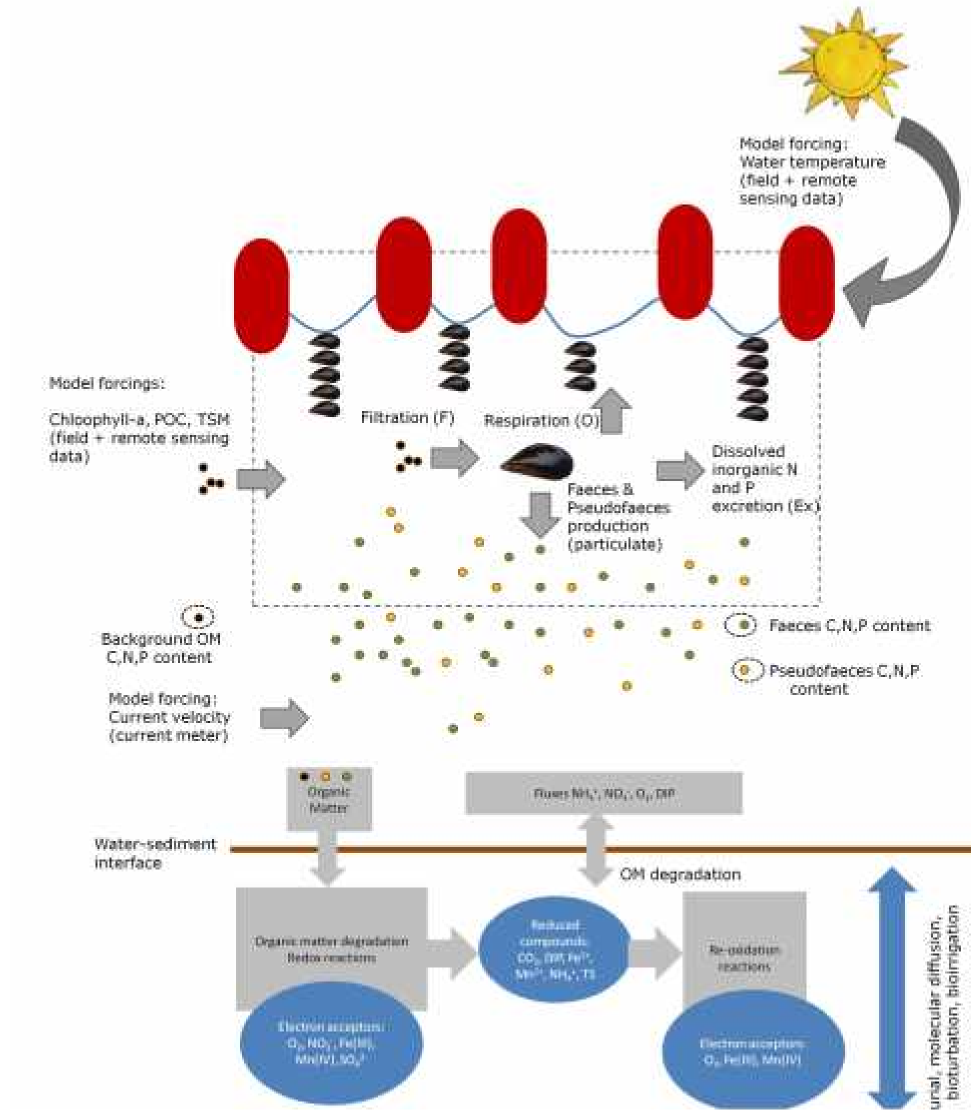

Figure 2: schematic representation of the model used in this work.

2.3 Sediment traps measurements

Two 48 hours sediment trap experiments were carried out as part of this study. The first experiment, T1, was performed between 29/08/2014 and 31/08/2014, at the end of the annual mussel rearing cycle. The second, T2, was carried out between 11/09/2015 and 13/09/2015, at the very beginning of the annual mussel rearing cycle. Three PVC sediment traps were deployed at each station: cylindrical shape; aspect ratio 5:1; collecting area of 0.0095 m^2 each (Cromey *et al*., 2002; Jusup *et al*., 2009). Sediment traps were deployed at 4 stations for T1 and 2 stations for T2. Two T1 stations st1 and st2 were located inside the modeled depositional footprint, and two outside st3 and st4. For T2, one station was located inside $st1_{T2}$ and one outside $st3_{T2}$. Stations are marked in Figure 1. Upon collection traps content was filtered through Whatmann GF/F pre-weighted filters. Filters were dried at 60 ◦C for 24 h and re-weighted. Organic carbon was determined using a flash - EA 1112 series thermo - Electron Corporation CHN analyzer, after acidification with HCl.

2.4 Sediment coring, microelectode measurements and pore-water analyses

Sediment were sampled at stations $st1_{T2}$ and $st3_{T2}$ in June 2015 (respectively on 23/06 and 24/06). Cores were collected by means of an Uwitech corer (10 cm diameter; 20 cm avg. penetration depth). Water was sampled 2 m above the bottom by means of a Niskin bottle, for dissolved oxygen, salinity and temperature determinations. After retrieval, cores were immediately brought to the laboratory and prepared for microprofiling which was conducted a few hours after coring. Cores were bubbled with air during measurements to allow aeration and gentle stirring. Overlying water was continuously homogenised with a rotating floating magnet fixed to the upper cap (Cowan and Boynton, 1996). The core was linked by tubing to an inflatable reserve tank filled with bottom-water. Plastic syringes were used to sample reserve tank and overlying water, and the volume removed in the core tube was replaced with bottom-water from the reserve tank. Microprofiling was conducted with a Unisense motorized microprofiler. Seven oxygen microprofiles were performed using 100 µm tip microsensors which were calibrated by a two-points method: winckler titration of the overlying water and zero-oxygen signal in the anoxic layer below the oxic zone.

Pore-water was analysed for ammonium (NH_4^+) (Helder, 1989a) and sulfate (Tabatabai, 1974). Ammonium was measured using a colorimetric method (Stainton *et al*., 1977) with a Bran + Luebbe™ auto-analyser Continuous Flow Analysis, according to the methods of Treguer and Le Corre, (1975). The detection limts is 0.55 µM. The $SO4_2^-$ dosage was measured by preparing the pore water samples in each stratum of carrot by making a dilution of 1/100 in distilled water to obtain a final volume of 10 mL. The samples were placed in tubes going high performance liquid chromatography (HPLC).

Total inorganic carbon (DIC) was measured using a flow injection-conductivity detection system as described in Aller and Aller, (1992).

2.5 Simulations set up, uncertainty analysis and EDM calibration

According to the rearing cycle characteristics, described in section 2.1, in model simulations shellfish are stocked in at the end of September, and harvested after 11 months, during August. In accordance with the objectives of this work, two types of simulations were carried out:

1) a nominal run, considering one rearing cycle, and aimed at assessing the variability in mussel deposition during the year;
2) a cluster of 10 runs, considering each one a rearing cycle under a different scenario of forcings.

The nominal run considered the average values of forcings: CHL-a and SST (EMIS data http://emis.jrc.ec.europa.eu/) (2003-2012 time series).

The cluster of 10 runs considered monthly time series of Sea Surface Temperature (SST) and concentration of Chlorophyll-a, extracted from the EMIS (http://emis.jrc.ec.europa.eu/) data base from July 2002 to December 2012 (longmin 12.5; longmax 12.6; latmin 45.4; latmax 45.5) by means of the R package EMISR v0.1 (R version 3.0.3). Chlorophyll-a and SST data were derived from the sensor Modis (Moderate Resolution Imaging Spectroradiometer) Aqua and Terra respectively, with a spatial resolution of 4km. These data were used as inputs for individual-based population dynamics model.

The steady state situation st1, data were reproduced by using the same parameterization adopted for the North Western Adriatic shelf by Brigolin *et al.*, (2011), and fitting bioirrigation parameters to the values of 10 y-1 and 5 cm depth.

The model was coded in Fortran. The ordinary differential equations were integrated numerically by means of a 4thorder Runge-Kutta scheme (Press *et al.*, 1987). The Lagrangian equation for the deposition model was solved following Jusup *et al.*, (2007).

Model runs were performed on SCSCF (www.dais.unive.it/scscf), a multiprocessor cluster system owned by Ca'Foscari University of Venice running under GNU/Linux.

3. Results

3.1 Deposition extent and seasonal variability: model simulation and sediment trap measurements

Figure 3 shows the map of the model predicted fluxes of organic C reaching the sediment at days 1, 120, 240 and 360. Organic carbon fluxes of 0.02 and 0.07 g C m^{-2} d^{-1}, are predicted, respectively, at day 10 (September 10) and 360 (August 26). Footprint induced by the presence of the lines is only visible at days 120 and 360. At day 240, a remarkable displacement of deposition towards SW (approximately 200 m) was detected. In the other cases (Figs. 3A,3B,3D), the maximum footprint distance from the lines is of 50 m.

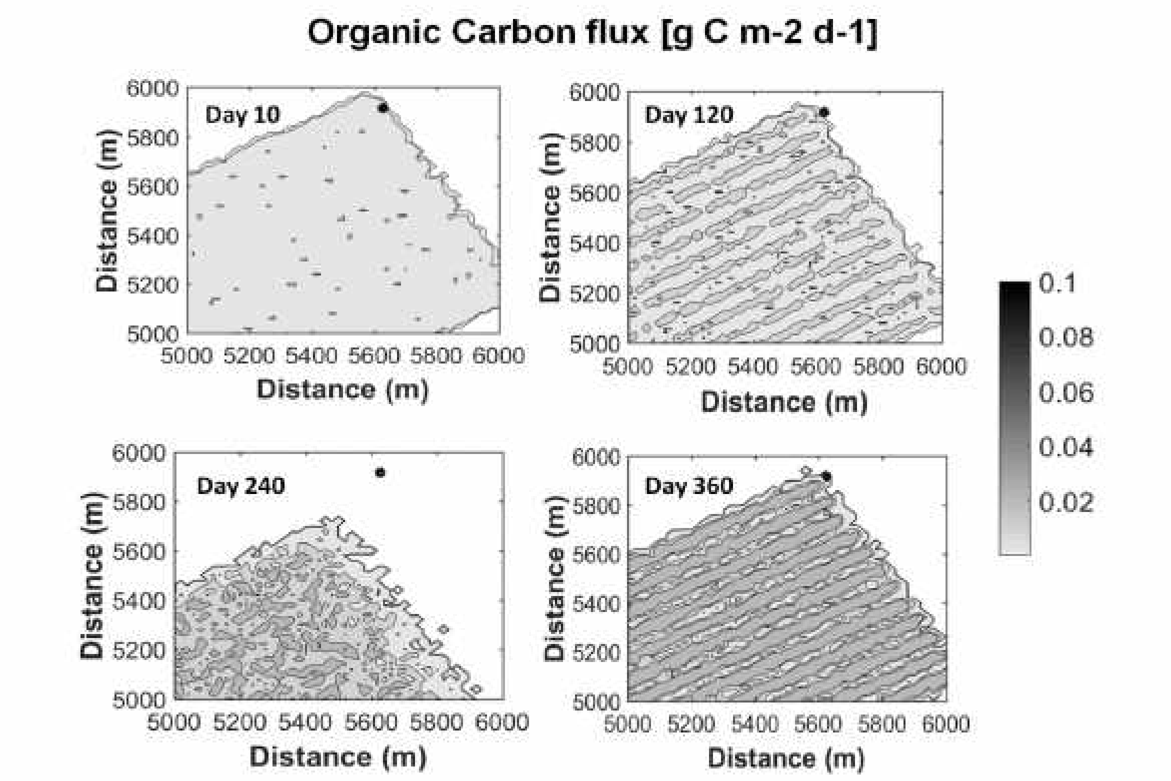

Figure 3: model predicted fluxes of organic C reaching the sediment at days 10 (A), 120 (B), 240 (C) and 360 (D).

TSS, OC%, and POC fluxes measured in August 2014 and September 2015 are reported in Table 1. TSS flux mean value is higher at st1 and st2, with respect to st3 and st4 reference stations, which values were not significantly different (Mann–Whitney one-tailed; n1=n2=6; p=0.01). Differently, in September 2015, higher solid fluxes were observed in st3T2 with respect to st1T2, but also here, no significant different was detect (Mann–Whitney one-tailed; n1=n2=3; p=0.1). As far as POC fluxes is concerned, in August 2014 st1 and st2 report higher values with respect to st3 and st4 (Mann–Whitney one-tailed; n1=n2=6; p=0.03), while differences among st1T2 and st3T2 detected in September 2015 were on the order of 0.04 g C m-2 d-1, and not significant (Mann–Whitney two-tailed; n1=n2=3; p>0.5). This value can be compared with model predicted differences of 0.02 g C m-2 d-1, at the beginning of the cycle.

Table 1: downward fluxes measured by sediment traps at the mussel farm in August 2014 and September 2015.

	Total mass flux [g m^{-2} d^{-1}]		**C. org [%]**		**Organic Carbon flux [g C m^{-2} d^{-1}]**	
Experiment	T1 Aug. 2014	T2 Sept. 2015	T1 Aug. 2014	T2 Sept. 2015	T1 Aug. 2014	T2 Sept. 2015
st1	6.51 ± 1.56	5.66 ±0.62	0.61±0.12	0.59±0.02	0.041±0.016	0.033±0.005
st3	4.59 ± 0.55	6.89 ±1.42	0.51±0.07	0.42±0.03	0.024±0.006	0.029±0.006
st2	5.92 ± 1.57		0.63±0.12		0.039±0.017	
st4	4.55 ± 0.69		0.55±0.07		0.025±0.006	

3.2 Diagenesis processes underneath the farm and at reference station

Bottom water temperature and salinity were respectively of 22 °C and 35.8 psu at both stations. Oxygen in bottom waters, measured through Winkler titration, was of 223.5 µM at $st3_{T2}$ and 229.8 µM at $st1_{T2}$. Sediment was classified as 'sandy mud' with a percentage of sand and mud respectively, included between 7.7-16% and 84-92.3 (data not shown).

Porosity profiles (Figure 4A) show a decreasing trend going downcore, with a steep gradient in the upper 2 cm. A discontinuity is visible in $st1_{T2}$ core, between 4 and 5 cm.

A total of 7 oxygen profiles were gathered at the two stations (Figure 4B). Oxygen shows a quasi-monotone decrease in concentration. A slight increase at interface (~ 20 µM), most probably due to microphytobenthic production, is visible at $st3_{T2}$, profile 3 (bubbles were visible on the core surface after long term exposure to light). Indeed, results obtained at the two stations suggested a low variability in the oxygen behavior - profiles were measured by sampling randomly the available portion of the core in which no shell debris and macrobenthos were visible at the surface. Oxygen is consumed by benthic respiration within the first mm, showing a higher penetration depth at $st3_{T2}$ (2.3 mm) with respect to $st1_{T2}$ (1.4 mm).

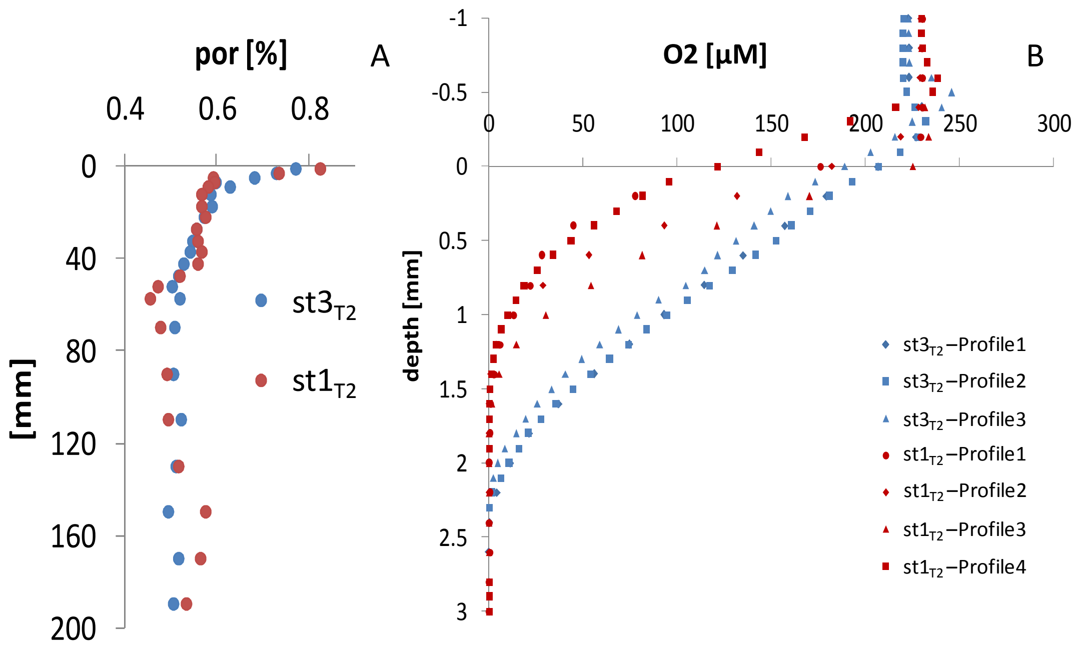

Figure 4: measured micro-profiles at two stations: a) sediment porosity [%]; b) dissolved oxygen [µM].

NH4, DIC, and SO4 data are shown in Figures 5 (A, B and C respectively). DIC concentration profiles at the two stations are comparables, although at depths >10 cm they stabilize at values around 3.6 mM at $st3_{T2}$ and 2.8 mM at $st1_{T2}$. A similar pattern is visible for ammonia, which average concentration below 10 cm depth reaches values of 50 µM at $st1_{T2}$ and 125 µM at $st3_{T2}$. The effect of bioirrigation is visible below the 10 cm, and, in particularly marked in the upper 5 cm, at $st1_{T2}$, where DIC present a decrease in concentrations between 0 and 2 cm depth (2487 vs 2485 µM). Sulfate reduction was observable, but limited, at both stations, and a local increase in sulfate between 6 and 10 cm depth, most probably linked to a bioirrigation effect, is visible at $st1_{T2}$.

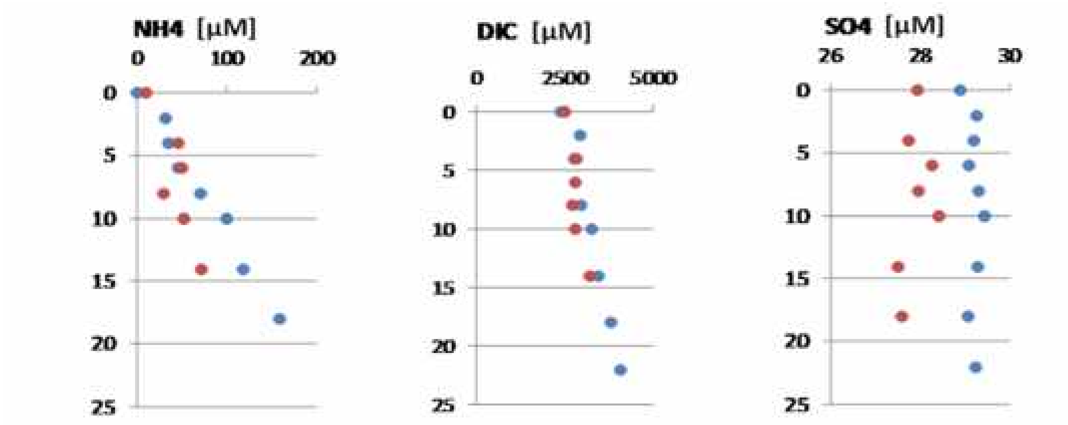

Figure 5: NH4, DIC, and SO4 concentration profiles at the two stations (red: $st1_{T2}$; blue: $st3_{T2}$)

Model predicted profiles (EDM) calibration are given in figure 6, and compared with the measured O2, DIC, NH4 field data.

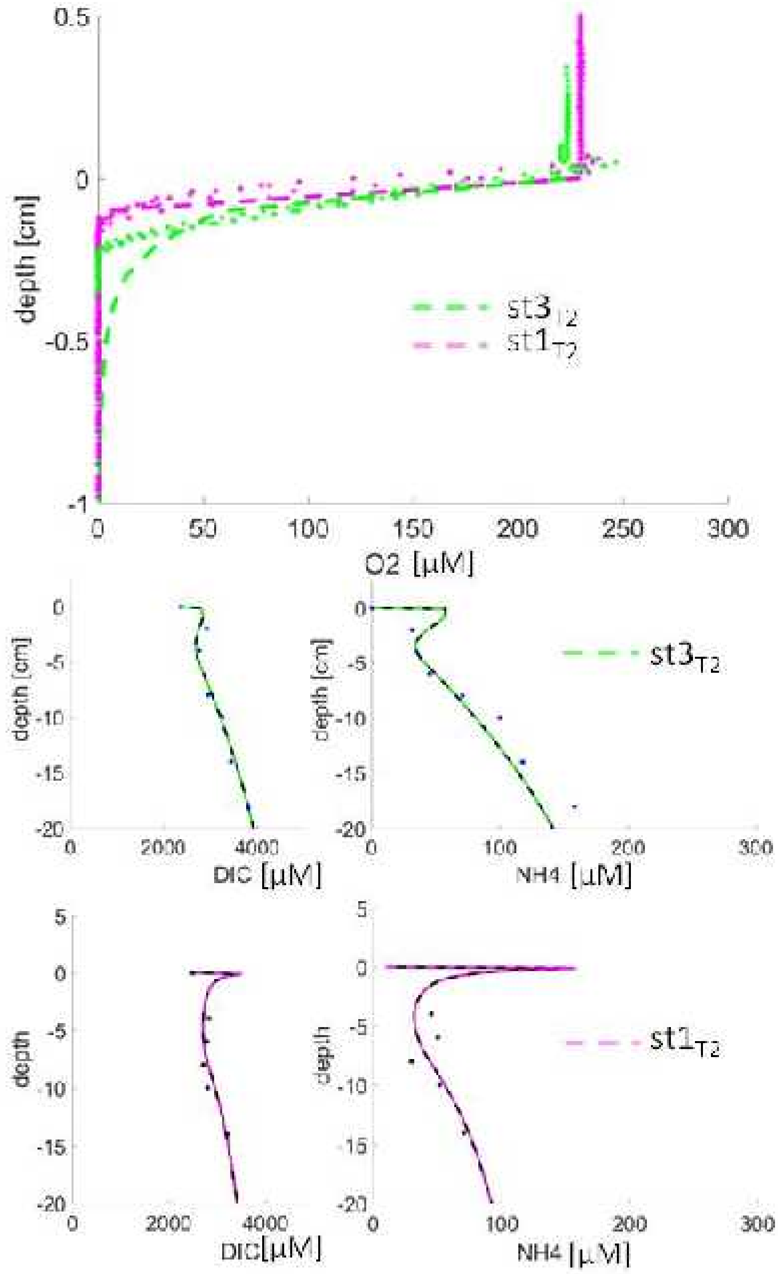

Figure 6: model predicted profiles (EDM) calibration compared with the measured O2, DIC, NH4 field data.

Parameters values used at the two stations are given in Table 2. A flux of 100 µmol C cm-2 y-1 and a 60% ratio of labile organic matter (OM1) on the total sedimented (OM1+OM2) was estimated through model calibration at st3. The ratio between OM1/(OM1+OM2) was estimated in 40% at st1, were an additional flux of highly degradable OM3 - 45 µmol C cm-2 y-1 estimated through the deposition model - was also present. DIC and NH4 profiles are both characterized by a concentration enhancement within the first cm, controlled by the degradation of the labile organic matter (OM1 and OM3), and subsequently modulated by the action of bioirrigation, which causes a local decrease going downcore. The depth distributions of bioturbation and bioirrigation coefficients were estimated independently at the two stations, obtaining values reported in figure 6, and indicating a higher macrofauna activity at st1.

Model predicts fluxes of 10 and 18 mmol O2 m-2 d-1, respectively at $st3_{T2}$ and $st1_{T2}$ (Fig. 7).

Table 2: early Diagenesis Model (EDM): calibration results - model features at the two stations studied.

Station $st3_{T2}$	**Station $st1_{T2}$**
100 µmol C cm	100 µmol C cm-2 y-1
60% labile (1 y-1); 40% refr.(0.001 y-1)	40% labile (1 y-1); 60% refr. (0.001 y-1)
	Mussel biodeposits: 45 µmol C cm-2 y-1 (10 y-1)
Bioirr (20 y-1 interface; 5 depth)	Bioirr (10 y-1 interface; 8 depth)

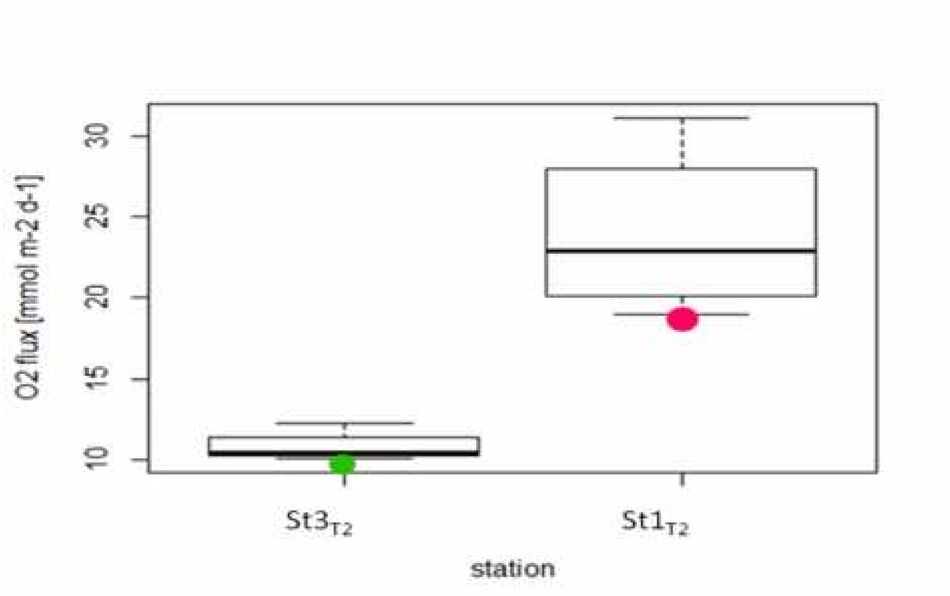

Figure 7: O_2 fluxes model predict at two stations.

4. Discussion

4.1 Characterization of the depositional footprint in presence of low gradients of OM rain

The integrated model allowed to simulate the extent of the deposition area, and its variability on time. Being integrated with a daily time step, the Mediterranean mussel population dynamic model allows to combine instantaneously the non-linear effects of the different environmental parameters (i.e. water temperature, chlorophyll-a concentration) acting on deposition, and integrate these effects along the time of the farming cycle. The combination of the bioenergetics based population model, which allows to estimate organic matter production from the lines, with the deposition model, which accounts for particles dispersion represents a novel aspect of the present work, with respect to previous modeling studies on mussel deposition. Hartstein and Stevens, (2005) modeling study applied a sensitivity approach to study organic deposition from *Perna canaliculus* New Zealand, comparing sites characterized by different hydrodynamic exposure, and assuming an arbitrary particle-release rate. Weise *et al*., (2009) modeled mussel biodeposition at different sites in the eastern coast of Canada, imposing organic waste from the farm lines as a model input, on the basis of site-specific field measurements, and extrapolation from other sites. It is worth remarking here that this consitutes a resource in terms of transfearability, allowing to implement the model at different sites in which environmental variables are known, without the need of performing in situ estimations of biodeposis production.

The extent of the depositional area obtained in our study (on average 50m from the edge of the farm) was comparable with results obtained in previous studies. Weise *et al*., (2009) at the exposed site located in Cascapedia Bay (20 m depth; mean current velocity of 10 cm s^{-1}), constrained the area of higher organic enrichment within 90m from the edge of the farm. Dispersal area reported by Hatstein and Stevens, (2005) is smaller, extending with a radius of approximately 30-40 m from the farm (20-30 m depth; mean current velocity of 3.4-4.0 cm s^{-1}). These differences in the extent of the dispersal areas seem to be primary associated to the action of current and wave energy inducing resuspension of biodeposits accumulated on the seabed - Cromey *et al*., (2002) indicated that fish farm organic wastage are re-suspended at currents around 9 cm s-1. In our study, mean current velocity was of 5.44 cm s^{-1}, and, based on this values, the effect of current resuspension was not modeled. In order to work at more exposed sites, and obtain an accuate prediction, it would be relevant to account for resuspension processes.

The magnitude of OC fluxes predicted by the model were corroborated by the two particle tracking experiments. Background Total mass fluxes found in these experiments were comparable with data measured with sediment traps by Giani *et al.*, (2001), who reported fluxes of 5.8 g m-2 d-1 (TSS) at an off shore station located in the Northern Adriatic Sea. The same authors reported mean fluxes of approximately 30.0 g m^{-2} d^{-1} in prodelta areas of Po and Adige rivers, with high annual variability (range 0.08 - 240 g m^{-2} d^{-1}). Relatively low background values obtained in our study can be associated to the short duration of our deposition experiments, which were primarily aimed at studying mussel deposition. Also, river Sile is reported to have a lower annual discharge (1,7x10^9 m^3 y-1), compared to Adige and Brenta (respectively, 7.4x10^9 and 3.0x10^9 m^3 y-1), and to the relatively low value of the discharge rate in August and September (ARPAV, 2010). It is worth remarking that the limited discharge of Sile river poses a constraint on its action as a confounding factor in our analysis, marking a difference with previous experimental assessment of the farm impacts performed in this area (Rampazzo *et al.*, 2013). C. org content in sedimented material found in the area of study, 0.42-0.63%, is markedly lower with respect to the ranges reported by Giani *et al.*, (2001) in different locations of the Northern Adriatic, which were found to be in the range 1.05-21.81 %.

4.2 Mussel faming and benthic organic matter degradation

According to Filgueira *et al.*, (2015), processes of faeces and pseudofaeces remineralization should be accounted for in an ecosystem approach to aquaculture. However, as emerged from a recent review of reactive-transport early diagenesis models developed and applied during the last two decades (Paraska *et al.*, 2015), a full representation of these processes have largely been neglected in previous aquaculture-focused biogeochemical modelling studies. An exception is represented by the models by Dedieu *et al.*, (2007) and Brigolin *et al.*, (2009). Dedieu *et al.*, (2007) compared seasonal cycles of C, N and O inside and outside a shellfish farming area in a lagoon located in Southern France, by combining a steady state diagenetic model (Soetaert *et al.*, 1996) with a comprehensive set of experimental data. Model results shown that organic matter accumulation at the farming area enhanced the anaerobic metabolism. Oxygen microprofiles recorded by Dedieu *et al*., (2007) inside and outside the mussel farm presented differences which are comparables to those recorded in the present work, with a decrease of 50% in oxygen penetration depth, and an increase up to 3x of diffusive O2 fluxes (30 mmol O_2 m^{-2} d^{-1} versus 90 mmol O_2 m^{-2} d^{-1}). In Dedieu *et al*., (2007) this was accompanied by a remarkable enhancement in NH4+ and TOC concentrations, which was not visible in the field data reported in the present study. This can be related to: differences in the rate of biodeposit accumulation, in local macrobenthic activity, and in coupled nitrification-denitrification rates, or, most probably, to a combined effect of all these factors. Mean OC fluxes estimated by Dedieu *et al*., (2007) by calibrating the diagenesis model at the mussel farm site, were of 38.4, 108.0 and 108.0 mmol C m^{-2} d^{-1}, respectively in winter, spring and summer, with increases of 26.4, 53.4 and 52.4 mmol C m^{-2} d^{-1} with respect to the pristine station in the respective seasons. In our work, the background flux (OC flux at st3) was an order of magnitude lower, of 2.74 mmol C m^{-2} d^{-1} with an increase of 1.23 mmol C m^{-2} underneath the farm, at st1. The relative increase, with respect to the background flux, was of 45%, which is comparable to the 48-49% increase found by Dedieu *et al*., (2007) in spring and summer. Difference in absolute values of OC fluxes can be related to a higher mussel stocking density (production in the Thau lagoon is 2333 tons km^{-2} versus 1450 tons km^{-2} at the farm in Jesolo), lower depth (7m Thau lagoon, 14m Jesolo), and hydrodynamic regime (data not available) of the site. Also, it is worth remarking that an estimation by Dedieu *et al*., (2007) were obtained by means of an inverse application of the Soetaert *et al*., (1996) model, while estimations presented here are based on sediment traps data and on the mussel farm biogeochemical model.

Model estimates an area of 159000 m^2 (approx 8% of the farm lease) characterized by deposition fluxes > 0.015 g C m-2 d-1. Enhancement of O2 influx induced by the farm - with respect to a non-farmed area of the same dimension – ranges from 4.6 10^5 mol O2 y-1 (via EDM estimation) to 7.2 10^5 mol O2 y-1 (calculated from profiles).

Biodeposits affect the biogeochemistry in the sediment and at the sediment – water interface. NH4+ and DIC fluxes predicted by EDM confirming the experimental data indicate as under the farm the bioirrigation is enhanced respect to an external area. The almost double oxygen penetration between the two studied sites, suggest a more active benthic community under the farm, as also reported for BPc index in chapter one of the present thesys. The bioturbation index point out as, although no statistical differences were recorded, the two stations under the farm show the higher BPc mean levels, suggesting a higher reworking sediment activity by benthic fauna under the farm. So biorrigation according to bioturbation data suggest as also in presence of depositional fluxes derived from the mussel farm activity, the interface sediment-water under the farm is characterized by efficient fluxes, that are a fundamental prerequisite for any well functioning ecosystem.

Finally, the absence of substantial differences in the analyzed biogeochemical cycles between inside and outside the mussel farm, highlights as the influence of the mussel farm on bentho-pelagic coupling can be considered negligible. This would be related to the location of the mussel farm within the context of the river plum (Bruno et al., 2006), a high nutrient, energy and organic carbon environment.

5. Conclusion

A deposition and early diagenesis model has been developed and used in the context of a mussel farm located in the Northern Adriatic Sea associated with some experimental data. Both model outputs, organic carbon fluxes at the bottom and biogeochemistry fluxes, are marked corroborated by sediment traps and sediment cores data. Moreover EDM model show how under the farm no negative effects due to the farming carbon fluxes activity are observed in the interface water-sediment. On the basis of these results, here is shown that the model is able to evaluate the alteration of environmental conditions (nutrients, toxic compounds) as a result of mussel farming activities. We suggest its use in combination with classical geochemical measures (e.g.NH_4^+, DIC) but also together with alternative indicators, such as pore water oxygen and sulphide concentrations.

The absence of negative effects recorded in relation to the carbon fluxes produced by the mussle farming are in accordance with the objectives of the descriptor 6 of Marine Strategy Framework Directive, and could represents and interesting element to be considered to promote the sustainable development of the coastal zone, as reported by the ICZM approach.

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http://emis.jrc.ec.europa.eu/

www.dais.unive.it/scscf

Appendix

Table A1: parameters used in the deposition model.

Name	Description	Value	Units	Reference
dx, dy	Horizontal resolution	20	[m]	-
Dt	Time step	60	[s]	-
K_x, K_y	Horizontal eddy diffusivity coefficient	0.1	[m^2 s^{-1}]	Cromey et al. (2002), Jusup et al. (2007)
K_z	Vertical eddy diffusivity coefficient	0.001	[m^2 s^{-1}]	Cromey et al. (2002), Jusup et al. (2007)
w_f	Normal distribution of settling velocity of faeces	μ=1.0; σ=0.1	[cm s^{-1}]	Weise et al. (2009)
w_p	Normal distribution of settling velocity of pseudofaecs	μ=0.1; σ=0.01	[cm s^{-1}]	Weise et al. (2009)

Table A2: early diagenesic model equations. (Reaction network implemented in the EDM model. The network is a simplified version of the one proposed by van Cappellen and Wang (1996).
Reactions 1–5 implemented separately for each OM fraction.

Primary redox reactions
1. Oxic respiration $(CH_2O)_x(NH_3)_y(H_3PO_4)_z + xO_2 + (-y+2z)HCO_3^- \xrightarrow{R_1} (x-y+2z)CO_2 + yNH_4^+ + zDIP + (x+2y+2z)H_2O$
2. Denitrification $(CH_2O)_x(NH_3)_y(H_3PO_4)_z + \left(\frac{4x+3y}{5}\right)NO_3^- \xrightarrow{R_2} \left(\frac{2x+4y}{5}\right)N_2 + \left(\frac{x-3y+10z}{5}\right)CO_2 + \left(\frac{4x+3y-10z}{5}\right)HCO_3^- + zDIP + \left(\frac{3x+6y+10z}{5}\right)H_2O$
3. Mn(IV) reduction $(CH_2O)_x(NH_3)_y(H_3PO_4)_z + 2xMnO_2 + (3x+y-2z)CO_2 + (x+y-2z)H_2O \xrightarrow{R_3} 2xMn^{2+} + (4x+y-2z)HCO_3^- + yNH_4^+ + zDIP$
4. Fe(III)reduction $(CH_2O)_x(NH_3)_y(H_3PO_4)_z + 4xFe(OH)_3 + (7x+y-2z)CO_2 \xrightarrow{R_4} 4xFe^{2+} + (8x+y-2z)HCO_3^- + yNH_4^+ + zDIP + (3x-y+2z)H_2O$
5. Sulphate reduction $(CH_2O)_x(NH_3)_y(H_3PO_4)_z + \left(\frac{x}{2}\right)SO_4^{2-} + (y-2z)CO_2 + (y-2z)H_2O \xrightarrow{R_5} \frac{x}{2}TS + (x+y-2z)HCO_3^- + yNH_4^+ + zDIP$
Secondary redox reactions
6. Nitrification $NH_4^+ + 2O_2 + 2HCO_3^- \xrightarrow{R_6} NO_3^- + 2CO_2 + 3H_2O$
7. Mn^{2+} oxidation by O_2 $Mn^{2+} + \frac{1}{2}O_2 + 2HCO_3^- \xrightarrow{R_7} MnO_2 + 2CO_2 + H_2O$
8. Fe^{2+} oxidation by O_2 $Fe^{2+} + \frac{1}{4}O_2 + 2HCO_3^- + \frac{1}{2}H_2O \xrightarrow{R_8} Fe(OH)_3 + 2CO_2$
9. Fe^{2+} oxidation by MnO_2 $2Fe^{2+} + MnO_2 + 2HCO_3^- + 2H_2O \xrightarrow{R_9} 2Fe(OH)_3 + Mn^{2+} + 2CO_2$
10. Sulphide oxidation by O_2 $TS + 2O_2 + 2HCO_3^- \xrightarrow{R_{10}} SO_4^{2-} + 2CO_2 + 2H_2O$
11. Sulphide oxidation by MnO_2 $TS + 6CO_2 + 4MnO_2 + 2H_2O \xrightarrow{R_{11}} 4Mn^{2+} + SO_4^{2-} + 6HCO_3^-$
12. Sulphide oxidation by $Fe(OH)_3$ $TS + 14CO_2 + 8Fe(OH)_3 \xrightarrow{R_{12}} 8Fe^{2+} + SO_4^{2-} + 14HCO_3^- + 6H_2O$
13. FeS oxidation by O_2 $FeS + 2O_2 \xrightarrow{R_{13}} Fe^{2+} + SO_4^{2-}$
Mineral precipitation
14. FeS precipitation $Fe^{2+} + TS + 2HCO_3^- \xrightarrow{R_{14}} FeS + 2H^+ + CO_2$

Chapter 3

Passive Acoustic Monitoring as a tool for investigating the potential role of a mussel farms for fish aggregation in the Northern Adriatic Sea

Submitted on Fishery Research, manuscript number FISH7112

PICCIULIN M, COLLA S, FIORIN R, PRANOVI F, BOLGAN M, MALAVASI S. The soundscape of a mussel farm: Biophony and man-made noise levels. Proceedings of Meetings on Acoustics. In press.

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1. Introduction

Marine habitats characterised by a high level of structural complexity have been shown to support a higher number of species than unstructured areas do (Orth and Heck, 1980); in this context, the artificial reefs have been proved to provide additional foraging, breeding, resting and sheltered habitats to fish populations, thus increasing fish production (Dealteris *et al*., 2004). The Italian Northern Adriatic coast is mainly characterised by sandy-muddy habitats, with some sparse natural outcrops characterised by high biodiversity (locally named *tegnùe*) (Newton and Stefanon, 1982). In this kind of soft environment, 3d artificial structures, such as those built to protect the coast from erosion (e.g. break waters and submerged break waters), have been colonised by a typical Mediterranean rocky reefs biocenosys, resulting in a remarkable increase in both richness and abundance of local benthonic and fish fauna (Rismondo *et al*., 2008). However, the potential ecological role of mussel farms for fish aggregation has been largely overlooked to date along the Venetian littoral zone. Mussel farms can be described as three-dimensional structures which are off-limits to commercial fishing; as a result, they potentially represent important sheltering and reproductive areas for different fish species, especially if located in shallow, two-dimensional homogeneous environments, such as the Northern Adriatic basin (Šegvić-Bubić *et al*., 2011).

The present paper aims to investigate the function of a mussel farm as a potential aggregating and breeding area for a species typically associated with hard bottom, i.e. the brown meagre (*Sciaena umbra*, L.; fam. Sciaenidae). In order to achieve this goal, Passive Acoustic Monitoring (PAM) was used on a mussel farm located on the West coast of the Adriatic Sea (Italy). Passive Acoustic Monitoring (PAM) is a non-invasive and relatively cheap method involving the use of hydrophones to record all component of underwater soundscapes, including fish communicative sounds (Gannon and Gannon, 2009: Rountree *et al*., 2006). The use of PAM is particular convenient because it neglects the need for traditional methods for fish population assessment, such as trawling and netting, which are more invasive and time consuming; the presence of the brown meagre (*Sciaena umbra* L., 1758; fam. Sciaenidae), which is an elusive nocturnal fish species, can be monitored through PAM by mean of its vocalizations only. Previous studies have demonstrated that *S. umbra* sound production is a reliable indicator of the species presence and it can highlight diel, seasonal and spatial pattern of activities (Bonacito *et al*., 2002, Picciulin *et al*., 2013a). This species is of particular interest considering it is targeted by professional and recreational fishing (Grau *et al*., 2009) and, especially, since it is included in Annex 3 of the Protocol on Specially Protected Areas and Biological Diversity of the Mediterranean to the Barcelona Convention (1995). Thus, the specific objectives of the present study were: i) to investigate the potential role of a mussel farm as an aggregating area for brown meagre by mean of PAM and ii) to assess the habitat preference of this species, with particular focus on its breeding activity.

2. Materials and methods

2.1 The study species

Sciaena umbra is a small, vocal sciaenid occurring along most of the Mediterranean coast (Bonacito *et al*., 2001), whose reproductive season ranges from May to August (Grau *et al*., 2009). The species is a sedentary and gregarious fish, living mainly in shelters on rocky bottoms (Tortonese, 1975) and usually becoming more active nocturnally (Chauvet, 1991; Harmelin, 1991; Harmelin and Marinopoulos, 1993). Its vocalizations consist of short broadband pulses with a dominant frequency of ca. 270 Hz, mainly emitted at night-time from May to September (Picciulin *et al*. 2013a,b). Since this calling activity matches the species spawning season (Chauvet, 1991, Grau *et al*., 2009), sounds are likely produced for reproductive purposes, in agreement with what observed in other species of the same family (Ramcharitar *et al*., 2006).

2.2 The study area

The study area was an active mussel farm located on a soft bottom (ranging from 13 to 15 meters deep) in the North- Adriatic Sea (45° 27.075’N 12° 35.028’E), in front of the city of Jesolo (Italy) and at 1.5 nautical miles from the Sile River estuary (Fig.1). It is a typical, longline culture farm in which mussels are grown into tubular nets, hanging from a back-boned rope supported by large plastic floats. Twenty lines (2 km long) are present on the whole farm surface (about 2 km^2), equally distributed every ca. 40 m. The mussel farm’s bottom is characterised by the presence of dead and living mussels as well as by some hard substrates (2 m side concrete cubes and unstructured construction units).

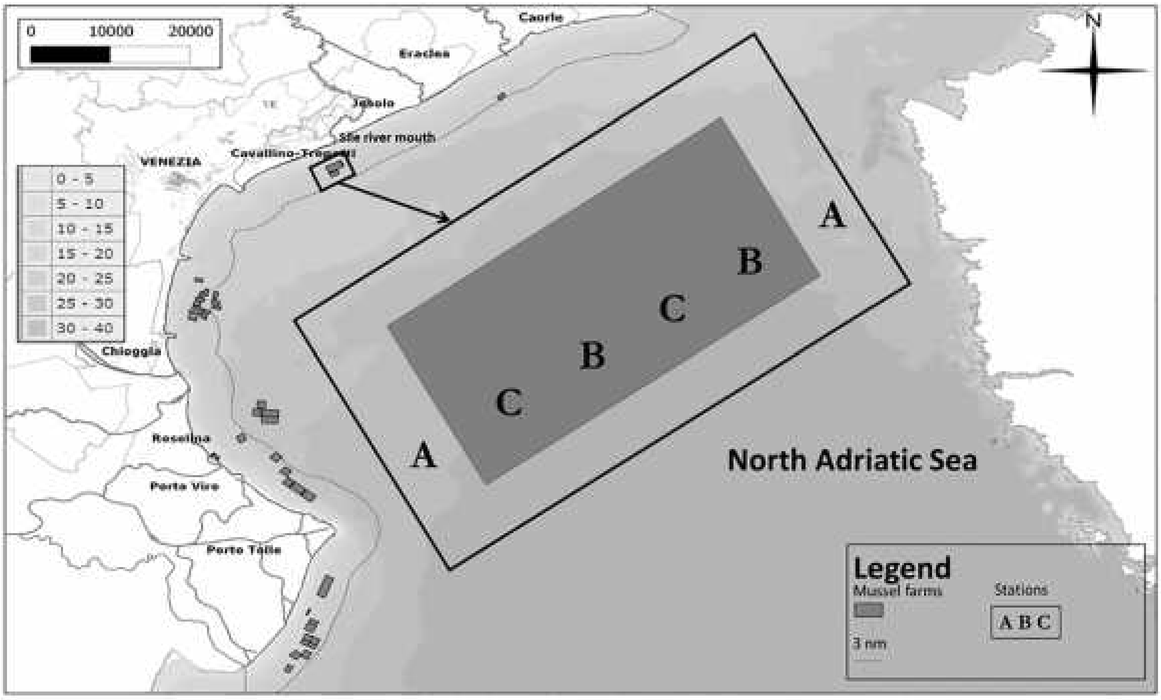

Figure 1: study site map.

2.3 The sampling design

PAM was carried out along a six stations transect, running parallel to the coastline (Fig.1). The six stations were distributed both outside and inside the mussel farm. Two stations (hereafter A stations) were located at 500 meters distance from the mussel farm's borders on a soft bottom. Among the four stations located inside the mussel farm, two were located directly over the artificial concrete structures (hereafter B stations) and two were located on soft bottom (hereafter C stations). B and C stations were at 500 meters distance from the each other.

By means of a boat, six station transect was always covered beginning from the north-eastern A station to south-western one and viceversa. In each station, multiple recordings, consisting of continuous recordings lasting about 10 minutes each, have been run. Due to technical reasons (mooring, recovery of the exact recording point), in each stations recordings were acquired within a range of 30 meters. All the recordings were obtained from about 6.30 p.m, until 11 p.m. in the evening for each sampling day, and within each month of sampling (June, July, August and September). This recording timeframe was selected in order to cover the brown meagre expected range of maximal vocal activity (see reference). Altogether, 42 recordings were used along the sampling transect from June to September (Tab. 1).

Table 1: Number of available minutes for the evaluation of the brown meagre pulse rate (after excluding those minutes saturated with boat noise) per station and per month.

Month	Station	N° of minutes	N° of recordings
June	A	30	3
June	B	49	6
June	C	21	2
July	A	30	3
July	B	48	5
July	C	23	3
August	A	20	2
August	B	45	6
August	C	35	4
September	A	20	2
September	B	40	4
September	C	10	2

2.4 Sound recording and analysis

Recordings were obtained using a pre-amplified Reson TC4032 hydrophone (sensitivity −170 dB re 1 V/Pa, frequency range 5 Hz–120 kHz) connected to a portable micro recorder (Zoom H1) generating WAV files. Prior to each survey, the signal was calibrated using a generator of pure waves of known voltage (100 mV rms @1 kHz). The hydrophone was lowered from a 8 m open boat to an average depth of 4 m. Bottom depth across the recording stations ranges from 13 to 15 m. Acoustic recordings were collected only with a sea state of less than 2 (Douglas scale), and with wind speed less than 12 km/h. Recordings were analysed using the Cool Edit Pro 2.0 software by audial and visual assessment of the spectrograms (sampling rate 44.1 kHz, 16 bit). After the first acoustic screening, the recording minutes characterised by intense anthropogenic noise, such as boat noise (which was common at many recordings, especially near sunset) were cut; recordings shorter than 2 minutes were not considered. Each 1-min so-obtained sample was subsequently classified into one of the three *S. umbra* vocal patterns reported by Picciulin *et al*., (2013b): irregular (I) vocal pattern, i.e. lacking a fixed repetition rate of the calls; regular (R) pattern, i.e. where calls were highly stereotyped in the sound intervals; and chorus (C), i.e. where the production of sounds is almost continuous. When no sounds were detectable, the file was defined as a 'no sound' sample. Finally, the percentage of recorded samples that contained I, R and C patterns was calculated.

In accord to Picciulin *et al*., (2013a) *S. umbra* sounds were also analysed quantitatively by scoring the number of pulses per minute, here defined as pulse rate (PR); subsequently the obtained pulse rates were scaled on a quantitative scale: 0 = no sound production, 1 = very few sounds (<30 pulses min^{-1}), 2 = some sounds (30–50 pulses min^{-1}), 3 = semi-continuous sound production (>50 pulses min^{-1}), 4 = continuous sound production (>100 pulses min^{-1}); 5 = chorus. As result each recorded minute has been associated to a value (hereafter called 'score') from 0 (no sound) to 5 (maximum pulse rate).

Two acoustical variables were therefore obtained: 1) the pulse number, that is the average number of pulses calculated on the total minutes of each recordings 2) the pulse rate, scored as explained, and averaged on the total minutes of each recordings.

Differences in pulse number and pulse rate scores across months and among the different stations were analized by mean of non parametric Kruskall Wallis Test, followed by a post-hoc Tukey HSD test, for significance between the groups. All statistical analysis were calculated using STATISTICA 9 software package.

2.5 Visual census

In order to validate the PAM survey, a *visual census* was carried out in June in order to evaluate the presence of the target species, i.e. *Sciaena umbra*, in the study area. The census was carried out by two scuba divers along two 50 meters orthogonal transects, centered on the system boat-hydrophone. Each transects were denoted by a graduated tape measure rolled out on the seafloor. Scuba divers went forward paired each transects counting fishes on either side of tape (Harmelin-Vivien *et al*., 1995). Due to visibility water conditions sampling days, only in June the UVC was performed.

3. Results

A total of 42 recordings (34 collected between June and August; 8 in September) were analysed. A statistically significant difference in the pulse rate (i.e. number of pulses *per* minute) was found when considering the first three months altogether (June, July and August) *vs.* September (Kruskal-Wallis Test, df = 3, Chi-square = 12,5, N= 42, P< 0.001; post-hoc Tukey HSD test September *vs.* all the other months P< 0.005). Indeed, *S. umbra* calls were mainly detected during June, July and August while in September the pulse rate was found to be very close to zero (i.e. almost absence of vocalisations) (Fig. 2).

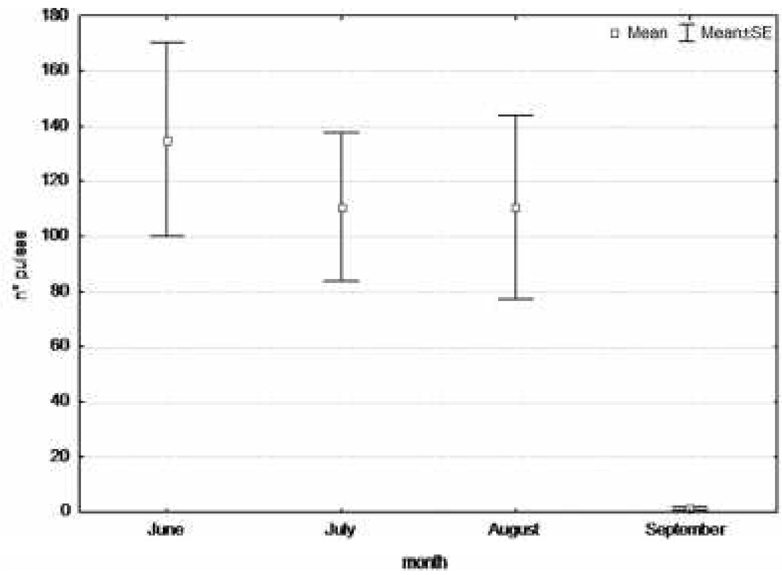

Figure 2: average number of pulses (mean ± SE) recorded *per* month, grouping all the sampling stations.

In particular, a minimum of 0 (in September) and a maximum of 250 pulses *per* minute were counted between June and August 2015 with an average of 120,46 (± 6.16 SE). Since the main aim of this paper was the spatial investigation of the presence of the brown meagre, the data of June, July and August were pooled together for subsequent spatial analysis. Once pooled altogether, the data indicated a spatial heterogeneity in the *S. umbra* pulse rate recorded inside and outside the mussel farm; a statistical significant difference in the pulse rate was indeed found among stations (Kruskal-Wallis Test, df = 3, Chi-square = 10,1, N= 42, P= 0.006). A further post-hoc Tukey HSD test indicated a significant difference between A and B stations (P= 0.01) and between A and C stations (P=0.011). Very few sounds were recorded outside the mussel farm (A stations, Fig. 3), while the highest pulse rate was found in stations located inside the mussel farm; furthermore, no statistically differences was found within the mussel farm stations between hard and soft bottom stations (B and C stations; Kruskal-Wallis Test, df = 3, Chi-square = 10,1, N= 42, P= 0.006; post-hoc Tukey HSD test B *vs.* C P = 0.9). The highest pulse rate was related to the occurrence of the chorus, i.e. nearly-continuous emission of calls, which was the most common *S. umbra* vocal pattern in both B and C stations.

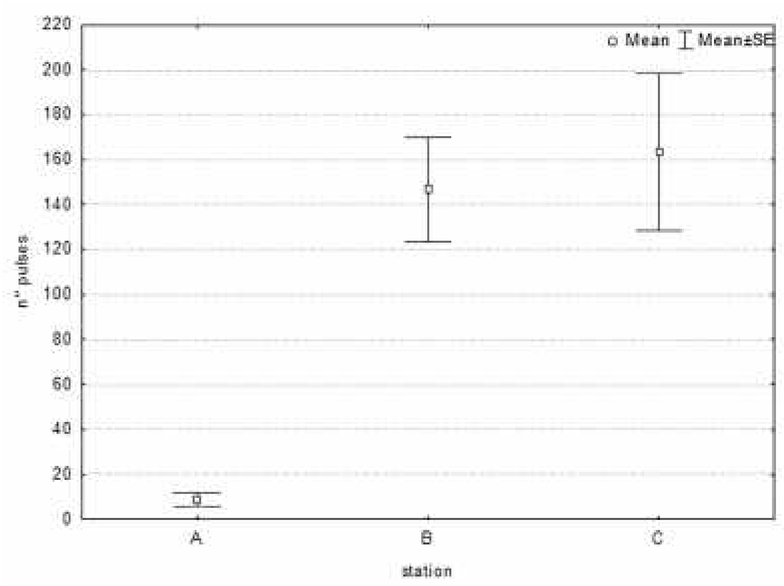

Figure 3: average number of pulses (mean ± SE) *per* station, grouping June-August data.

As shown in Fig. 4, the ‘irregular’ pattern, i.e. characterised by sounds randomly emitted, was almost the only one detected in the A stations outside the mussel farm, whereas both the regular and irregular vocal patterns of emission were recorded at the B and C stations.

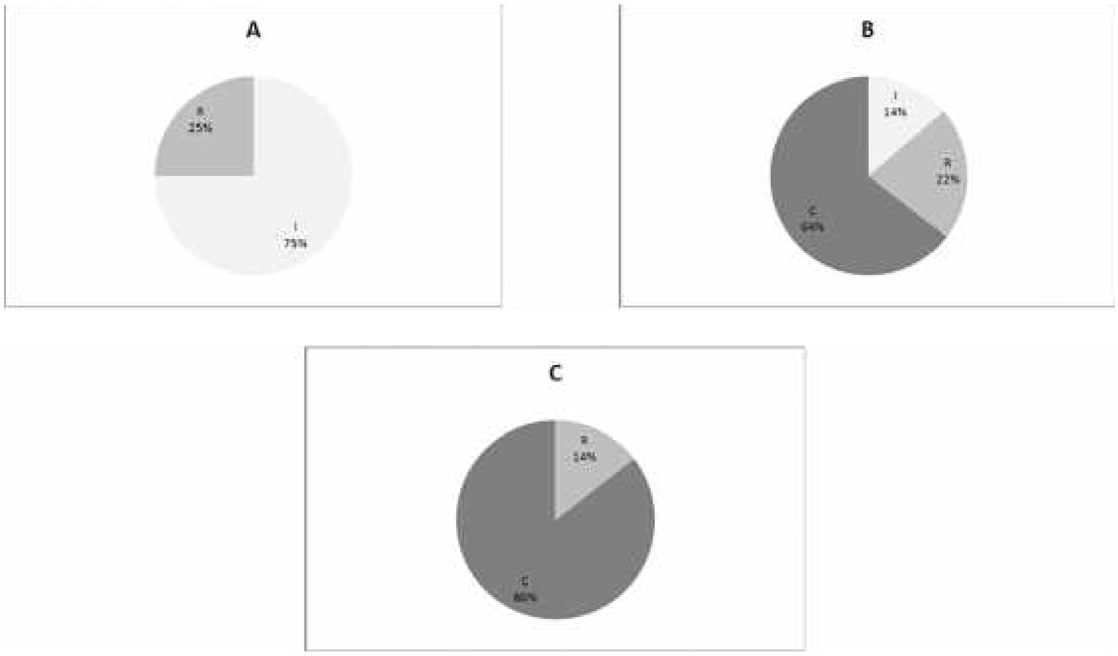

Figure 4: vocal patterns percentages (I: irregular; R: regular; C: chorus) *per* sampling station grouping June-August data.

A similar trend is evident when summarising the pulse rates by using a quantitative scale from 0 (no sound) to 5 (maximum pulse rate) (Fig. 5). Once considering the pulse rate scored as described above, a statistical significant difference between the A stations and the stations located inside the mussel farm was detected (Kruskal-Wallis Test, df = 3, Chi-square = 12,5, N= 42, P= 0.002; post-hoc Tukey HSD test A *vs.* the other stations P < 0.005).

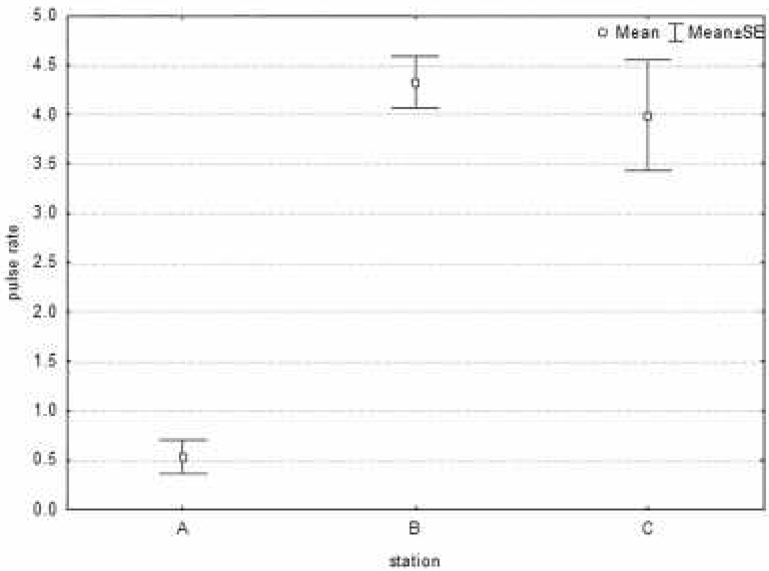

Figure 5: Mean ± SE pulse rate scale score (from 0 - no sound - to 5 - maximum pulse) *per* sampling station grouping June August data.

Visual inspection by scuba divers (*visual census*) confirmed the presence of *S. umbra* above the structures of the B stations.

4. Discussion

Mussel farms provide extensive, three-dimensional substrata (such as ropes, mussel socks, buoys, mooring posts) that are potentially suitable for both macrobenthos and nekton species which are typically associated with hard substrates (Morrisey *et al*., 2006). In comparison to other 3-dimensional artificial structures, first of all the presence of a great availability of mussels then and of other organisms colonising the mussel farm hard substrates, is potentially able to attract demersal fish, such as Sparids, and/or to trigger food chains reactions toward other pelagic species (Morissey *et al*., 2006; Powers *et al*., 2007; Segvic-Bubic *et al*., 2011). Despites of this, the potential of mussel farms to act as fish aggregating areas has been poorly investigated to date. In the present study, PAM was used to highlight the presence of a typical rocky bottom fish, i.e. the soniferous species brown meagre (*Sciaena umbra*, fam. Sciaenidae) inside a mussel farm, for the first time. Fronting the few available data on mussel farm fish fauna (Morrisey *et al*., 2006; Segvic-Bubic *et al*., 2011) with the data existing for our study area (Riccato *et al*., 2011), it is interesting to notice that only in the last mussel farm species attracted by tigmotropic effect and typical of hard bottom, as brown meagre, were found. In particular, this investigation highlights the presence of brown meagre individuals, likely reproductively active, inside the farm. It is therefore suggested that the concrete structures characterising the mussel farm bottom are able to attract *Sciaena umbra*, because they mimic the typical reproductive habitat of this species, i.e. rocky habitat with holes and shelters not far located from soft bottom feeding habitats (Chater *et al*., 2012; Fabi *et al*., 1998).

This PAM results are also of particular interest considering that *S. umbra* sound production appeared related to its reproductive season, according to what has been observed in other Scienids (Ramcharitar *et al*., 2006); indeed, a nearly absence of sounds was detected in September, i.e. when *S. umbra* is no longer in its reproductive season (Grau *et al*., 2009). As consequence, it is suggested that a mussel farm characterised by a seabed with both natural (live and dead mussels) and artificial (concrete materials) hard substrates, can attract fishes for feeding purposes and it can also rapresents an important habitat for their reproduction (Bohnsack, 1989). In another Sciaenidae species (i.e. the red drum *Sciaenops ocellatus*), a positive relationship was found between sounds features (i.e. calls duration and number of pulses) and the likelihood of spawning, as well as with the number of eggs released by the females (Montie *et al*., 2016). If this relationship would be confirmed also for *S. umbra*, the presence of the "chorus" detected inside the farm, regardless of the type of substrata, would confirm the ecological importance of the mussel farm. This is likely applicable to a wider range of fish species: a previous study showed the association of *S. umbra* to a well identified group of teleost species, where *S. umbra* acoustic behaviour was proposed as a biological indicator for a fish community typical of Mediterranean rocky habitats, including species of Labridae, Sparidae and Serranidae (Picciulin *et al*., 2013a). Altogether, this study suggests that the mussel farm can play an important role in terms of fish aggregation and reproduction, likely due to the presence of both natural and artificial materials and to the absence of fishery in the area. The mussel farm seems to act as a "B zone" of a typical Italian marine protected areas (MPA); i.e. an area prohibited to commercial fishery and spearfishing, but where amateur fishing is allowed (Dempster *et al*., 2006; William, 2005).

From a methodological point of view, the employment of PAM as here described represents a new way of monitoring fish aggregating areas. Traditionally, fish population assessment is carried out by mean of underwater visual census or by netting and trawling. All these methods, especially the first one, are affected by some biases so that, normally, it is suggested to couple them to obtain the best results (Cappo and Brown, 1996; Harmelin-Vivien *et al*., 1985; Harmelin-Vivien and Francour, 1992; Lowe and Bray, 2006; Samoilys, 1997; Watson *et al*., 2005; Willis *et al*., 2000). The latter methods are invasive, and therefore they are not suitable in the cases of rare or protected species. PAM can be considered as a relative cheap, easy (for what concern data acquisitions) and not destructive technique to be used also in absence of light or in condition of poor visibility (Rountree *et al*., 2006) Although PAM is applicable only to species that produce sounds in relation to their activities, further studies are required in order to identify the biological association of species and to further evaluate the possibility of using soniferous species as ecological indicators.

5. Conclusion

The mussel farm here investigated by mean of PAM appeared to act as a potential spawning area for the brown meagre. In the Veneto coastal waters 41 mussel farms, covering about 35-40 km^2, are present (Trevisiol, 2013). From the perspective of Integrated Coastal Zone Management, the present study suggests that sea-areas mussel farms may play an important ecological role in terms of fish aggregations and reproduction. This might result in i) restocking of overexploited species (in the cases of an area forbidden to the commercial fishing); (ii) help in balancing the legal fishing of species whose exploitation has to be regulated (RAC-SPA Barcelona Convention, 1995); (iii) provide to mussel farmers an alternative potential income by regulating the entry in their farm to recreational anglers. An area forbidden to commercial fishing and acting as a fish aggregating zone function as lure for recreational fishermen, that, upon payment, want to fish in a particularly teeming with fish area. Payment might represent a second income for the mussel farm owners, always in competition with national and European producers, for a resources that get very low selling prices.

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Chapter 4

Emergy analysis of a mussel farm (Mytilus galloprovincialis) in the Northern Adriatic Sea.

Manuscript in preparation

Congresso S.It.E Società italiana di Ecologia, 30 August-2 September 2016, Milano-Italia.1° Congresso Nazionale Congiunto SITE-UZI-SIB. 'Emergy analysis of shellfish production along the North-Western Adriatic coast'. Oral communication. Work in press on Congress abstract book.

1. Introduction

Italian marine aquaculture is characterized by ancient origin (Cataudella and Bronzi, 2001) rooted in Etruscan and Ancient Roman cultures (Cataudella *et al*., 2005). Modern aquaculture in Italy dates back to early 1980s and the sector both in term of production and of human employment increased since early 2000s. During the last decades the sector appear stable with only little annual fluctuations. In such a scenario, also the farming of Mediterranean mussel, *Mytilus galloprovincialis* has been well develop before in transitional waters as coastal lagoons and bays, and then, little by little, in the open sea, but without leaving at all the first environments. According to the more recent data, in 2013 shellfish represented 63% of Italian aquaculture production and with 64.235 tons harvested (72% of shellfish production), Mediterranean mussel is the most important species (FAO, 2016). By these quantities, at global level, Italy contribute with about 4% to total mussel production (Veneto Agricoltura, 2016). The mussel production in the last years has been modernized and nowadays all farms are based on long-line systems. In Italy production of mussel is typical of Emilia Romagna, Veneto, Sardinia and Apulia regions (Meloni *et al*., 2010). In Veneto (Northern East Italy) mussel farming is present both in on transitional waters (Venice lagoon and Po delta bays) and in open sea (Provincia di Venezia, 2014; Trevisiol, 2013), where it represents the main mariculture activity. Leased areas cover about 35 km^2 and produced about 35.000 tons and about 21 millions euro in values in 2013, representing more than 50% of the Italian production (Veneto Agricoltura, 2016). This activity involves directly about, 304 employees; both number of employees and income are increasing, compared with previous years according to the increasing in leased area. Most of the firms involved in mussel farming at open sea (67%), carry out also farming (mussel, oyster and carpet shell) in lagoon and the entire productive cycle of their products (farming and commercialization) (Veneto Agricoltura, 2016). For these reasons, mussel farm activities currently represent a very important economic asset for the local sea food production industry.

Shellfish aquaculture is perceived as a sustainable source of animal proteins, able to provide important ingredients in the Mediterranean diet and to guarantee internal demand of seafood.

Longline mussel culture farms, may be assimilated to an extensive culture type, that does not require the addition of artificial feed (Dumbauld *et al*., 2009) and antibiotics: therefore, it is generally regarded as more sustainable than fish farming (Fabi *et al*., 2009; McKindsey *et al*., 2012). Mussel culture, however, is not free from impact and globally there is a steady growing literature in the field (Fabi *et al*., 2009, Ysebaert *et al*., 2009, McKindsey *et al*., 2011, Wong and O'Shea, 2011, Wilding and Nickell, 2013, Neofitou *et al*., 2014). The principal worldwide environmental impact detected is the production of large amounts of biodeposits (faeces and pseudofaeces). Even if mussel discharge products are not always detected being a negative effect (Fabi *et al*., 2009; Wong and O'Shea, 2011; McKindsey *et al*., 2012; Wilding and Nickell, 2013; Neofitou *et al*., 2014), in same circumstances they can produce an enrichment in carbon at the bottom and changes in benthic community (Stenton-Dozey *et al*., 1999, Mirto *et al*., 2000, Chamberlain *et al*., 2001, Christensen *et al*., 2003, Ysebaert *et al*., 2009, Ivanov *et al*., 2013). The unclear on biodeposit impact is probably due to the different hydrological characteristics of the study areas (Longdil *et al*., 2008; McKindsey *et al*., 2011) or to some farm variables as the densities of the organisms on the ropes (McKindsey *et al*., 2006). Beside of local investigation, a wider analysis considering the impacts of mussel farming activity along all the Scottish coasts was performed by means of carbon footprint analysis (Fry, 2012). Results there reported, revealed as mussel cultivated in the UK produced 252 kg CO_2-eq per MT of mussel produced at farm gate and that, extrapolating the data across all Scottish mussel farmers, the total carbon footprint is 1,585,948 kg CO_2-eq (production of 2010). More than half of CO_2 is due to farm operations, i.e. electricity and fuel used in harvesting operations. Finally, environmental impacts made by mussel farm were also investigated by few authors by means of Life Cycle Assessment (LCA) (Iribarren *et al*., 2010a, b, c; Aubin and Fontaine, 2014). Considering LCA approach revealed as mussel, by filtering, carry out a potential mitigation effect in eutrophication environmental even if no influence was observed in C sequestration. Moreover, considering the productivity chain, from culture to different type of marketing, the more environmental impacts sub-sector of mussel productions were the cultivation and the dispatch-center; boats operations and the traditionally family-business structures were identified as the main causes, suggesting as fresh products have the least favourable environmental profile compared to smoked and frozen mussels.

In this context, mussel culture activity plays an important role in economic and social terms. On the other side, mussel culture has many interactions with the surrounding environment, depleting resources and producing change in the ecological system. So in order to define a general management strategy relevant at national scale for this fundamental sector of the Italian aquaculture, it is important to define the environmental sustainability of a farm, evaluating the quality of the internal resources and the contribution of the external ones that are involved in the system to maintain stability and the exportations out of the system. Sustainability is widely recognized as a paradigm upon which future policies must be based. However, a universally accepted definition for sustainability still has not been established (Khazzari *et al*., 2014). In this contest It is critical to employ methodologies that properly account for all energy flows of a system including those from economic sectors and natural flows. In order to merge ecological, economic and social components trying to define the sustainability of open sea longline mussel farming as fostered by FAO, according to Kharrazi *et al*., 2014, an emergy analysis of a mussel farm was performed. Emergy analysis (Odum, 1983) is a method of analysis able to consider both natural and economic systems and to compare their products. Emergy is defined as the amount of available energy of one type previously used up directly and indirectly to make a product or service (Odum, 1996), usually expressed as solar emjoules (sej). Emergy can be used to convert energy, material and monetary flows of all kinds to solar emjoules allowing direct comparison, addition and subtraction among them (Lan *et al*., 2002). Environmental sustainability can be evaluated quantitatively by comparing emergy inputs from the human economy to the renewable emergy supplied by the environment (Williamson *et al*., 2015). Emergy analysis has been already applied to marine systems (Bastianoni *et al*., 2002; Vassallo *et al*., 2007; Garcia *et al*., 2014; Williamson *et al*., 2015) but the present study represents the first application to a long line mussel farm.

In this study, we quantified the renewable and non-renewable emergy flows in a longline mussel farm (*Mytilus galloprovincialis*) located in North Adriatic. We determine the transformity of mussel, and we applied some indicator in order to quantify the sustainability of this human activities that insist in the study area and compare results with other farming system.

2. Materials and methods

2.1 Study area: long-line aquaculture site

The long line mussel farm here considered represent is located north of Venice, at 1.5 nm off-shore the city of Jesolo (Italy) near Sile river mouth (Fig.1). The equipment consists of 20, 2000-m-long, long-lines that are kept in place by big plastic buoys and anchors. On the long-line mussel tubular nets are suspended. The distance between each long-line is about 40 m, and the average distance between suspended mussel ropes is of 1 m. Tubular nets, which are approximately 4 m long, are placed at depth comprised between 2 and 4 m. Mussel farm has been carried out since 1990. At present the mussel farm counts 5 employees and it owns one vessel, used to collect and process the product on site. The mussels farm covers a total surface area of c.a. 2 km^2 and actually the production is about 600-800 tons per year (farmer personal communication). The average water depth at the farm is 14 m and the area is quite exposed to first and second quadrant winds (Bruno *et al.*, 2006). Due to the proximity to the coast, the predominant current is parallel to the coast from north-east to south-west.

2.1.1 Mussel production cycle

The mussels on-growing cycle lasts 10 to 12 months. Mussel seed takes place naturally in spring, and the harvesting period starts the following July and goes on until October. During the mussel growth period, tubular nets are changed three times in relation to the growth of mussels, consuming 1875 kg of nets each time (farmer personal communication). During the mussel production cycle, regular cleaning operations are carried on by workers in order to eliminate the possible fouling that can be formed on the tubular nets.

At the end of the production cycle, mussels are collected and processed on board of the vessel. Specimen are sorted according to their size by means of a mechanical device. Marketable specimen (ML>50 mm) are cleaned and packaged, since the farm is located in an area classified as 'zone A' in regard to shellfish culture and fishery, which means that mussels do not need to be treated at a depuration centre. All the mussel farm operations from the seed take to the packaging are machinery powered performed on board. The boat runs on gasoline and has a diesel fuel generator to run the machinery onboard.

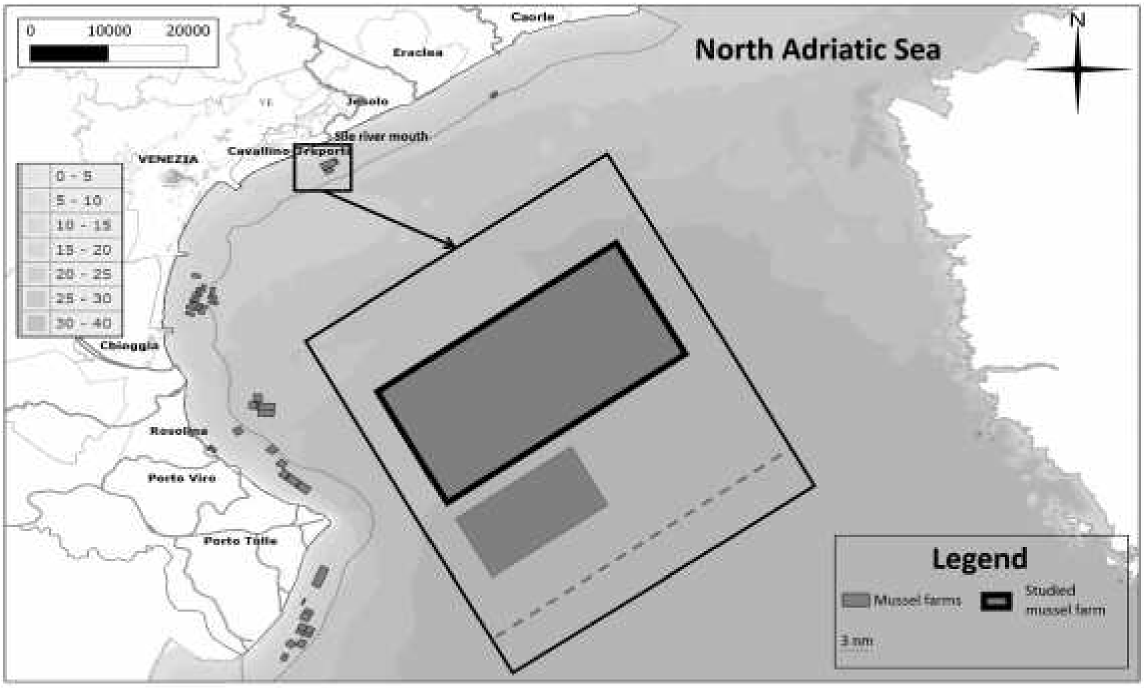

Figure 1: study area.

2.2 Emergy analysis

Emergy, is defined as the sum of the available energy of one kind previously required directly and indirectly through input pathways to make a product or service (Odum, 2000). Emergy analysis is a type of embodied energy analysis that allows one to take into account both environmental and economic inputs to a given production/process. The concept of emergy was introduced by Odum (1996) and the methodology for applying the emergy analisys is described in details in several papers: see, for example, Odum (1996) (Brown and Ulgiati, 2004; Ulgiati and Brown, 1998). The first steps consist in defining the system boundaries and inventorying the energy and matter flows: the results of this phase is a diagram, usually drawn using the symbols proposed by Odum (1996). The second step is the quantification of all energy, materials and monetary flows and their conversion into emergy flows, using the emergy algebra for combining them and avoiding double counting (Bastianoni *et al.*, 2009). As result, one can determine the emergy embodied in a given product, usually expressed as emergy per unity mass or unity energy: these ratios are also called transformities. From the emergy budget, one can also derive a set of indicators, which could provide useful insights on the sustainability of a product/process (Appendix 1). The indicators most frequently used are summarized in Table 1. In this way one can assess process's performance, quality of the product, environmental stress, short and long sustainability of production. From the emergy budget, a set of indicators, which could provide useful insights on the sustainability of a product/process, are originated (Tab. 1).

Transformity, "the emergy required to make one joule of a service or product" (Odum, 1996) is a reflection of the relative efficiency of system or process of energy transformation (Odum, 1996; Brown and Ulgiati, 2004).

Percent renewable (R%) of the total emergy inputs, is an indicator of system sustainability.

ELR is the ratio of the sum of non-renewable to the renewable emergy inputs to a process, and is important to the evaluation of environmental services. The ELR is an indicator of the potential stress that a process can have on its local environment (Williamson *et al.*, 2015). By this equation, a system that is able to maximize the use of local renewable emergy inputs has a lower ELR, while, a system that extract raw material for production, or that transform purchased inputs from the economy into new products, has a high ELR (Williamson *et al.*, 2015).

EYR is the ratio of total emergy output of a system divided by the non-renewable emergy (Williamson *et al.*, 2015). A system that use high free local environmental resources, has a high emergy yield ratio; a high EYR indicates a greater use of local renewable emergy and free non-renewable emergy for production, while a low EYR indicates a dependence on purchased imported emergy flow from the economy (Williamson *et al.*, 2015).

Table 1: emergy indices used in the present analysis; N: non-renewable resources, R: renewable resources, Y: total emergy and E: energy of the products.

INDICATOR	EXPRESSION	MEANING
Transformity (Tr)	Y/E	A measure of how much emergy is taken to generate one unit of output.
Renewability (%R)	100xR/Y	The percentage of renewable emergy used by the system.
Emergy Yield Ratio (EYR)	Y/N	An indicator of the production efficiency of a system or process to exploit local resources.
Environmental Loading Ratio (ELR)	N/R	A measure of the potential pressure on local environment due to human activity.

In order to understand the indicators more completely, we compared our results with other aquaculture products.

2.3 Data collection

Data concerning the matter and energy flows from the economic system were collected interviewing mussel farm owner about annual mussel farm production, fuel use, boats costs, human labour, the types and amounts of materials used in the activity system. The owner was very accommodating, showing us also the invoices regarding the costs of boat and system maintenance and the amount of tubular net bought.

All data were referred to the year 2014, in which the farm produced about 800 tonnes of market size mussel (ML> 50 mm). In order to estimate the flows of matter and energy, we assumed that mussels were harvested after 12 months.

The annual fuel consumed is about 16000 kg; the annual boasts maintenance costs is about 5000 € (antifouling, boat insurance policy, maintenance costs), the annual human labour is about 8520 hours (5 employees, 8 working hours per day, 213 days a year) and the annual mechanical (maintenance of the machine on boat board) and farm costs (maintenance costs of the long-line, floating buoys, anchors) are respectively 9000 and 10000 €.

Once established the boundaries of the system, which coincide with mussel farm area and the phases of the production process ranging from the arrival of the seed to mussel harvest and preparation for marketing, the flows of matter and energy that support the system are identified and described. Inputs were calculated as the annual flow of matter or energy per m2.

The environmental data were collected from reports of two public agencies (ARPAV and ISPRA) available on the web on the url: http\\www.arpa.veneto.it and http:\\www.isprambiente.gov.it. All data are referred to the year 2014. Data concerning solar radiation, wind and rain were acquired by means of a continuous acquiring data station placed on the coastline in front of mussel farm and then elaborated monthly and yearly by ARPAV personnel. Data regarding tide were acquired by means of a tide gauge placed in the sea at 8 nm in front on Venice Lido and about at 9 nm from the study site and then elaborated by ISPRA personnel in order to obtain the annual average tide. Data are not site-specific but they are referred to a wider area that include also mussel farm. Solar emergy is calculated from the incoming solar radiation of the mussel farm area minus 30%; rain is calculated from mean rainfall data; wind Energy is calculated considering average speed and drag coefficient due to wind on the sea surface; to evaluate tides emergy the generated kinetic energy from the variation of the sea level in the estimated area is considered (Tab.4). Mussels, as many other bivalves, feed on phytoplankton and also non-living Particulate Organic Matter, POM (Davenport and Woolmington, 1982; Lehane and Davenport, 2002). In accordance with Williamson et al., (2015) we assumed that mussel feed embodies emergy from sunlight and nutrients such as nitrogen and phosphorous: therefore, these flows were not estimated as separate emergy inputs, in order to avoid double counting. We estimated the flow of emergy related with mussel feeding using the individual model presented in (Brigolin et al., 2009). The model simulates the growth of an individual using as forcings time series of water temperature and concentration of Chlorophyll a, as a proxy of phytoplankton density and of Particulate Organic Matter. Time series of water temperature and concentration of Chlorophyll a data, are the same used in the present thesis, in the chapter 2 (Modeling mussel farm influence on sediment biogeochemistry). In coastal areas characterized by a high productivity, such as the Adriatic, phytoplankton represents the main energy input: therefore, we estimated its cumulative uptake from the water column throughout the farming cycle by integrating the daily amount cleared by a representative individual. Daily time series of water temperature and *Chlorophill a* concerning the years 2014 and 2015 at the study site were interpolated from monthly satellite data downloaded from Copernicus data base (http://marine.copernicus.eu/web/69-interactive-catalogue.php).

3. Results and discussion

The results of the emergy inventory are shown in figure 2 and tables 2 and 3. The diagram of emergy flows, shows the interfaces between local environment production and the human economy, the money circulation, and the pathways evaluated by emergy into, within and out of the mussel farm system (Fig. 2). The diagram shows that a mussel farm system takes resources by local renewable ones such as phytoplankton, wind, tide and rain and matches those with non-renewable inputs such as fuel, human labour and nets. Emergy inputs and the transformity per energy and mass unit of mussel are summarized in table 2. Emergy inputs were grouped in two categories: renewable and non-renewable resources. The first group includes five free inputs from the environment, namely: solar radiation, wind, rain, tides and phytoplankton. The second group includes external inputs from human management, that are classified as goods and services (e.g. fuels, nets, boats, etc...). Table 3 presents the emergy indicators estimated in this study, in comparison with those concerning other seafood from both extensive and intensive acquaculture.

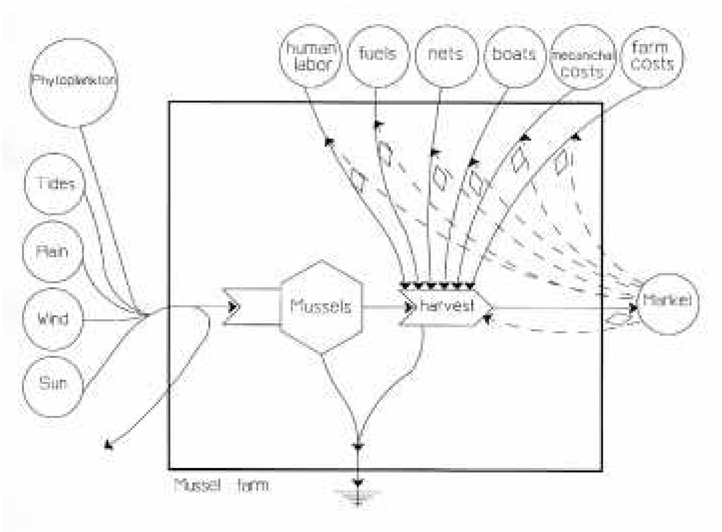

Figure 2: diagram of analyzed mussel farm.

Total renewable emergy input was calculated as the sum of rain, tides and phytoplankton inputs. This because solar radiation, wind and rain are considered co-products of the same process (the flow of solar energy to the Earth) and in order to avoid counting twice the same phenomena under different names, only the largest (rain) it has to be chosen (Odum, 1996; Vassallo *et al.*, 2007). Total non-renewable emergy input was calculated as the sum of all goods and services inputs. Nets input is reported in grams, while boat, equipments and farm maintenance costs are reported in monetary terms. As one can see from the table 2, the contributions of the renewable resources to the total emergy input is much higher than that concerning non-renewable ones. The transformity per energy and mass units of mussel are given in the last row of table 2. This values were obtained by assuming a total weight of 8 x 10^8 grams for market size mussels of 50 mm (Brigolin *et al.*, 2009) and a caloric content of 860 kcal per kg of edible mussels (https://ndb.nal.usda.gov/ndb/foods/show/4642?manu=&fgcd=).

Table 2: emergy inputs and transformity per energy and mass.

Inputs	Unit of measure	Flux (unit/m^2/year)	Solar transformity (sej/unit)	Emergy flow (sej/m^2/year)	Emergy folw (E+11 sej/m^2/year)
Renewable resources					
1. Sun	J	4.69E+09	1	4.69E+09	0.05
2. Wind	J	8.70E+03	2.45E+03[a]	2.13E+07	0.00
3. Rain	J	6.22E+06	1.54E+04[a]	9.59E+10	0.95
4. Tides	J	2.69E+06	1.68E+04[b]	4.54E+10	0.45
5. Phytoplankton	J	6.95E+06	8.10E+04[c]	5.63E+11	5.63
Non-renewable resources					
6. Goods and services					
6a. Human labour	J	1.86E+03	1.24E+06[b]	2.30E+09	0.02
6b. Fuel	J	3.34E+05	5.30E+04[b]	1.77E+10	0.18
6c. Nets	G	2.81E+00	5.85E+09[d]	1.65E+10	0.17
6d. Boats maintenance costs	€	2.50E-03	2.22E+12[e]	5.55E+09	0.06
6e.	€	4.50E-03	2.22E+12[e]	9.99E+09	0.10

Equipments maintenance costs					
6f. Annual farm costs	€	5.00E-03	2.22E+12[e]	1.11E+10	0.11
Renewable resources (sum3-5)					7.03
Non-renewable resources (sum 6a-6f)					0.61
Total emergy flow (sum 3-6)					7.64
Mussels	J	5.79E+05	1.32E+06	7.64E+11	7.64
	Kg	0.4	1.91E+12	7.64E+11	7.64

[a] Odum *et al*., (2000).

[b]Brown and Bardi, (2001).

[c] Brown *et al*., (2015).

[d] Brown and Buranakarn, (2003).

[e] Bastianoni, (2002).

The indicators presented in table 3 show that the renewable emergy inputs account for 92% of the total emergy embodied in farmed mussel: therefore, the contribution of the non-renewable emergy amounts to only 8%. The most important flows, is by far, related to the filtration of phytoplankton (73% of the total emergy inputs). Considering the renewable emergy inputs, phytoplankton shows the highest value (80% of the total renewable inputs). All other renewable inputs show percentages equal (rain) or less than 13%.

Fuel (28%) and nets (27%) are the largest contributions to non-renewable emergy. Being the mussel farm located 1.5 nm far from the coastline, the use of a boat is necessary for the maintenance of the farm, the harvesting operations and the packaging facility. In the same way, the consumption of tubular nets for the change operations during the mussel growth period and the packaging for the sale is high.

Emergy from human labour was the lowest (3%).

To estimate non-renewable resources, we based on farm owner data produced and personal communications. While regarding costs of boat, nets, equipment and farm, they were considered reliable on the basis of the invoice showed, it was possible that we don’t right estimate human labour and fuel consumption. For these latter two variables, instead, it was not possible to consult the mileage claim forms to know the exact amount of fuel consumed nor the mussel farm personnel attendance register to know the exact amount of working days. No literature in the field was find and so to estimate these variables we based only on farm owner personal communications.

In order to understand the indicators more completely, we compared our results with those about other aquaculture products (Tab.3).

The transformity provides a measure of the emergy efficiency of production (Brown and Ulgiati, 2004) allowing comparisons among systems, even if using different forms of energy. The transformity obtained for mussels (1.32E+06) show the same value of a *S. aurata* (seabream) (Vassallo *et al*., 2007) and similar to *O. niloticus* (tilapia) (Garcia *et al*., 2014) intensive farm; while it is lower than Raft and Cage Oysters (Williamson *et al*., 2015) (Tab.4).

Considering the emergy indicators, ELR showed that the mussel productions needs for the larger part renewable resources: in other words, renewable inputs are eleven times higher than non-renewable ones. A low ELR value, indeed a system that is able to maximize the use of local renewable emergy inputs. If compared this result with other similar production systems (Tab.4), only the seabream extensive farm showed similar value (Bastianoni, 2002), whereas for all the other production systems a higher ratio (higher dependence from non-renewable resources) has been recorded. Seabream extensive farm, indeed, depends mostly on renewable inputs as freshwater, earth cycle and rain; the highest not-renewable sources value, electricity, is about half of the third renewable ones (rain). On the contrary, the seabream intensive farm showed non-renewable inputs about one or two order of magnitude higher than renewable ones, being remarkably dependent on fingerlings supply and human labour (Vassallo *et al*., 2007). With reference to the oyster farming, on the other side, the production chain depends mainly on human labour (Williams *et al*., 2015). This is due to the fact that oyster farming systems are more complex than the mussel one; in the case of the oyster, the larvae must first grow in a land-based system to attain a certain shell size, then animals are deployed in the open water. In the case of mussels the seed settles directly at sea and does not require a breeding period in a dedicate nursery structures. Furthermore, employees in the floating raft oyster aquaculture, do not use machinery to sort, clean and package oysters but the work is done by hand.

The high EYR in the mussel farm indicates that the system produces much more emergy available to the economy than it consumes, i.e. the system denotes greater capacity to incorporate contributions from nature and lower dependence on not-renewable resources. This is true also for the other semi-natural and extensive system such as the seabream extensive farm in Venice lagoon (Bastianoni, 2002). Considering instead other production systems such as seabream intensive farm (Vassallo *et al*., 2007), oysters farm (Williamson *et al*., 2015) and especially tilapia cage aquaculture (Garcia *et al*., 2014), the low EYR (close to 1), indicates that the systems dissipate as much emergy as they make available to the economy. These data are also confirmed by the percent renewable (%R) values (Tab. 3). The mussel farm is characterized by the highest value among the considered. Both oyster cultures and intensive fish farm are characterized by values included in a range of about 1/3 and 1/5 lower than the mussel farm's one.

Table 3: emergy indicators comparison among different aquaculture.

Emergy indicators	Mussel farm	*S. aurata* fish (Vassallo et al., 2007)	*S. aurata* fish (Bastianoni, 2002)	Raft Oysters (Williamson et al., 2015)	Cage Oysters (Williamson et al., 2015)	*O. niloticus* fish (Garcia et al., 2014)
Transformity (sej/J)	1.32E+06	1.32E+06	2.45E+07	4.45E+06	13.12E+06	1.35 E+06
ELR	0.087	5.00	0.34	2.5	3.2	90.51
EYR	12.52	1.20	3.95	1.40	1.31	1.01
%R	92	16.69	73.89	28.7	23.8	1.09

4.Conclusions

The emergy application to the Northern Adriatic mussels farm revealed a system characterized by a large predominance of renewable inputs. This is related to the strong influence exerted by the phytoplankton production. On the contrary, the human influence, for farm management, appeared to be marginal. In comparison with other aquaculture products, such as oysters and fish, mussels showed a lower environmental impact and higher use of renewable sources of emergy; this is due to fact that mussel farm can be assimilated to an extensive farming, that doesn't require human labour for feeding and seed recruitment. The mussel farm, in fact, every year exploits the natural recruitment from wild mussel populations. The evaluation of indicators of environmental sustainability of the mussel farm and the comparison with other productive systems demostrated that the analyzed mussel farm exploits natural renewable resources for its maintenance and needs low quantity of non-renewable emergy contribution to perform its activity. Transformity of mussels resulted quite efficient and comparable or lower than similar products. According to Iribarren *et al*., (2010) and Fry, (2012), within the context of the mussel economic sector, the culture, together with the dispatch center sub-sector, present the largest contributions to the potential environmental impacts. Fuel, type and consumption, and capital goods (mainly boats, in terms of maintenance and utilization timing) are indicated as the main potential sources. The high dependence on renewable resources and the elevated emergy available to the economy produced by analyzed mussel farm system, clearly suggested that the mussel farming in Northern Adriatic Sea is by-now an energy-efficient system. Moreover, the present analysis indicates that the mussel production and processing, e.g. considering results obtained for the other sub-sectors for Spanish mussel farm, resulted to be an environmental sustainable sector. In order to complete the analysis about the sustainability of the entire process, a LCA analysis would be required, according to the method reported by Iribarren *et al*., (2010), applied both on a local and national scale, in order to understand the potential of this sector in Italy.

Table 4: equations and calculations involved in the emergy evaluation for this study.

Source	Calculation	Units	References
Mussel farm area	2.00E+06	m^2	
1.Sun Insolation Albedo Energy per year per unit area	 5.04E+09 0.93 (5.04E+09) x (0.93)= 4.69E+09	 $J/m^2/year$ $J/m^2/year$	ARPAV Database www.arpa.veneto.it
2. Wind Density of air	 1.3	 Kg/m^3	ARPAV Database www.arpa.veneto.it

Drag coefficient Wind velocity Time Energy per year per unit area	1.00E-03 1.728 3873600 (1.3) x (0.001) x (1.728) x (3873600)= 8701.65504	 m^3/s^3 s/year $J/m^2/year$	
3. Rain Rainfall Rain density Joule/kg Energy per year per unit area	 1.26 1000 4940 (1.26) x (1000) x (4940)= 6224400	 m/year kg/m^3 J/kg $J/m^2/year$	ARPAV Database www.arpa.veneto.it
4. Tide Average tide range Density Tides/years Gravity Energy per year per unit area	 0.366025 1030 730 9.8 (0.366025) x (1030) x (730) x (9.8)= 2697099.136	 m^2 kg/m^3 n./year m/s^2 $J/m^2/year$	ISPRA Database www.venezia.ispraambiente.it
5. Phytoplankton Annual number of mussels Individual fluxes of C, N and P associated with the metabolic activity of *Mytilus galloprovincialis* Energy per year per unit area	 44444444 312.6396 (44444444) x (312.6396)/2.00E+06= 6.95E+06	 KJ $J/m^2/year$	
6.a Human labor Man-hr Kcal consumed Joule/kcal Energy per year per unit area	 8520 2500 4186 (8520) x (2500/24) x (4186)/2.00E+06= 1.86E+03	 h/year kcal/day J/kcal $J/m^2/year$	
6.b Fuel Annual kg mass Kcal/kg J/Kcal Energy per year per	 15646.2585 10200 4186 (15646.2585) x	 Kg Kcal/kg J/kcal $J/m^2/year$	

unit area	(10200) x (4186)/ 2.00E+06=3.34E+05		
6.c Boats costs Annual boats coasts Energy per year per unit area	 5000 (5000)/ 2.00E+06= 2.50E-03	 € €/m^2/year	
6.d Nets Grams of nets per year Energy per year per unit area	 5625000 (5625000)/ 2.00E+06= 2.81E+00	 gr gr/m^2/year	
6.e Equipments costs costs of equipments Energy per year per unit area	 9000 9000/2.00E+06= 4.50E-03	 € €/m^2/year	
6.f Farm costs Annual farm costs Energy per year per unit area	 10000 10000/2.00E+06= 5.00E-03	 € €/m^2/year	
Renewable emergy	Sum of emergy inputs from item 3 to 5		
Non renewable emergy	Sum of item 6a-6f		
Total emergy flow	Sum of item 3-6f		
Mussel production Annual mussel production Energy content of 1 kg market sized mussel (wet weight) J/kcal Dry weight-wet weight conversion coefficient Dry weight-total weight conversion coefficient	 800000 860 4184 7.0	 kg/year Kcal/mussel J/kcal Kg	Taken from:http://ndb.nal.usda.gov/ndb/foods/show/4696?qlookup=15245&max=25&man=&lfacet=&new=1 Brigolin et al., 2009 Brigolin et al., 2009

Conversion from 1 kg wet mussel energy content to total weight	17.4	gr	Taken from: www.agraria.org/pesci
Number of mussel for 860 energy content	(1/7.0)x17.4=2485		
1 mussel total weight	2485/18=138	Kcal	
Energy content of 1 market size mussel	18 860/138=6.23	Kcal	
Energy content of total mussel produced in a year	6.23x44444444=276972624.8		
Mussel energy produced/unit area/year	(276972624.8)x(6.23)x(4184)/2.00E+06= 1.32E+06	$J/m^2/year$	
Embodied emergy per kg/m2 of product	800000:2000000=0.4 1.32E+06/0.4=1.91E+12	Kg of mussel/m^2	

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Appendix 1 – Emergy evaluation procedure: steps for evaluating a system with an emergy evaluation table.

Step	Description
A	Definition of the limits of the system and of the resources fluxes feeding it.
B	Draw an energy system diagram that helps convert verbal models to quantitative energy and mathematical systems languages.
C	Set up an emergy evaluation table with a line item for each input, product and sale.
D	Evaluate flows with common units (joules, grams, euro, etc.).
E	Converte each rate of flow into annual emergy flow by multiplication by transformities.
F	Sum the emergy inputs to evaluate the products.
G	For interpretation, calculate some emergy indices.

Chapter 5

The role of artisanal fishery in the Northern Adriatic coastal area

PRANOVI F, COLLA S, VALERI P, ANELLI MONTI M, 2016. Present and future status of artisanal fisheries in the Adriatic Sea (western Mediterranean Sea). DOI:10.1016/j.ocecoaman.2016.01.004. pp.49-56. In OCEAN & COASTAL MANAGEMENT - ISSN:0964-5691 vol. 122

46° Congresso della Società Italiana di Biologia Marina, Giugno 2015, Roma-Italia. 'Vulnerabilità della piccola pesca costiera del nord Adriatico ai cambiamenti climatici'. Poster. Short communication.
http://www.sibm.it/46%20SIBM/preprint%20Roma.pdf

47° Congresso della Società Italiana di Biologia Marina, 13-17 Giugno 2016, Torino-Italia. 'Pesca artigianale e gestione della fascia costiera: due tipologie di habitat a confronto'. Poster.
http://www.sibm.it/47%20SIBM/47%20Pre-print%20Torino.pdf

1. Introduction

Artisanal and small-scale fisheries are often equated (see FAO glossary), because they share common features, such as low capital investment, ownership by fishermen, and the exploitation of coastal fishing grounds located within a few hours' travel from the port (Colloca *et al*., 2004). Generally, artisanal activities can be characterized by the relative level of technology (or “artisanality”) and by whether they are multitarget and multigear, as seasonal changes in fishing techniques are implemented to maximize catches and, therefore, profitability (Farrugio *et al*., 1993, Battaglia *et al*., 2010 and Forcada *et al*., 2010). Despite these common features, artisanal fisheries tend to be highly heterogeneous in space, and strictly depend upon local environmental and socio-economic conditions (Stergiou *et al*., 2006 and Guyader *et al*., 2013). Typically, these activities are deeply rooted in coastal populations, and play crucial socio-economic roles in both developing and developed countries, including those along European coastal zones. These factors may be magnified in the Mediterranean basin, where the multispecificity of catches and dispersion of fleets across a high number of small ports are the main features of all of its fisheries. Such characteristics could represent major reasons why the artisanal fisheries in the Mediterranean Sea and Europe are generally not well characterized (Battaglia *et al*., 2010 and Guyader *et al*., 2013).

Small scale and artisanal fisheries are often attributed with the potential to contribute to food security, economic growth, the development of coastal areas, and the preservation of marine ecosystems (FAO, 2005 and Garcia *et al*., 2008). However, limited data are available at the regional level regarding production or the socio-economic and ecological implications, which substantially limit opportunities to produce a real assessment of such issues and generate effective management strategies.

Within this context, the Italian situation may represent an interesting case study. Since June 2010, the implementation of Council Regulation (EC) no. 1967/2006 introduced a ban of trawling activities within three nautical miles of the coast or within the 50 m isobaths where this was closer to the shoreline. As a consequence, artisanal fishing remained almost the only exploitative activity within the coastal area. For example, on the West coast of the Adriatic Sea within the three-mile area, artisanal fisheries and hydraulic dredging for striped venus clams (*Chamelea gallina*) are the only permitted activities (Pranovi *et al*., 2015). Nevertheless, very few studies have been carried out to characterize the possible ecological effects and management strategies that result from this regulation (Fabi, 2005 and De Mauro *et al*., 2007).

To begin to address this issue, this present study aims to assess the following criteria:

(1) the basic features of artisanal fisheries along the Venetian coast, in terms of fishing strategies and catches;

(2) the potential vulnerability of artisanal fisheries, also in relation to the potential effects of climate change; and

(3) the sustainability of exploitative activities, also considering the expected modifications of fishing effort and/or environmental features.

2. Materials and methods

2.1 Study area

The Northern Adriatic Sea includes all of the critical elements attributed to a 'typical' coastal area, such as the concentration of many economic activities and the presence of different types of anthropogenic pressures, including important fisheries, aquaculture activities (mussel farms), widely distributed seaside tourism, and extended seaport activities. Furthermore, the provision of many goods and services, including renewable resources, are particularly critical in the trade-off between ecological status and the impacts of exploitation. Additionally, this area is particularly exposed to the effects of climate change because of its local geographic features. Indeed, the zone has been described as an area where Mediterranean climatic conditions are replaced by boreal conditions, supporting the presence of 'glacial relicts' and representing a type of '*cul de sac*' for some species (Ben Rais Lasram *et al*., 2010 and Libralato *et al*., 2015).

The study area is located on the West coast of the Northern Adriatic Sea, between Caorle and Cavallino–Treporti (Fig. 1). It is a flat coastal area characterized by the presence of sandy beaches, transitional water systems (laguna di Caorle e laguna del Mort) and river mouths (Tagliamento and Sile), which results in high habitat diversity. Caorle and Jesolo represent the two most important ports in this area, and they are the home to the major fishing fleets of the region apart from Chioggia, which is the largest port in the entire basin.

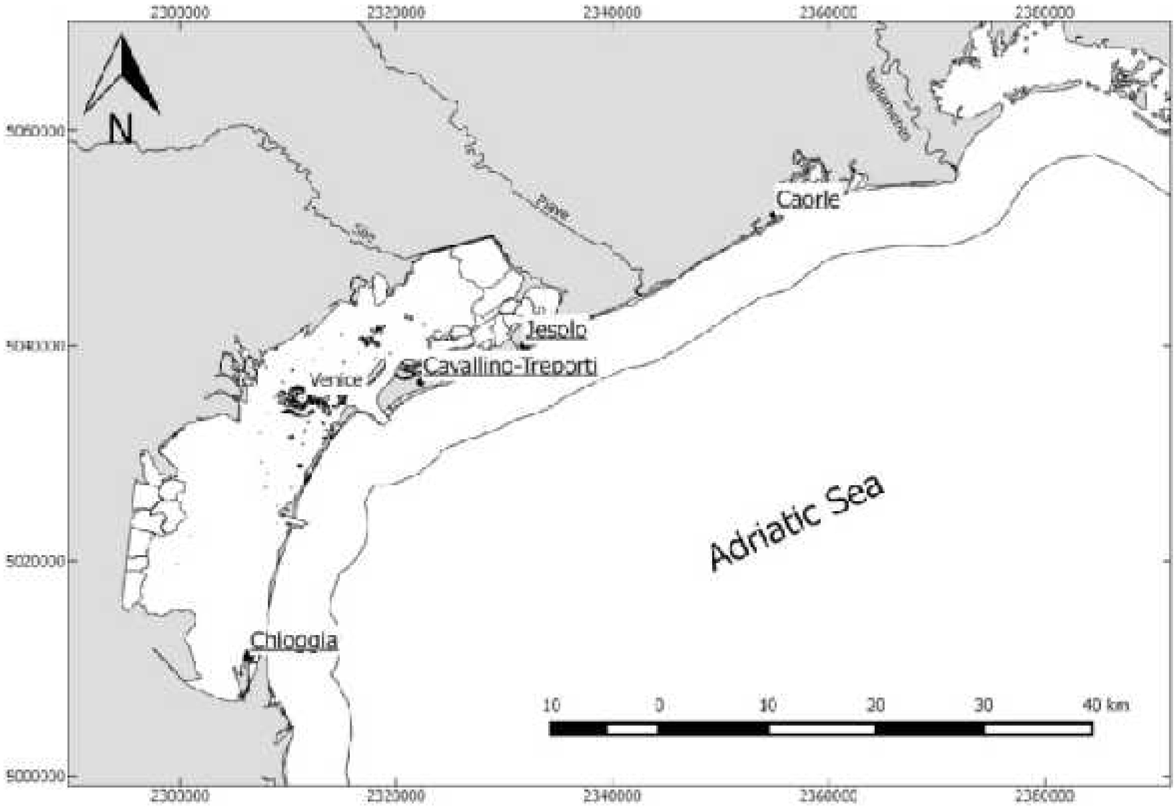

Figure 1: the study area, located on the West coast of the Northern Adriatic Sea; the solid line represents the three miles area; underlined the main fishing ports quoted in the text.

2.2 Fleet characteristics and sampling activities

This study was focused on two main fleets (Jesolo and Caorle) located along the northern part of the Venetian coast (Fig. 1). A preliminary description of these fleets was performed based on the EU Fleet Register (number of vessels and licences) and local fishermen's cooperatives (number of fishermen per vessel and days at sea). These data were subsequently validated by interviewing fishermen and performing direct observations at the quay.

Descriptions of catches, both in qualitative and quantitative terms, were performed by onboard observations that were carried out bi-monthly on four vessels (two per fleet) from January to December 2014. According to the sampling protocol, each individual organism that was caught was classified at the species level and weighed (grams of wet weight); in cases of uncertain classification, samples were collected and successively identified in the laboratory. All catches were divided into target species, by-catch, and discarded organisms (both commercial and non-commercial species). Data were integrated with weekly observations on the quay in which the same vessels were followed.

2.3 Data analysis

Based on the collected data, the catch per unit of effort (CPUE) for each gear and species was estimated in terms of biomass per day per vessel (kg v^{-1} d^{-1}). To assess the total catches per year at the fleet level, the following criteria were used: CPUE data, number of days at sea, and number of artisanal fisheries vessels in the area. For the number of days at sea, two different estimates were used: 150 days, which was based on the official statistical data from 2012, to 214 days, which was based on observations from 2014 carried out during this present study. The bootstrapping method was applied to estimate the 95% confidence interval (Shao, 1996 and Lehtonen, 2004). According to the procedure, CPUE samples were randomly drawn from the database, repeating the process for 1000 times. Once built, the new dataset (composed by all targeted species) was used to estimate the confidence interval ($\alpha = 0.05$).

To investigate the sustainability of artisanal fisheries and their associated ecological effects, the Primary Production Required (PPR) to sustain the fishery (Pauly and Christensen, 1995) and L-index (Libralato *et al.*, 2008) were estimated.

The PPR enabled the quantification of fishing pressures on the ecosystem, as it calculated the amount of energy exported from the system by landings. It is usually standardized as a percentage of the annual Primary Production of the area, and can be calculated as follows,

$$PPR = \sum_{i=1}^{n} \frac{L_i}{CR} \left(\frac{1}{TE}\right)^{(TL_i - 1)}$$

with L_i = landing of *i*-species; CR = conversion rate of wet weight-to-carbon (fixed at 1:9, according to Pauly and Christensen, 1995); TE = transfer efficiency (fixed at 10.5%, according to Libralato *et al.*, 2015); TL = trophic level of *i*-species (assigned according to Pranovi *et al.*, 2014).

Primary production for the NAS was estimated by using monthly chlorophyll-a data derived from the MODIS satellite (http://neo.sci.gsfc.nasa.gov/), according to Behrenfeld and Falkowski, (1997).

The L-index is a synthetic index that takes into account both ecosystem properties (primary production and transfer efficiency) and features of fishing activities (trophic levels of catches and PPR). This index allows for estimates about how the effects of energy extracted from the system by exploitative activities can be propagated through the trophic chain.

The L-index is defined as,

$$Lindex = \frac{PPR\,TE^{TL_c-1}}{PP\ln(TE)}$$

where PPR = Primary Production Required (see above); TE = transfer efficiency (fixed at 10.5%, according to Libralato *et al.*, 2015) TLc = the mean trophic level of catches; PP = Primary Production (see above).

The method allows also for estimates of the probability that such energy loss is sustainable based on a non-linear empirical relationship between the L-index and the probability to be sustainably exploited (psust) for an ecosystem (Libralato *et al.*, 2008).

To simulate the possible effects of changes in both social and environmental conditions, the PPR% and L-index indicators were applied to three different scenarios, in which the recent trends recorded in the Northern Adriatic were taken into account:

a) an increase of the fishing effort, resulting from reconversion of fishermen from small trawling to the artisanal fisheries, based on recent findings in the area as a response to the implementation of new management strategies (Pranovi *et al.*, 2015);
b) a reduction of the primary production (PP) in the Northern Adriatic Sea, as consequence of a tendency towards oligotrophy, which was recently described by Giani *et al.*, (2012);
c) a combination of 'a' and 'b', *i.e.* increased fishing effort and reduced PP.

In order to estimate the indicators, landings data were changed accordingly to the fishing effort variations for the artisanal (increase) and small trawling (reduction) activities.

Finally, to investigate the vulnerability of artisanal fisheries to the potential effects of climate changes, the composition of catches based on thermal affinity groups (Pranovi *et al.*, 2013) were analysed. In this approach, each species was categorised based on the mean distribution area in terms of latitudinal range: species with a distribution over 45°N, species within the 30°N–45°N range, and species mainly found below 30°N. These categories allowed for the identification of three climatic affinity groups—cold, temperate, and warm. Thresholds of 30° and 45° were arbitrarily selected with 30°N representing the southern limit of the Mediterranean basin and 45° N representing its northern limit, excluding the northernmost regions of the Adriatic and Black Sea (Pranovi *et al*., 2013).

3. Results

3.1 The fleet and fishing techniques

According to the EU Fleet Register, the fleet in the study area included 216 vessels, among which 79 belonged to an artisanal fisheries, as confirmed by quay observations. The features of this component of the fleet can be summarized as follows: length, 4.30–12.08 m; gross tonnage, 1–2 tons; and crew, 1–2 fishermen. These vessels mainly operate in fishing grounds located between 0.1 and 3 miles from the coastline.

The collected data indicated that artisanal fishermen adopt four different fishing techniques—gill nets, trammel nets, pots, and basket traps—that vary seasonally (Table 1).

Table1: description of the artisanal fishery, in terms of gears, number of vessels, main target species and fishing season.

Fishing technique	Total vessels	Target species	Fishing period
Gillnets	79	Sole, mantis shrimp and tub gurnard	May – Jun, Sep – Nov
Trammel nets	79	Flatfish	Jan – Mar, Nov – Dic
Pots	79	Cuttlefish	Apr – Jul
Basket traps	75	Mantis shrimp	Jul – Oct

Gillnets are employed from May to June and from September to November, and these target sole (*Solea solea*), mantis shrimp (*Squilla mantis*), and tub gurnard (*Chelidonichthys lucerna*) (Table 1). The net length ranges between 1.000 and 5.000 m, and the length used mainly depends upon the vessel size. Catches can include up to 78 species (8 target, 27 by-catch, and 43 discarded species, reflecting 78.5%, 13.3%, and 8.2% of the total biomass, respectively). Notably, sole, mantis shrimp, and smooth-hound shark (*Mustelus mustelus*) represented 73% of the commercial biomass (Table 2 and S1). The resulting discarded fraction is dominated by three species—spined murex (*Bolinus brandaris*), grey swimming crab (*Liocarcinus vernalis*), and common eagle ray (*Myliobatis aquila*) (Table S1). Regarding the total CPUE, gill nets represent the second most common fishing technique (Fig. 2) and the most important species yielded are sole (15.0 kg d^{-1} v^{-1}), smooth-hound shark (7.1 kg d^{-1} v^{-1}) and mantis shrimp (4.3 kg d^{-1} v^{-1}; Table S2).

Table 2: description of artisanal fishery catches, in terms of incidence (%) on the total catch of target species, by-catch and discard, per fishing gear.

Fishing technique	Target	By-catch	Discard
Trammel nets	73.8	23.1	3.1
Gillnets	78.5	13.3	8.2
Pots	99.6	0	0.4
Basket traps	86.0	0	14.0

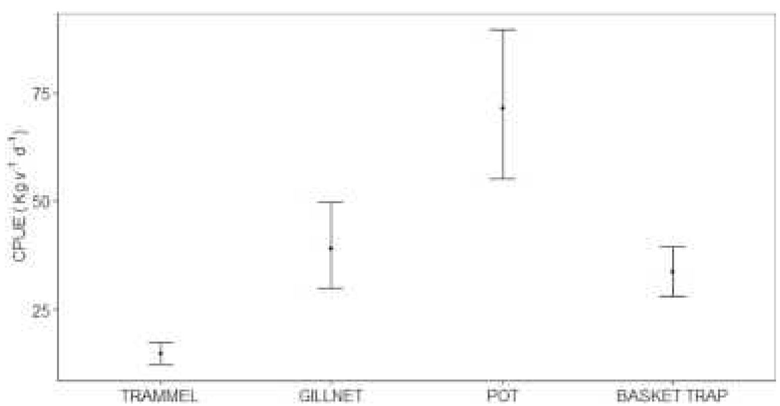

Figure 2: comparison among the different fishing gear in terms of Catch per Unit of Effort (kg v^{-1} d^{-1}); mean and 95% interval confidence.

Trammel nets are employed in the periods from January to March and November to December, and they target flatfish - turbot (*Scophthalmus maximus*), brill (*Scophthalmus rhombus*), European flounder (*Platichthys flesus*) – and cuttlefish (*Sepia officinalis*) (Table 1 and S2). The net length is between 350 and 2000 m, and mainly depends upon the vessel size. Catches can include up to 37 species (5 target, 21 by-catch, and 11 discarded species, reflecting 74%, 23% and 3% of the total biomass, respectively) (Table 2 and S1), among which turbot, cuttlefish, and brill represent 62% of the commercial biomass. The discarded fraction is almost entirely composed of three species—grey swimming crab (*Liocarcinus vernalis*), twait shad (*Alosa fallax*), and spined murex (*Bolinus brandalis*) (Table S1). In terms of the total CPUE, trammel nets represent the fourth most common fishing technique (Fig. 2), and the most important species that it yields are turbot (4.5 kg d^{-1} v^{-1}), cuttlefish (2.5 kg d^{-1} v^{-1}), and brill (2.1 kg d^{-1} v^{-1}) (Table S2).

Pots are employed from April to the beginning of July, and they target cuttlefish. This activity is regulated by the Port Authority, which establishes annual monitoring of the fishing season and monitors fishing vessels. In 2014, the fishing period was from April to 10 July with an allowance of 300 pots per fisherman (in cases of three or more embarked fishermen, the maximum limit of pots was 600 per vessel). Catches are composed of 99.6% target species, with a few grey swimming crabs being the discarded species. In terms of the total CPUE, pots represent the best fishing technique (Fig. 2), with 71.4 kg d^{-1} v^{-1} of cuttlefish (Table S1).

Basket traps are employed from July to October and they target mantis shrimp. Catches are composed of 86% target species. The discarded fraction represents four species of invertebrates—spined murex, banded dye-murex (*Hexaplex trunculus*), sea snail (*Nassarius mutabilis*), and netted dog whelk (*Nassarius nitidus*). In terms of the total CPUE, basket traps represent the third best fishing technique (Fig. 2), with 33.9 kg d^{-1} v^{-1} of mantis shrimp (Table S1).

Based on the CPUE data and vessel numbers for each fishing technique, an annual catch of 735 or 1050 tons is estimated (Table 3) for different fishing effort estimates of 150 or 214 days at sea, respectively. Cuttlefish, mantis shrimp, sole, and turbot showed the highest values, ranging from 58 to 440 tons per year (Table 3).

Table 3: CPUE (kg per vessel per day) of commercial species (target and bycatch), estimates of the annual catches and fishing gear; catch 1 refers to the 150 days at sea scenarios, catch 2 refers to the 214 days at sea scenarios; the 95% confidence interval is reported for each estimate (LB = lower boundary and UB = upper boundary); TL = trophic level; G: gillnet; T: trammel net; P: pot; B: basket trap.

Species		**TL**	**LB**	**CPUE ($kg\ v^{-1}\ d^{-1}$)**	**UB**	**LB**	**Total catches 1 (tonnes)**	**UB**	**LB**	**Total catches 2 (tonnes)**	**UB**	***gear***
Common cuttlefish	*Sepia officinalis*	3.60	55.5	74.3	95.3	233.6	311.5	398.8	333.3	444.4	568.9	P-T-G
Mantis shrimp	*Squilla mantis*	2.60	59.1	72.1	87.3	151.1	190.3	240.3	215.5	271.6	342.8	B-G
Common sole	*Solea solea*	3.13	11.2	15.7	21.1	62.0	86.1	114.8	88.5	122.8	163.8	G-T
Smooth-hound shark	*Mustelus mustelus*	3.83	3.5	7.6	12.3	19.3	41.2	65.8	27.6	58.8	93.9	G-T
Turbot	*Psetta maxima*	3.96	3.1	4.6	6.2	11.2	16.7	22.4	15.9	23.8	32.0	T
Tub gurnard	*Chelidonichthys lucerna*	3.65	2.3	3.3	4.5	11.6	17.1	23.4	16.5	24.3	33.3	G-T
Brill	*Scophthalmus rhombus*	3.96	1.8	2.6	3.5	6.9	10.4	14.0	9.9	14.8	20.0	T-G
Gilthead seabream	*Sparus aurata*	3.26	1.1	2.6	4.3	6.2	13.8	22.9	8.8	19.7	32.6	T-G
Sand Steenbras	*Lithognathus mormyrus*	3.42	0.6	1.8	3.3	3.4	10.0	18.2	4.8	14.2	25.9	T-G
Mediterranean scaldfish	*Arnoglossus laterna*	3.59	0.7	1.7	3.0	3.7	9.3	16.6	5.3	13.3	23.6	G
Shi drum	*Umbrina cirrosa*	3.46	0.6	1.4	2.3	3.1	6.7	10.8	4.5	9.6	15.4	T-G
European seabass	*Dicentrarchus labrax*	3.80	0.3	1.1	2.2	1.2	4.2	8.4	1.7	6.0	12.0	T-G
European flounder	*Platichthys flesus*	3.19	0.3	1.1	2.1	1.2	3.8	7.6	1.7	5.4	10.8	T-G
Spiny dye-murex	*Bolinus brandaris*	3.25	0.3	0.7	1.1	1.9	3.9	6.3	2.8	5.6	9.0	T
Golden grey mullet	*Liza aurata*	2.76	0.1	0.6	1.5	0.4	2.7	6.2	0.6	3.9	8.9	G

Species		**TL**	**LB**	**CPUE (kg v^{-1} d^{-1})**	**UB**	**LB**	**Total catches 1 (tonnes)**	**UB**	**LB**	**Total catches 2 (tonnes)**	**UB**	***gear***
European lobster	*Homarus gammarus*	2.60	0.0	0.3	0.9	0.0	1.6	4.4	0.0	2.2	6.3	G
Thinlip grey mullet	*Liza ramada*	2.76	0.0	0.3	0.6	0.2	1.2	2.7	0.3	1.7	3.9	G
Brown ray	*Raja miraletus*	3.76	0.1	0.1	0.2	0.4	0.7	1.1	0.5	1.0	1.5	G-T
Leaping mullet	*Liza saliens*	2.76	0.0	0.1	0.2	0.2	0.5	1.0	0.2	0.8	1.5	G
Caramote prawn	*Penaeus kerathurus*	2.70	0.0	0.1	0.2	0.3	0.5	0.9	0.4	0.8	1.3	G
Bluefish	*Pomatomus saltatrix*	4.50	0.0	0.1	0.2	0.0	0.3	0.9	0.0	0.5	1.2	T
Nursehound	*Scyliorhinus stellaris*	3.69	0.0	0.1	0.3	0.0	0.5	1.4	0.0	0.7	2.0	T-G
Red scorpionfish	*Scorpaena scrofa*	4.11	0.0	0.1	0.2	0.0	0.4	1.3	0.0	0.6	1.9	T-G
Atlantic horse mackerel	*Trachurus trachurus*	3.59	0.0	0.1	0.1	0.2	0.4	0.7	0.2	0.6	1.1	T-G
Brown meagre	*Sciaena umbra*	3.70	0.0	0.1	0.2	0.0	0.4	1.0	0.0	0.5	1.4	T-G
Annular seabream	*Diplodus annularis*	3.50	0.0	0.1	0.2	0.0	0.3	0.7	0.0	0.4	1.1	G-T
Leerfish	*Lichia amia*	4.50		<0.1		0.0	0.2	0.6	0.0	0.3	0.8	T-G
Common octopus	*Octopus vulgaris*	4.10		<0.1		0.0	0.1	0.5	0.0	0.2	0.7	T
White seabream	*Diplodus sargus*	3.04		<0.1		0.0	0.1	0.4	0.0	0.2	0.5	G-T
Common Pandora	*Pagellus erythrinus*	3.48		<0.1		0.0	0.2	0.5	0.0	0.2	0.7	G
Atlantic mackerel	*Scomber scombrus*	3.65		<0.1		0.0	0.1	0.2	0.0	0.1	0.3	G

Species		**TL**	**LB**	**CPUE (kg v^{-1} d^{-1})**	**UB**	**LB**	**Total catches 1 (tonnes)**	**UB**	**LB**	**Total catches 2 (tonnes)**	**UB**	***gear***
John dory	*Zeus faber*	4.5		<0.1		0.0	0.1	0.1	0.0	0.1	0.2	G
Thicklip grey mullat	*Chelon labrosus*	2.42		<0.1		0.0	0.1	0.2	0.0	0.1	0.3	T
European squid	*Loligo vulgaris*	3.20		<0.1		0.0	0.1	0.2	0.0	0.1	0.2	T
Whiting	*Merlangius merlangus*	4.37		<0.1		0.0	0.1	0.2	0.0	0.1	0.2	G
Great scallop	*Pecten jacobaeus*	2.39		<0.1			<0.1			<0.1		G
Red mullet	*Mullus barbatus*	3.15		<0.1			<0.1			<0.1		G-T
Spotted weever	*Trachinus araneus*	4.18		<0.1			<0.1			<0.1		G
Salema	*Sarpa salpa*	2.00		<0.1			<0.1					

3.2 Ecological effects

While the mean trophic level of catches remained stable (3.29), the Primary Production Required to sustain catches (PPR%) for the entire fleet ranged from 10% to 14% (Table 4), depending on the fishing effort estimate, which was either 150 or 241 fishing days. The L-index and the relative probability to be sustainably fished showed a similar pattern (Table 4).

Table 4: ecological effects of the artisanal fishery in the study area estimated by using Primary Production Required to sustain catches (PPR%), L-index and the derived probability to be sustainably fished (psust), considering both commercial and discard fraction for all the fishing techniques combined; for description of the scenarios see the main text.

	Present situation		Increased fishing effort		PP reduction (present fishing effort)		PP reduction (increased fishing effort)	
	150 dd	214 dd	150 dd	214 dd	150 dd	214 dd	150 dd	214 dd
PPR%	10.2	14.5	15.2	21.8	12.7	18.1	19.1	24.2
Lindex	0.025	0.036	0.037	0.054	0.033	0.045	0.048	0.068
Psust	0.71	0.61	0.61	0.49	0.63	0.55	0.53	0.29

For the scenario of a potential 50% increase of the fishing effort (in terms of the vessels number) in the area as a result of fishermen reconversion (see M&M), the PPR% slightly increased and the probability of sustainable fishing is reduced to 61% or 49% for 150 or 241 fishing days, respectively (Table 4). A similar trend has been recorded taking into account a possible reduction in primary production, with a reduction of the probability of sustainable fishing (Table 4).

Finally, combining the two scenarios by increasing the fishing effort and decreasing the primary production resulted in an increase of the ecological effects, with PPR% values that ranged between 19% and 24%, and the probability to be sustainably fished (psust) decreasing around of far below the 50% threshold (Table 4).

In order to analyse the contribute of each fishing gear, the PPR (%) and the probability of sustainable fishing are estimated under the four scenarios, considering an increase of the fishing effort ranging from 10 to 100%. The observed pattern is similar for all the tested scenarios. In terms of PPR (%) the highest values are recorded for the pot (5–17%), whereas the lowest were referred to the basket traps (<2.5%) (Fig. 3). With reference to the probability of sustainable fishing, values remained over than 70%, with the lowest recorded for the gillnet (Fig. 4).

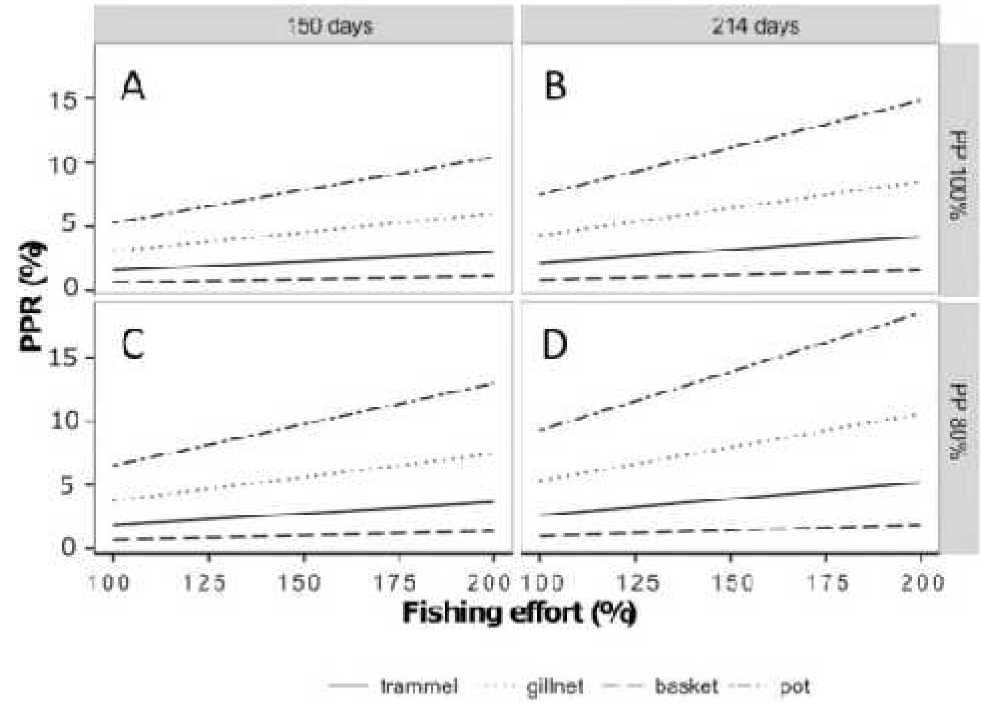

Figure 3: changes in the Primary Production Required to sustain catches (PPR%) of each fishing gear, related to the fishing effort increase (in terms of the vessels number); A = 150 fishing days and 100% of primary production, B = 214 fishing days and 100% of primary production, C = 150 fishing days and 80% of primary production, and D = 214 fishing days and 80% of primary production.

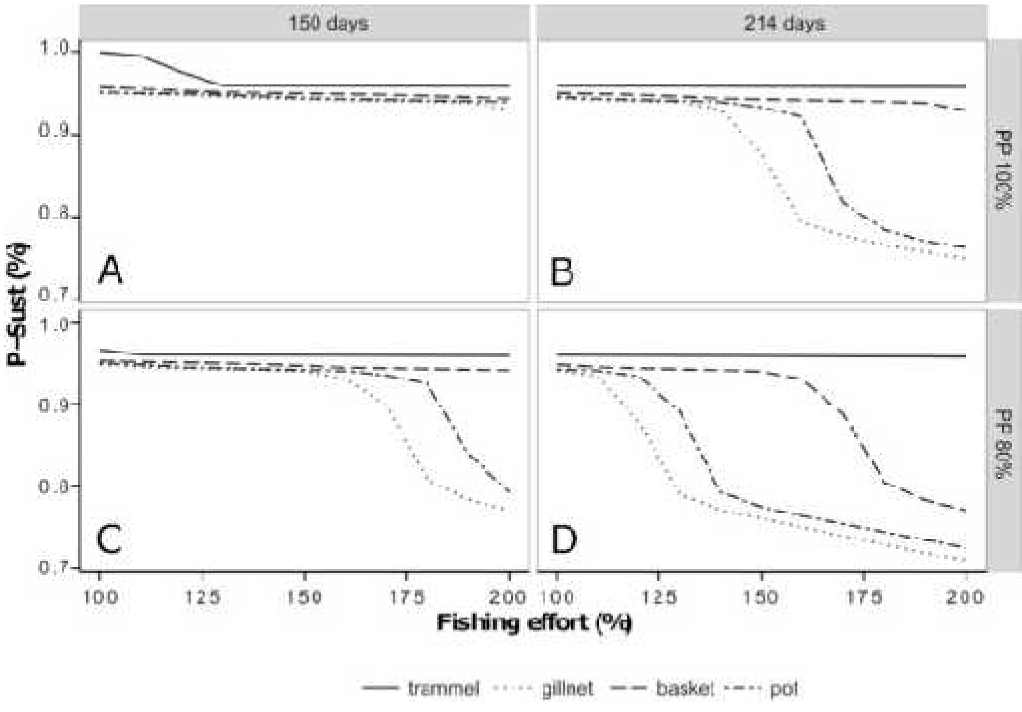

Figure 4: changes in the probability to be sustainably fished (psust), estimated according to the Lindex values, for each fishing gear, related to the fishing effort increase (in terms of the vessels number); A = 150 fishing days and 100% of primary production, B = 214 fishing days and 100% of primary production, C = 150 fishing days and 80% of primary production, and D = 214 fishing days and 80% of primary production.

3.3 Climate change vulnerability

Regarding the potential vulnerability to climate change effects, an analysis of the catch composition based on thermal affinity groups revealed that the cold and temperate affinity species represent the two main caught groups, accounting on average for 64% and 31% of the total catch, respectively (Table 5). A similar pattern also resulted from analyses of catches in relation to different fishing techniques, with the exception of the basket traps, in which the catch is composed only of temperate species, because the mantis shrimp belongs to this affinity group (Table 5).

Table 5. Catch composition in terms of incidence (%) on total catch of thermal affinity groups (cold, temperate, warm and ubiquitous species) for each fishing gear and all of them combined (total catches).

	Cold	Temperate	Warm	Ubiquitous
Trammel nets	81.7	9.1	3.2	6.0
Gillnets	57.0	31.6	3.5	7.9
Pots	100	0	0	0
Basket traps	0	100	0	0
Total catches	64.0	31.1	0.9	4.0

4. Discussion

Similar to other regions throughout the world, the artisanal or small scale fisheries in the Mediterranean Sea is recognised as a fundamental factor for the cultural and traditional identity of the region, and also represents an important source of employment and income for coastal communities (Farrugio *et al*., 1993 and AdriaMed, 2005). Nevertheless, artisanal fisheries have been scarcely managed or studied (Guyader *et al*., 2013). For example, the large heterogeneity and variability of artisanal fisheries among different areas has presented an important obstacle to the development of standardized data collection routines that are based in many harbours and small ports (Colloca *et al*., 2004).

The importance of this role has recently increased, at least along the Italian coasts, in relation to the introduction of bans for trawling activities within three miles of the coastline. Consequently, in the western region of the Adriatic Sea artisanal fisheries have remained along with hydraulic dredging, which represent the only ongoing commercial fishing activities (Pranovi *et al*., 2015). Within this context, it is necessary to increase our knowledge and monitoring of these activities to best implement effective management strategies.

Given the difficulty involved in monitoring artisanal fisheries landings, as fishermen sell a large portion of their catch outside of the fish market in areas that are often difficult to reach and/or are far from the landing port, an on-board and on-quay data collection system has been implemented.

Our findings confirmed that the artisanal fishing is a multitarget and multigear activity, as has been described for other Adriatic (AdriaMed, 2005; Fabi, 2005 and Matić-Skoko *et al*., 2011), Mediterranean (Stergiou *et al*., 2006; Tzanatos *et al*., 2005 and Forcada *et al*., 2010) and European areas (Guyader *et al*., 2013). Although features of the fleet (on average, 1.5 t of GT and 1.5 crew members) were aligned with those reported for the region (MIPAAF, 2014) and other European ports (Guyader *et al*., 2013), our estimates of fishing effort were higher than that of official Italian statistics (89 days at sea for 2012). Our estimates, which ranged between 150 and 214 days at sea per year, fell within the upper part of the range reported for various fisheries throughout Europe (Guyader *et al*., 2013). Finally, as reported for other European fisheries (Guyader *et al*., 2013), our collected data indicated a high amount of vulnerability as even though 39 target species were targeted, 76% of total catches depended upon only three species—cuttlefish, mantis shrimp, and sole. This partially occurs because, within the context of polyvalence, fishermen seasonally employ two types of fishing gear—pots and basket traps, which results in nearly monospecific (for cuttlefish and mantis shrimp) exploitation in coastal waters of these temporary resources. These patterns are in contrast with the common idea that artisanal fishing, is a highly dynamic activity that can switch *metiérs* depends upon the abundance of target species and dynamic environmental conditions, so it can therefore be considered a highly resilient activity (Colloca *et al*., 2004, Tzanatos *et al*., 2005 and García-Rodríguez and Fernández Á.M., 2006).

Within this context, the potential vulnerability to thermal changes must also be considered because of the species composition in terms of thermal affinity groups. Cold and temperate species contribute to all catches, exposing these fisheries to negative effects resulting from expected modifications of nekton assemblages (Fortibuoni *et al*., 2015 and Libralato *et al*., 2015). For example, the northern Adriatic Sea can be considered to be a particularly vulnerable area that hosts several species that are adapted to boreal climatic conditions and is configured as a cul-de-sac that prevents the northward migration of species (Ben Rais Lasram *et al*., 2010).

Based on the seven species reported in official statistics (MIPAAF, 2014), CPUE values recorded in this present study resulted to be higher than those previously reported for the region (33.2 and 53 kg per vessel per day, respectively). This discrepancy could be related to different periods of time, as the official statistics referred to 2012, but could also reflect the previously mentioned difficulties in monitoring actual catches. This has been partially confirmed by comparing collected data with those from the Chioggia fish market, the most important in the Northern Adriatic Sea. Considering the eight most abundant species (representing at least 2% of the total catch), in the two different scenarios for fishing effort, only cuttlefish, common sole, and brill showed higher values at the fish market. This again confirms the poor reliability of fish market data from the area.

All of the fishing gear analyses confirmed a very low discard incidence (in terms of biomass), which were even lower than those reported for other Adriatic areas (Fabi and Grati, 2005). This situation is quite similar to that described for the Croatian coast, where the by-catch of commercial species is often utilized by fishermen for personal consumption or as bait (Matić-Skoko *et al*., 2011).

The PPR (Pauly and Christensen, 1995) and L-index (Libralato *et al*., 2008) are two indicators that have been proposed to assess the ecological footprint of fishing activities. For PPR, the results that we obtained were slightly higher than the mean values for the Mediterranean and Italian seas, which were 15% and 9%, respectively (Sherman and Hempel, 2008 and de Leo *et al*., 2014). Accordingly, the L-index showed values within the sustainable fishing range. However, increased fishing efforts and/or reduced primary production scenarios highlight the importance of artisanal fisheries in the area, reflecting increased PPR (also reaching 20%) and reduced sustainability (with a probability reduced to less than 40%). These two scenarios can be considered to be realistic because they are based on very recently measured trends. Indeed, the ban of trawling activities inside the three miles area is now leading to the reconversion of small trawlers towards artisanal fishing (Pranovi *et al*., 2015), although a recent study suggested a tendency towards water oligotrophy of the Northern Adriatic Sea (Giani *et al*., 2012). The analysis preformed at the level of single fishing gear revealed that the most ‘impacting’ gear resulted the be the pot and the gillnet, in terms of PPR and Lindex/psust, respectively. All this could partially be useful in addressing the management strategies, possibly promoting the use of less impacting gear, namely trammel net and basket trap. However, it is worthy to note that the artisanal fisheries resulted to be a dynamic combination of different fishing gear, according to the target species seasonality, making difficult to force the use of one fishing gear despite the others.

5. Conclusions

Artisanal fisheries along the West coast of the Northern Adriatic Sea exhibit features similar to those recorded in many other European areas, such as the large number of exploited species and polyvalence. Nevertheless, it also showed a high potential vulnerability because of the species dependence and catch composition in terms of thermal affinity groups. Finally, our analyses showed artisanal fishing to be a sustainable practice, but it also highlights how small modifications both in the fleet structure and environmental conditions could drive the situation towards unsustainability in the future (see also Whitmarsh *et al.*, 2003). Within the context of the Integrated Coastal Zone Management, obtained results suggested the importance of supporting the artisanal fishery, as a sustainable exploitation activity, implementing clear management policies and adopting spatially explicit planning strategies. Considering our findings together, if the present levels of artisanal fishing remain along with current levels of hydraulic dredging, and remain the sole fishing activities within the three-mile area, a real management strategy will be required. Such a strategy must achieve the following two goals: to reduce conflicts between the two industries for fishing grounds, as both prefer the shallowest zones, and to avoid uncontrolled increases in fishing effort, which could overcome the positive effects of the trawling ban if unchecked.

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Appendix A. Supplementary data

The following is the supplementary data related to this article:

Table S1: CPUE of commercial species for pot and basket trap; the 95% confidence interval is reported for each estimate (LB = lower boundary and UB= upper boundary).

Species		Pot			Basket trap		
		LB	CPUE (kg v^{-1} d^{-1})	UB	LB	CPUE (kg v^{-1} d^{-1})	UB
Common cuttlefish	*Sepia officinalis*	55.0	71.4	89.5	-	-	-
Mantis shrimp	*Squilla mantis*	-	-	-	28.6	33.9	39.4

Table S2: CPUE of commercial species for gillnet and trammel net; the 95% confidence interval is reported for each estimate; TL= trophic level, TAG=thermal affinity group (1=cold species, 2=temperate species, 3=warm species, X.5= intermediate affinity species), LB = lower boundary and UB= upper boundary.

Species				Gillnet			Trammel net		
		TL	TAG	LB	CPUE (kg v^{-1} d^{-1})	UB	LB	CPUE (kg v^{-1} d^{-1})	UB
Common sole	*Solea solea*	3.13	1	11.0	15.0	19.7	0.2	0.6	1.3
Smooth-hound shark	*Mustelus mustelus*	3.83	2	3.5	7.1	11.0	0.0	0.5	1.3
Mantis shrimp	*Squilla mantis*	2.60	2	2.0	4.3	8.4		<0.1	
Tub gurnard	*Chelidonichthys lucerna*	3.65	u	1.8	2.6	3.6	0.5	0.7	1.0
Gilthead seabream	*Sparus aurata*	3.26	2	1.1	2.3	3.8	0.0	0.2	0.4
Sand steenbras	*Lithognathus mormyrus*	3.42	2	0.6	1.7	3.1	0.0	0.1	0.2
Mediterranean scaldfish	*Arnoglossus laterna*	3.59	1	0.7	1.7	3.0	-	-	-
Shi drum	*Umbrina cirrosa*	3.46	u	0.5	0.9	1.4	0.1	0.4	0.9
Brill	*Scophthalmus rhombus*	3.96	1	0.3	0.5	0.8	1.5	2.1	2.8
Common cuttlefish	*Sepia officinalis*	3.60	1	0.1	0.3	0.7	-	-	-
European lobster	*Homarus gammarus*	2.60	1	0.0	0.2	0.7	0.0	0.1	0.2
Golden grey mullet	*Liza aurata*	2.76	2	0.1	0.2	0.4	0.0	0.4	1.1
Brown ray	*Raja miraletus*	3.76	4	0.1	0.1	0.2	-	-	-
European seabass	*Dicentrarchus labrax*	3.80	1	0.0	0.1	0.4	0.3	1.0	1.8
Thinlip grey mullet	*Liza ramada*	2.76	1.5	0.0	0.1	0.3	0.0	0.2	0.3
Turbot	*Scophthalmus maximus*	3.96	1	0.0	0.1	0.2	3.1	4.5	6.0
Caramote prawn	*Penaeus kerathurus*	2.70	2.5	0.0	0.1	0.2	-	-	-
Leaping mullet	*Liza saliens*	2.76	2	0.0	0.1	0.2		<0.1	
Nursehound	*Scyliorhinus*	3.69	1	0.0	0.1	0.3	-	-	-

	stellaris								
Red scorpionfish	*Scorpaena scrofa*	4.11	2.5	0.0	0.1	0.2	-	-	-
Atlantic horse mackerel	*Trachurus trachurus*	3.59	2	0.0	0.1	0.1	-	-	-
Brown meagre	*Sciaena umbra*	3.70	3	0.0	0.1	0.2		<0.1	
Leerfish	*Lichia amia*	4.5	2.5		<0.1			<0.1	
European flounder	*Platichthys flesus*	3.19	1		<0.1		0.3	1.0	2.0
Common pandora	*Pagellus erythrinus*	3.48	2		<0.1		-	-	-
Atlantic mackerel	*Scomber scombrus*	3.65	2		<0.1			<0.1	
European squid	*Loligo vulgaris*	3.20	1.5		<0.1		-	-	-
White seabream	*Diplodus sargus*	3.04	2		<0.1			<0.1	
Annular seabream	*Diplodus annularis*	3.50	2		<0.1		0.0	0.1	0.2
Whiting	*Merlangius merlangus*	4.37	1		<0.1			<0.1	
Great scallop	*Pecten jacobaeus*	2.39	2		<0.1		-	-	-
Red mullet	*Mullus barbatus*	3.15	1.5		<0.1		-	-	-
Spotted weever	*Trachinus araneus*	4.18	1.5		<0.1		-	-	-
Bluefish	*Pomatomus saltatrix*	4.50	2.5		<0.1		0.0	0.1	0.2
Salema	*Sarpa salpa*	2.00	2		<0.1		-	-	-
Spiny dye-murex	*Bolinus brandaris*	3.25	1.5	-	-	-	0.3	0.7	1.1
Thicklip grey mullat	*Chelon labrosus*	2.42	1.5	-	-	-	0.00	0.02	0.05
Common octopus	*Octopus vulgaris*	4.10	2.5	-	-	-		<0.1	
Common cuttlefish	*Sepia officinalis*	3.60	1	-	-	-	0.4	2.5	5.2
John dory	*Zeus faber*	4.50	u	-	-	-		<0.1	

Table S3: list of discarded species, as percentage on the total catch, for the different fishing gears; * = incidence <0.01.

Species	Phylum	Pots	Basket traps	Trammel net	Gillnet
Porifera	Porifera				*
Calliactis parasitica	Antozoa				*
Acanthocardia tuberculata	Mollusca Bivalvia				*
Acanthocardia aculeata	Mollusca Bivalvia				*
Acanthocardia deshayesii	Mollusca Bivalvia				*
Chamelea gallina	Mollusca Bivalvia				*
Ensis ensis	Mollusca Bivalvia				*
Mimachlamys varia	Mollusca Bivalvia				*
Modiolus barbatus	Mollusca Bivalvia				*
Ostrea edulis	Mollusca Bivalvia				*
Aporrhais pespelecani	Mollusca Gastropoda				*
Bolinus brandaris	Mollusca Gastropoda		2	*	2

Hexaplex trunculus	Mollusca Gastropoda		9		*
Nassarius mutabilis	Mollusca Gastropoda		*		*
Nassarius nitidus	Mollusca Gastropoda		2	*	*
Carcinus aestuarii	Artropoda Crustacea			*	*
Dorippe lanata	Artropoda Crustacea				*
Dromia personata	Artropoda Crustacea				*
Eriphia verrucosa	Artropoda Crustacea			*	
Ethusa mascarpone	Artropoda Crustacea				*
Gonaplex romboides	Artropoda Crustacea				*
Ilia nucleus	Artropoda Crustacea				*
Inacus dorsettensis	Artropoda Crustacea				*
Liocarcinus corrugatus	Artropoda Crustacea				*
Liocarcinus depurator	Artropoda Crustacea				*
Liocarcinus vernalis	Artropoda Crustacea	*		1	2
Maja verrucosa	Artropoda Crustacea				*
Paguristes eremita	Artropoda Crustacea				*
Pagurus prideaux	Artropoda Crustacea				*
Partenope myersi	Artropoda Crustacea				*
Astropecten irregularis	Echinodermata Asteroidea				*
Schizaster canaliferus	Echinodermata Echinoidea				*
Ocnus planci	Echinodermata Holoturidea				*
Ophiotrix quinquemaculata	Echinodermata Ophiuroidea				*
Phallusia mamillata	Ascidiacea				*
Alosa fallax	Fish			1	*
Arnoglossus laterna	Fish				*
Belone belone	Fish			*	
Dasyatis pastinaca	Fish				*
Engraulis encrasicolus	Fish			*	*
Hippocampus guttulatus	Fish			*	*
Myliobatis aquila	Fish				5
Pegusa lascaris	Fish				*
Sardina pilchardus	Fish			*	*
Torpedo marmorata	Fish				*

General conclusions

Human population is not evenly distributed across the globe. The favourable opportunities for livelihoods, economic activities and trade have attracted people along coastal zones over the course of the human history. Today, millions of people rely on proximity to the coast for their livelihoods and strongly depend, directly and indirectly, on services that marine ecosystem provides in a two-way interaction. High people density translates into high pressures on environment that if not appropriate managed, may threaten the health of the environment itself. Anthropogenic pressures as fishery, aquaculture or nutrient discharge in coastal areas lead to a degradation of the ecosystem and a reduction of the services provided with the consequent affection of human activities relied on these resources.

The growing concern about the vulnerability of coastal areas had promote the development of environmental policies aimed at the sustainable management of the marine resources, such as the Marine Strategy Framework Directive (2008/56/CE), and of the entire coastal zones, such as the Integrated Coastal Zone Management (ICZM) in Europe. Coupling a legislative instrument that aims to achieve a Good Environmental Status starting from actual one's, with a process for the management of the coast, EU had shown a remarkable planning ability in safeguarding its coastal areas. Both Marine Strategy and ICZM are "integrated instruments" that enshrine in a legislative and institutional framework the ecosystem approach, merging the concepts of environmental protection and sustainable use.

Prior to the analysis of the interconnections among the fundamental fields of the ecosystem approach, i.e. economic, societal and ecological systems, a robust knowledge on the marine ecosystem functioning is needed as a prerequisite. This task is complex because of the scarce knowledge on the synergistic effects of many different pressures acting on the marine ecosystems.

Shallow coastal and transitional environments host ecosystems that play a key role in the nutrient cycling, water purification and biodiversity. Moreover, coastal ecosystems are among the most productive zones on Earth and are of great importance for nutrient budgets and primary productivity. High nutrient levels, multiple sources of primary and secondary production, shallow depths, organically rich sediments, energy inputs from wind and tidal currents, and freshwater inflows combine to establish the high natural productivity of near-shore areas (Livingston, 2003).

Within this framework, the present thesis aims to improve the knowledge of the ecosystem functioning in the Northern Adriatic Sea (NAS) coastal area, in relation to the present conditions of high level of renewable resources exploitation (both in terms of primary and secondary production), providing scientific bases for the definition of reliable management objectives. The high level of exploitation of the ecosystem provisional services (e.g. by fishery and aquaculture activities), on the other side, gives the evidence of the important role played by this area in economic and social terms. The five chapters have not the pretence to completely explain marine ecosystem functioning of the area due to the high complexity of the overall system and the unfeasibility to consider all the factors involved, but can be viewed as pieces of the same mosaic, and can help to give a description of the NAS coastal area and possible interactions of some exploiting activities with the ecosystem structure and functioning.

In Chapter 1, the potential impact of the mussel farming on the seabed has been investigated, considering both abiotic and biotic factors inside and outside the farm. No significant differences were found neither for the abiotic (sediment seafloor composition and POC fluxes) or for biotic factors (meiofauna and macrozoobenthos), suggesting quite homogeneous conditions all over the studied area. Probably environmental factors such as the rivers inputs, the exposure to strong longline current and winds and the relatively high trophic conditions of the Western Adriatic coast play a fundamental role in the dynamics of all biological components in the study area, reducing potential mussel farm impacts.

In Chapter 2 the two models outputs are well corroborate by the environmental data. Furthermore EDM model results suggest that the farm acts as a selective filter on suspended organic matter, affecting the bioirrigation profile: bioirrigation contribute to increase all fluxes at the sediment-water interface, including both particulates and solutes. Efficient fluxes are a prerequisite for any well functioning ecosystem and understanding these fluxes will help manage our coastal ecosystems efficiently and sustainably.

In Chapther 3, the investigation of the potential fish aggregating and reproductive role of the mussel farm, highlighted the important ecological role played by these structures. All this suggests that farms could be used as a restocking of overexploited fish species (in the cases of an area forbidden to the commercial fishing) site and, by managing recreational fishing, a second income for the mussel farm owners.

In order to quantify and compare the sustainability of mussel farm, an emergy analysis was performed (Chapter 4). A large predominance of renewable inputs due to the strong phytoplankton influence on the system was detected. In comparison with other aquaculture products, such as oysters and fish, mussel show a lower environmental impact and a higher use of renewable sources of emergy due to the type of farming (extensive) that doesn’t require human labour for feed and seed recruitment.

Finally, in Chapter 5, the artisanal fishery was analyzed. Artisanal fishery in the Northern Adriatic Sea is a widespread activity performed for about at least 150-214 days/year that showed a high potential vulnerability, in relation to the species dependence and to the catch composition in terms of thermal affinity groups. At present time is a sustainable practice, but it has been highlighted how small modifications both in the fleet structure and environmental conditions could drive the situation towards unsustainability.

The results of the present study show that a mussel farm located in a transitional environment near coast can be considered a sustainable activity, with scarce impacts on the bottom, acting as a fish aggregating area, also for some commercial species. Assimilating to an “extensive” acquaculture system, mussel farm is a structure characterised by the predominance of renewable inputs that, probably due to environmental factors such as currents and winds, doesn’t interfere both with benthic community and biogeochemical cycles of the area. Moreover, the normal aggregating effects due to the confluence of great quantities of available food is increased by the presence, at the bottom, of hard substrates, able to attract fish species beyond for feeding supply, also for reproductive purposes. In a spatial planning management context and ICZM approach, the creation of further mussel farms even if may be encouraged by these results and also concerning nutrient captation (Trevisiol, 2013), nowadays, at regional scale, it is not a firm economically sustainable. According to the most recent published data (2014), in Veneto region, despite a growth in the occupational sector, production showed a, even if small, decrease. Furthermore, from 2008, the mussel wholesale price is characterised by lower and lower values and, during 2014, the annual mean mussel wholesale price was about 0,55 euro/kg (Veneto Agricoltura, 2014). Mussel market in Veneto region and, similarly, in nearby regions, is saturated due to the overproduction; this, beyond to burocracy, production costs and foreign competition of product available all year long, is the most relevant sector threat. Moving from this, modernization of the production system by coupling mussel farming also with other incoming sources, may represent the right choice to maintain this type of sustainable activity. Breeding other species of molluscs, such as oysters or scallops and manage recreational fishing, seem, nowadays, the more feasible solutions. While the first, in order to obtain economically favourable results, needs further studies, the second is already put in place in the analysed farm. In a year, a flow of about 600 recreational fishermen who pay a fee for accessing to the mussel farm, was recored (farmer personal communications)

Taking advantage of bottom reproductive structures, the farm, being off-limits to commercial fishing, may act one-sidedly also as a “source of fish”, for the nearby areas, where artisanal fishery is allowed. By the present, this fishing activity is a sustainable practice, but, due to the species dependence and to the catch composition in terms of thermal affinity groups show a high potential vulnerability. Small modifications both in fleet structures and in environmental conditions could drive the situation towards unsustainability. An increase in available fish biomass may act as buffer effect towards vulnerability causes. The fish species that might reproduce in the structures deployed on bottom farm, would be typical rocky bottom species. Due to the sandy-muddy bottoms in the Veneto region, these species are not common and mostly relegated to the few rocky habitats, many of which are legally commercial fishing forbidden. Some of these species, such as sea breams and drums, are very appreciated and show quite high prices. So, an increase of these species coupled with a prudent management of the entire artisanal fishing sector, might support new fishermen, fronting the problem of small modification in fleet structures. Moreover, mostly of North Adriatic Sea breams and drums are temperate or warm species. Given the dependence of local artisanal fishery from cold or temperate species, a shift of catches toward temperate and warm ones’, without affecting incomings, might, at least partially, release this type of activity from the variations of the thermal regime as forecast by IPCC.

With reference to the Marine Strategy Framework Directive objectives, the mussel farm here investigated resulted to be able to positively contribute to:

- the biodiversity at the local scale (descriptor 1), as developing in three dimensions and offering concrete structures at the bottom, is expected to increase habitat availability for hard bottom species, in a general context of incoherent substrates;

- the commercial fish and shellfish abundance in the coastal area (descriptor 3), as consequence of the spill-over effect, from inside the farm, where the fishing activities are completely banned, to the outside ones;

- the seafloor integrity (descriptor 6); since no relevant differences have been detected in benthic communities, sediment texiture and biogeochemical cycles, inside and outside the farm, the presence of this structures are expected to positively affect the maintainance of the benthic compartment and associated ecological processes.

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RINGRAZIAMENTI

Il presente lavoro non è semplicemente una Tesi di Dottorato … ma sono tre anni della mia vita, racchiusi più o meno in 100 pagine.

Tre anni di …

dubbi,

domande,

sofferenze,

incazzature atomiche,

sorrisi,

pacche sulle spalle,

botte sui denti,

incontri,

sorrisi,

divertimento,

sacrifici,

paure,

ansie,

adrenalina pura,

amicizie,

condivisioni,

delusioni,

speranze …

Potrei continuare con la lista delle emozioni e degli stati d'animo che ho provato all'infinito …

Sono emozioni che a volte mi hanno scioccata, nel bene e nel male, e che sono state provocate da persone accanto a me da una vita ma anche da persone incontrate lungo il percorso di questa avventura…

Credo che nella vita nulla accada per caso … sono nata e cresciuta tra mare e laguna … fin da piccola Nonno Giorgio e Papà Vincenzo mi hanno messo una fiocina in mano e insegnato l'arte del fiocinare … mi hanno insegnato a riconosce i 'busi da go' e da bisato, come segna i concoi, e cappe tonde e cappe onghe' … la differenza tra granchio e 'moecca' e tra granchio e 'masaneta'.

Il Bisnonno Almiro mi aspettava tutti i pomeriggi per andare a ‘tirar su i cogoi’ e il nonno Giorgio aspettava sotto il portico per ‘insernir i sgransi boni da moecche’.

Ecco così sono cresciuta … come non potevo fare Scienze Ambientali all’Università??? Come non potevo fare una Tesi di Dottorato che mi rappresentasse???

I primi ringraziamenti, quindi, sono per i miei Genitori, i miei Nonni e Bisnonni: è grazie a tutti loro se IO sono Silvia Colla, quella che cammina in ‘fango’, quella che va a ‘concoi’, quella che ‘caea e sorbere e tira su i cogoi’.

Vi ringrazio per avermi trasmesso l’amore ed il rispetto per l’acqua e la terra.

Un ringraziamento che non ha limiti va a mia Figlia Carlotta Maria che spesso mi ripete:

“Mamma, è da quando sono nata che ti sopporto che studi, quando la smetterai???”

“Mamma da grande voglio essere una pescatrice brava come te!!!”

Grazie Carlotta per tutti i portafortuna che con amore mi hai disegnato e consegnato prima di ogni esame e grazie per avermi sopportata nei momenti pre-esame (sono consapevole di essere infinitamente intrattabile!!). Grazie per tutti i tuoi sorrisi, i tuoi sguardi, i tuoi abbracci e baci, ma soprattutto grazie alle tue parole di conforto che ‘magicamente’ mi dici al momento giusto!!!! Grazie per essere venuta con me ai Congressi e, a volte, a campionare!! Grazie per essere sempre con me!!! Grazie per spronarmi a finire di scrivere la Tesi di Dottorato per poi andare in vacanza insieme!

E ‘tu’ marito mio!!! Non sei di certo arrivato per caso!! Mamma mia che antipatico mi stavi!!!! Un aiuto Prof. decisamente insopportabile!!! Ma come dicono tutti … era amore!!!

Non sto qui a scriverti cose belle e belline perché non siamo i tipi!!! In questi anni di Grazie te ne ho detti moltissimi … ma non saranno mai abbastanza!!!! GRAZIE Riccardo!!!

Grazie perché la tua presenza, il tuo aiuto pratico e mentale è stato fondamentale per arrivare fino a qui.

È stato bello lavorare con te e accanto a te … siamo due belle teste dure … e quando uno dei due molla … c’è l’altro pronto a tirare e spronare … Grazie per esserci sempre! Grazie per essermi stato accanto nel momento a me più ostico della tesi: la fase della scrittura!! Grazie per tentare di evitare ogni mio incubo notturno e grazie per sdrammatizzare tutti quelli che faccio!

Ti voglio bene!

Passiamo ora ai compagni di viaggio!!

Si, perchè questa Tesi è stata proprio un viaggio! Iniziato e sempre caratterizzato dalla bufera e dalla tempesta (in tutti i sensi)!!

Esito del Bando di Dottorato:

- Silvia Colla: 6^classificata (ovvero la prima esclusa dalle borse ministeriali, ovvero niente Dottorato per la sottoscritta) = bufera e tempesta.

Poi una sera di metà luglio una mail dalla Scuola Dottorale:

“La candidata Silvia Colla, prima esclusa dalle Borse Ministeriali, è tenuta ad iscriversi al Dottorato entro 10 giorni lavorativi dalla ricezione di questa mail, in quanto un candidato ha rifiutato la borsa”. E così … Testa Dura ha vinto!!!!

Inizia così il mio viaggio!!

E come ogni viaggio per mare che si rispetti … ci si deve imbarcare!!!

Ecco che arrivano i miei colleghi di viaggio!!!

Ringrazio tutto il personale dell’Ufficio Pesca della Capitaneria di Porto di Venezia ed in particolare Capo Andrea Schiattino per la cortesia e la collaborazione nell’ottenere le autorizzazioni di imbarco nei pescherecci.

Ringrazio la Cooperativa di pescatori di Cortellazzo per aver accettato di collaborare con me per la raccolta dati, necessari allo sviluppo della Tesi.

Ringrazio i pescatori Raffaele e Marco Polo per tutte le uscite in mare fatte assieme, per avermi fatto provare il brivido della tempesta in mare e avermi fatto mettere un secchio sporco di nero di seppia come protezione dalla grandine! Li ringrazio per avermi fatto innamorare ancora di più del mare e di tutte le sue bellezze.

Strada facendo … parla di qua … parla di là …

Arrivo al Porto peschereccio del Faro …

Non ho incontrato e conosciuto solo dei pescatori, ma dei veri e propri amici!

Grazie Infinite Stefano e Davide del peschereccio Ester! Siete straordinari!!! Non ho mai incontrato delle persone splendide come voi!!! Venire tutti i giorni (per un anno e mezzo) in banchina per la raccolta dati del pescato non è stato un lavoro, ma un piacere!!!! E ancora di più un piacere è stato fare le cassette di pesce con voi …

Stefano: “Varda mi no capisso … questa no a xe na tosa … mi no ho mai trovà na tosa che a sia bea, bona, inteigente e che ghe piase mettar e man sol pesse e saver da freschin!!!”

Quante risate mi sono fatta!!!! Grazie per tutte le cose che mi avete insegnato!!! Vi porto nel cuore!!!

Siete due persone meravigliose!!!

Come non ringraziare poi il mitico e saggio Gabri!!!! Un grazie anche al mitico Papo che ‘go fatto innamorar’!!!!

Un grazie anche ad Andrea per avermi tenuto gli scarti dei nassini da canocce, grazie per essere il mio fornitore ufficiale di canocce e grazie per voler aprire una pescheria con me!!

Grazie veramente a tutti i pescatori del Faro per la preziosa collaborazione, per la gentilezza (è vero con me non ne serve molta perché sono un ometto mancato!!) e per avermi sempre accolta con un sorriso e vista come portafortuna delle pescate!!! Alla faccia del mio capo che sosteneva che i pescatori non vogliono le donne in barca!!

Porterò sempre con me tutte le battute di Stefano e Davide!!! Siete fantastici e persone con un cuore immenso. Grazie infinite, per aver reso possibile questo mio viaggio/lavoro!! Sono fiera di avervi incontrati e conosciuti.

In questo viaggio, ovviamente, ho avuto a che fare anche con persone negative e non di grande aiuto … anzi, ma cosa dire … un grazie anche a voi … grazie per avermi resa ancora più testa dura …

GRAZIE, ANDRO’ SEMPRE AVANTI!

Ringrazio, inoltre, la società Laguna Project e Papà Vincenzo per le attività di campionamento; il Dott. Marco Picone (nonché amico) ed il dott. Riccardo Fiorin (nonché marito) per l’aiuto nella classificazione della comunità macrozoobentonica e la Mamma Mara per aver permesso che la sua cucina e il suo portico diventassero per un anno e mezzo il mio laboratorio, non avendone uno a disposizione all’Università.

Ringrazio Kety, Zara e Chiara, le amiche di una vita, per aver avuto sempre un messaggio o una telefona da dedicarmi nei momenti di bisogno!!!

Grazie di cuore a tutte le persone nominate perché senza di voi e senza il vostro prezioso contributo ed aiuto questi tre anni non sarebbero stati così meravigliosi, intensi ed indimenticabili!!!