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# Biological characterization of aggregates clogging fishing nets on the Basque coastal waters of France

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ABSTRACT

Over the past fifteen years, gillnets used by fishermen of the Basque coast of France have been seasonally covered with aggregates. By making the nets more visible, this disrupts the coastal fishing activity and sometimes causes skin allergies. In 2010, we deployed for the first time a fine mesh device which was immersed permanently and attached to the bottom off the Bay of Saint-Jean-de-Luz in order to collect samples of these aggregates throughout the summer period.

The first results reported in this work deal with the origin and biology of organisms forming these aggregates, excluding biochemical and bacteriological aspects. A remarkable feature is the wide variety of both planktonic and benthic components in the collected matter. More than 111 taxonomic units have been so far identified. In addition to these elements of marine origin, these aggregates deposited on fishing nets also contain exogenous matter of continental origin, mainly Grey Willow *Salix atrocinerea* silk's seeds, mammals' hairs and pollen. In this work, particular attention is also given to the potentially irritating and stinging organisms present in the aggregates. Finally, hypotheses are developed about the aggregation process of these living organisms and their pelagic sedimentation induced by the presence of fishnets in the water column.



## 1. Introduction

The marine pelagic environment, particularly in coastal areas, includes a wide variety of particles of any size and composition forming the sestonic compartment. Planktonic organisms live surrounded by a large number of mineral and organic abiotic particles they produce or consume. Complex interactions between living and inert fractions sometimes produce aggregation phenomena forming mucilaginous clouds or ribbons in the water.

Many species of phytoplankton and bacterioplankton and even benthic organisms exude colloidal substances that contribute to the development of these aggregates. They exude dissolved polysaccharide molecules, precursors to the formation of transparent exopolymer particles (TEP) or directly produce TEP into the water (Malpezzi, 2010). These sticky and biogenic TEP make up mainly microaggregates that sometimes further develop to form much larger macroaggregates (Giani et al., 2005a, b, c).

These aggregates can remain dispersed and settle slowly in the water column as "marine snow" (Kiørboe, 2001) or form much larger clouds: in the Adriatic Sea, they can reach several kilometres long (Precali et al., 2005). Most of them grow and persist in the water column above the pycnocline or thermocline which prevents their sedimentation (Malpezzi, 2010), but some are located more deeply and cover sediments or benthic fauna (Giuliani et al., 2005; Lorenti et al., 2005; Aktan and Topaloglu, 2011). Regardless of their location in the oceanic environment, these aggregates have a fundamental and often overlooked role in determining the biogeochemical pathways of food and energy necessary for the functioning of the ecosystem.

For thirty years many studies have investigated the determinism, composition and frequency of these pelagic mucilaginous aggregates. In Europe, the Mediterranean seems to be particularly affected by these phenomena especially in the Adriatic and Tyrrhenian seas (Giani et al., 2005a, b; 2012). Most of these studies

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concern the non-living fraction and there is little data concerning the French Atlantic coast. Off the Seine estuary (English Channel), Dupont and Lafite (1986) have shown the importance and the contribution of autotrophic and heterotrophic micro- and meso-zooplankton populations in the formation of aggregates from inert particulate fraction.

The rapid development of these aggregates in coastal areas induces serious disturbances affecting human activities such as the quality of bathing water, the development of aquaculture or local fisheries (Giani et al., 2005c; Aktan and Topaloglu, 2011).

Over the past fifteen years, gillnets used by fishermen on the French Basque coast have been regularly covered with a sticky and irritant aggregate locally called « liga ». The occurrence of this phenomenon has not been studied so far, and is based on the increasingly numerous testimonies and complaints from coastal fishermen collected by the local fisheries committee in Saint-Jean-de-Luz. At present, these complaints are almost yearly. By making the nets more visible, these aggregates disrupt the coastal fishing activity and sometimes cause skin allergies. At the request of the local committee of marine fisheries and considering the limited number of studies on these aggregation phenomena on the French Atlantic coast, a first research program was set up in 2010 in order to establish the origin and composition of these aggregates. The latter's collection has required the design and realization of a specific sampler similar to that used by fishermen to catch fish.

The results presented here concern the species composition, abundance and diversity of microplankton (20–200 μm) and mesoplankton (0.2–20 mm) and those of benthic organisms within the same size range. Other inert and exogenous elements of continental origin are added to this endogenous fraction and also participate in the aggregation of particulate organic matter constituting these sticky aggregates clogging fishing nets on the Basque coast.

## 2. Material & methods

### 2.1. Study area and aggregate matter sampling

The single station (43°37N; 1°43W; depth ≈ - 30 m) for aggregate sampling was located off the Bay of Saint-Jean-de-Luz in the southern French Atlantic (Fig. 1). A special fine mesh device similar to the nets used by the fishermen was built to sample the aggregated matter (Fig. 2). Two floats and two anchors attached to the frame of the device maintained the three nets vertically at various depths in the water column. In order to capture a maximum amount of aggregates, a mesh size of 750 μm similar to those used for fishing *leptocephalus* eel larvae was selected. For taxonomic, biodiversity and abundance purposes, aggregate sampling was

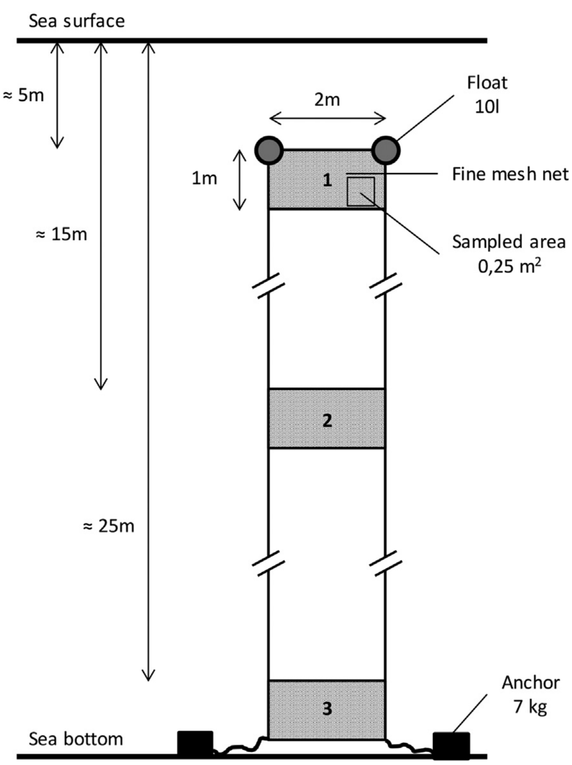


**Fig. 2.** Diagram of the device to collect the pelagic aggregates.

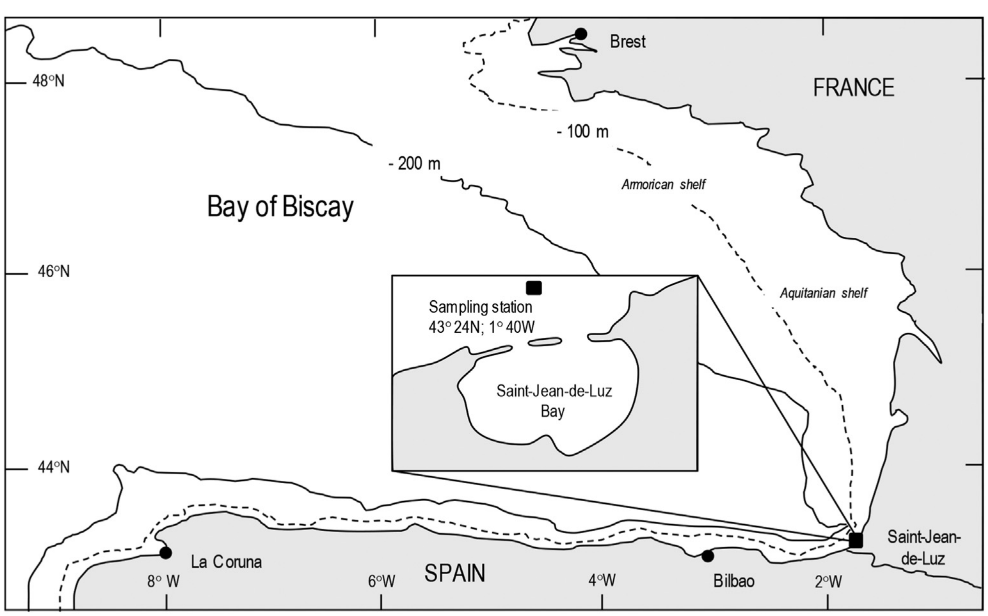


**Fig. 1.** Location of the sampling station near the Bay of Saint-Jean-de-Luz (France).

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performed on an area of 0.25 $m^2$, i.e. 1/8 of the total surface of each net. The amount of aggregates collected was more than sufficient for the analyses of the present study. The remaining collected matter will serve in the future for further biochemical and bacteriological analysis. This preliminary phase of our research program focused only on samples from the upper net (Fig. 2, net n° 1) whose depth of immersion was identical to gillnets and driftnets. A total of 24 samples were collected on a weekly basis from the upper net with this device immersed permanently throughout the summer season during a 6 month period running from April to September

**Table 1**
List of 111 taxonomic units identified on 24 aggregate samples. (B: benthic components; C: continental components; Blanks: planktonic components).

| Macrotaxa (52) | | |
|---|---|---|
| Cnidaria (3) | Hydrozoa medusae | |
| | Hydrozoa polyps | B |
| | Siphonophorae Diphyidae | |
| Copepoda (13) | *Acartia clausi* | |
| | Benthic Harpacticoida | B |
| | *Calanus helgolandicus* | |
| | *Caligus* sp. | B |
| | *Candacia armata* | |
| | *Centropages chierchiae* | |
| | *Centropages hamatus* | |
| | *Centropages typicus* | |
| | *Euterpina acutifrons* | |
| | *Oithona* sp. | |
| | *Oncaea* sp. | |
| | *Paracalanus parvus* | |
| | *Temora stylifera* | |
| Other Macrotaxa (18) | Amphipoda | B |
| | Amphipoda *Caprella* sp. | B |
| | Appendicularia | |
| | Black filaments | B |
| | Chaetognatha | |
| | Doliolida | |
| | *Evadne nordmanni* | |
| | Fish scales | B |
| | *Globigerina* sp. | |
| | Isopoda Cirolanidae | B |
| | Isopoda Gnathiidae | B |
| | Mammals hairs | C |
| | Nematoda | B |
| | Oligochaeta | B |
| | Ostracoda | |
| | *Penilia avirostris* | |
| | *Podon intermedius* | |
| | *Salix atrocinerea* seed's silks | C |
| Eggs & Larvae(18) | Annelida larvae | |
| | *Belone belone* eggs | B |
| | Bivalvia veligers | |
| | Brachyura megalopa | |
| | Brachyura zoae | |
| | Cirripedia cypris stages | |
| | Cirripedia nauplii stages | |
| | Copepoda nauplii | |
| | Copepodite stages | |
| | Cyphonaute larvae | |
| | Echinodermata larvae | |
| | Fish eggs | |
| | Fish larvae | |
| | Gastropoda veligers | |
| | Natantia larvae | |
| | Other larvae | |
| | Phyllosoma larvae | |
| | Porcellanidae larvae | |

| Microtaxa (59) | | |
|---|---|---|
| Diatoms (31) | *Amphora laevis* | |
| | *Amphora ostrearia* | B |
| | *Asterionella glacialis* | |
| | *Chaetoceros* sp. | |
| | *Cocconeis* sp. | B |
| | *Cylindrotheca closterium* | |
| | *Guanardia floccida* | |
| | *Gyrosigma* sp. | B |
| | *Hantzschia* sp. | |
| | *Haslea ostrearia* | |
| | *Leptocylindrus danicus* | |
| | *Licmorpha abbreviata* | B |
| | *Licmorpha flabellata* | B |
| | *Mastogloia* sp. | |
| | *Nitzschia longissima* | |
| | *Nitzschia punctata* | |
| | *Nitzschia seriata* | |
| | Other diatoms | |
| | *Pleurosigma* sp. | B |
| | *Podocystis adriatica* | |
| | *Proboscia alata* | |
| | *Pseudo-nitzschia delicatissima* | |
| | *Pseudo-nitzschia seriata* | |
| | *Pyrocystis* sp. | |
| | *Rhizosolenia delicatula* | |
| | *Rhizosolenia imbricata* | |
| | *Rhizosolenia styliformis* | |
| | *Skeletonema costatum* | |
| | *Striatella unipunctata* | |
| | *Thalassionema nitzschioides* | |
| | *Thalassiophysa hyalina* | |
| Other Microtaxa (12) | Acantharia | |
| | Ciliata | |
| | Cyanophyta | |
| | Pollen *Pinus* sp. | C |
| | Fecal pellets | |
| | *Phaeocystis* sp. | |
| | Silicoflagellata *Dictyocha* sp. | |
| | Sponge spicula | B |
| | Tintinnida *Acanthostomella* sp. | |
| | Tintinnida *Favella* sp. | |
| | Tintinnida *Parundella sp.* | |
| | Tintinnida *Salpingacantha* sp. | |
| Dinoflagellates(16) | *Ceratium furca* | |
| | *Ceratium fusus* | |
| | *Ceratium tripos* | |
| | *Dinophysis acuminata* | |
| | *Dinophysis rotundata* | |
| | *Dinophysis tripos* | |
| | *Diplopsalis* sp. | |
| | *Gymnodinium* sp. | |
| | *Gyrodinium* sp. | |
| | *Heterocapsa triquetra* | |
| | Other Dinoflagellates | |
| | *Prorocentrum micans* | |
| | *Prorocentrum minimum* | |
| | *Prorocentrum triestinum* | |
| | *Protoperidinium* sp. | |
| | *Scrippsiella trochoidea* | |

2010. The aggregate matter deposited between each sampling period was collected using a fine brush across the surface of the net, and preserved in 4% sea water formalin. In addition, we used a YSI 556 MPS multiparametric probe to measure hydrological variables: temperature, salinity, dissolved oxygen and turbidity at the immersion level of net n°1 (−5 m depth).

### 2.2. Laboratory work

In the laboratory, because the size range of organisms collected was very wide, two methods of identification and counting were taken. All organisms larger than 200 μm size (hereafter referred to as “Macrotaxa”) were identified and counted under a Nikon SMZ 18 stereo microscope on the entire sample. When concentrations were high, subsamples of 5 ml were taken with a 1–10 ml Eppendorf Research pipette after sample homogenization. The taxa less than 200 μm size (hereafter referred to as “Microtaxa”) were analysed under an inverted Leitz microscope. A subsample of 40 μl was taken with a 10–100 μl Eppendorf Research pipette after sample homogenization. This subsample was deposited between slide and cover slip for identification and counting. In all cases, the ratio between the volume of the analysed sub-sample and the total volume of sample was known, and the abundance values referred to the whole aggregate matter collected on the sampled area of 0.25 $m^2$. The aggregate matter biovolume was measured after 48 h of sedimentation.

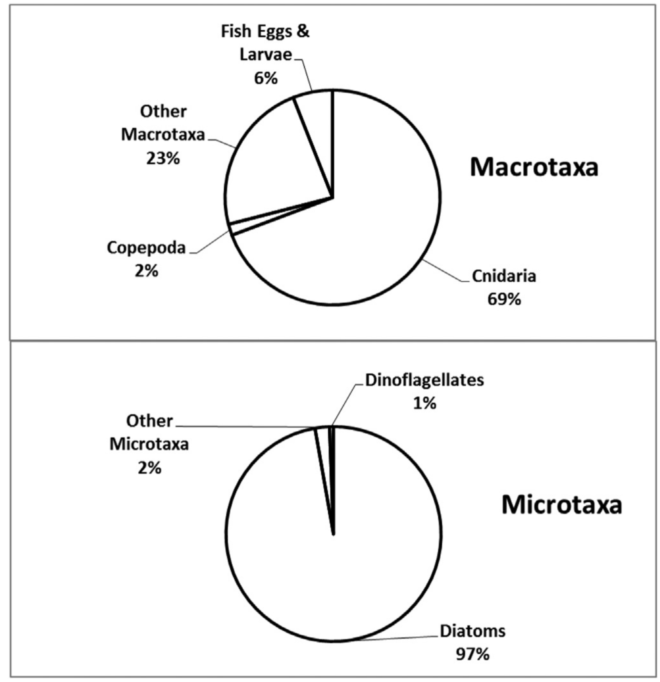


**Fig. 3.** Composition of the aggregates, breakdown by percentage of total abundances.

## 3. Results

### 3.1. The hydrological situation during the aggregate sampling period

Throughout the sampling period, minimal temperatures, in April (12.7 °C) gradually increased to a peak in August (22.6 °C) (Cf. Supplementary material). Conversely, the dissolved oxygen concentrations after reaching their maximum value in April (8.6 mg $l^{-1}$), were reduced to reach minimal values in July (6.6 mg $l^{-1}$) and then remained stable at about 7 mg $l^{-1}$. Water salinity was highly variable and ranged from 33.2 to 36.2. Finally, water turbidity values remained stable (0.5 mg $l^{-1}$) throughout the sampling period except a peak in May (1.6 mg $l^{-1}$).

### 3.2. Taxonomic composition of the aggregate matter

One hundred and eleven taxonomic units were identified in this study (Table 1). Among them, some have a planktonic origin (38 macrotaxa + 51 microtaxa), and were respectively the mesoplanktonic (size range: 200 μm − 20 mm) and microplanktonic (size range: 20–200 μm) components of the aggregates. Pelagic copepods and a number of benthic organisms larvae were highly diversified. Other organisms which are benthic and therefore normally missing from the water column, such as Harpacticoid crustaceans, isopods and amphipods, nematoda or oligochaetes make up the aggregates. The number of these benthic elements represents approximately 20% of all taxonomic units (12 macrotaxa + 7 microtaxa). Finally organic particles of continental origin were found to include very large amounts of Goat Willow *Salix atrocinerea* seed's silks, *Pinus* sp. pollen and mammals hairs. To facilitate graphical analysis, all these taxa were grouped into four macrotaxa (Cnidaria, Copepoda, Eggs & larvae and Others), and three microtaxa categories (Diatoms, Dinoflagellates and Others). Cnidarians represented 69% of the macrotaxa abundance and diatoms make up 97% of microtaxa abundance, so they were both highly dominant organisms (Fig. 3).

### 3.3. Comparative analysis of the abundances

Comparing the abundances of the various components of aggregates revealed significant quantitative differences: they were several orders of magnitude in the four categories of benthic and planktonic microtaxa and macrotaxa (Fig. 4). The smaller components were much more abundant than the larger components.

Microplanktonic components of the aggregates were dominated by diatoms, particularly *Cylindrotheca closterium* as well as a number of heterotrophic protozoa (Acantharia, Tintinnida) and dinoflagellates. Among them were some toxin producers (*Pseudo-nitzschia delicatissima, Dinophysis acuminata, D. rotundata, D. tripos*) typical of French coastal waters (Trainer et al., 2012; Suresh et al., 2014). Fecal pellets, an abiotic component, were also common and abundant in the samples.

Benthic microtaxa were mainly diatoms and sponge spicules. Pelagic copepods, eggs and fish larvae (ichthyoplankton), cladocera (*Evadne* sp., *Penilia* sp., *Podon* sp.) and a wide variety of invertebrate larvae, particularly of crustaceans, annelids and molluscs make up the mesoplanktonic fraction of the aggregates. Benthic macrotaxa consisted mainly of hydrozoan polyps together with other organisms including crustaceans (harpacticoid copepods, isopods and amphipods) and worms (nematoda, oligochaeta). Fish scales were also found in some samples. Finally, some particles of continental origin carried by wind or rivers into the sea were also included in the aggregates. This is basically pollen of *Pinus* sp., *Salix atrocinerea*'s seeds silks and mammalian hairs.

### 3.4. Temporal variability of taxonomic richness and abundances

Total taxonomic richness of the samples, i.e. the number of taxonomic units of all benthic and planktonic micro- and macrotaxa, varied between 15 and 40 per sample (Fig. 5). It was always higher for the planktonic fraction, especially for the smallest particles (“Planktonic microtaxa”). Taxonomic richness of benthic living organisms did not exceed 10 taxa per sample. The highest abundances were found amongst the smallest living organisms that

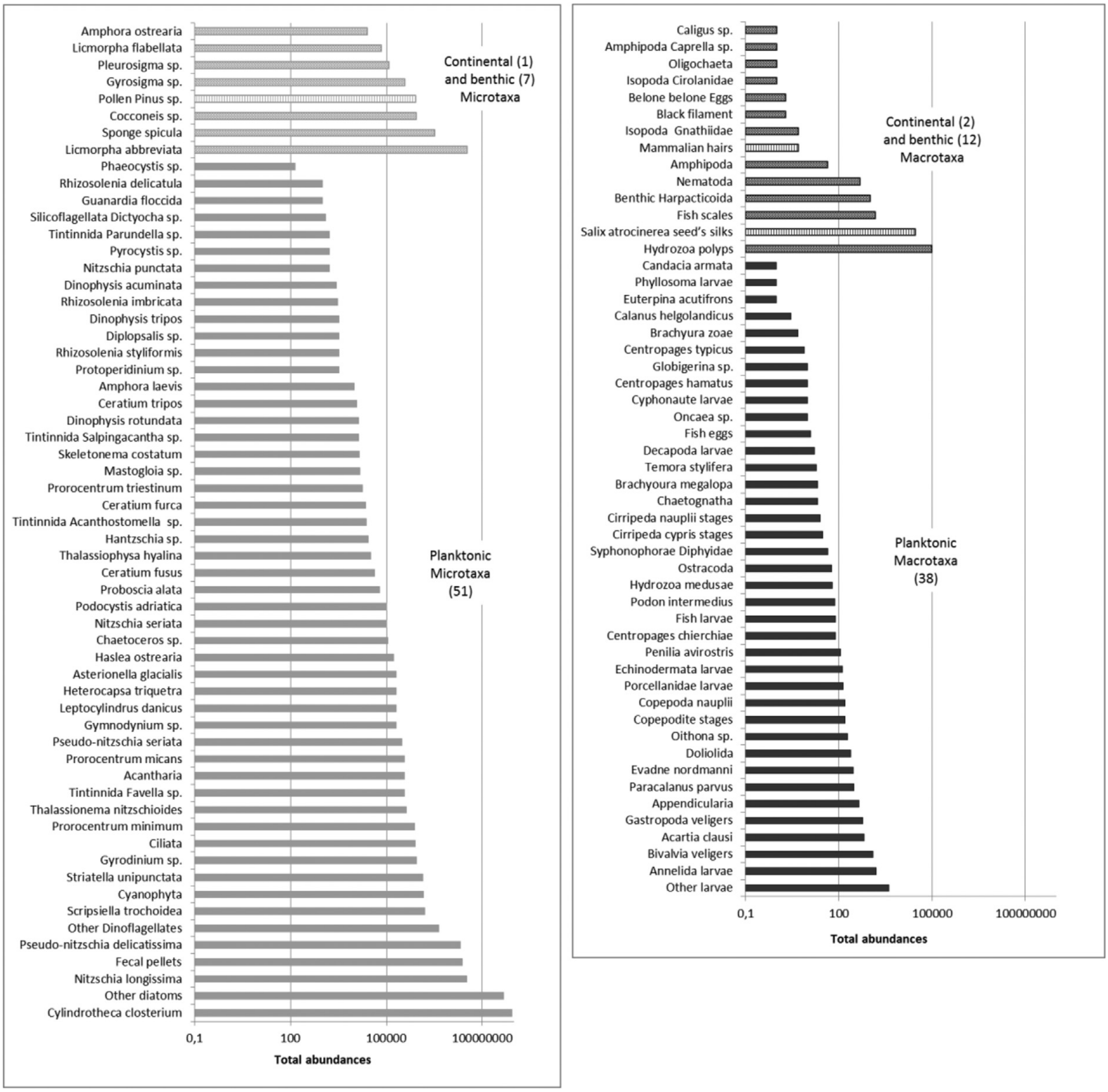


**Fig. 4.** Total abundances cumulated over the 24 samples of the various components of aggregate collected in 0.25 $m^2$ net sampled area and sorted in ascending order.

make up the aggregate, i.e. benthic microtaxa and especially planktonic microtaxa. Throughout the study period they varied between $10^5$ and $10^9$ individuals/0.25 $m^2$. They exceeded four to five orders of magnitude those of macrotaxa whose values were between $10^2$ and $10^4$ individuals. Finally, there was no correspondence between the volume of collected aggregate and abundance of living organisms therein (Fig. 5).

### 3.5. Potentially stinging and irritating organisms entrapped in the aggregates

Potentially stinging and irritating taxa were found in the aggregate samples (Fig. 6). Among them, sponge spicula were siliceous or calcareous particles often fitted with sharp spikes which gives them potentially irritating character despite their small size. Their high levels of abundances ($10^3$–$10^6$ individuals) observed throughout the study period might favour this character when handling fishing nets.

Stinging living organisms were represented mainly by the cnidarians, which all have stinging cells, the cnidoblasts, particularly abundant on their tentacles. The fixed forms (polyp forms) of the hydrozoa, present from April to August, were replaced at the end of summer by free hydrozoa forms (medusae forms) and siphonophorae Diphyidae.

Other organisms such as annelid larvae provided with abundant setae on their parapodia, or juvenile sea urchin larvae fitted with sharp arms were also potentially stinging and irritating, but their levels of abundances remained low.

### 3.6. Presence of organisms which could enhance the aggregation processes

Some other abiotic particles or living organisms can facilitate the aggregation process of particulate organic matter (POM), phytoplankton and even small zooplankton (Fig. 7). The Grey Willow *Salix atrocinerea* seeds with a length of about 1 mm were

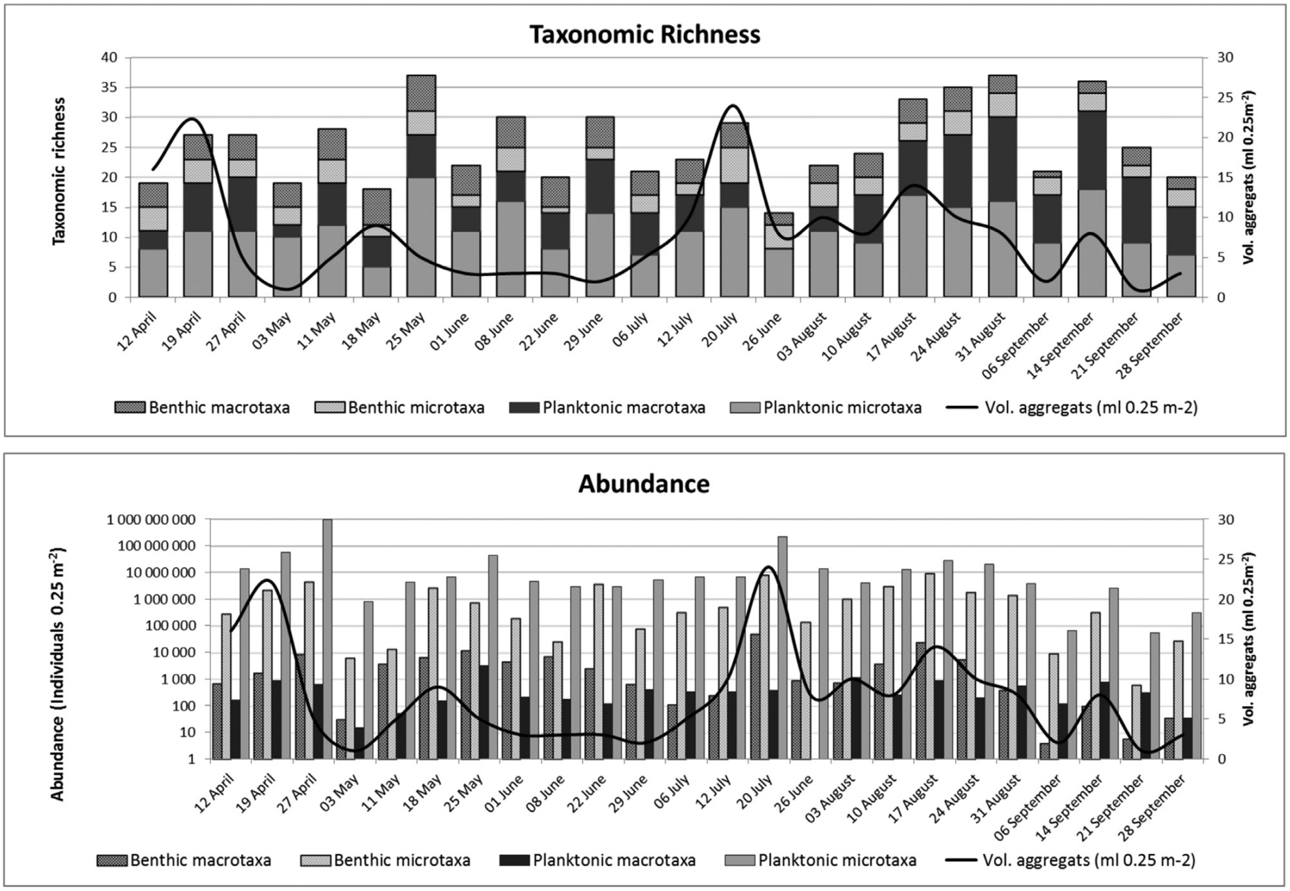


**Fig. 5.** Temporal variation of species richness (above) and abundance (below) of the four major components of aggregates throughout the study period (April–September 2010).

surrounded by a ring of ~50–100 trifid bristles angled on their base, which remain together despite their removal by the air or by the flow of inland waters to the sea through estuaries. They were particularly abundant in spring between April and July, and formed a trap by retaining and aggregating particulate organic matter between their bristles. Some big eggs (diameter: 3 mm) of Garfish *Belone belone* carrying at their surface many long filaments were also occasionally identified and have the same agglomerative properties of particulate organic matter (Aizpuru et al., 2007). The retention of POM was also provided by the fine network of hydrozoan polyps unfolding throughout the summer period or by mucous colonies of the Primnesiophyta *Phaeocystis* sp. in autumn (Fig. 7). In some samples, retention of organic matter was also provided by a tight network of benthic filamentous algae that have not been identified and accounted for, due to their low abundance.

## 4. Discussion

### *4.1. The planktonic components of the aggregates*

The results of our study show that the aggregates formed on the Basque coast are mainly composed of planktonic organisms whose size range is particularly wide.

The smallest phytoplanktonic organisms, especially diatoms and dinoflagellates are the most abundant. The lack of relationship between the volume of aggregates collected on the sampler and the abundances of taxa can be explained firstly by the wide size range of organisms identified, and secondly by the preponderance of the small taxa forming these aggregates. All other larger planktonic organisms (mesoplankton), whether holoplanktonic organisms living throughout their life cycle in the water column or meroplankton are also incorporated in the aggregates. Despite significant swimming abilities, these organisms remain near the mucilaginous deposits which gradually accumulate on the sample set in the water column.

Mesozooplankton is involved in different ways in the use or formation of mucilaginous aggregates. Some copepods (*Candacia* sp., *Oncaea* sp., *Oithona* sp.) found in our samples prefer to colonize the pelagic aggregates which they feed on (Green and Dagg, 1997). In the northern Adriatic, polychaete annelid larvae can be dominant in marine snow they use as a food source (Bochdansky and Herndl, 1992) and we also denote widely this dominance in our samples.

### *4.2. The benthic components of the aggregates*

Although their diversity and abundances are low, the presence of benthic elements in the aggregates may seem surprising, but two considerations need to be taken into account here.

Firstly, the withholding sampling stations are located near the coast, in shallow waters, where long shore currents generated by waves are large and permanent. They induce resuspension of a part of the benthic biological matter which ends up temporarily in the pelagic compartment (D'Elbée and Castel, 1982; Dupont and Lafite, 1986; D'Elbée and Castel, 1991; Giani et al., 2005c). Taxa affected by this resuspension in the water column are living organisms (some benthic harpacticoids or diatoms, nematodes, oligochaetes, *Belone belone* eggs) or abiotic components such as sponge spicula and fish scales. All these particles are gradually deposited on the sampler.

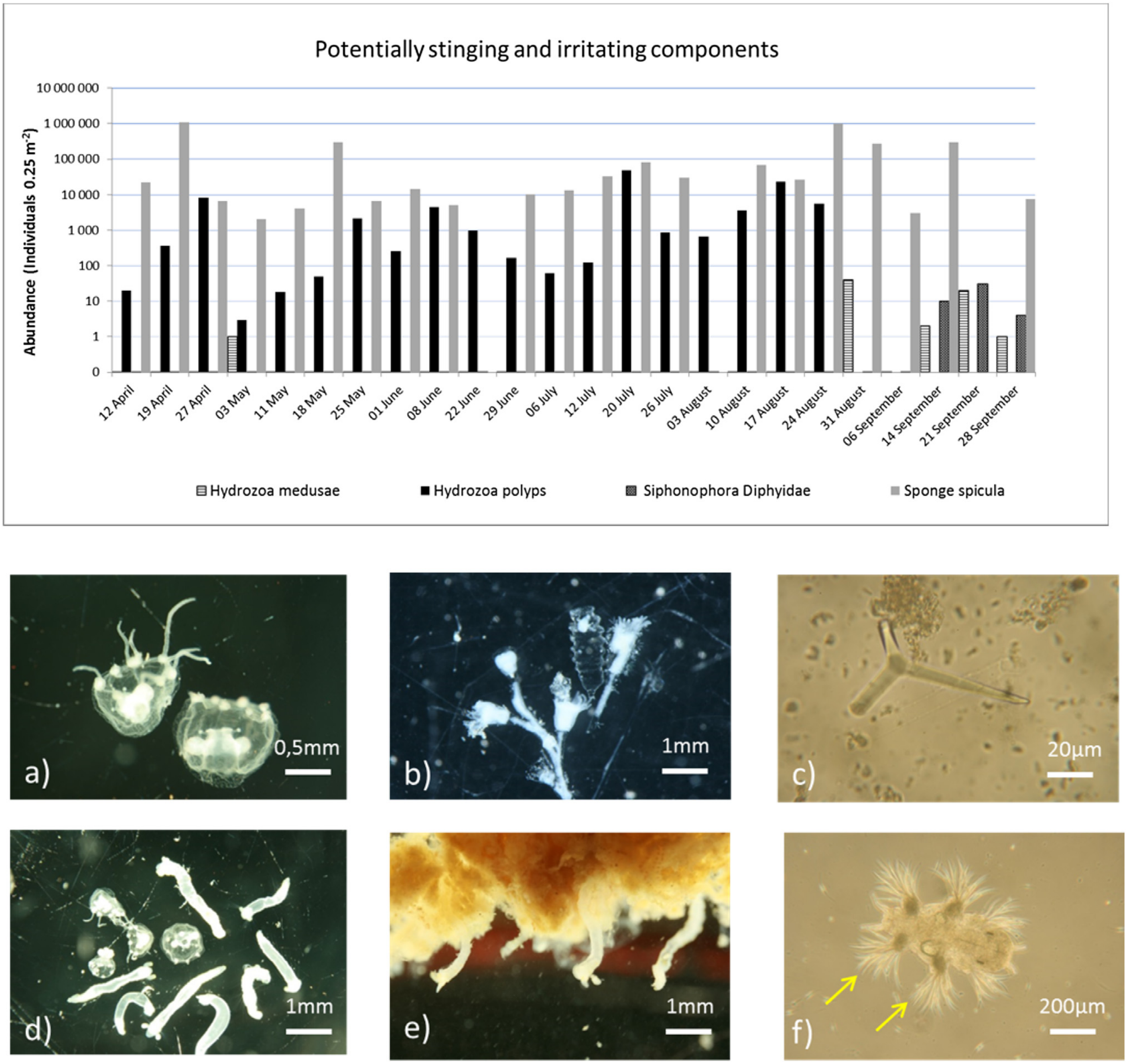


**Fig. 6.** Above: Temporal variation of potentially stinging and irritating components of the aggregates throughout the study period (April–September 2010). Below: Photographs of potentially stinging and irritating components of the aggregates: a) Anthoathecate hydromedusae; b) Thecate Hydroid polyps and gonotheca; c) Sponge spicula; d) Magelonidae polychaete larvae with hydromedusae isolated from the aggregates; e) Magelonidae polychaete larva included in the matrix of the aggregates; f) Nereidae polychaete larvae with numerous parapodial setae (arrows).

Secondly, some elements such as polyps of hydrozoans usually fixed on the benthic substratum were also found in abundance in the gelatinous matrix covering our sampler. Their constant presence may result from a progressive colonization by planula larval settlement dropped by planktonic medusae. The significant levels of abundance of this last stage found in our samples could support this hypothesis.

### 4.3. The continental components of the aggregates

Mammal's hairs, Grey Willow *Salix atrocinerea* seeds or pollen of *Pinus* sp. have a continental origin. They are carried by wind (anemophilous) or by water runoff coming from the continent. *Salix atrocinerea* is widely distributed in Europe down to North Africa (Saule, 2002). This pioneer species colonizing widely all wetlands and marshy environments is abundant throughout the south-west of France, and particularly in the Basque Country (Aizpuru et al., 2007). The high levels of abundances of Grey Willow *Salix atrocinerea* silk's seeds in the aggregates correspond to the period of seed dispersal initiated by the first warm weather of spring. Thus, the abundance of these seeds in water and consequently in aggregates depends on both the state of the local hydrographic network (floods, low water) and weather conditions (heat, wind) for seed dispersal.

### 4.4. Potentially stinging and irritating properties of the aggregates

Few observations were made on the stinging and irritating

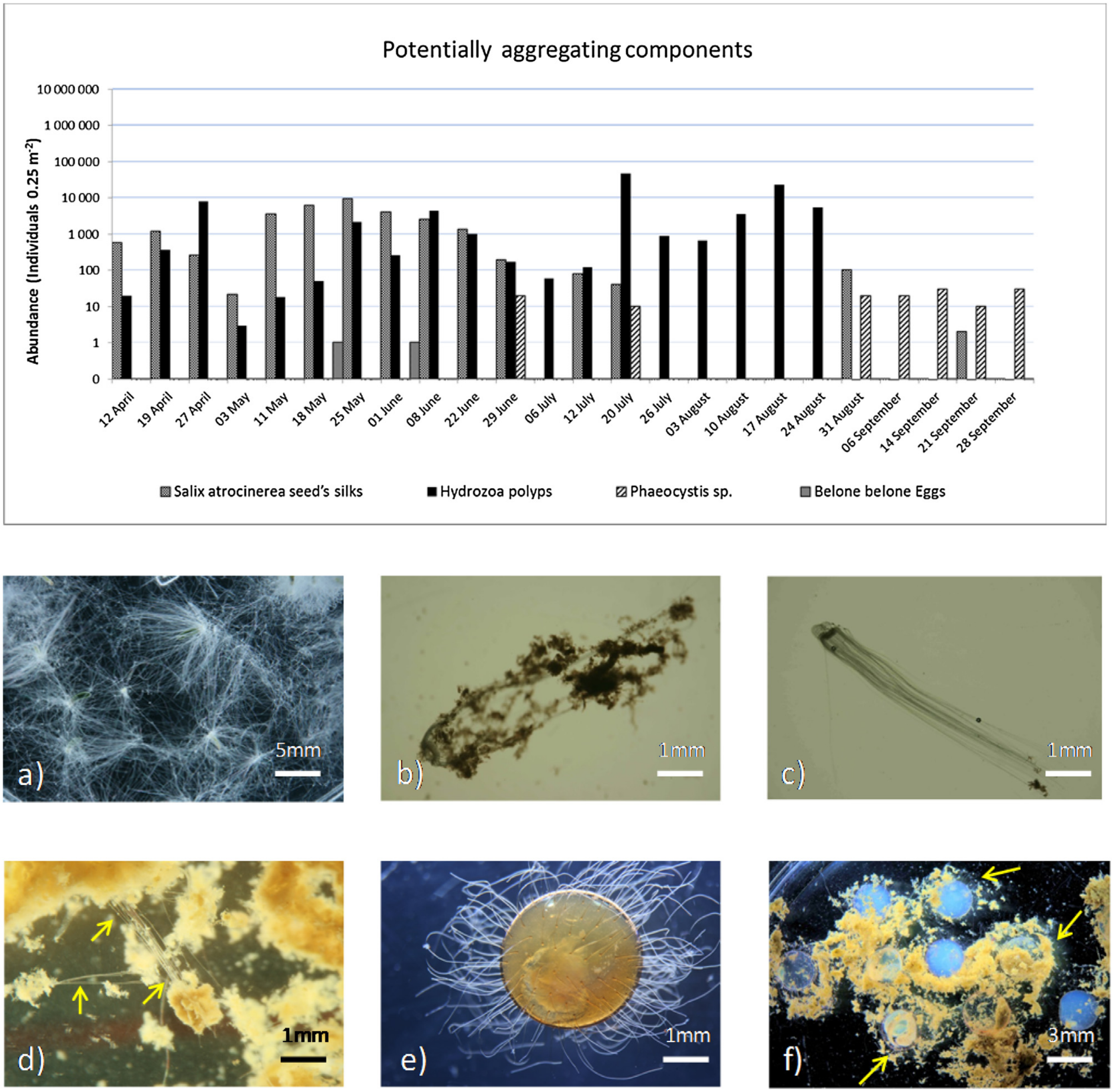


**Fig. 7.** Above: Temporal variation of potentially aggregating components throughout the study period (April–September 2010). Below: Photographs of potentially aggregating components: a) Goat Willow Salix atrocinerea seeds taken from the plant; b) Seed's silks crown scavenging particulate organic matter; c) Seed's silks crown clean specimen; d) Network of filaments (arrows) scattered in the aggregating particulate organic matter; e) Garfish *Belone belone* egg with many long filaments; f) Other eggs of garfish *Belone belone* which agglomerate particulate organic matter and phytoplankton with their filaments (arrows).

properties of mucilaginous aggregates in the marine environment. In the Mediterranean, where these aggregates are the most common and best-studied, dermatological inflammations and irritations are rare (Giani et al., 2005c). During our study, testimonies of fishermen revealed some cases of irritation due to prolonged contact of unprotected hands with nets covered with aggregates and seawater. The potentially stinging elements identified in our study partially explain some of the dermatological reactions observed among fishermen in the Basque coast.

### 4.5. Some hypotheses on pelagic aggregation process

In the light of the wide variety of elements constituting the aggregates on the Basque coast and their significant size range, we can consider that this substance results from two processes of aggregation of living and inert particulate matter that develop at different scales (Fig. 8).

The aggregation of the organic matter can be a process involving physiological and biochemical mechanisms such as exudation of sticky and biogenic transparent exopolymer particles (TEP), or their precursors (Malpezzi, 2010; Passow, 2002, 2012). Such mechanisms (Fig. 8, (1)) have been widely described in recent years (Wurl et al., 2011; Barrera-Alba et al., 2012; Giani et al., 2012; Hoppe, 2013; Turner, 2002, 2015). The dimensional scale of these processes is of the order of microns (Giani et al., 2005c). In the Adriatic Sea, diatoms blooms exuding TEP causing macroaggregates in the water

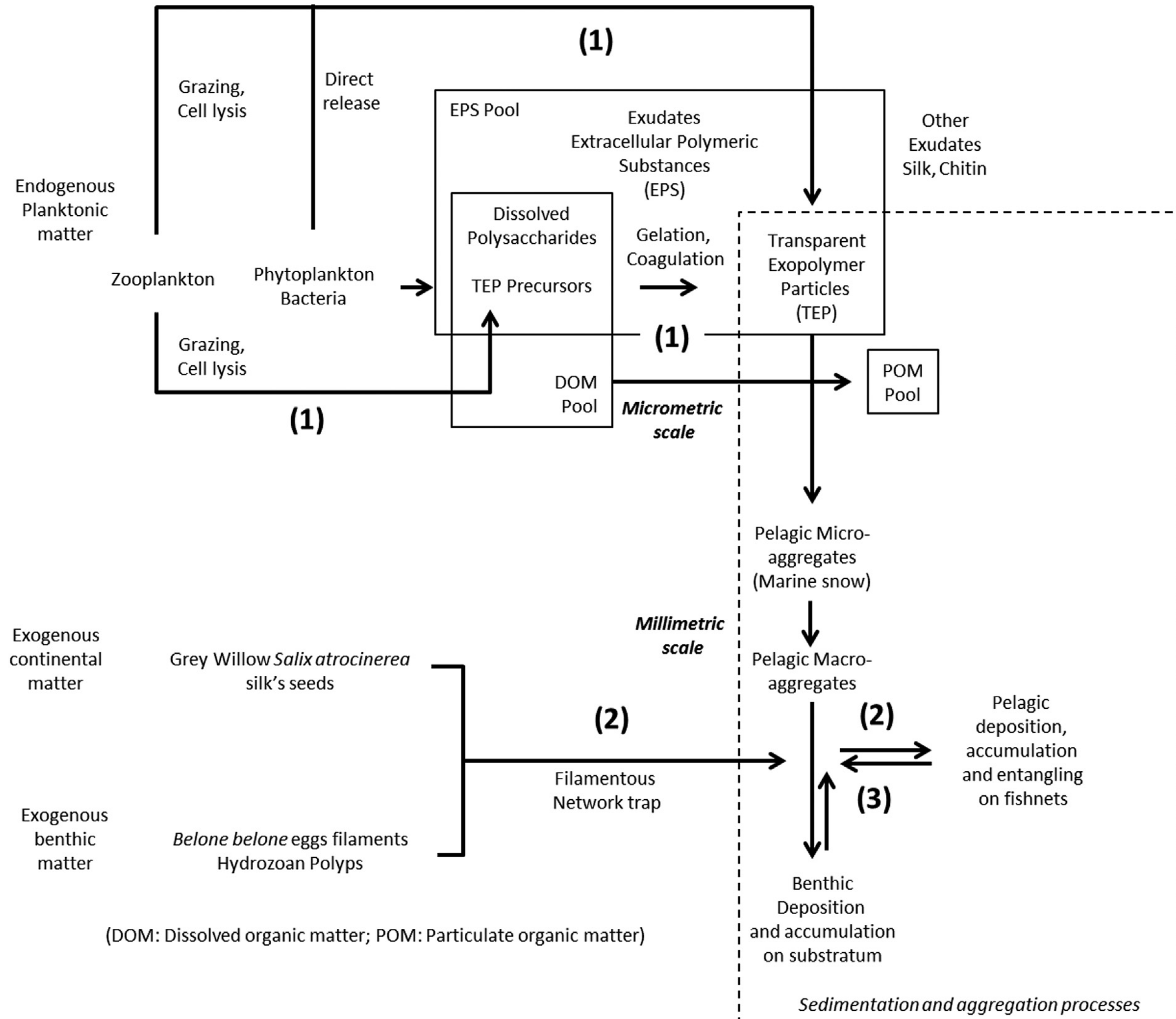


**Fig. 8.** Diagram summarizing hypothetical formation steps and processes of aggregates in marine pelagic environment off the Basque coastline. (1) Aggregation at micrometric scale involving physiological and biochemical processes. (2) Aggregation at millimetric scale involving mechanical processes. (3) Resuspension processes of benthic and pelagic deposited and accumulated POM.

column (Radić et al., 2005) consist of the same species (especially *Cylindrotheca closterium*, *Skeletonema costatum*, *Pseudo-nitzschia seriata*, *P. delicatissima* and *Asterionella glacialis*) as those contained in the aggregates on the Basque coast. These microprocesses involved in the formation and development of marine snow (Kiørboe, 2001), pelagic (Giani et al., 2012; Hoppe, 2013) and benthic aggregates (Giuliani et al., 2005; Lorenti et al., 2005; Aktan and Topaloglu, 2011) have not been covered in this study. It is noteworthy that the highest abundance of microalgae found in the aggregates on the Basque coast concerned *Cylindrotheca closterium*, a planktonic and epipelic diatom which is a major producer of TEP (Staats et al., 2000; Najdek et al., 2005). Regarding zooplankton, the production of fecal pellets by mesozooplankton increases the stock of particular organic matter in water and also contributes to the formation of aggregates (Dupont and Lafite, 1986; Turner, 2002, 2015). Grazing activity of herbivorous plankton especially copepods can regulate the amount of TEP in the water column which therefore in turn increases the levels of aggregation of particular organic matter (Prieto et al., 2001).

A second aggregation process appears in this study to complete the first one. It is induced by the presence of filamentous benthic (Garfish *Belone belone* eggs filaments; Hydrozoan Polyps) and continental (Grey Willow *Salix atrocinerea* silk's seeds) components forming a dense tangled network trapping particulate organic matter (Fig. 8, (2)). In fresh waters, Extracellular Polymeric Substances (EPS) include silks structure and are used in tube construction, to make nets used in feeding or as a means of fixing systems (Wotton, 2011) i.e. with similar properties to those included in the aggregates of the Basque coast, despite their different origins. The dimensional scale range of this mechanical process is of the millimetre.

### 4.6. The pelagic deposition and accumulation of aggregates on fishing nets

Instead of remaining stationary or drifting in the pelagic environment as commonly observed (Giani et al., 2012; Hoppe, 2013; Turner, 2015), some of these aggregates undergo on the Basque coast a pelagic deposition and accumulation because of the presence of rigid structures set in the water column. On the Basque coast, the fishing gears used by fishermen are either linear structures as longlines or mesh structures such as driftnets, all in invisible nylon. Deposition of aggregates on the nets gradually forms a compact and sticky substance, making them more visible and ineffective for catching fish.

The sampler provides a fixed grid structure on which planktonic organisms with reduced natatory abilities can settle and accumulate. These midwater deposition and accumulation, like those of the sea floor, depend on coastal current patterns. In the northern Adriatic Sea, water circulation especially horizontal flows is decisive in the formation of aggregates and their dispersion in the water column. When the flow intensity or direction increases the residence time of water masses, this induces the development of pelagic mucilage (Grilli et al., 2005a, b). A strong local hydrodynamism may also resuspend particulate organic matter deposited and accumulated on the fishing nets or benthic substratum by the sedimentation process (Fig. 8 (3)).

Using a specific device permanently immersed in the water column was justified because it allowed us to collect exactly what the local fishermen bring in their nets. In addition, the sampling strategy we used of leaving our sampler upright for several days in the water column replicates the technique used by fishermen to catch fish.

The organic matter collected is the result of an aggregation process and/or deposition of organic matter that is progressive over time, whose duration in our study is of the order of one week (see Material & Methods), held on a solid structure located in the water column. This particular methodology, which integrates a temporal component of the aggregative process is quite different from the other methodology which consists in collecting samples aggregates of organic matter or plankton at regular intervals in the water column with a sampling bottle or plankton net (Radić et al., 2005; Danovaro et al., 2005; Malpezzi, 2010; Giani et al., 2012).

Unfortunately, it was not possible for technical and logistical reasons to carry out both plankton and aggregate matter by sampling the water column, and taking organic matter deposited on the device, in order to compare the composition and evolution of biological communities in these two compartments. Indeed, we can assume that the sedimentation, deposition and accumulation processes are not identical for all living or inert particles present in the water column. Bochdansky and Herndl (1992) showed that in northern Adriatic Sea plankton communities within the aggregates and the surrounding pelagic environments can be quite different in their composition and abundance.

## 5. Conclusion

As with the nets used by the fishermen, the sampler used experimentally to catch aggregates seems to play the role of a trap accumulating and concentrating the entire particulate fraction suspended in the water column (seston). Exogenous elements of benthic or continental origin are added to strictly planktonic components living close to the sampler. They form together a dense tangled network trapping particulate organic matter. The particular matter deposited and accumulated on vertical fishing nets or drifting lines can be considered as a temporary ecosystem artificially maintained in the water column by the activities of local fisheries. Under these particular conditions, a number of species of benthic origin can ensure their development and fixation in the surrounding pelagic environment. These exogenous organisms further increase the already high level of biodiversity of this particular environment, which is maintained by inputs from the surrounding plankton community. Finally, the biochemical processes of aggregation and the role of nano-and bacterioplankton are not covered in this work, and will be the subject of further studies.

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ecss.2016.01.023.

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