Mediterranean Marine Science

Vol 18, No 1 (2017)

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doi: [10.12681/mms.1806](https://doi.org/10.12681/mms.1806)

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net
DOI: http://dx.doi.org/10.12681/mms.1806

Fouling assemblages associated with off-coast aquaculture facilities: an overall assessment of the Mediterranean Sea

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Handling Editor: Maria Thessalou-Legaki

Received: 8 June 2016; Accepted: 27 October 2016; Published on line: 13 February 2017

Abstract

Aquaculture facilities provide a suitable habitat for a wide group of marine species that are able to colonise and settle on artificial structures. This study aims to determine the composition of fouling communities in off-coast facilities, with special emphasis on motile epifauna and amphipods as a main group. Seventeen aquaculture sites were sampled along the Mediterranean coast, collecting samples by scraping fouling organisms directly from the ropes. Additionally, thirty publications were reviewed, in order to assess the similarity of aquaculture fouling with other fouling communities. Our results reflect that amphipods accounted for more than 80% of the epifauna associated with farms fouling communities. This characteristic epifauna was defined by seven amphipod species well-adapted to colonise and survive in these off-coast habitats. Most species common in farms have also been commonly found in harbours, marinas, and/or offshore on turtles, buoys or platforms etc., showing a great resistance to polluted areas but also to dispersal via rafting on floating objects. In this study, two exotic species were identified: *Caprella scaura* and *Stenothoe georgiana*, the latter being the first report from the Mediterranean Sea. The presence of *Jassa slatteryi* was also confirmed, underestimated until now in the Mediterranean.

Keywords: fish farms, macrofauna, amphipods, exotic species.

Introduction

The practice of intensive aquaculture by many countries has constantly increased during the last five decades (FAO, 2014). Mediterranean aquaculture is characteristically developed in off-coast areas, between 0.5 to 3 km from the shore and between 10 to 50 m water depth (Holmer, 2010), where floating net cages are the main aquaculture method for fish growth and long-lines for shellfish culture.

These aquaculture facilities work as artificial structures out at sea, which are moored to a particular position and remain there for long periods. All the structures, nets, ropes and buoys, serve as surface to colonising and settlement of coastal species transported by sea currents or through other dispersal strategies, forming the collectively termed biofouling (Sarà *et al.*, 2007; Fitridge *et al*., 2012). The fouling community on farms differs from other off-coast fouling communities in various ways. The main differences are related to the floating features of the installation, in which the benthic communities are influenced by exposure to the hydrodynamic conditions (Perkol-Finkel *et al*., 2008), and to the high food and nutrient levels originating from production releases (Cook *et al*., 2006 and references therein).

Colonising organisms result in added weight and drag to the structures, reducing water flow and affecting cage behaviour in the case of fish farms (Swift *et al*., 2006) or damaging the farmed organisms in the case of shellfish farms (Antoniadou *et al*., 2013). They involve additional economic cost to the aquaculture industry because of the need for cleaning to prevent negative effects on production (Ross *et al*., 2004; Willemsen, 2005). Farms staff carries out a routine mechanical cleaning of the structures, during which most of the organisms are removed. This procedure leads to opportunities for colonisation by additional species, initiation of ecological succession and absence of climax community structure (Greene & Grizzle, 2007; Fitridge *et al*., 2012), and this fact is the factor that differentiates farm fouling most from other fouling communities such as at harbours or oil platforms.

A wide range of literature has been published about fouling communities that develop on immersed fish-cage nets or net panels at farms (e.g. Hodson *et al*., 1995; Cook *et al*. 2006; Guenther *et al*., 2010 and references therein). Bivalves, especially mussels, algae, hydroids and ascidians are the main fouling organisms found on aquaculture fish cages (Sarà *et al*., 2007; Fitridge *et al*., 2012) and shellfish long-lines (Antoniadou *et al*., 2013). These benthic sessile organisms can act as ecosystem engineers, creating biogenic habitats through the provision of an additional biofouling surface, shelter or food for associated flora and motile fauna (Roberts *et al*., 2008 and references therein). Moreover, macroinvertebrate fauna present in fouling are able to assimilate the organic matter derived from coastal fish farms, reducing production waste and its accumulation on the seabed (Gonzalez-Silvera *et al*., 2015). However, alongside native species, alien species could also reach these off-coast structures (Minour *et al*., 2012). Off-coast farms are thus potential vectors for introductions and secondary spread of alien species (Fernandez-Gonzalez & Sanchez-Jerez *et al*., 2013).

Published information on motile fauna associated with aquaculture fouling is still scarce. Several studies highlight the presence of amphipods, especially caprellids, occurring in high numbers and/or biomass in fish farms (Cook *et al*., 2006; Greene & Grizzle, 2007; Guenther *et al*., 2010; Fernandez-Gonzalez *et al*., 2014; Gonzalez-Silvera *et al*., 2015), but little is known about the species involved and their distribution, particularly in the Mediterranean Sea.

The overall objective of the present study was to explore the composition of fouling assemblages on aquaculture facilities, mainly fish farms, around the Mediterranean Sea, aiming to: (1) determine the species composition of sessile organisms acting as ecosystem engineers; (2) assess the importance of amphipods as the main motile fauna group associated with fish farm fouling in the Mediterranean; (3) define amphipod species composition, with special emphasis on the presence of exotic species, evaluating possible large-scale changes from western to eastern Mediterranean; (4) analyse the interaction between biogenic habitats and abundance of the main epifauna species; and finally, (5) compare aquaculture fouling with other fouling communities such as those in harbours and marinas, and on offshore structures and floating elements.

Materials and Methods

Sample collection

A total of seventeen off-coast aquaculture facilities were sampled around the Mediterranean coast as part of a qualitative study: nine in Spain (one in Málaga, one Granada, one Murcia, four Alicante, two Tarragona), one in Italy (Follonica), two in Tunisia (Ghar el Mesh and Mahdia), two in Malta (Qawra and Il-Hofriet), two in Croatia (Brac and Ugjlan) and one in Greece (Crete). The sites included sea cages stocked with farmed gilthead sea bream *Sparus aurata* and European sea bass *Dicentrarchus labrax*, and young Atlantic bluefin tuna *Thunnus thynnus* from the wild, shellfish longlines stocked with *Ostrea edulis*, and an inactive fish farm, which still has all its structures except net-pens and had not been in production for the previous two years. More information about each farm, such as locality, sampling date, cultured species and number and type of replicates is included in Table 1. Main differences between the three kinds of farms are related to the use of an external source of feed (formulated fish pellets for sea bream and sea bass, whole bait fish for tuna and no external feed for shellfish), the composition of faeces and pseudo-faeces (carnivorous species vs filter feeders) and the location and size of the farms (larger and deeper for tuna farms). Studied farms can be also influenced by general sea water features of the two Mediterranean basins separated by the Sicilian Channel, where sea water of

Table 1. Information on sampling work, including location, sampling date and cultured species from each aquaculture facility, as well as number of replicates and kind of habitat.

Country	Locality	Latitude /Longitude	Date	Cultured species	Replicates	Habitats
Spain	Malaga	36° 42.32’ N / 4° 21.51’ W	May 2010/ November 2012	Sea bass –Sea bream	2	Hydroids, Mussels
Spain	Granada	37º 13.79’ N / 01º 44.80’ W	May 2010	Sea bass –Sea bream	1	Non dominant species
Spain	Murcia	37º 48.93’ N / 0º 41.73’ W	May 2010	Sea bass –Sea bream	1	Mussels
Spain	Alicante A	38° 6.01’ N / 0° 36.02’ W	June 2010	Inactive	2	Non dominant species
Spain	Alicante B	38° 5.32’N / 0° 36.06’ W	July 2010	Sea bass –Sea bream	3	Algae, Hydroids, Mussels
Spain	Alicante C	38° 5.24’ N / 0° 36.02 W	September 2010/ March 2011	Sea bass –Sea bream	4	Algae, Hydroids, Mussels, Anemones
Spain	Alicante D	38º 9.03N / 0º 32.12 W	July 2011	Oyster	2	Algae, Mussels
Spain	Tarragona A	40º 52.73’ N / 0º 48.50’ E	October 2010	Sea bass –Sea bream	1	Non dominant species
Spain	Tarragona B	40º 31.86’ N /0º 35.28’ E	October 2010	Sea bass –Sea bream	2	Non dominant species
Italy	Follonica	42° 54.86’ N / 10° 38.54’ E	April 2011	Sea bass –Sea bream	1	Non dominant species
Malta	Qawra	35º 97.1’ N / 14º 41.5’ E	October 2010	Tuna	1	Non dominant species
Malta	Il-Hofriet	35º 83.98’ N / 14º 56.4’ E	February 2011	Tuna	1	Non dominant species
Croatia	Brac	43°17.73′ N / 16° 27.60′ E	October 2010	Tuna	4	Non dominant species
Croatia	Ugljan	44° 01.67′ N / 15° 13.17′ E	October 2010	Tuna	4	Non dominant species
Greece	Crete	35° 35.05’ N / 25°14.99′ E	September 2010	Sea bass –Sea bream	3	Algae, Hydroids, Mussels
Tunisia	Ghar el Melh	37° 19.0’ N / 10°16.83’ E	May 2013	Sea bass –Sea bream	1	Algae
Tunisia	Mahdia	35° 27 34’ N / 11°05.68’ E	May 2013	Sea bass –Sea bream	1	Algae

eastern basin is warmer, saltier and more oligotrophic than that of the western basin (Millot & Taupier-Letage, 2005; Tanhua *et al*., 2013).

Samples were collected from each farm by scraping fouling organisms from shallow mooring ropes (1-10 m depth). At least 20 cm of each rope was thereby cleared per sample. The off-coast hydrodynamic conditions caused considerable movement of all structures, impeding a quantitative analysis due to the possible loss of individuals. The samples were sieved through a 500 µm mesh with seawater and subsequently preserved in 4% formalin seawater solution. In the laboratory, all motile epifaunal species and sessile organisms were sorted and identified, if possible to species level. Epifaunal individuals per sample were counted and sessile organisms were dried at 100ºC and weighed.

Statistical analysis

Since Amphipoda was the most abundant taxon in epifaunal assemblages, only data for these species were statistically analysed exclusively. A non-metric multidimensional scaling (MDS; Clarke & Warwick, 1994) was used to explore differences in assemblage composition along the Mediterranean coast. Since it was considered a qualitative study, relative abundances of amphipods formed a matrix of similarities using the Bray–Curtis coefficient. The percentage similarities procedure (SIMPER) was then used to calculate the contribution of each species to the similarity in each zone: western, central and eastern Mediterranean. Multivariate statistical analyses were performed using PRIMER-E software (PRIMER software; Clarke & Gorley, 2006).

Sessile organisms, considered as ecosystem engineers, were classified into five classes of habitats: algae, hydroids, bryozoans, bivalves and others. A redundancy analysis (RDA) was used as an ordination method to study the relationship between amphipod species and habitat variables. Due to differing sampling procedures, the total amount of each habitat could not be calculated in some samples and RDA was performed including Spanish, Tunisian and Croatian samples. The resulting ordination biplot approximated the weighted average of each species with respect to each of the habitat variables, both represented as arrows. The length of these arrows indicated the relative weight of that factor, while the angle between arrows indicated the degree of correlation between two environmental factors. A Monte Carlo test with 999 permutations ensured the significance of the canonical axes. This analysis was performed using the software package CANOCO 4.5 (ter Braak & Smilauer, 2002).

Literature analysis

A comparison of similarity among amphipod assemblages associated with fish-farm fouling, harbours or marinas and other marine elements such as offshore platforms, floating devices or turtles was conducted based on published data on their occurrence. Thirty publications were reviewed (25 peer-reviewed articles, 1 book and 4 conference papers), limited to studies carried out in the Mediterranean Sea.

Results

Sessile organisms at aquaculture facilities were mainly represented by eleven taxa of algae (*Jania* sp., *Polysiphonia* spp., *Spyridia filamentosa*, *Ceramium* spp., *Antithamnion cruciatum, Sphacelaria* sp., *Cladophora* spp., *Acinestospora crinita*, *Gelidium crinale, Hydroclathus clathratus, Cystoseira compressa* as more representative), five hydroids (*Obelia* sp., *Tubularia* sp., *Eudendrium sp*., *Aglaophenia* sp., *Pennaria disticha*), three bryozoans (*Aetea anguina*, *Bugula neritina*, *Schizoporella errata*), four bivalves (mainly *Mytilus galloprovincialis*, *Ostraea edulis*, *Musculus* spp., *Hiatella arctica*), one anthozoan (*Actinia* spp.), one echinoderm (*Antedon* sp.) and one crustacean (*Chthamalus* sp.).

A total of 40878 individuals from motile epifaunal assemblages were identified. Amphipods, with 37644 specimens representing between 79.2 – 99.5 % of the macrofauna associated with fish-farm fouling, were the dominant group above polychaetes (0.1- 28.9 %), tanaidaceans (0.03-15.9%) and pantopods (0.05 – 5.2 %) (Table 2). Twenty-two species of amphipods were identified, of which seven were classified as frequent in farms fouling, being present in up to 50 % of the samples: *Elasmopus rapax*, *Caprella equilibra*, *Stenothoe tergestina*, *Jassa marmorata*, *Jassa slatteryi*, *Ericthonius punctatus* and *Caprella dilatata* (Table 3). These seven species also showed the highest dominance values in the whole amphipod assemblage (Table 3). Two exotic species were detected in this study: *Caprella scaura* and *Stenothoe georgiana* (Fig. 1), the latter being reported for the first time in the Mediterranean Sea. Additionally, this study confirms the presence of *J. slatteryi* in the Mediterranean; it is the second time this species is reported for this area, with seven new records: three in Spain (Granada, Alicante and Tarragona), two in Malta (Qawra and Il-Hofriet) and two in Croatia (Brac and Ugjlan).

Table 2. Percentage contribution of the main taxonomic groups to epifauna abundance.

Taxonomic group	% Dominance
Amphipoda	79.24 - 99.50
Polychaeta	0.10 - 28.91
Tanaidacea	0.03 - 15.90
Pantopoda	0.05 - 5.23
Nematoda	0.03 - 1.31
Others (Gastropoda, Decapoda, Nemertea Echinodermata, Isopoda, Platyhelminthes and Sipuncula)	0.01 - 1.42

Table 3. Amphipod species present in fish-farm fouling in this study.

Species	Abbrev.	% Freq.	% Mean Dom.
Ampithoe ramondi Audouin, 1826	Aramo	6.06	0.31
Aora spinicornis Afonso, 1826	Aspin	3.03	0.01
Aora gracilis (Bate 1857)	Agrac	3.03	0.04
Caprella dilatata Krøyer, 1843	Cdila	54.55	9.89
Caprella equilibra Say, 1818	Cequi	81.82	7.53
Caprella grandimana (Mayer, 1882)	Cgran	3.03	0.55
Caprella scaura Templeton, 1836	Cscau	27.27	5.59
Apocorophium acutum (Chevreux, 1908)	Aacut	6.06	1.24
Monocorophium insidiosum (Crawford, 1937)	Minsi	3.03	0.00
Cymadusa filosa Savigny, 1816	Cfilo	6.06	0.29
Elasmopus rapax Costa, 1853	Erapa	96.97	19.50
Ericthonius punctatus (Bate, 1857)	Epunc	63.64	10.54
Gammaropsis maculata (Johnston, 1828)	Gmacu	24.24	2.61
Hyale perieri (Lucas, 1849)	Hperi	6.06	0.13
Jassa marmorata Holmes, 1905	Jmarm	75.76	17.50
Jassa slatteryi Conlan, 1990	Jslat	75.76	10.53
Stenothoe georgiana Bynum & Fox, 1977	Sgeor	12.12	1.19
Stenothoe cattai Stebbing, 1906	Scatt	12.12	2.30
Stenothoe tergestina (Nebeski, 1881)	Sterg	81.82	12.52
Stenothoe valida Dana, 1852	Svali	33.33	0.57
Phtisica marina Slabber, 1769	Pmari	3.03	0.00

The MDS analysis (Fig. 2) showed a separation of amphipod assemblages among western, central and eastern Mediterranean regions. Samples from the Adriatic Sea (Croatia), however, were more similar to those from the eastern Mediterranean (Greece). The SIMPER analysis showed that the species contributing most to the similarity of western Mediterranean were *J. marmorata*, *C. equilibra*, *S. tergestina* and *J. slatteryi*, while for the eastern Mediterranean they were *E. rapax*, *S. tergestina*, *A. ramondi* and *S. cattai*. In the central Mediterranean, they were *C. dilatata* and *E. puntatus* in the Ionian Sea and mainly by *E. rapax*, *C. scaura* and *G. maculata* in the Adriatic (Table 4).

No significant differences were found between habitat variables and axes in the RDA analysis. However, some species seemed to be related to certain habitats. For example, *E. rapax* tends to appear in habitats with high presence of algae or hydroids, *C. equilibra* with bivalves and hydroids and *J. marmorata* and *J. slatteryi* with bryozoans (Fig. 3).

The comparison of species found in aquaculture fouling with other fouling assemblages such as those found in harbours, floating elements or off-coast structures is shown in Figure 4. *Elasmopus rapax*, *E. puntatus* and *J. marmorata,* three of the most common species at farms,

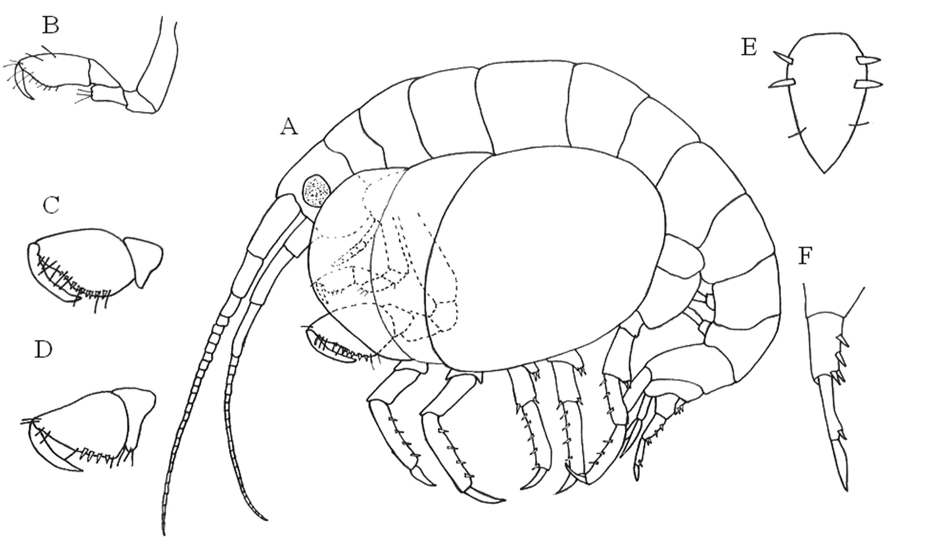

Fig. 1: *Stenothoe georgiana* (original drawing) A: Habitus of *S. georgiana* (male); B. Gnathopod 1; C: Gnathopod 2 (male); D: Gnathopod 2 (female); E: Telson and F: Uropod 3.

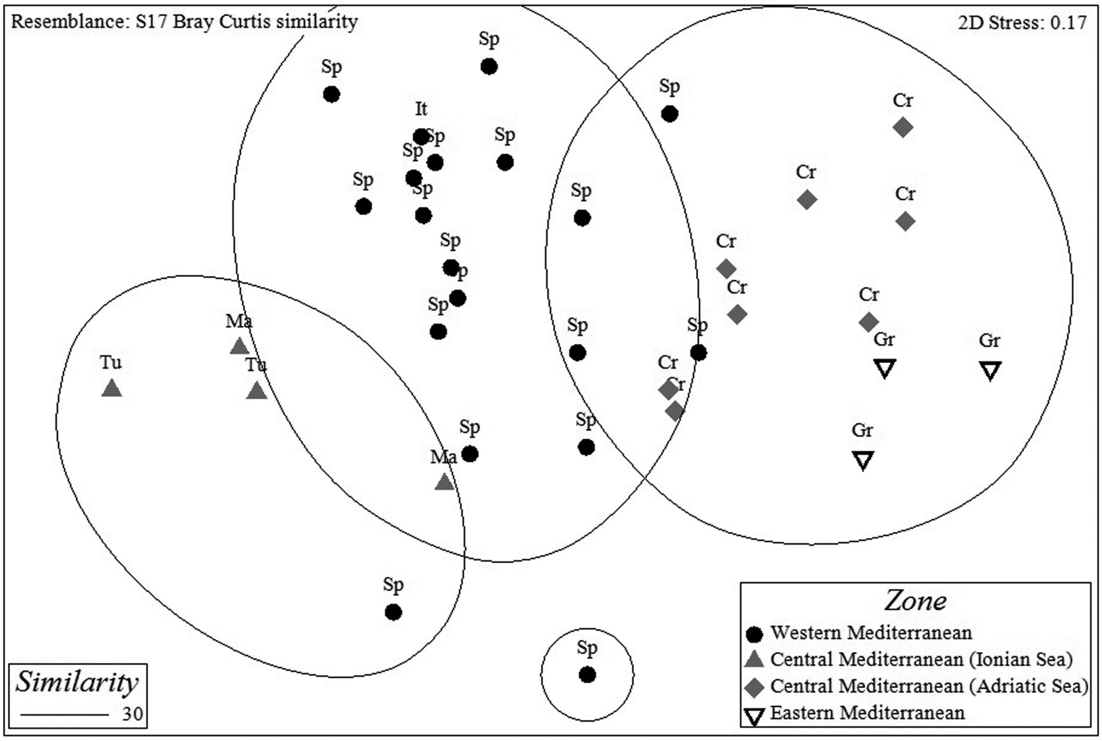

Fig. 2: Non-metric multi-dimensional scaling (MDS) plot in two dimensions of amphipod species composition from western, central and eastern Mediterranean Sea. Sp: Spain; It: Italy; Ma: Malta; Tu: Tunisia; Cr: Croatia; and Gr: Greece.

Table 4. Summary of SIMPER analysis results showing the average similarities and the percentage contribution of the most important amphipod species in farms fouling of each area of the Mediterranean Sea. WM: Western Mediterranean; CM: Central Mediterranean; EM: Eastern Mediterranean; Io: Ionian Sea.

	Similarity				**Dissimilarity**					
	WM	**CM (Io.)**	**CM (Ad.)**	**EM**	**WM *vs* Io**	**WM vs Ad**	**WM *vs* EM**	**Io *vs* Ad**	**Ad *vs* EM**	**Io vs EM**
Average	54.6	53.3	67.8	57.4	57.2	59.2	74.1	75.5	60.1	88.5
Jassa marmorata	24.4	45.4				11.7	14.3			15.1
Caprella equilibra	17.9		7.4		10.1		10.7			
Stenothoe tergestina	17.5		12.3	17.7	13.6					
Jassa slatteryi	16.2				11.7		10.9			
Elasmopus rapax	9.5		30.0	62.8		11.2	14.4	15.8		20.6
Ericthonius punctatus	7.2	7.6	5.2		11.2					
Caprella dilatata		40.3			17.9			15.8		17.8
Caprella scaura			23.2			16.3		13.8	18.6	
Gammaropsis maculata			13.2			11.3		10.1	12.8	
Ampithoe ramondi				8.7						
Stenothoe cattai				6.1					9.07	

have been widely reported in harbours and off-shore on turtles, buoys, platforms, etc., along Mediterranean coasts. Contrasting cases are *A. acutum* and the invasive species *C. scaura*, frequently reported in harbours along the Mediterranean; their presence at off-coast fish farms are low or even non-existent. Differences between Mediterranean basins are also observed in published data where the most abundant caprellids at farms, *C. equilibra* and *C. dilatata,* are mainly found on harbours and off-coast elements on western and central Mediterranean Sea, while the gammarids *A. ramondi* or *Dexamine spiniventris* are almost exclusively reported on harbours at eastern Mediterranean. Finally, the presence of *Caprella acanthifera*, *Stenothoe valida*, *Stenothoe cattai* and *Phtisica marina* in other fouling communities is also recorded, whereas these species are rarely found in aquaculture facilities.

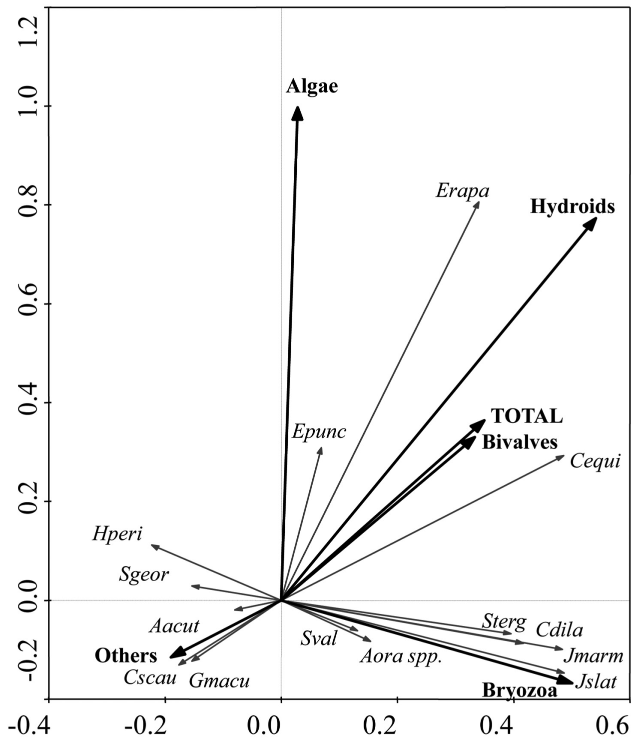

Fig. 3: RDA ordination diagrams for amphipod abundance and habitat data. Abbreviations are shown in Table 3.

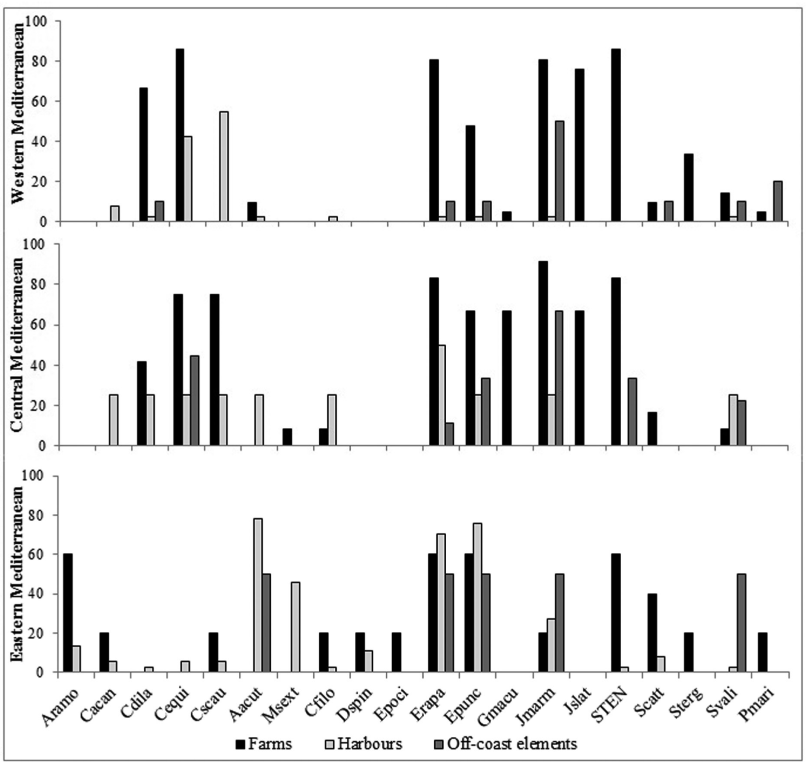

Fig. 4: Comparison of frequency of occurrence based on presence/absence data of amphipod species in farms fouling of this study and that in farms, harbours and off-coast elements (platforms, buoys, marine debris, ships and turtles) of published bibliography of the western (n=12), central (n= 8) and eastern (n=12) Mediterranean sea. Abbreviations are shown in Table 3, except for: Cacan: *Caprella acanthifera*; Msext: *Monocorophium sextonae*; Dspin: *Dexamine spiniventris*; Epoci: *Elasmopus pocillimanus* and STEN*:* *Stenothoe* sp. Data were published in: Ruffo, 1998; Relini *et al.*, 1998; Relini *et al.*, 1999; Relini *et al.*, 2000; Baxevanis & Chintiroglou, 2000; Aliani & Molcard, 2003; Karalis *et al.*, 2003; Chintiroglou *et al.*, 2004a; Chintiroglou *et al.*, 2004b; Kitsos *et al.*, 2005; Sconfietti *et al.*, 2005; Ramadan *et al.*, 2006; Cook *et al.*, 2006; Savini *et al.*, 2006; Krapp *et al.*, 2006; Muscat *et al.*, 2007; Çinar *et al.*, 2008; Cabezas *et al.*, 2010; Zakhama-Sraieb *et al.*, 2010; Antoniadou *et al.*, 2011; Bakir & Katagan, 2011; Ros *et al.*, 2013; Krapp-Schickel, 2013; Fernandez-Gonzalez & Sanchez-Jerez, 2013; Ros *et al.*, 2014; Domenech *et al.*, 2015; Gonzalez-Silvera *et al.*, 2015; Guerra-Garcia *et al.*, 2015; Krapp-Schickel *et al.*, 2015; Ros *et al.*, 2015.

Discussion

Fouling communities at aquaculture facilities in the Mediterranean Sea were represented by algae (11 species), hydroids (5 species), bryozoans (3 spp), bivalves (4 spp) and others groups (3 spp). These sessile organisms act as ecosystem engineers, creating habitats for an associated fauna dominated largely by amphipods. Seven amphipod species were detected as frequent and dominant in samples from different points of the Mediterranean. Thus, the gammarids *E. rapax*, *J. marmorata*, *J. slatteryi*, *E. punctatus* and *S. tergestina* and the caprellids *C. equilibra* and *C. dilatata* can be considered characteristic of fish-farm fouling, being well-adapted to colonise and survive in these off-coast habitats.

Despite this homogeneity in amphipod assemblage, the whole species composition and the relationships among the dominant species show a gradient from western to eastern Mediterranean. Differences between eastern, central and western Mediterranean were based on the greater presence of *S. cattai* and *A. ramondi* in the aquaculture facilities of the eastern Mediterranean, of *C. scaura* and *G. maculata* in the Adriatic and *J. slatteryi* in the western Mediterranean. The distributions of all these species are not exclusive to these areas, as they are found across the Mediterranean (Ruffo, 1998; Ros *et al*. 2014; Krapp-Schickel *et al*., 2015), but their higher presence in a specific area may drive a higher probability of spreading to off-coast areas. This is the case of *A. ramondi* which has been exclusively reported from harbours of eastern Mediterranean (Chintiroglou *et al*., 2004a, b) and was found only in farms of this part of the Mediterranean or the case of non- indigenous *C. scaura*, which was commonly found in tuna farms of the Adriatic Sea, where its first Mediterranean occurrence was recorded (Krapp *et al*., 2006) and thus its presence spanning longer time. In any case, samples from the eastern Mediterranean and Adriatic were more similar than those from the west, whereas those from Malta and Tunisia together showed a position separated from the western Mediterranean. This gradient may be related to the different oceanographic conditions in the two basins of the Mediterranean Sea and the different inflows from the Atlantic, the Red Sea and the Po River (Millot & Taupier-Letage, 2005; Tanhua *et al*., 2013).

Two exotic species were detected in this study: *S. georgiana* and *C. scaura*. The gammarid *S. georgiana* was first described from a fouling community on a pier in North Carolina, characterised by sponges and bryozoans (Bynum & Fox, 1977). In this study, individuals of *S. georgiana* were found within algae, anemone and mussel habitats at the Alicante and Murcia localities and this is the first report in the Mediterranean Sea. The presence of the other non-indigenous species *C. scaura* in the Mediterranean fish farms was already discussed (Fernandez-Gonzalez & Sanchez-Jerez, 2013). It has commonly been reported on the shoreline of the Mediterranean (Krapp *et al*., 2006; Martínez & Adarraga, 2008; Ben Souissi *et al*., 2010; Bakir & Katagan, 2011; Ros *et al*., 2014) but its presence at off-coast fish farms is still low. Clearly aquaculture facilities are providing suitable habitat and can act as a new dispersal vector to favour the invasion success of exotic species in the Mediterranean (Fernandez-Gonzalez & Sanchez-Jerez, 2013).

From this study, relationships between some of the amphipod species and particular habitats can be suggested. For example, *E. rapax* seems to show higher abundances in algal habitats, which is consistent with previous reports (Ruffo, 1998; Ortiz & Jimero, 2003) and *Jassa* species seem to be related to bryozoans and the provision of living space, also previously reported in the bibliography (Franz, 1989; Conradi *et al*., 2000). Special associations of amphipods with different sessile organisms such as molluscs (Vader & Tandberg, 2013), bryozoans (Lörz *et al*., 2014; Gillon *et al*., 2016), ascidians (Vader, 1984; White & Reimer, 2012), hydroids (Ros & Guerra-Garcia, 2012; Guerra-Garcia *et al*. 2014; Tandberg & Vader, 2015), anemones (Vader, 1983; Krapp-Schickel *et al*., 2015) or sponges (Poore *et al*., 2000) have been described in marine environment. However, further studies are necessary to ascertain the relationship between each sessile bioengineering species and the inhabiting amphipods of farms fouling.

The comparison of amphipod species in aquaculture fouling with other fouling assemblages from harbours, floating elements or off-coast structures showed that five of the most common species in farms (*E. rapax*, *E. puntatus* and *J. marmorata, C. dilatata*, *C. equilibra*) have been commonly found in harbours and offshore on turtles, buoys or platforms, among others. This reflects a great resistance to polluted areas but also to dispersal via rafting on floating objects, which contributes to their cosmopolitan distribution and high presence in aquaculture facilities. Despite their high presence on fish farms in the present study, the gammarids *J. slatteryi* and *S. tergestina*, have been not previously reported in other kinds of fouling. This study confirmed the presence of *J. slatteryi* in the Mediterranean, providing seven new records. This cosmopolitan species was first reported from artificial substrates in a marine cave of the western Mediterranean (Alboran Sea) by Beermann (2013) and Navarro-Barranco *et al*. (2015). *Jassa* species showed wide polymorphism with frequent co-occurrence of several species in the same area, which could lead to taxonomic confusion (Beermann, 2013). Given the cosmopolitan distribution of *J. slatteryi,* its presence in the Mediterranean has probably been underestimated due to a mixture of *Jassa* individuals being attributed to a single species of for example *J. marmorata* or *J. cadetta* (Navarro-Barranco, 2015). Separately, *S. tergestina,* although it has not been reported previously in fouling habitats, is common in natural habitats such as algae (Vazquez-Luis *et al*., 2008; Izquierdo & Guerra-García, 2011), mussels (Kalkan *et* *al*., 2006), soft-bottoms (Sezgin *et al*., 2007; Fernandez-Gonzalez *et al*., 2016) or bryozoans (Conradi *et al*., 1997; Conradi & Lopez-Gonzalez, 1999), which may be present as biogenic habitats within the fish-farm fouling (Fitridge *et al*., 2012).

Other species such as *A. acutum*, *C. acanthifera*, *C. scaura, S. valida*, *S. cattai* and *P. marina* are frequently found in harbours, on buoys, ships or marine debris; however they are rarely detected at fish farms and in lower abundances than other species. These species, capable of colonising off-coast structures, seem to be worse competitors for space or food than the species already established in fish-farm fouling. The routine cleaning of cages by fish-farm staff removes most organisms and allows ecological succession to initiate, favouring r-strategy species (Greene & Grizzle 2007; Fitridge *et al*., 2012).

The aforementioned absence of climax community structure due to mechanical cleaning, together with the high nutrient levels and specific location of aquaculture facilities provides a unique habitat for fouling species (Fernandez-Gonzalez & Sanchez-Jerez, 2013). This study highlights the importance of the associated fauna, particularly amphipods in fish farms of the Mediterranean Sea. Fish farms are able to maintain high population densities of amphipods that presumably support high predation rates by fish or other fauna aggregated around the cages (Deudero & Morales-Nin, 2001; Arechavala-Lopez *et al*., 2011, 2012). More studies are necessary to quantify the real densities reached by amphipod species and their relationship to a specific habitat in order to assess their ecological role on artificial structures.

Acknowledgements

We would like to thank Joseph A. Borg (University of Malta), Lydia Png and Nikolaos Papandroulakis (Hellenic Centre for Marine Research, Greece), Tanja Segvic (Institute of Oceanography and Fisheries of Split, Croatia), Paolo Tomasseti (ISPRA, Italy), Houssam Hamza (National Agronomic Institute of Tunisia, Tunisia), Felipe Aguado (IMIDA, Spain), Ignasi Gairin (IRTA, Spain) and Pablo Ávila (Junta de Andalucía, Spain), for kindly providing fouling samples. We are also grateful to Marc Terradas for helping us with algae identification and Traudl Krapp-Schickel and Jan Beerman for confirming the presence of *S. georgiana* and *J. slatteryi*, respectively, in our samples. English proof-reading was carried out by Guido Jones. This work is part of the doctoral thesis of V.F-G.

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