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Jellyfish blooms perception in Mediterranean finfish aquaculture

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ABSTRACT

In recent years, negative impacts of jellyfish blooms (JB) on marine human activities have been increasingly reported. Aquaculture has been affected by jellyfish outbreaks, mostly documented through repeated episodes of farmed salmon mortalities in Northern Europe; however, the valuation of JB consequences on the aquaculture sector still remains poorly quantified. This study aims to provide the first quantitative evaluation effects of JB on finfish aquaculture in the Mediterranean Sea and to investigate the general awareness of JB impacts among Mediterranean aquaculture professional workers. The aquaculture workers' perception about JB was assessed through a structured interview-based survey administered across 21 aquaculture facilities in central and western Mediterranean. The workers' awareness about JB impacts on aquaculture differed among countries. Italian and Spanish fish farmers were better informed about jellyfish proliferations and, together with Tunisian farmers, they all recognized the wide potential consequences of JB on sea bream and sea bass aquaculture. On the contrary, the majority of Maltese respondents considered JB as a non-significant threat to their activity, mostly based on off-shore tuna farming. This study for the first time shows that JB may negatively affect different Mediterranean aquaculture facilities from Tunisia (Sicily Channel) and Spain (Alboran Sea), by increasing farmed fish gill disorders and mortality, clogging net cages, or inflicting painful stings to field operators, with severe economic consequences. Available knowledge calls for the development of coordinated preventive plans, adaptation policies, and mitigation countermeasures across European countries in order to address the JB phenomenon and its impacts on coastal water activities.

1. Introduction

In spite of the lack of scientific consensus in identifying global trends in jellyfish blooms (hereafter referred to as JB) [1], negative impacts of JB on human activities in coastal waters are remarkably increasing in frequency and severity [2,3]. Assessing the ecological and societal consequences of these events is one of the pressing challenges for marine researchers [4,5]. Separately or in combination, several anthropogenic stressors have been suggested as potential causes of increasing jellyfish: a) ocean warming, boosting higher reproduction rates and wider distribution areas; b) eutrophication, leading to higher availability of nutrients and plankton food sources; c) overfishing, by removing jellyfish predators and competitors; and d) the proliferation of artificial hard substrates, providing suitable habitats for jellyfish-producing polyps [2,6–8]. In turn, massive proliferations of gelatinous organisms may have broad negative consequences on many sea-based human activities [2]: tourism and maritime leisure may be negatively affected because of dangerous jellyfish stingers (medusae and their relatives), forcing temporary beach closures [9]; fishing activities may be impaired by net clogging, fish deterioration, increased fishing time and costs [10]; and overall fishery catches may be reduced by jellyfish outcompeting fish for food or directly preying on fish eggs and larvae [6]; coastal industrial plants (e.g. energy or desalination plants) may be forced to shut down by jellyfish clogging of cooling systems [2]. Open-

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sea finfish aquaculture may be particularly threatened by the envenomation potential[1] of stinging jellyfish. Jellyfish can enter fish cages pushed by currents and waves washing in through the net cages [11,12] causing physical injuries on caged fish (skin lesions and gill epithelium damage), metabolic distress, and mass mortality [13,14]. In the last decade, Northern European aquaculture has experienced important economic losses due to JB, repeatedly killing several hundred thousands of farmed salmon in Ireland and Scotland [15–17].

In the Mediterranean, recent studies highlighted the negative impacts of JB on tourism [18], on public health [19] and on fisheries [10,20], as well as the increasing occurrence of large populations of invasive native and non-indigenous species [7,21–23]. Aquaculture represents a key source of food production worldwide [24], however the impact of JB on Mediterranean caged finfish aquaculture is still poorly understood. JB events have been reported in Spanish and Tunisian facilities [25,26] whereas recent laboratory based studies showed jellyfish stings may represent a high potential risk for the Mediterranean finfish aquaculture, by triggering gill disorders and mortality or affecting fish metabolic performances [25,27]. Even if fish survive after the jellyfish sting/envenomation, fish growth may be reduced, with relevant economic consequences for the facilities [26]. In addition, the impacts of low-medium jellyfish densities are usually neglected or under-documented.

For this reason, the main objectives of this work were a) to assess the extent of impact on caged finfish (detection of epidermal damage, gill disorders and/or fish mortality) induced by JB in central and western Mediterranean farms, and b) to investigate the general awareness of JB impacts among Mediterranean aquaculture professional workers. Also, this research aimed to verify whether (c) the perception of JB impacts may change among different countries, different professional categories of aquaculture workers, or operators with different level of experience.

2. Methods

2.1. Study area

Structured interviews were carried out between February 2014 and February 2015 with fish farmers of four countries (Italy, Spain, Tunisia and Malta) in the framework of the European project Med-Jellyrisk (http://jellyrisk.eu) for the integrated transnational monitoring of JB across the Western and Central Mediterranean Sea. The visited facilities were all represented by grow out offshore floating cages.

2.2. Survey structure and data collection

A total of 42 finfish aquaculture facilities were contacted, obtaining the collaboration of 21 of them. Fish farm facilities were identified through information provided by Unimar Institute from Roma and from the Technical Secretary of the FAO/GFCM Aquaculture Committee in Rome, Dr. Alessandro Lovatelli. Surveys were performed face-to-face or by telephone, depending on the availability of fish farm workers. Workers were interviewed individually to minimize 'group effect' bias. Interviews were performed in the native or official language of each country. People were interviewed on the basis of a structured questionnaire (appendix A) which included 19 questions organized in 3 different sections: (I) *general knowledge on jellyfish and their blooms* (e.g. which jellyfish sp. the interviewees recognized and which are the most frequently sighted, the frequency of jellyfish blooms, etc.); (II) *JB qualitative impacts on farm's activity* (i.e. on structures and material, health of workers and farmed fish); (III) *JB quantitative impacts* (categorical estimation of potential impact on aquaculture economy). Answers were structured in a categorical and dichotomous formats (yes/no), with the exception of the economic impact valuation, where an increasing number scale from 0 to 5 was presented (0= mean none effect of JB on aquaculture activity, 1–2= low effect, 3–4= medium economic effect and 5= high economic impact). The answers to the open-ended questions were subsequently converted into discrete values in order to perform the data analysis. Fish farmers were also invited to provide any further information they deemed useful to substantiate their answers. To facilitate species identification, jellyfish pictures of the most commonly blooming taxa were shown to the respondents.

2.3. Statistical analysis

The jellyfish species mentioned in each interview were used to build a presence/ absence dataset, in which each survey was considered as an independent sample with the different species as variables. This dataset was explored through the application of multivariate analyses, so as to test for possible relationships between the recorded jellyfish species and both social and geographic factors. To test for any differences between the factors "location" (fixed with 4 levels) and "professional profile" of workers (fixed with 6 levels and orthogonal with "location") a two-way permutational multivariate analysis of variance (PERMANOVA [28]) was performed. The same statistical analysis was used to test for any differences between the "location" and "years of experience" in the sector factors (fixed with 5 levels and orthogonal to "location") and between the "location" and "farmed fish species" in the involved facilities factors (fixed with 2 levels and nested in "location"). A one-way PERMANOVA analysis was also carried for testing the factor "season" (4 levels).

Answers to perception questions about the impact of JB on anthropogenic activities were similarly organized in a matrix and two-way PERMANOVA analysis was carried out with the same experimental design previously used for the jellyfish matrix. In addition, one-way PERMANOVA analysis (for location factor) was performed to test different respondents' answers about the potential economic impact of JB on aquaculture.

Subsequently, post hoc Pair-wise t-test and Similarity Percentage analysis (SIMPER) were performed on the factor interactions for which significant differences were identified to determine the independent variable level which contributed most to the observed differences [29]. Statistical analyses were performed with the PRIMER6 & PERMANOVA+ software package [30].

3. Results

3.1. Characteristics of the respondents

A total of 51 fish farmers were interviewed (9 from Italy; 11 from Spain; 7 from Tunisia and 24 from Malta) hailing from 21 different fish farms (6 from Italy; 5 from Spain; 4 from Tunisia and 6 from Malta). Interviewed employees all had a number of years of aquaculture experience behind them, ranging from 3 to 50 years, with 43% of them having worked in this sector for more than 10 years. The interviewed professional profiles varied from field technicians, divers or skippers to fish farm directors, veterinarians, administrators and technical, production and quality managers. Over the course of an entire calendar year, the average number of hours spent at sea per day by field workers was 6.

3.2. General knowledge on jellyfish and their blooms

General knowledge of jellyfish held by respondents varied much among countries. The jellyfish species that interviewees were able to identify were significantly different among places (F_3=6.67, p=0.001), except for Italy and Spain (t=1.58, p=0.057); but in all cases, *Pelagia*

[1] The tentacles of stinging jellyfish (phylum Cnidaria) are covered by cnidocytes, specialized cells able to fire – upon contact – penetrating filaments and inject venoms, with a variety of cytotoxic, neurotoxic, hemolytic properties.

noctiluca was the best-known jellyfish species, with a contribution to similarity higher than 45%, according to SIMPER analysis. Differences among countries were independent from the farmed fish species and the interviewees professional profile (F_1=1.759, p=0.124 and F_5=0.739, p=0.729, respectively). However, the number of years of experience in the sector resulted in significant differences in the jellyfish species that fish farmers were able to identify (F_4=1.995, p=0.016), but it was not related with the location factor (non significant interaction: F_3=1.277, p=0.198). Significant differences were found between respondents having 1–5 years experience and those having 10–20 years or even more than 20 years experience.

In Malta and Tunisia, the awareness of the risks associated to these gelatinous organisms was relatively low and more than 70% of interviewed people affirmed that '*do not know anything about jellyfish*'. In Spain and Italy, 91% and 67% of respondents respectively shared their knowledge on potential causes jellyfish and JB increased frequency and distribution, mainly referring to climate change (ocean warming), overfishing, and loss of jellyfish predators. Respondents also reported that most (65%) of the information was obtained from the media, such as television (news and scientific outreach programs, etc.) and in cases, from prior knowledge about the biology and ecology of cnidarians and scientific literature.

All of the respondents observed jellyfish in the areas where the fish farms were located (beaches and harbours) and described jellyfish blooms as occurring each year, mainly in summer (p < 0.005 in all pair-wise comparisons) (Fig. 1). More than half of the respondents expressed concern about the increase of the density and frequency of jellyfish blooms in the last 10 years; one third stated that these events occurred constant over time and a very low percentage mentioned a decrease in jellyfish density and frequency over the years (Fig. 2).

Significant differences among countries were also found regarding the species composition of the observed JB at the aquaculture facilities. Species recorded by Maltese respondents were different from those recorded in all the other countries (p=0.001 in all pair-wise comparisons). These differences were attributable to comb jellies, being the third most sighted species in Malta after *P. noctiluca* and *Cotylorhiza tuberculata*. Italy, Spain and Tunisia did not show significant differences among them (p > 0.05) (Fig. 3). *Pelagia noctiluca* blooms were recorded in all four countries by more than 90% of respondents, followed by *C. tuberculata, Rhizostoma pulmo,* and *Velella velella* (Fig. 4). Moreover, respondents affirmed to have seen these species in different areas (harbour, beaches, open sea and close to the aquaculture cages).

3.3. JB qualitative impacts on farm's activity

Differences among countries were also observed regarding the impact of JB on marine anthropic activities and the ecosystem (F_3=4.280, p=0.001) (Table 1). SIMPER analysis showed that according to fish farmer's perceptions, tourism was the most affected sector by jellyfish blooms in all the countries, followed by aquaculture and fisheries, except for Tunisia, where aquaculture was perceived as the most affected activity. Italian and Spanish respondents expressed concern about the negative effect of JB on fisheries, while Maltese and Tunisian fish farmers did not consider this interaction as being important. The impact of these gelatinous organisms on the ecosystem was considered of low importance for the majority of respondents from all four involved countries.

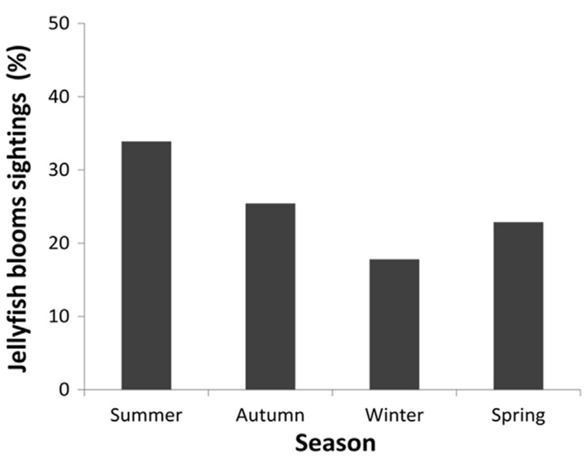

Fig. 1. Occurrence of jellyfish blooms by season according to interviewees (represented by percentages).

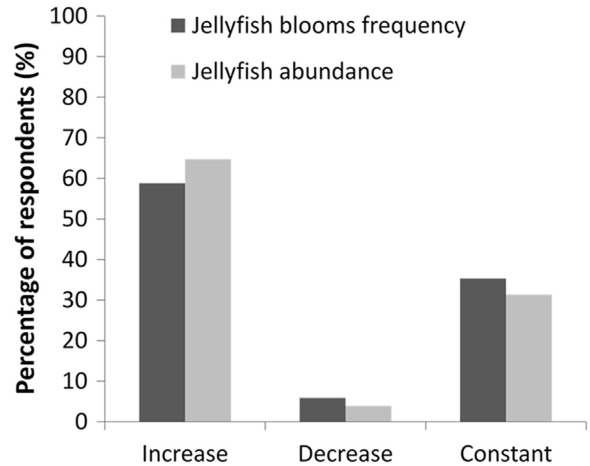

Fig. 2. Fish farmers' perception on jellyfish blooms frequency (A) and jellyfish density (B) variations in the last 10 years (represented by percentages).

The operators' perception about the impact of JB on aquaculture was significantly different among countries (F_3=7.706, p=0.001). Pair-wise analyses showed that answers from Maltese fish farmers about this issue were significantly different from the other three countries, which gave similar answers among them (Table 2). In Italy, Spain and Tunisia, 78%, 91% and 86% respectively of fish farmers considered the proliferations of gelatinous organisms as a factor that negatively affects fish farm activities. Of these responses, 77% affirmed that the biggest impact on aquaculture would be due to the jellyfish stings on divers working at the facility, and 86% considered that this phenomenon could have a negative impact on the health of cultured fish. Otherwise, just 30% of Maltese respondents opined that JB may have a real practical effect on aquaculture activities (Table 1).

The perceptions of fish farmers about the impact of JB on aquaculture were not significantly influenced by the workers professional profile (F_5=0.993, p=0.46) and years of experience factors (F_4=0.813, p=0.608), as well as their interaction with location (F_3=0.9926, p=0.46 and F_3=0.8132, p=0.608 respectively). Nevertheless, farmed species was an important factor in influencing such respondent perceptions (F_1=12.063, p=0.001).

The settlement, growth and accumulation of unicellular and multicellular organisms on underwater structures (commonly referred as biofouling) is a major problem and cost factor in finfish aquaculture worldwide. Fouling organisms significantly increase the weight of cage and mooring systems and decrease water flow through the cages, which compromises the environmental quality in cages [31]. Also, stinging organisms are among the most common foulers of aquaculture cages. Among them, colonial hydrozoans (also known as hydroids) are formed by stinging polyps that seasonally liberate free-living stages (medusae or other types of propagules) with the same stinging potential. These organisms were identified as a problematic issue for aquaculture facilities by respondents from Italy (100% of affirmative answers), Spain (90.9%) and Tunisia (87.5%), but being of minor importance for Maltese facilities (25%). The Maltese respondents listed the Mediterranean oyster and common barnacle as problematic fouling

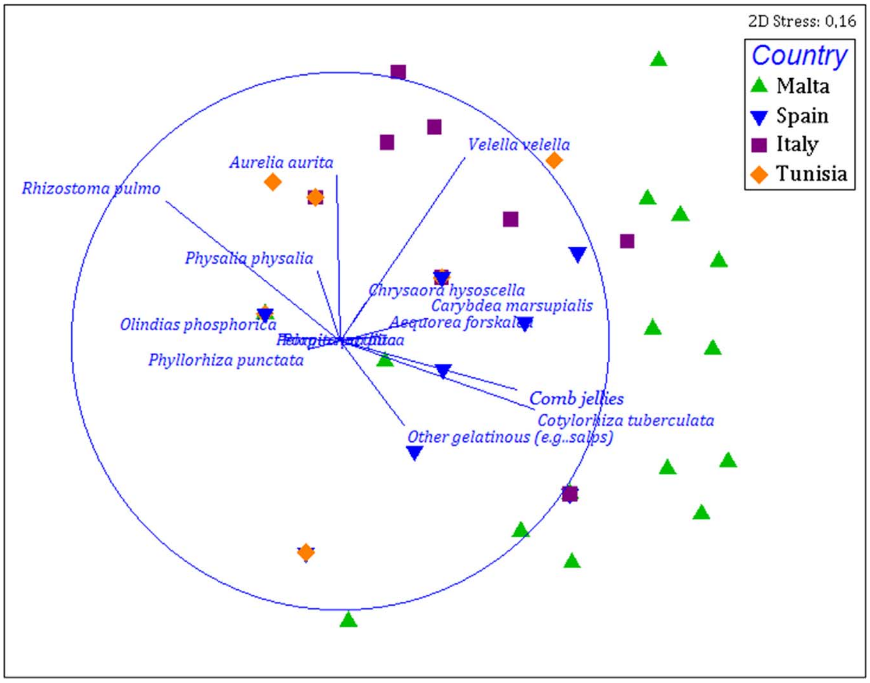

Fig. 3. Non–metric multidimensional scaling (nMDS) representing differences in jellyfish sightings among countries and the main species responsible of these differences.

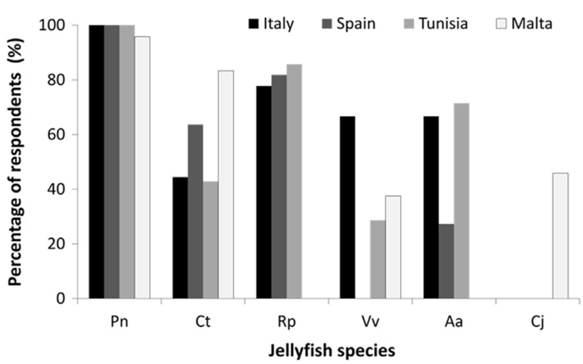

Fig. 4. Most sighted jellyfish species by country (Pn: *Pelagia noctiluca*, Ct: *Cotylorhiza tuberculata*, Rp: *Rhizostoma pulmo*, Vv: *Velella velella*, Aa: *Aurelia aurita, Cj: Comb jellies*).

Table 1
Jellyfish blooms impact on different marine human activities and the ecosystem according to Mediterranean fish farmers (results presented as percentage of positive answers).

	Malta Yes (%)	Italy	Spain	Tunisia
Tourism	95.8	100	100	71.4
Ecosystem	25.0	22.2	63.6	28.6
Fisheries	29.2	55.6	90.9	28.6
Aquaculture	29.2	77.8	90.9	85.7
Structures	28.6	0.00	20.0	16.7
Human health	100	71.4	100	50.0
Fish health	28.6	100	100	50.0

organisms, whereas the other three countries recorded different species of bivalves, algae and hydroids. Only Spanish and Italian fish farmers (56% and 50% respectively) named hydroids as annoying fouling organisms, specifically the species *Ectopleura larynx* and *Pennaria disticha*, which affected facilities by clogging the net cages and by inflicting painful stings to field technicians.

Overall, 20% of total respondents recognized serious problems with jellyfish in their facilities. These related to harmful stings to divers, fish

Table 2
Pair–wise comparison among countries about fish farmers' perception regarding jellyfish blooms impacts on aquaculture activities (categorical answer: yes/no).

Groups	t	P (perm)
Malta – Spain	40.215	0.002
Malta – Italy	27.131	0.025
Malta – Tunisia	29.396	0.014
Spain – Italy	0.790	0.563
Spain – Tunisia	0.323	1
Italy – Tunisia	0.379	1

mortalities, clogging of nets or boat engines. Through the performed interviews, it was possible to document three different fish mortality events in the surveyed aquaculture facilities as a result of the interaction with jellyfish (Table 3). Moreover, 36% of fish farmers recorded fish mortality events without a clear causative agent identified by veterinarians, but gill injuries and respiratory distress were the main pathological signs in such circumstances. Fish farmers also asserted to have never considered jellyfish or any planktonic organism as a possible threat to their operations.

3.4. JB quantitative impacts

Significant differences about the potential economic impact that JB could have on the aquaculture sector were found among locations (F_3=18.604, p=0.001). Post-hoc pair-wise analysis showed that just Malta differed from the three other countries ($p < 0.01$ in all comparisons). According to more than 80% of fish farmers from Spain and Tunisia and 50% of respondents from Italy, JB could have a medium to high economic impact on the aquaculture sector (Fig. 5); and according to more than 80% of respondents from aforementioned countries, the occurrence of dense jellyfish blooms should be an important factor to be considered when identifying appropriate locations for the siting of marine aquaculture facilities. In Malta however, just 12% of the respondents thought that jellyfish blooms could have a potentially significant economic impacts on their activity, and less that the 30% agreed that jellyfish blooms should be considered as a relevant factor when identifying possible sites for aquaculture facilities.

Table 3
Reported problems with *Pelagia noctiluca* jellyfish in different Mediterranean aquaculture facilities; where ED means: External damage; GD: Gill damage; RD: Respiratory distress; FM: Fish Mortality.

Country	Date	Jellyfish sp.	Fish sp.	Jellyfish (ind m^{-3})[a]	Bloom duration	Fish damage	Problem resolution	Impact
Tunisia	2009	*P. noctiluca* (juveniles)	*D. labrax S. aurata*	8000	10 h	ED, GD	Nothing	FM (150 T/18 T)
Tunisia	Mar–May 2014	*P. noctiluca* (juveniles)	*D. labrax*	100–150	–	RD	Nothing	FM
Spain	Apr–Oct 2011–2014	*P. noctiluca*	*D. labrax*	7–10	Days	–	Net change	Structural damages
Spain	2011	*P. noctiluca*	*D. labrax*	–	48 h	RD, GD	Formalin bath	FM (10 T)

[a] Adult jellyfish observations were made by scuba diving, while density of juveniles was calculated after sampling with zooplankton net.

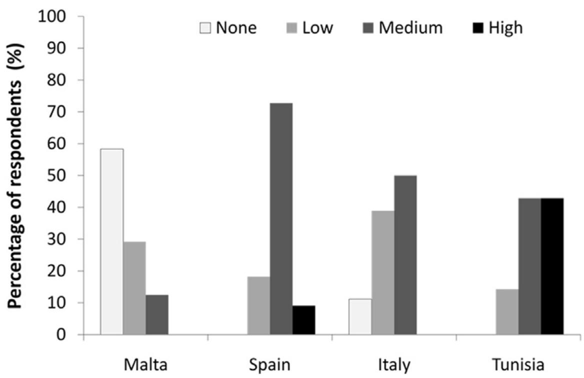

Fig. 5. Interviewees' opinion by country about the potential economic impact of jellyfish blooms on aquaculture activities.

Remarkable examples of JB economic impacts were recorded during the course of the study interviews. Fish mortality event due to interactions with jellyfish reported in a Spanish aquaculture facility in 2011 had serious economic consequences, with losses of approximately 50,000 € for the company. In addition, every time that a net cage is changed, the estimated costs sum up to 4000 €, whilst 3000 € are needed for a formalin bath treatment. In 2009, fish mortalities in Tunisian facilities entailed dramatic economic losses for the company in question, leading to near bankruptcy.

4. Discussion

This research highlights that JB may severely interfere with Mediterranean open sea aquaculture operations, affecting culture facilities, and fish health as well as underwater technicians during their daily routine work. The majority of interviewed fish farmers were well aware of the risks on the aquaculture sector associated with JB and were able to recognize some of the most common blooming jellyfish species in the Mediterranean Sea. According to the fish farmers' knowledge, *P. noctiluca* was the most frequent species and the primary cause of gill disorders and mortality events in caged fishes. This species is one of the most common stinging jellyfish across the Eastern Atlantic and the Mediterranean Sea and similar caged fish mortality events have been reported in Northern Europe [13]. It has been demonstrated that *P. noctiluca* has the potential to reproduce all year long in some areas of the Mediterranean [32,33], generating large blooms that interfere with different marine human activities [21].

In addition, fouling species with stinging potential have been identified as annoying organisms for Mediterranean fish farms. *Ectopleura larynx* and *Pennaria disticha* are two common hydroid species in the Mediterranean Sea, whose colonies have a rapid growth and reproduction rate [34]. Interviewed fish farmers declared that these species are known to produce painful stings to field technicians when manipulating the cages nets. Nevertheless, few studies about the impact of fouling stinging species on human health [35] and farmed fish stocks [36] exist in the literature and the consequences for fish welfare are still poorly understood. Fish may enter in contact with these stinging organisms when swimming in the proximity of the nets or when net cleaning process is performed [34,36,37]. Furthermore, small colonial hydroids have the potential to release swarms of tiny planktonic medusae (or other medusoid-like propagules) during reproductive periods. Many of these planktonic propagules are small-sized (from few millimeters to 2–3 cm) and usually neglected by aquaculture operators, but they enter the cages causing severe injuries to fish [11,17].

The majority of respondents expressed their concern about the increasing frequency of jellyfish blooms in the last decade. No differences were detected in the perception of the different professional categories employed in fish farms. This may indicate that in fish farms jellyfish blooms are consistently considered as potential issue by different operator categories. The degree of awareness on JB showed significant differences among countries. For example, in comparison to Tunisian and Maltese respondents, Italian and Spanish farmers showed a better knowledge about JB and generally a greater ability to provide information on this subject. In most cases, they properly reported climate change and overfishing - with loss of jellyfish predators - as two of the most probable causes for JB increased occurrence, as suggested by the scientific available evidence [2,7,38]. The perception about the impact of JB on aquaculture differed among countries and also among facilities hosting different farmed fish species. In fact, more than 65% of Maltese respondents opined that JB do not have significant effects on aquaculture activities. The majority of interviewed Maltese workers (79%) were employed in facilities hosting exclusively caged bluefin tuna (*Thunnys thynnus*), while all the other Mediterranean facilities cultivated European sea bass and Gilthead sea bream (*Dicentrarchus labrax* and *Sparus aurata* respectively). According to the Maltese respondents, tuna fish apparently do not suffer any detectable consequence from jellyfish stings. This might be due to the larger size and higher swimming ability of tuna than sea bass and sea bream, or to the larger cages and mesh sizes in tuna facilities, which have therefore a lower probability of cage clogging. Because of a low or no impact of JB on farmed tuna, Maltese aquaculture workers consider jellyfish outbreaks having no detectable effect on farmed fish health, without significant potential economic impacts on aquaculture facilities.

Nevertheless, facilities affected by jellyfish experience significant economic impacts. Tunisian fish farmers did not take any countermeasures and one of the facilities went nearly bankrupt due to the mortality of almost all of the caged fish stocks. In absence of a standardized countermeasure protocol, Spanish facilities are used to mitigate abnormal gill disorders and mortality events by *in situ* formalin baths (a common treatment against fish ectoparasites). As an alternative, on numerous occasions between 2011 and 2014 Spanish farms replaced the fish net cages (at high economic costs), whenever huge swarm of *P. noctiluca* surrounded their sea bass aquaculture pens. In the past years, Irish and Scottish aquaculture facilities in the

Eastern Atlantic repeatedly suffered huge economic losses up to £1 million due to mass salmon mortalities caused by recurring *Pelagia noctiluca* blooms [16,39]. Even if economic impact suffered so far by finfish facilities in the Mediterranean is much lower than to in Northern European farms, the expected rise of jellyfish densities due to ocean warming together with the increase use of marine environment by human activities, as well as the increasing development of caged aquaculture is expected to worsen the consequences for marine aquaculture facilities across all European waters.

5. Conclusion and future perspectives

The present work provides first information about the overall perception of fish farmers and recorded impacts (as fish mortality events) of JB on cage aquaculture facilities in the central and western Mediterranean. Considering the current lack of knowledge and technological solutions to mitigate the JB impacts on fish farms [37], increased understanding of the spatial and temporal distribution trends of JB is of primary importance to reduce or prevent economical losses [15]. The development of jellyfish and biofouling monitoring plans at aquaculture farms may allow adoption of appropriate preventive countermeasures at the time when JB are foreseen or the occurrence of stinging biofouler organisms may threaten fish health. For instance, the impact of JB in surface waters may be reduced by adopting submergible cages to displace cultured fish near the bottom or at depths in the water column to avoid negative surface events, such as JB [40]. Air bubble curtains alone or in combination with surface water suction pumps have been also suggested as tools for protecting cultured finfish from JB impacts [41] and new efficiency testing is currently undergoing in the framework of the EU project CERES (www.ceresproject.eu) with field trials in Northern Europe to assess suitability of bubble curtains against JB and their operational energetic requirements. The reduction of biofouling is a long lasting issue in marine aquaculture and new technologies (vacuum based net cleaning system) are now available to clean the nets and prevent any removed fouling organisms to enter the cage and harm fish (e.g., MIC 2.0, http://www.micmarine.com.au/home).

As a result of the continuous growth of the aquaculture sector [24], the interaction of aquaculture activities with jellyfish outbreaks should receive more attention. Due to the potential severe consequences for caged fish health and for the companies' economic prospects, evidence from this study and elsewhere in the literature calls for further consideration. Participative monitoring programs with active involvement of fish farmers into daily, all-year-round reporting on jellyfish occurrence near fish farms may help to develop a better understanding of environmental drivers and mechanisms leading to jellyfish proliferation events. In turn, this may lead to a reduction of jellyfish impacts on caged fish stocks. A greater cooperation between fish farmers and research institutions is advisable, in order to estimate, evaluate and react against the consequences of JB on Mediterranean aquaculture facilities. Outreach and training programs to fish farms staff would help raise awareness on this emerging issue and assist in evaluating the feasibility of action plans, with a case-by-case definition of management guidelines and countermeasure protocols for prevention, mitigation and adaptation against recurrent jellyfish proliferations in coastal areas.

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Appendix A. Supplementary material

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.marpol.2016.11.005.

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