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Cumulative climatic stressors strangles marine aquaculture: Ancillary effects of COVID 19 on Spanish mariculture

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ABSTRACT

Marine aquaculture takes advantage of marine ecosystem services to produce goods that can be relevant from a food security point of view. However, this activity is subject to multiple stressors as the ones exerted by global climate change. Local stressed conditions due to environmental drivers may be exacerbated by the COVID19 pandemic crisis. In this paper we analyze the pre-COVID-19 situation in two Spanish regions with the highest aquaculture production, Galicia and the Valencian Community. The incidence of storms, heat waves and mussel farming closure were analyzed, and surveys were used to define the perception of producers in terms of economic problems derived from COVID-19 and synergistic environmental concerns. Also the temporal trend of mussel production was analyzed. Spanish marine aquaculture has been intensively subjected to climatic stressors that made it more vulnerable to COVID-19, showing some weakness in terms of production as can be seen in mussel production and fresh consumption. Anyway, extensive aquaculture and aquaculture developed by Integrated Multi-Trophic Aquaculture (IMTA) was reported as somewhat more resilient to the impact of COVID-19. In order to ensure the environmental and economic sustainability of marine aquaculture - under a future uncertain pandemic scenario – our outcomes underline the need for more resilient adaptation programs and recovery plans taking into account the climate change effects.

1. Introduction

Global fish production is estimated to have reached about 179 million tonnes in 2018, of which 82 million tonnes came from aquaculture production. 20.5 kg per capita for human consumption (FAO, 2020a). Aquaculture production grow at 7.5% since 1970, however, in the European Union the global growth rate of aquaculture, essentially fish and mollusks, has decreased since 2000 by an average of −0.5% per year. Marine cold-water such as salmons species represent 70% of total production, freshwater species 16% and marine Mediterranean aquaculture accounts for about 14%. (FEAP, 2020). Regarding to Spain, the aquaculture production in 2019 was 342,867 t, reaching a value in its first sale of 501 million €. The main species produced were mussels (261,513 t), followed by sea bass (27,335 t), rainbow trout (18,955 t) and seabream (13,521 t) (APROMAR, 2020).

It is frequently agreed that economic sectors depend on the ecological services of natural ecosystems, such as marine aquaculture, will be impacted in many ways by climate change. The vast range of species, environments, regions, systems, and practices suggests that many aquaculture sectors and regions will be susceptible to a variety of climate change impacts, and indeed, some of the largest aquaculture producer nations (e.g. China, Vietnam, Bangladesh, Egypt) are predicted to be highly vulnerable to climate change (Handisyde et al., 2017). Also, the impacts of climate change on the Mediterranean environment in rainfall, extreme events, such as heat waves, droughts or floods, are likely to be more frequent and violent (Rosa et al., 2012; Sarà et al.,

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2021a). Degrading this functional aspect of coastal ecosystem due to climate change may affect to future aquaculture production by reduction of its resiliency to accumulative stressors. Spanish aquaculture is also affected by climate change. For example, the mussel production at the Galician region appear to be threaten by the general temperature increasing, exposing cultivated mussels to wider thermal stress conditions never experienced before (Des et al., 2020).

In 2020 Spanish aquaculture has been seriously affected by an additional stressor, the disruption resulting from the management measure took in place to reduce the spreading of COVID-19 epidemic waves that have that acted in a synergic way affecting this productive sector (Sarà et al., 2021b). In Spain, the virus arrival and spread were first confirmed on 31 January 2020 (with the first death declared the 13th of February 2020). Due to the increase of transmission, a lockdown was imposed on 14 March 2020 until 21 June 2020, with the population mobility reduced to a minimum and all non-essential businesses, such as bars and restaurants, closed. The short and long-term effects of COVID-19 appear to impair crucial economic sectors in coastal regions such as marine aquaculture. FAO (2020b) in an initial assessment on COVID-19 indicated that marine farming got disrupted as supply chains were broken, labour shortage emerged and market access got affected. This situation may affect Spanish aquaculture because the consumption of fresh fish represented 43.3% of the volume of fish consumed, being the most consumed type in 2019. In addition, there is a global change scenario that has affected Spanish aquaculture in the last years, which likely synergistic effects with the effect of COVID-19 during 2020. In order to develop mechanisms to promote the resilience of marine aquaculture, it is necessary to understand how predictable ecological and oceanographic processes, derived from climate change, can negatively affect the resilience of aquaculture in the face of unexpected events such as the SARS-CoV-2 pandemic. Under these premises, the present study attempt to analyze the impact of COVID-19 on Spanish aquaculture in a scenario of multiple stressors derived from climate change, focusing on Galician mollusk production and Mediterranean fish production. Additionally, we investigated the perceptions of COVID-19 effects on stakeholders operating in the Spanish marine aquaculture sector through a web survey (Sarà et al., 2021b). Specifically, we analyzed how relevant was the economic loss due to COVID-19, the different reasons for these losses and the environmental factors affecting to marine aquaculture.

2. Material and methods

2.1. Cumulative impacts deviated from climate change

For the present study, we focus on two areas of the Iberian Peninsula with a higher aquaculture production: Galicia and Valencia regions (Fig. 1). Galicia holds the higher mussel production, with 255,514 t in 2019 (www.ige.eu). The Valencia Community has led the production of fin fish (meagre, seabream and seabasss) in Spain with 11,380 t (27.8%; APROMAR, 2020). We select main mussel production areas, Ría de Arousa, Ría de Pontevedra and Ría de Vigo as representatives of the areas where mussel production takes places (Fig. 1). Mussel production was analyzed in relation to market closure due to biotoxins, which affect mussel farming, using the database of INTECMAR (www.intecmar.gal/) for evaluating their impact on mussel production. Mussel production values were obtained from Pesca de Galicia website (https://www.pescadegalicia.gal/gl/publicacions). In the Valencian Community, two locations were also selected as representative of fish farming areas in floating cages, Burriana and Guardamar del Segura (Fig. 1). We evaluate the potential impact of oceanographic extreme events by analyzing the temporal trend of waves in two locations along Valencia costal line for the period 2018–2020. in two locations were fish farming is using the data provided by Puertos del Estado based on the wave modelling system SWAN (www.puertos.es

Also, thermal anomalies of superficial waters for the period 2018–2020 were analyzed using the Copernicus Marine Environment Monitoring Service (CMEMS), which has been operational and publicly available since May 2015 (EU Copernicus Marine Service Information). SST records from 1988 to 2017 have been employed as reference values in order to obtain the anomaly SST levels from 1 January 2018 to 31 July 2020 on a daily basis. A 3-sample (i.e. 3 days) mean filter was applied for smoothing the 2018–2020 SST time series. Despite other filtering strategies are also possible, the selected window size allows not only to

Fig. 1. Geographical location of the two study areas in Spain. Numbers indicate the quantity of mussel farming facilities (Galicia) and fish fattening cages (Valencian Community)(https://servicio.pesca.mapama.es/acuivisor/).

minimize the effect of the unrepresentative noisy values due to unavoidable artifacts in both the sensors and processing chain, but also to keep the potential short term SST variations appearing within half a week.The CNR-5ISAC-GOS (Consiglio Nazionale delle Ricerche, Istituto di Scienze dell'Atmosfera e del Clima - Gruppo di Oceanografia da Satellite, Italy) has reprocessed Pathfinder V5.3 (PFV53) AVHRR data (Walker and Wilkin, 1998) by means of a processing chain including several modules, from the data extraction and preliminary quality control, to cloudy pixel removal and satellite images collating/merging. A two-step algorithm finally allows to interpolate SST data at different spatial resolutions applying statistical techniques. In this work 0.0417° × 0.0417° and 0.01° × 0.01° have bee used. Further details can be found in Pisano et al. (2016) and Buongiorno Nardelli et al. (2013).

2.2. Impact of COVID-19 on marine Spanish aquaculture: producers' perception

To investigate the perceptions of COVID-19 effects on stakeholders operating in the Spanish aquaculture sector, specifically on marine aquaculture, we launched a global web survey in May 2020, with a total of 33 responses. The semi-structure questionnaire was designed and circulated through a web survey (transferred on Qualtrics, Qualtricshttps://www.qualtrics.com) to rapidly assess the perceptions of global aquaculture stakeholders - specifically people involved in production at the farm or within the company - on the threats posed by COVID-19 and related control measures (i.e. lockdown and social distancing). Respondents were asked to report the associated economic loss, data were also collected regarding type of aquaculture strategy, intensive vs extensive (study approved by the Ethical Committee at the University of Palermo, UNPA-183-Prot. 767–05/05/2020 n. 1/2020 29/04/2020).

To in parallel evaluate the potential effects of climate-driven stressor, respondents were also asked to report previously experienced impacts from anthropogenic-driven changes (in last decade) that had led to greater economic losses than those from the current COVID-19 pandemic. A list of anthropogenic stressors was provided (more than one could be chosen) including: heatwaves, hypoxia/anoxia, harmful algae, local pollution, storms, diseases caused by bacteria, viruses and parasites affecting target species, sudden changes in salinity, flooding and eutrophication. Farmers were also asked to report their use of Integrated Multi-Trophic Aquaculture (IMTA) and to compare this information with the perceived economic loss of either COVID-19 or anthropogenic stressors.

3. Results

3.1. Cumulative impacts deviated from climate change

In the years prior to the COVID-19 crisis, storms on the Mediterranean coast, where sea bream, sea bass and meagre fattening cages are concentrated, were recurrent. From 2018 to the end of 2020, in the Burriana location 21 storms produced waves higher than 2 m and 6 storms waves of 3 m. Particularly relevant was the storm Gloria, with waves exceeding 6 m in height. The pattern was very similar in the Guardamar del Segura bay, located further south (Fig. 2). In relation to the thermal parameter of the aquaculture production zones, both localities showed similar trends, despite being separated by more than 200 km. Temperatures oscillated seasonally between 12 and 28 °C, being slightly warmer in Guardamar del Segura (Fig. 3A and B). The effect of the heat wave of the early 2020s on water temperature throughout the year is very noticeable, unlike previous years where only the winters and summers were warmer. When analyzing the anomalies (Fig. 3C and D) at both locations, it was found that the periods after the summer exceeded 1.5 °C. The thermal instability of winter 2019–20 is very remarkable, with a strong negative anomaly, followed by an increase in temperature throughout 2020, reaching anomalies greater than 3 °C at Burriana in May 2020.

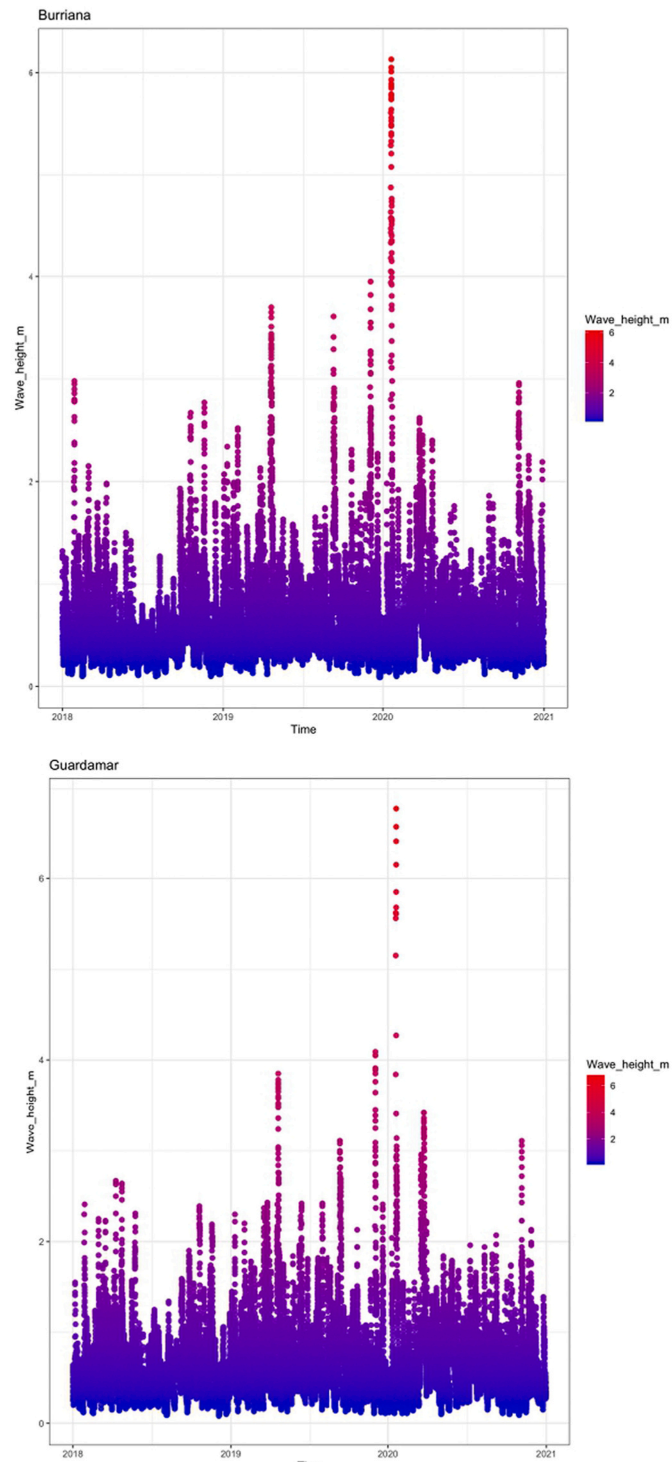

Fig. 2. Daily wave height (m) from 2018 to February 2021 in two locations, A) Burriana and B) Guardamar del Segura, according to the SWAN model of Puertos del Estado (www.puertos.es).

Mean mussel production values for Galicia (NW Spain) during the period 2017–2019 were 267,042 tons that that corresponded to 168,193 (63%) and 98,849 (37%) tons for fresh and industry products, respectively (Fig. 4). For 2020, total mussel production was 232,756 tons that represented approximately 13–15% decrease for the fresh market for the comparisons 2020 vs. 2019 or 2017–2019 but 1–9% for the product derived to the industry using the same time comparisons, respectively

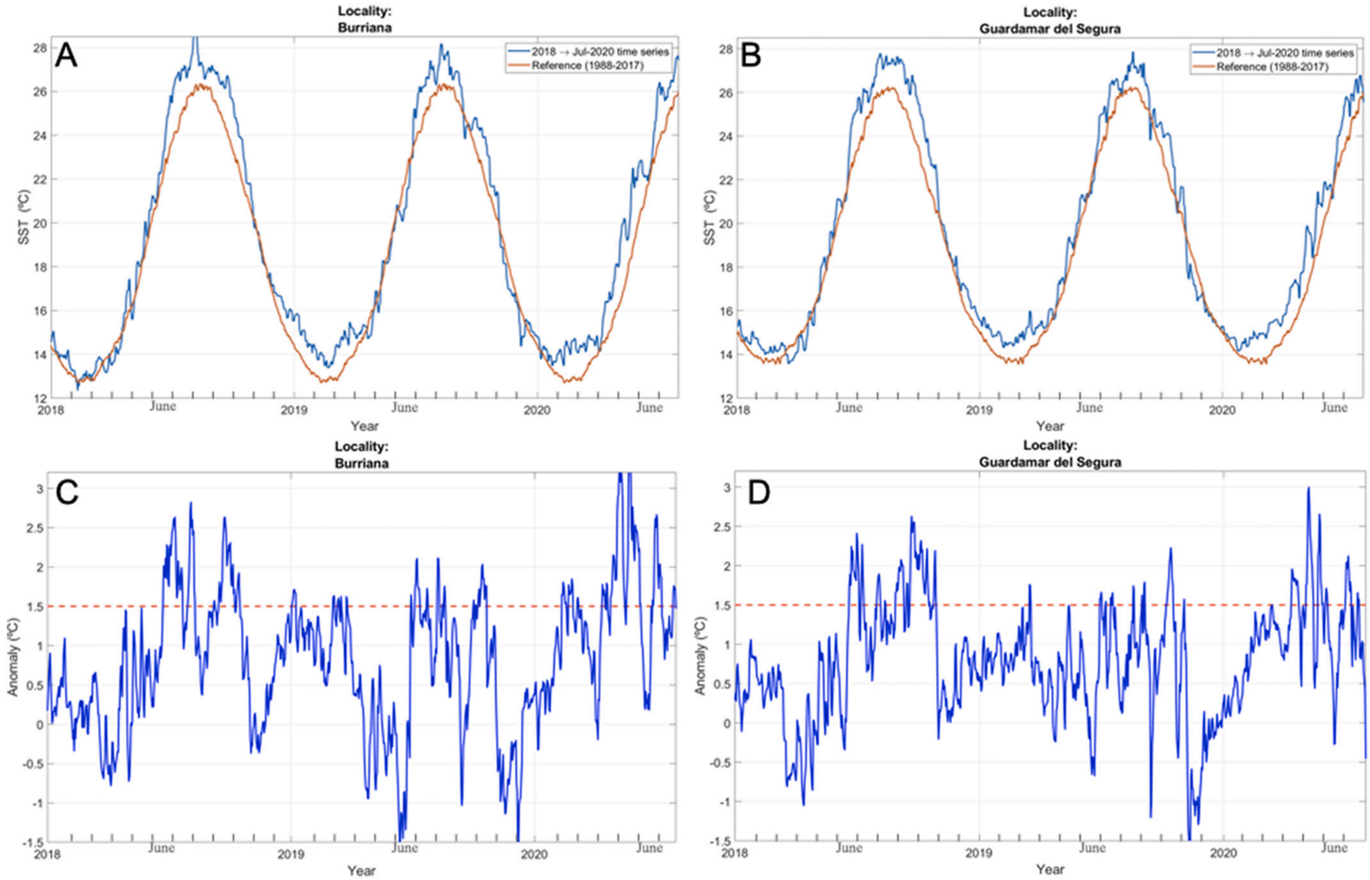

Fig. 3. Temporal pattern of temperatures (°C) in the localities of a) Burriana and B) Guardamar del Segura, showing the studied period (blue line) and the historical average (red line). Thermal anomalies (°C) calculated from the historical series of 1988–2017 for the period under study (January 2018–July 2020) for the localities of C) Burriana and D) Guardamar del Segura. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

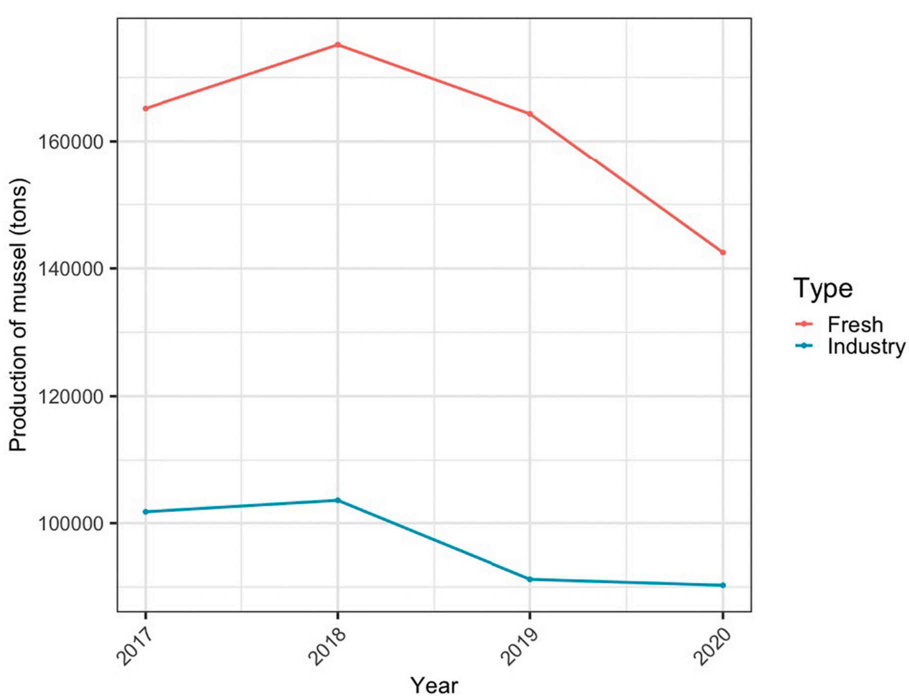

Fig. 4. Mussel production values (tons) in Galicia (NW Spain) for the period 2017–2020 considering both fresh and industry markets.

(Fig. 4). In general terms, Covid-19 outbreak has caused a significant decrease for the fresh product available in markets due to closure of distribution channels and cease of activity. As noted before, fresh market represents greater production values and therefore, it would be the most significantly affected through changes and cancelations in the distribution sectors. Such impact for the fresh market (sales) has been noted to be approximately 20% lower for 2020 with regard to previous year. Moreover, Covid-19 outbreak also caused disruptions and changes in the cultivation cycles well-established for the Galician mussel raft cultivation according to the sector. Due to market restrictions for getting fresh product, it has been reported that industry product benefited from consumer shifts during Covid-19 pandemic towards less perishable product (e.g. canned mussel products). With regard to certification of the Galician mussel done by the Protected Designation of Origin (PDO) with the aim of satisfying the European demands in order to preserve high quality, it has been noted a decrease of 11% during 2020 in comparison to 2019 (https://www.mexillondegalicia.org/). Linked to mussel production values noted before, it is important to highlight that mussel harvest closure as consequence of biotoxins appearance and proliferation of harmful algal blooms (HABs) in main cultivation zones of the Rías Baixas (Rías de Arousa, Pontevedra and Vigo) increased up to 37 (±28) days for 2020 with regard to 2017–2019 period (www.intecmar.gal).

3.2. Impact of COVID-19 on marine Spanish aquaculture

When analyzing the survey data regarding the economic effect of COVID-19 on Mediterranean marine aquaculture, it can be observed that extensive marine aquaculture suffered a lower percentage of economic loss than the intensive aquaculture, with a higher number of responses with losses above 60% (Fig. 5). When comparing IMTA and non-IMTA installations, it appears that the existence of multi-trophic aquaculture mitigated the negative impact of COVID-19 (Fig. 6). The IMTAs were composed of a combination of crustacean and mollusk species and fish and algae. Among the examined potentially negative effects generated by the COVID-19 crisis and associated management measure, in intensive aquaculture (fish farming in the Mediterranean Sea), respectively: the difficult to trade juvenile or fry supply, the loss of international markets, loss of markets absence of consumers, the logistical restrictions on transportation and the loss of usual customers and retailers were the most reported as the relevant. For extensive aquaculture (mollusk production in the Atlantic region of Galicia), the factors reported as mostly affecting the sectors have been respectively: the decrease in prices, the loss of international markets, loss of markets absence of consumers, difficulties of suppliers collecting seafood, loss of usual customers and retailers and the logistical restrictions on transportation (Fig. 7). The interviewees indicated that with respect to the negative influence of environmental conditions on aquaculture production in intensive systems in the years prior to COVID-19, storms and diseases had more weight. However, in extensive aquaculture, heat waves, storms, and diseases were relevant. HABs and local pollution were highlighted only by this type of aquaculture as a problem to be taken into account (Fig. 8).

4. Discussion

When analyzing the years prior to the COVID-19 crisis, it can be observed that the Spanish marine aquaculture sector was already under pressure due to a multitude of stressors, partly derived from the problems of climate change. With the arrival of the pandemic and the associated lockdown and mobility limitations, companies operating into the

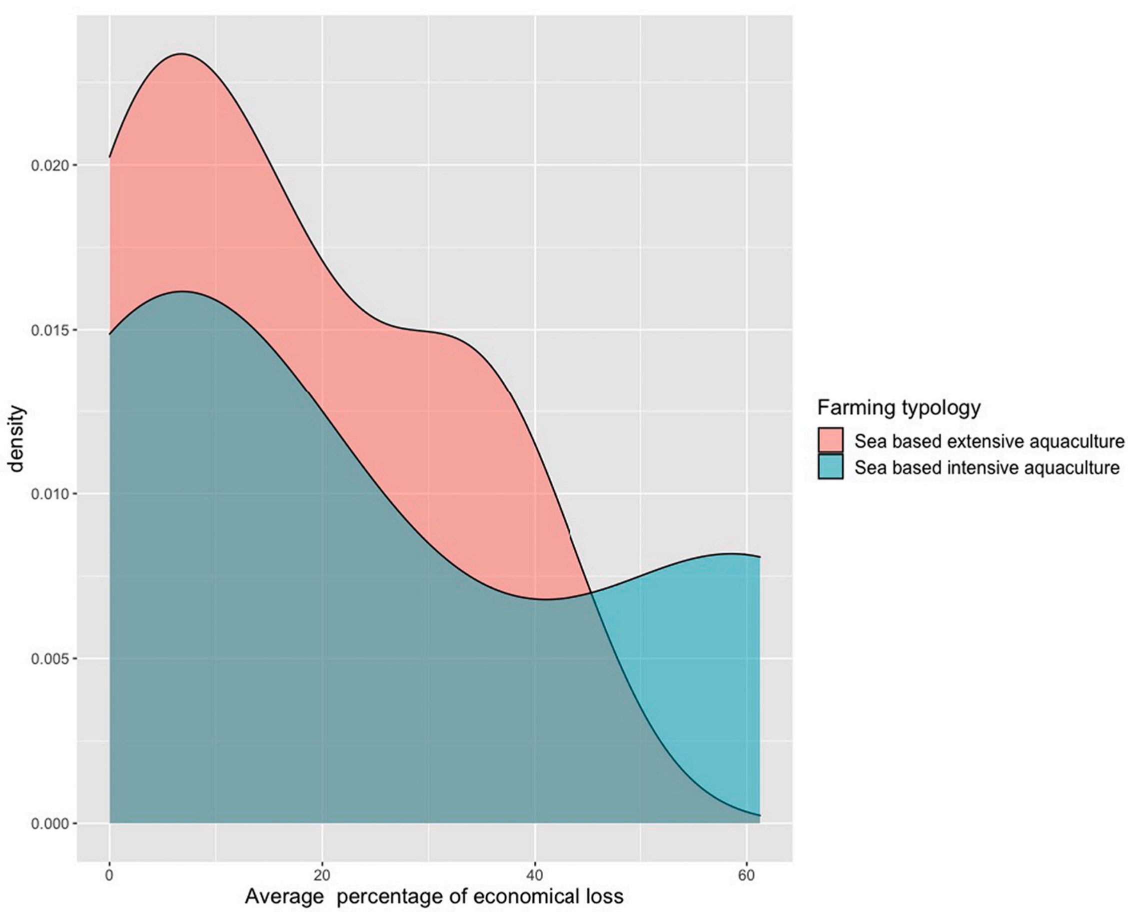

Fig. 5. Loss estimated by producers due to COVID-19 in relation to the type of marine aquaculture: extensive and intensive, in Spanish marine aquaculture.

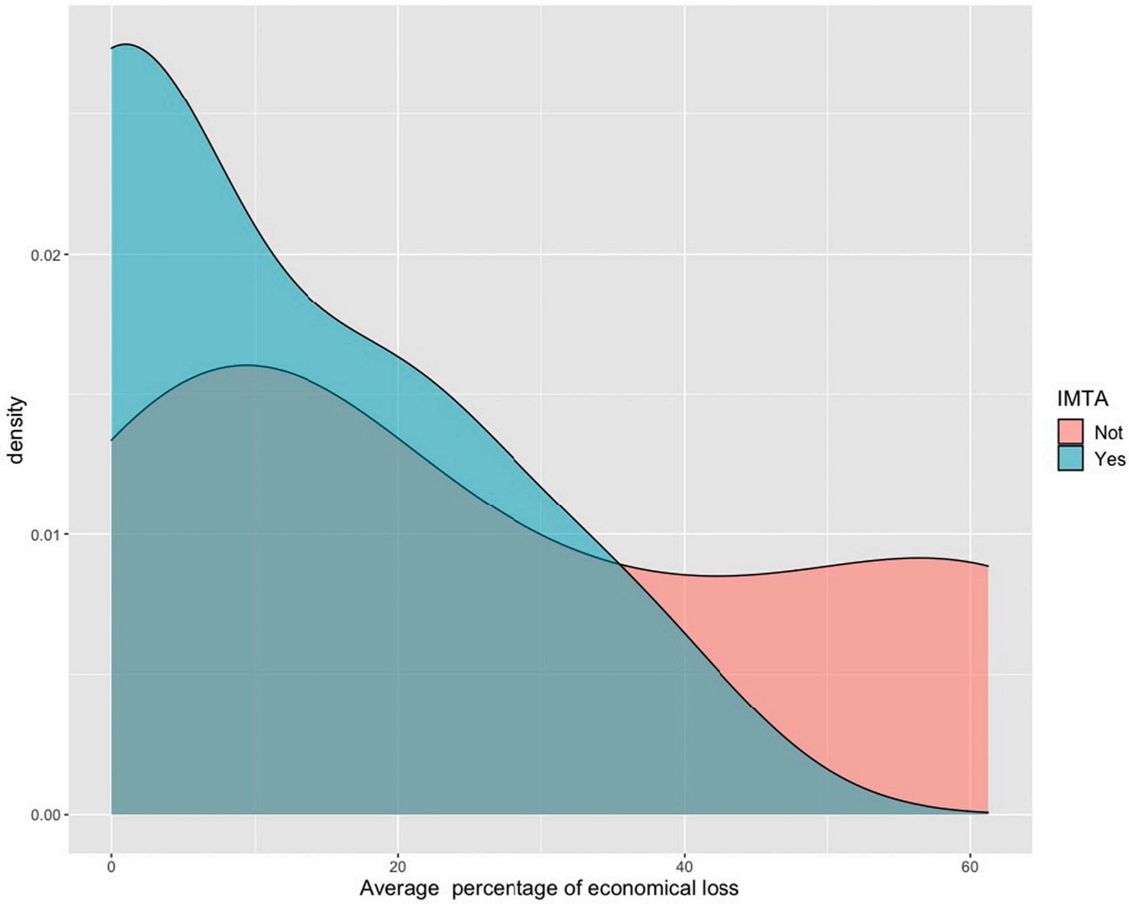

Fig. 6. Loss estimated by the producers due to COVID-19 in relation to the implementation of IMTA, in Spanish marine aquaculture.

sector suffered logistical difficulties in trade, particularly in relation to transportation and border restrictions. In this regard, it should be noted that the sector was weakened by environmental problems largely due to climate change, making it less resilient to the global crisis resulting from the COVID-19 pandemic. This empirically demonstrated condition for Spanish aquaculture was in line with a global scale assessment and with perception of stakeholders from other countries across the world (Álvarez-Salgado et al., 2008; Pérez et al., 2010; Sarà et al., 2021b). Taking into account this complex picture with respect to climate change and other human pressures on marine ecosystems such as nutrient increases or HAB, it has been postulated that the greatest threat for sustainable aquaculture development is the co-occurrence and interaction of multiple environmental stressors (Sarà et al., 2018a, 2018b). The effects of these climatic stressors on aquaculture can basically act in two ways. Multiple stressors effects could be often the additive accumulation of impacts associated with single stressors, however in some situation the multiple stressors can exacerbate negative impacts to systems when acting in concert (Crain et al., 2008). Also, to understand the effect of multiple stressors it is essential to analyze the temporal and spatial scale at which they act (Sarà et al., 2018a, 2018b).

Climate change may bring a number of negative factors to the development of marine aquaculture, and potential impacts on farming activities cannot be attributed to one single factor of climatic change, and in many cases there will be a series of negative consequences derived from different climatic stressors that are difficult to discern and that may act synergistically (Reid et al., 2019). The IPCC indicate in the report entitle "Special Report on the Ocean and Cryosphere in a Changing Climate" (IPCC, 2019) that the ocean warming trend documented in the IPCC Fifth Assessment Report (AR5) has continued. Also, anthropogenic climate change has increased observed precipitation, winds, and extreme sea level events associated with some tropical cyclones, which has increased intensity of multiple extreme events and associated cascading impacts. In the Spanish Mediterranean, the most intense storms, especially Gloria, caused multi-million dollar losses that are difficult to quantify due to fish escapes caused by broken infrastructures which is on o the major problem in open ocean fish aquaculture (Jackson et al., 2015), and climate change seems to be increasing their recurrence. Regarding to HABs, the speedy growth of toxic algae cause negative impacts on pelagic system, affecting negatively to mussel production, affecting additionally to pH and dissolved oxygen (Avdelas et al., 2021). The number, intensity and consequences of harmful algal blooms episodes have been increasing (Glibert et al., 2005), which makes it more difficult to predict and effectively respond to these events. Harmful algal blooms affect mainly Spain, Portugal, Italy, France, Greece, Ireland (mostly longline culture), the UK, Bulgaria, Croatia and Slovenia (Avdelas et al., 2021).

In the case of Spanish marine aquaculture, it seems that it is under pressure from different stressors, such as heat waves or extreme storms, which has undermined its resilience to other stressors such as the COVID-19 crisis. The month of February 2020 was extremely warm and very dry in the Valencian Community. The average temperature, 12.3 °C, was 3.5 °C higher than the reference climatology (8.8 °C). Thermally, February 2020 has been an extraordinary month. It was the warmest February since records have been kept, surpassing February 1990. The average temperature of February 2020 (12.3 °C) was even 1.1 °C higher than that of a normal March (11.2 °C). In fact, in the climatic series of the Valencian Community there are very few months of March with an average temperature higher than that of this February 2020 (https://www.aemet.es/es/web/datos_abiertos/estadisticas/vigilancia_clima). The water surface temperature was a reflection of

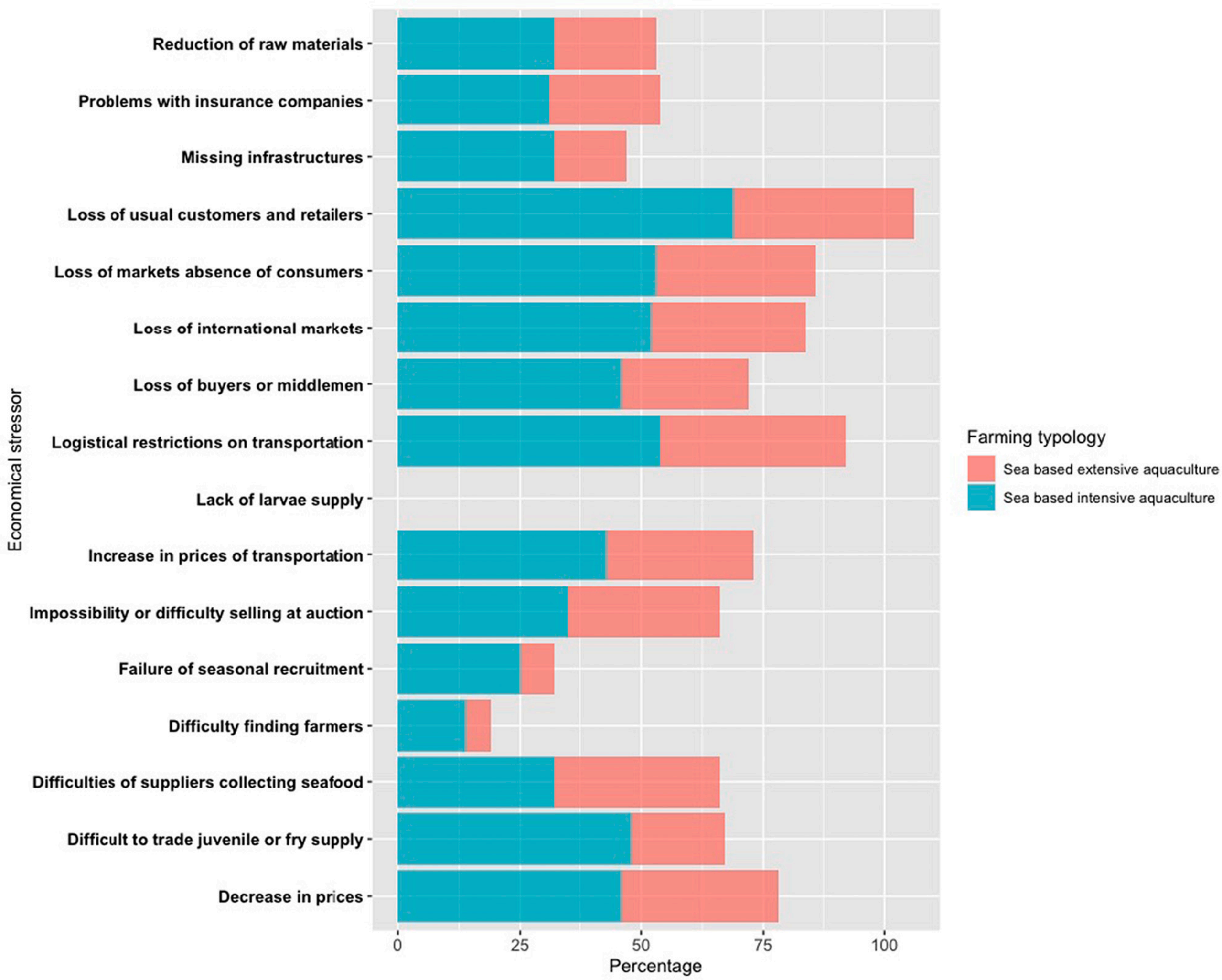

Fig. 7. Factors and processes, in percentage of their relevance, that caused economic losses due to COVID-19 in Spanish marine aquaculture.

this extreme warming of atmospheric conditions. For a long period the fish in culture suffered cumulative heat stress that could affect disease resistance. In this sense, it is relevant not only to evaluate the chronic effects of sea water warming, but it is also relevant to account for stress recovery during periods of fluctuating temperature. We determined also relevant fluctuations in water temperature as a result of heat waves in winter periods. In this thermally fluctuating environments, it is likely that a single maximum temperature criterion would be exceeded repeatably for short durations rather than continuously for a long period (Bevelhimer and Bennett, 2000) but the dynamics of stress recovery in fish under these circumstances is poorly understood and to know the thermal tolerance of target aquaculture species such as seabass could be relevant (Dülger et al., 2012). Rising temperature up to a certain limit favors aquaculture production, but beyond optimum limit, the metabolic stress caused by temperature adversely affects growth, food consumption and/or health of the fish under culture. For example, the upper and lower thermal tolerance of European sea bass might be limited by physiological constraints (Sarà et al., 2018a, 2018b; Mangano et al., 2019; Giacoletti et al., 2021). European sea bass have poor acclimatization capacity in order to survive in aquatic systems characterized by temperature variations (Kır and Demirci, 2018). Future production of this target species for Mediterranean aquaculture could be jeopardize for these processes.

To ensure sustainable growth of European aquaculture, the sector should to enhance resilient aquaculture production systems, agains multiple climate changes stressors (Reid et al., 2019). European aquaculture has to reduce the lower carbon footprint, helping to achieve the UN Sustainability Development Goals (SDGs). For that apart of the current lines of research in aquaculture are directed towards systems that favour the development of more sustainable aquaculture, seeking alternative sources of protein for feed supply, diversifying alternative sources of protein for feed supply, diversifying cultivable species of lower trophic level and implementing more environmentally friendly, such as integrated multi-trophic aquaculture systems (IMTA; Bostock et al., 2010; FAO, 2009). IMTA could provide a wide range of environmental services (Ahmed and Glaser, 2016), for example, reducing eutrophication risk because the dissolved nutrients provided by fish farming could be indirectly transfer to the filter feeders though primary producers (Sanz-Lazaro and Sanchez-Jerez, 2020). Developing IMTA models can provide quantitative tools for the development and management of these production systems (Ren et al., 2012) may help to design farming systems that are more resilient to climate change.

Also, IMTA allows for a better capitalization of natural resources, creates new sustainable products, value chains and markets in support of coastal communities while enhancing resilience to climate changes (FAO, 2009). Using local resources, IMTA creates new economic niches, increasing the opportunities for local investment and employment, supporting rural development and counteracting the fading of coastal communities (Correia et al., 2020). Therefore, within the sustainable development of aquaculture enterprises, there is therefore the option of

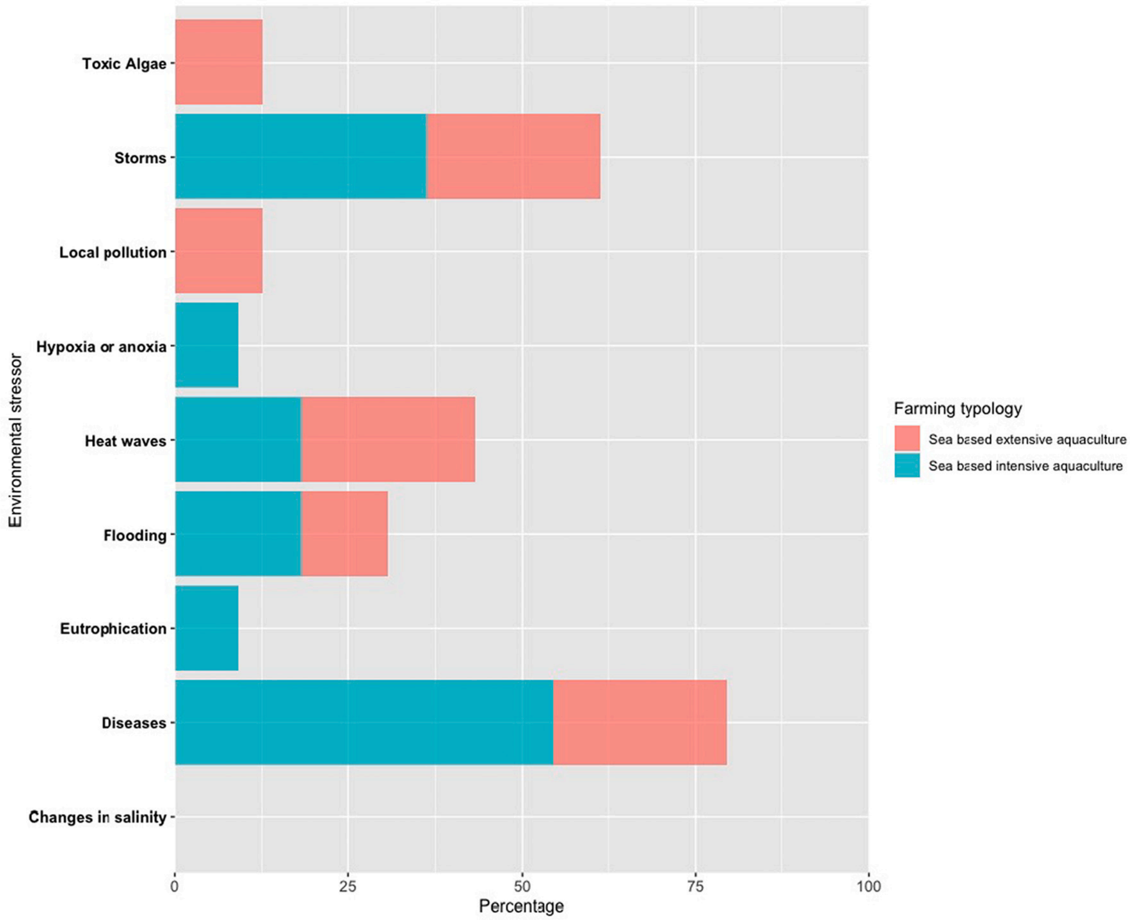

Fig. 8. Environmental factors that caused problems to production prior to COVID-19, in percentage of their relevance.

simultaneously producing different species for a better use of resources by reducing the possible excess of organic matter generated in aquaculture organic matter generated in aquaculture culture, mainly through the incorporation of secondary cultures (Chopin et al., 2012), and therefore secondary crops, and therefore providing an improvement in the environment, with the diversification of species, and a business of species, and a business economic benefit being more resilient to additional impact such as the COVID-19. However, in spite of potential benefits and adaptation to climate change, the development of IMTA in Europe faces inherent social, economic, technological, and environmental difficulties, which reasonably limit its wider adoption across Europe (Kleitou et al., 2018). Potential negative impacts of IMTA such as spatial and location issues, disease outbreak possibilities and food safety concerns has been highlighted, as well as potential risks related to containment and governance issues (Alexander et al., 2016).

COVID-19 has halved demand for fish and fish products, and massively disrupted the supply system, leading different operational sectors to close, feed imports to stop, and many value chain actors to suffer economic losses. This has particularly affected small and medium-sized entrepreneurs and fish producers who have still not been able to resume their regular business. Sarà et al. (2021b) indicate a world scale that the main lesson learnt from the COVID-19 pandemic is the importance of taking rigorous, strict and fast disaster-risk management approaches to adapt to a novel sudden shock condition and to safeguard life. In addition to this, the concomitant effects of the COVID-19 crisis acting together with multiple anthropogenic stressors, specifically on local scale, must be managed jointly and proactively to make the aquaculture sector more resilient as supported by our Spanish evidence. Specific measures to reduce aquaculture vulnerability in accordance with the ecosystem approach to aquaculture include the improved management of farms and choice of farmed species, the improved spatial planning of farms that takes climate-related risks into account the improved environmental monitoring involving users and the improved local, national and international coordination of prevention and mitigation actions (Soto et al., 2018).

5. Conclusions

Spanish marine aquaculture has been intensively subjected to climatic stressors that made it more vulnerable to COVID-19. It seems that extensive aquaculture and aquaculture developed by IMTA is somewhat more resilient to the impact of COVID-19. In order to ensure the environmental and economic sustainability of marine aquaculture in an uncertain pandemic scenario, it needs to be more resilient to climate change and therefore needs imminent climate change adaptation programs tailored on the specific farming strategies. If marine aquaculture, based on an ecosystem management of its activity and a forecast of the effects of climate change, is less vulnerable to unpredictable oscillations of environmental changes, it will also be less vulnerable to unexpected crises such as that of COVID-19. A proper spatial planning can also mitigate the effects of climate change (Sanchez-Jerez et al., 2016). Also, the spread of the COVID-19 pandemic in 2020 has led to profound social, economic and geopolitical shifts that will likely prevail for many years to come. These impacts present challenges and opportunities for marine and climate governance. The economic slowdown has reduced greenhouse gas emissions and exploitation of ocean resources. It creates the potential for a policy reset as economic activity resumes (McDonald et al., 2020).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. We are grateful to all the respondents who took the time to take the survey and to many colleagues for their effort done in facilitating the circulation of questionnaires. M.C.M.'s research activity was supported by the European Union's Horizon 2020 Research and Innovation pro- gramme under the Marie Skłodowska-Curie Action (Grant agreement no. 835589, MIRROR Project). We are grateful to QUALTRICS (Inc. USA) Product Specialists based in Italy to have always answered to queries about software technicality. We recognised the wide, prompt and effective support offered by the Ethical Committee at the University of Palermo in assessing the questionnaire.

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