Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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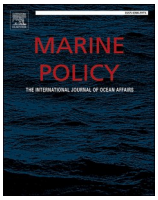

Impact of COVID-19 on Croatian mariculture: Findings from the first national surveys

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ABSTRACT

An overview of the negative effects of the COVID-19 pandemic on the mariculture industry of the republic of Croatia is provided. An initial online survey was circulated early after the onset of the pandemic and a follow-up field survey was performed a year into the pandemic. The surveyed companies varied in size (micro to medium enterprises), location (north, central and southern coast) and cultured organism (European flat oyster, Mediterranean mussel, European sea bass, Gilthead sea bream and/or Bluefin tuna) and were asked questions on the subject of economic and job losses, aquaculture supply chain processes and implemented or proposed measures for mitigation of negative effects. Results from the online survey showed higher economic loss than job loss, but companies reported increased job loss in the period leading to the field survey. Most companies reported reductions in sales and avenues of procurement, which, in addition to direct stressors, indirectly affected business processes. Micro enterprises fared well due to their part-time nature, low capital investments and running costs, while small to medium enterprises were under the most pressure. Large enterprises were barely affected as they had secure local and/or international distribution chains and dominated the market. Producers most affected were those that relied on the HoReCa market for product placement and/or had difficulty coping with existing stressors. Bivalve producers generally experienced a higher drop in sales than finfish farms and companies with specialized production were not able to adapt to market changes to the degree that more versatile businesses seemed capable of.

1. Introduction

The aquaculture sector represents an essential source of food and income for a large portion of the global population. Aquaculture production is constantly increasing [1]. However, the COVID-19 pandemic has forced the sector to reduce production as a result of the associated pandemic management measures and the disruption of associated services. The effects have been recorded at all levels of the aquaculture supply chain affecting demand, logistics, prices, labour force and business planning [2–5].

Croatia is a country naturally suited for marine aquaculture activities, with a coastline that includes more than 1200 islands and numerous bays with perfect conditions for farming of marine species, which play an important role in the country's economy. Farming of marine organisms has a long tradition in Croatia, with first written documents on harvest fisheries dating back 1000 years [6]. The first site for bivalve farming in the Mediterranean was Mali Ston Bay in the south of Croatia, which today is known for healthy (Bonamia-free) populations of the European flat oyster (*Ostrea edulis*). Croatia pioneered the farming of European sea bass (*Dicentrarchus labrax*) and gilthead sea bream (*Sparus aurata*) in the early '70s. The first floating cages were set up in 1974 around the island of Cres [7]. The first hatchery dedicated to European sea bass and gilthead sea bream was built in 1984 in Nin (Cenmar), which led to the beginning of commercial farming of this species

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in Croatia. By the end of the previous century, other smaller farms were opened, and total production was around 50 t [8]. Atlantic bluefin tuna (*Thunnus thynnus*) fattening and farming started in the early nineties in the Mediterranean Sea as capture-based aquaculture production where the smaller specimens of wild-caught tuna were fed to market size in cages. The development of Croatia's aquaculture was interrupted in the 1990 s by the war, which had detrimental consequences for the industry. Nevertheless, with subsequent stabilisation of the economy numerous companies emerged and today present a staple of Mediterranean aquaculture, with farmed species such as gilthead sea bream, European sea bass, meagre (*Argyrosomus regius*), Atlantic bluefin tuna, Mediterranean mussel (*Mytilus galloprovincialis*) and European flat oyster. Aquaculture production has been steadily increasing, especially in recent years, mainly thanks to an increase in production of European sea bass, gilthead sea bream and the introduction of new species such as meagre (Table 1), but it is important to highlight the production of European flat oyster which, although not on the rise, accounts for more than 80 % of total Mediterranean production of this species [9,10].

As of August 2021, a total of 118 companies in Croatia were registered for bivalve farming, 32 for marine finfish farming, of which 4 were for tuna and 2 for polyculture - finfish and bivalves [11].

European sea bass and gilthead sea bream are farmed along the whole coast, but the largest share of total production comes from the central part of the coast and accounts for around 63 % and 62 % of Croatia's aquaculture production quantity and value, respectively. A single large enterprise, Cromaris, is responsible for the majority of this production. It is Croatia's largest aquaculture producer, the sixth largest producer of European sea bass and gilthead sea bream in the world and the fastest growing national company with a tendency for further growth (www.cromaris.com). Four companies farm tuna at 10 sites, all located in the central part of the coast. Bluefin tuna is the third most important individual species of this region, accounting for 13 % of the total aquaculture production and 26 % of the total value [12]. These large marine finfish companies account for around 64 % of the total number of employees, 79 % of the total sales mass and 92 % of the total sales value in Croatia [12], which makes them the most important segment of Croatia's aquaculture industry.

Bivalve production is primarily located in the southern coast, specifically in Mali Ston bay, where 65,8 % of Croatian companies involved in bivalve aquaculture are based [11]. In 2019, these produced 86 % of European flat oysters and 45 % of mussels in Croatia. The farms in Mali Ston bay are mainly small family businesses that use bivalve farming as an additional source of income, while the somewhat larger SMEs in the area focus on farming as their primary source of income and have invested large amounts of capital into their businesses resulting in higher levels of automation and/or higher numbers of employees. The bivalve farms located on the central and northern coast of Croatia are fewer in number and focus primarily on mussel production [9].

Farmed finfish, especially those from larger fish farms, are sold both domestically and exported to the EU (around 50 % of total production) [12], while finfish from smaller farms with an annual production of less than 200 t are mainly sold domestically, where they have found a niche market and fetch good prices (personal communication). The exception is tuna, which is produced almost exclusively for the well-established Japanese market. Bivalves on the other hand are placed almost exclusively on the domestic market. Thanks to the proximity and trade relations of the central and northern coast with important EU and international markets, the share of aquaculture products in total exports is growing steadily, in addition to the continuously increasing domestic market, which has enabled a steady growth in production [13].

The recent COVID-19 pandemic has triggered a global economic crisis and impacted all sectors of economy worldwide with tourism and tourism-dependent activities being especially affected [14]. Tourism in Croatia accounts for the highest share of the GDP of all EU countries, equal to 19.4 % in 2019, while in 2020, this value dropped to just 9.8 % as a result of the COVID-19 pandemic [15].

Given that a large portion of Croatian aquaculture production (around 30–50 %) is tightly linked to the HoReCa sector [12], it was expected that the aquaculture sector in Croatia would undergo severe direct and/or indirect negative effects caused by the COVID-19 pandemic [16,17].

Here we present a snapshot – based on stakeholders' perception – of the socio-economic effects caused by the COVID-19 pandemic on marine aquaculture activities in Croatia. An online survey was conducted in May 2020, amid the COVID-19 crisis and in-depth interviews were performed with farmers in the period from January till May 2021 to obtain more information from the farmers after a year into the global pandemic. Furthermore, inquiries were made to assess the type of measures that were put in place to mitigate negative effects of the pandemic.

Table 1
The production of finfish and bivalves in Croatia from 2015 to 2020 in tonnes (MA, 2021b).

Species	2015	2016	2017	2018	2019	2020*
European sea bass (*Dicentrarchus labrax*)	4075	5310	5616	6220	6089	6754
Gilthead sea bream (*Sparus aurata*)	4488	4101	4830	5591	6774	7780
Atlantic bluefin tuna (*Thunnus thynnus*)	2603	2934	2162	3227	2747	3323
Mediterranean mussel (*Mytilus galloprovincialis*)	746	699	920	882	947	496,8
European flat oyster (*Ostrea edulis*)	52	64	62	54	61	14,4
Other	78	127	253	808	725	618
Total (tonnes)	12043	13235	13843	16782	17343	18986

*Preliminary data.
**Meagre (*Argyrosomus regius*), turbot (*Scophthalmus maximus*), common dentex (*Dentex dentex*), greater amberjack (*Seriola dumerili*).

2. Materials and methods

2.1. Study area

The Adriatic Sea is an elongated semi-enclosed basin in the northeastern Mediterranean Sea. The Croatian coastline represents 74 % of the total Adriatic coastline and almost 9 % of the total Mediterranean coastline. It extends in a southeast – northwest direction and, considering its main characteristics, three biogeographic regions can be recognized: a deep southern sub-basin, a central sub-basin of intermediate depth and shallow northern sub-basin [18]. The areas used for the purpose of the current study loosely followed this biogeographic classification and were adapted to encompass aquaculture industries representative of each region, with the south part focusing mainly on Dubrovnik-Neretva county, the central part ranging from the Split-Dalmatia to Lika-Senj county and the north focusing on the Istria county.

Geomorphologically and ecologically suitable sites for farming of finfish and bivalve species exist along the entire coast, and both groups of organisms are cultured in each of the studied areas, bivalve production is predominant in the southern part, while finfish are mainly produced in the central basin, with tuna cages being exclusive to the central basin.

2.2. Online survey

The first set of data was collected through an online questionnaire, which was sent to mariculture companies by email in May 2020 amid the COVID-19 crisis. The online survey was based on a semi-structured questionnaire that was conducted to investigate the effects of COVID-

19 on the aquaculture sector (study approved by the Ethical Committee at the University of Palermo, UNPA-183-Prot. 767–05/05/2020n. 1/2020 29/04/2020).

The semi-structured questionnaire [4,5] was transferred on Qualtrics (https://www.qualtrics.com), an online platform that allowed the creation of a web survey that was distributed to stakeholders. The web survey was accessible during three weeks, 5–29th May 2020, amid the COVID-19 pandemic. Replies were coded as a function of geographic position of the farms and the type of farmed species.

Participants were asked to select among four aquaculture categories a priori selected, i.e. land based extensive aquaculture (fish, invertebrates, algae etc.; LBE), land-based intensive aquaculture (tanks/ponds; LBI), sea-based extensive aquaculture (mollusc farming, algae, echinoderms etc.; SBE) and sea based intensive aquaculture (cages; SBI).

2.3. Field survey

In-depth field interviews with employees or owners of mariculture companies were conducted from January till May 2021. In total, 16 companies (6 in the southern part, 5 in the central and 5 in the northern part of the coast) were assessed using field surveys and information regarding production, COVID-19 impacts, adjustment measures and possible solutions was analysed.

The aim was to collect more personal observations and comments on the COVID-19 crisis after one year of the pandemic during which all sectors, including mariculture, were observed to suffer significant losses. The questionnaire was unstructured, but covered the main topics from the online survey and related control measures. The questions were open-ended, allowing us to gain insight into individual experiences and perspectives of the farmers during the COVID-19 crisis. A random sample of farms from the south, central and north coast of Croatia were interviewed, but did not necessarily coincide with stakeholders from the online survey.

2.4. Data analyses

2.4.1. Online survey

To collect information on the participants' perceived economic distress, the survey started by asking to report economic and job losses associated with COVID-19 outbreaks. Replies were quantified using a scale from 1 = no economic loss at all, to 10 = very high economic loss and subsequently ranked into four categories: 1 no effect, 2 – 4 low, 5 – 7 moderate and 8 – 10 high. To explore potential effects on the four stages of the aquaculture perishable food supply chains (i.e., hatchery; production / transformation; distribution / logistics; market), we asked respondents to indicate whether they experienced economic loss (scaled from 1 = no economic loss at all, to 10 = very high economic loss and subsequently ranked into four categories: 1 no effect, 2 – 4 low, 5 – 7 moderate and 8 – 10 high) associated with several stage's specific aspects. At the hatchery stage we asked to report economic loss associated with: lack of juvenile/fry supply; lack of raw materials provision (e.g. feeds, packaging material); difficulty with insurance companies. At the production / transformation stage we asked companies to report economic loss associated with: infrastructure (i.e. missing freezing container, smoking room, packaging, etc.); labour's failures (i.e. seasonal hiring of farmers); difficulties of suppliers (wholesalers) in purchasing seafood products; absence of middlemen (markets, stores). At the distribution / logistics phase we asked to report economic loss associated with: increases in transportation prices; restrictions on transportation availability (e.g., flight cancellation, closure of geographical borders between countries). At the market stage we asked to report economic loss associated with: price decrease of farmed products (i.e. depreciation due to surplus production or a loss in orders); impossibility / difficulty of selling to the national market; impossibility / difficulty to enter international markets; absence of customers in distribution channels (e.g., tourists, schools, restaurants, etc.). A list of mitigation solutions was provided to check for preferences among respondents. These were divided into internal (reduction of farm dimension and change of farming techniques) and external solutions (direct sales, exploration of new markets, new stocking solutions, request of external economic support, e.g. regional, national, European level).

2.4.2. Field interviews

The questionnaire for field interviews used a qualitative, rather than quantitative approach (only for farm size, production quantities, numbers of employees) to collecting and processing the data.

Only the main points from the online interview were addressed, and included questions related to: cultured species, production quantities, farm size, numbers of employees, negative effects of the COVID-19 pandemic on sales and other business aspects and implementation of current and ideas for future mitigation mechanisms. The surveyed subjects were also asked to compare COVID-19 effects and other past negative effects on business processes. The list of questions is provided in Supplement 1.

3. Results and discussion

3.1. Analysis of COVID-19 online survey

The online questionnaire reached a total of 23 stakeholders, primarily practicing sea-based farming, of which 74 % were bivalve farms and 26 % were finfish (cage) farms.

All participants working on bivalve farms reported economic loss due to the COVID-19 pandemic, of which 76 % reported to have experienced high economic loss, while 12 % reported for both low and moderate economic losses (Fig. 1). A total of 65 % of interviewed stakeholders did not report a reduction in employees – job loss (Fig. 1).

All participants working on finfish farms reported high economic losses, 100 % (Fig. 2), while 83 % of interviewed stakeholders did not report a reduction in employees (Fig. 2).

The economic losses reported per each of the four stages of the aquaculture supply chain are reported in Figs. 3 and 4 for bivalves and finfish, respectively. Both bivalve and finfish farms suffered more from the lack of raw material provision than from an inadequate supply of juveniles and fry, especially in the case of bivalve farms, as juveniles are collected from the wild. Difficulties with insurance companies were reported by 67 % of the participants working on bivalve farms, confirming a lack of money resulting in insolvency or the ability to maintain the farming business. At the distribution and logistics level, both the increase in transportation price (69 % bivalve farms, 60 % finfish farms) and the transport / mobility restriction resulting from the lockdown (85 % bivalve farms, 80 % finfish farms) affected the sectors to a high degree. At the production / transformations level, the absence of suppliers and middlemen followed by a reported lack of infrastructure and by labour's failure were recognised as one of the most significant reasons

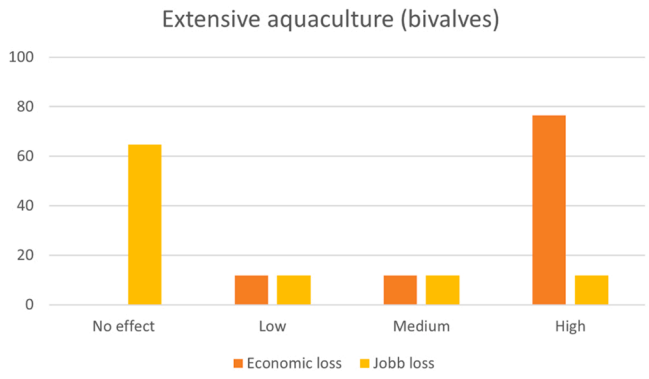

Fig. 1. Trends of economic and job losses reported by stakeholders operating bivalve farms, based on online survey.

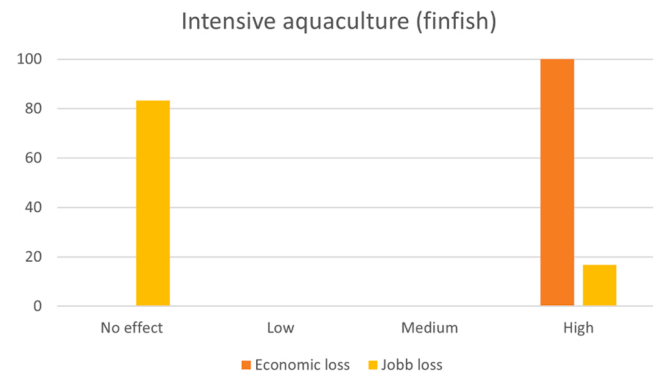

Fig. 2. Trends of economic and job losses reported by stakeholders operating finfish farms, based on online survey.

for economic loss in both extensive and intensive farms. The lack of national and HoReCA channels were reported as a high reason for economic loss; the highest both with participants practising bivalve and finfish aquaculture (79 % and 100 %, respectively). Looking at the respondent's preference on the proposed mitigation solutions, the internal ones, based on solutions at farming system level were considered less relevant for both bivalve and finfish farms (Figs. 7a and 8a) with a preference on change of farming techniques among finfish farmers (60 %). Mitigative solutions based on direct sales were preferred by both farm types (62 % bivalve farms, 100 % finfish farms), followed by the exploration of new markets (54 % bivalve farms, 80 % finfish farms) and by the request external economic support (43 % bivalve farms, 80 % finfish farms).

3.2. Analysis of COVID-19 field survey

The six analysed companies in the southern Adriatic were located in the main aquaculture site of the region – Mali Ston bay. These were small and medium-sized enterprises (SME) varying in size, producing exclusively flat oysters (one company), a combination of flat oysters and mussels (three companies) and a combination of bivalves and marine finfish (two companies).

The five companies in the central Adriatic corresponded to four bluefin tuna farms, one of which also produced European sea bass and gilthead sea bream, and the largest Croatian aquaculture company – Cromaris. Unfortunately, due to tight policies on disclosing information, it was impossible to obtain any information through the field survey, but quantitative data on the company's performance was taken from national statistics [11] and has been included in the results due to the importance of this company to Croatia's aquaculture sector.

The five analysed companies on the northern coast were located on the Istria peninsula, specifically in Raša, Medulin and Lim bays and Savudrija. All five farms were SMEs by definition, whose main product were farmed Mediterranean mussels, with three of them additionally growing European flat oysters and some trading in wild-caught finfish and shellfish.

3.2.1. Impacts of COVID-19 on sales in Croatia's mariculture industry

All surveyed SMEs in south Croatia exhibited a high drop in sales, from 50 % to over 90 % from 2019 to 2020 (Table 2), which primarily corresponded to their individual market placement strategies. In accordance to the online survey which reported economic loss due to disruption of HoReCa channels in the whole of Croatia, the highest drops were associated with SMEs in south Croatia that relied on the booming tourist industry for market placement (restaurants, hotels, farm tours with on-site product tasting etc.), a market strategy that had previously benefited both small family farms and larger SMEs. However, the few

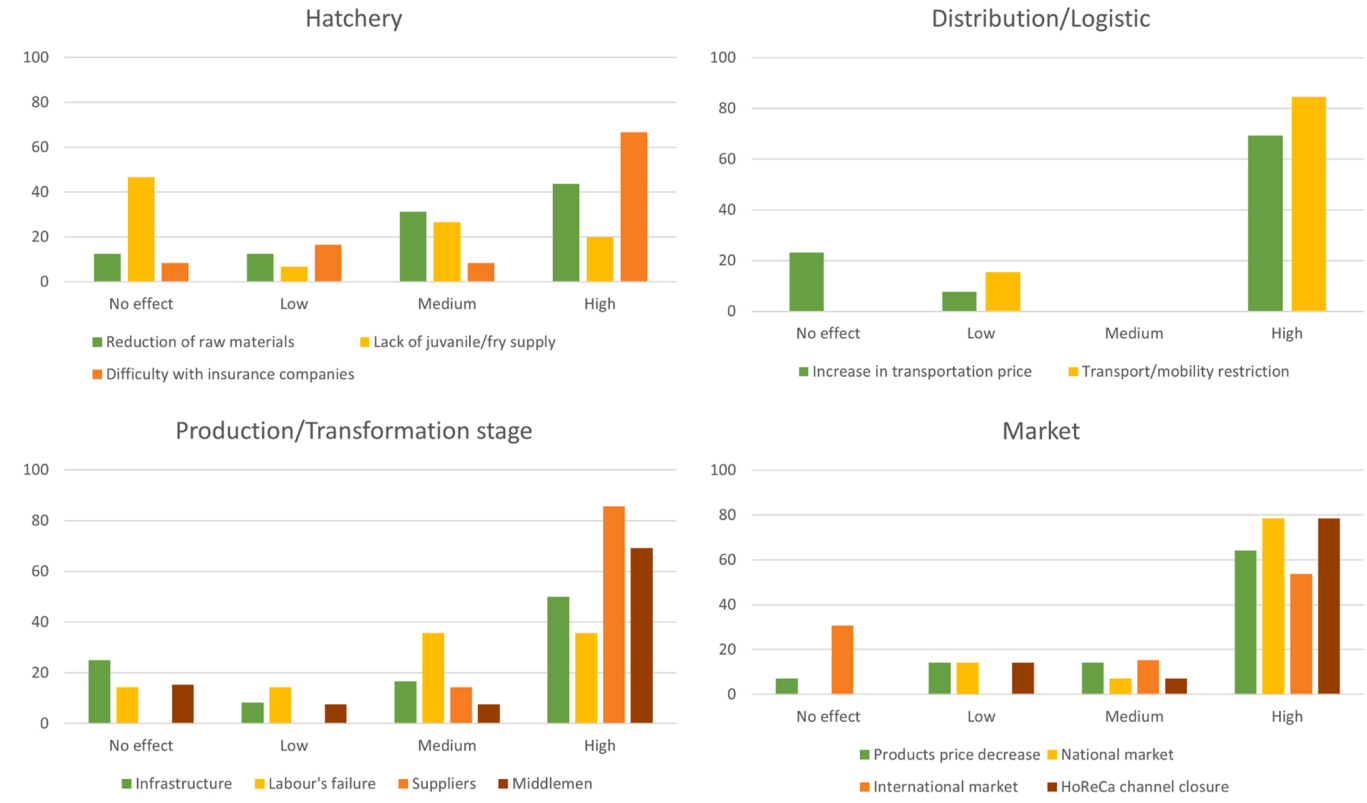

Fig. 3. Trends of economic loss reported by stakeholders operating bivalve farms across the four examined steps of the aquaculture supply chain: hatchery; production / transformation; distribution / logistics; market, based on online survey.

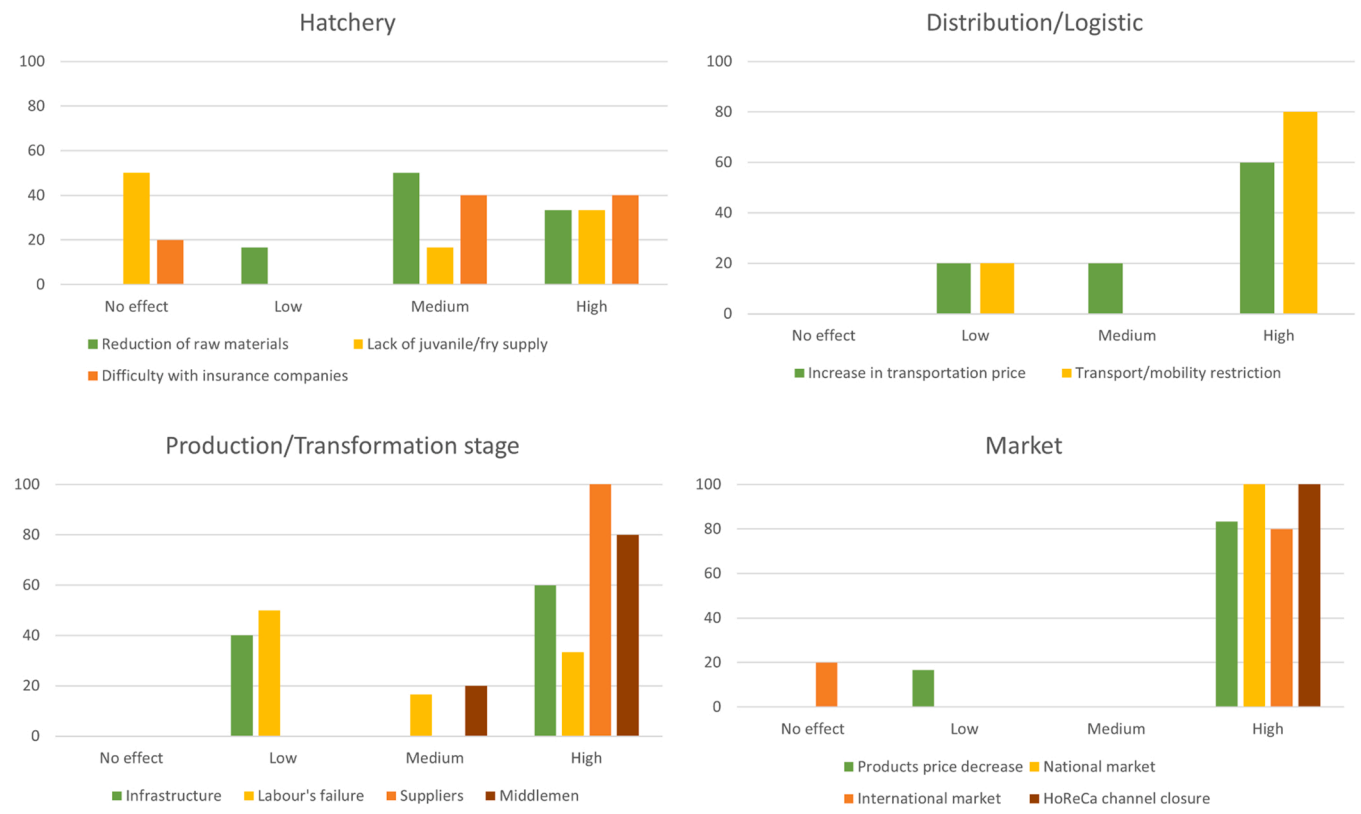

Fig. 4. Trends of economic loss reported by stakeholders operating finfish farms across the four examined steps of the aquaculture supply chain: hatchery; production / transformation; distribution / logistics; market, based on online survey.

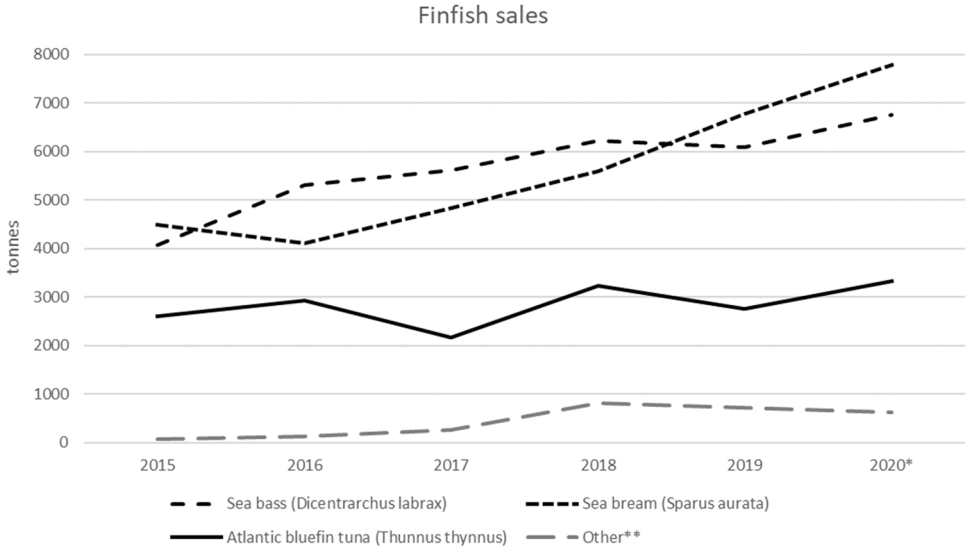

Fig. 5. Croatian sales of farmed finfish by species from 2015 to 2020 (MA, 2021b). *Preliminary data. **Meagre (*Argyrosomus regius*), turbot (*Scophthalmus maximus*), common dentex (*Dentex dentex*), greater amberjack (*Seriola dumerili*).

farms that had based their businesses on wholesale to local retailers (seafood suppliers) or had directly retailed in situ (Table 2, SME 2 and 5) fared better, with a decline in sales of around 50 %, which was an exception to the general trend observed in the online survey and contrasted other European countries where export was attenuated due to logistics related to transportation and border restrictions [19]. On the other hand, in the United States and Canada, the decline in export-oriented seafood trade had been accompanied by a rapid increase in demand for local and directly sourced seafood [20]. Due to the presence of such a large local market in Croatia, incidences of export of bivalves from Mali Ston bay had been non-existent during certain years and never exceeded 10 % and 2.5 % of total oyster and mussel sales, respectively [9]. During 2020, attempts were made by the tourism-dependent SMEs to change their business model and attempt to export or retail locally (with the introduction of home deliveries), but both options were met with limited success. Those that had explored export options faced low demand and low prices for their products (0.40 EUR per oyster, as opposed to 0.53 EUR in previous years) [9] of that

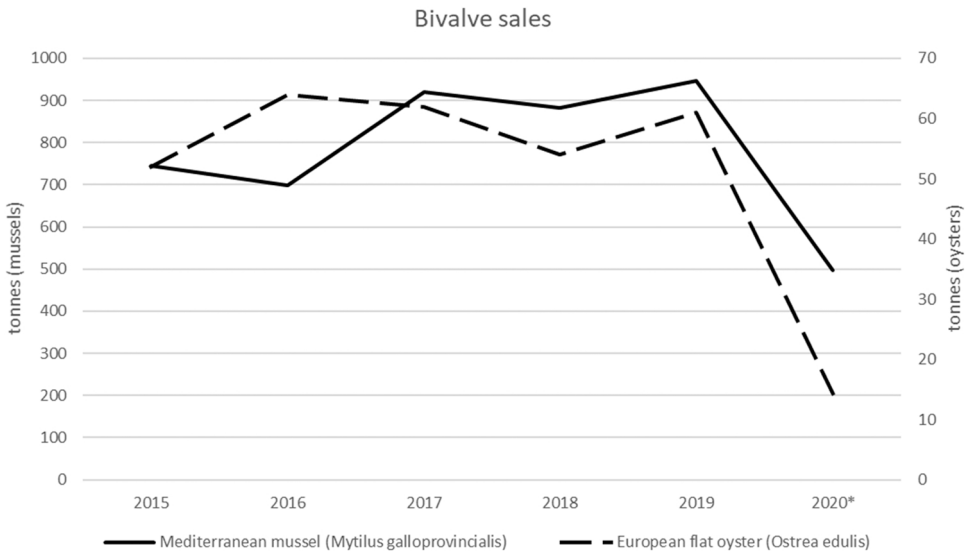

Fig. 6. Croatian sales of farmed bivalves by species from 2015 to 2020 (MA, 2021b). *Preliminary data.

barely covered production costs, while the local retail market already had established distribution chains and did not allow new entries. Furthermore, most affected were businesses that relied primarily on flat oyster production, while the local market demand for mussels did not seem to decline to this degree. This was likely a result of oysters being more of a luxury food item that is not consumed to such a degree by the local populace in comparison to mussels. Since restaurants typically sell more expensive live and fresh seafood, the closure of restaurants affected the market for these products, resulting in a 30 % decline in prices of imported live and fresh seafood products in Europe [21].

Nevertheless, all bivalve producers experienced a decline in sales, which was also observed in the online survey. On the other hand, marine finfish farms that already had established local retail markets and distribution chains fared well, while those dependent on the restaurant market did not, which differed from the general trend of results from the online survey. This discrepancy was likely due to the subsequent recovery of fish markets after the initial wave of COVID-19 lockdowns.

In short, SMEs in south Croatia that seemed to fare the best were those that avoided the tourism market altogether and sold to local retailers or directly retailed themselves, while focusing mainly on mussels.

In 2019, the Croatian production of European sea bass, gilthead sea bream and meagre totalled at 13,588 tons, of which 9557 tons (70.3 %) were produced by Cromaris - Croatia's largest aquaculture company situated in the central part of the coast. Their production in 2019 equated to a 2.14 % share in quantity and a 3.22 % share in value of the global aquaculture market for European sea bass and gilthead sea bream. Despite the uncertain economic situation caused by the COVID-19 pandemic, Cromaris was not affected negatively in this sense and actually had a 20 % growth in total sales in 2020 (Table 3). It managed to maintain export channels, especially to Italy, and to supply fish to the international market under very difficult conditions. Market shares were also gained in a number of other European markets in 2020. Market positioning, advanced technologies and recognition of market needs were key factors in overcoming the COVID-19 crisis (www.cromaris.com).

Aside from Mediterranean finfish species, the central Croatian coast is associated with bluefin tuna farming. The negative impacts of COVID-19 on the production of tuna was not as pronounced and was observed in only one of four surveyed farms (Table 4). It is important to note that most of the Croatian farmed bluefin tuna ends up in the Japanese sushi and sashimi market which means that the demand and prices are governed by it, or more precisely by the Tokyo's Toyosu market that has the largest volume of seafood sales in the world. The COVID-19 pandemic caused the Toyosu market to crash in the beginning of 2020 with consumers shifting to eating at home instead of outside [22]. Fresh bluefin tuna was affected more strongly than frozen, as frozen bluefin tuna could be stored until market conditions improved. Nevertheless, quantities of sold bluefin tuna drastically dropped for both products, as was the general trend for international sales of finfish observed through the online survey. However, by the end of 2020, Toyosu market had recovered as it adapted to the new COVID-19 pandemic situation by reducing prices and switching to online sales, which enabled access of these products to a wider array of consumers [23]. While this meant Croatian farmers could finally harvest and sell their products, it came at a reduced price.

Sales of the 5 companies on the northern coast were mainly oriented to the HoReCa sector and some wholesalers in the adjacent county, thus closely connecting them to the tourism industry. The COVID-19 pandemic drastically reduced the inflow of tourists in Istria in 2020. However, in contrast to the rest of the coast, the region's close proximity and land transport connections to other European countries allowed tourists to easily reach it by car. Therefore, the 2020 tourist season in Istria was mainly characterised by car travelling tourists, which partially mitigated the overall reduction of tourists. Nevertheless, a reduced demand for bivalves was observed in comparison to previous years, which had a negative impact on sales. The interviewed farms reported a 25–70 % reduction in sales from 2019 to 2020. As a result, farmers had to accept lower sales prices as an effort to sell the product and/or make changes in the business processes of their company.

3.2.2. Effects of COVID-19 on business processes in Croatia's mariculture industry

The direct effects of COVID-19 have been illness and isolation of employees, as well as restrictions of movement and entries, which have had an acute effect on reduced labour, disrupted supply lines and logistics and a medium- to long-term effect on reduction of economic resources available for production processes [24,25]. This has further been exacerbated by increased resources used for protection of employee health. As a result, a large number of the surveyed aquaculture companies in Croatia had to reduce stocking and production quantities, reduce the number of employees and/or cancel fry orders in the case of finfish farms, similar to what has been observed in other countries [3]. Furthermore, cultured organisms that were not sold had to be left on the farms to grow above established market sizes, which inferred additional costs mainly related to maintenance and feeding [21,26].

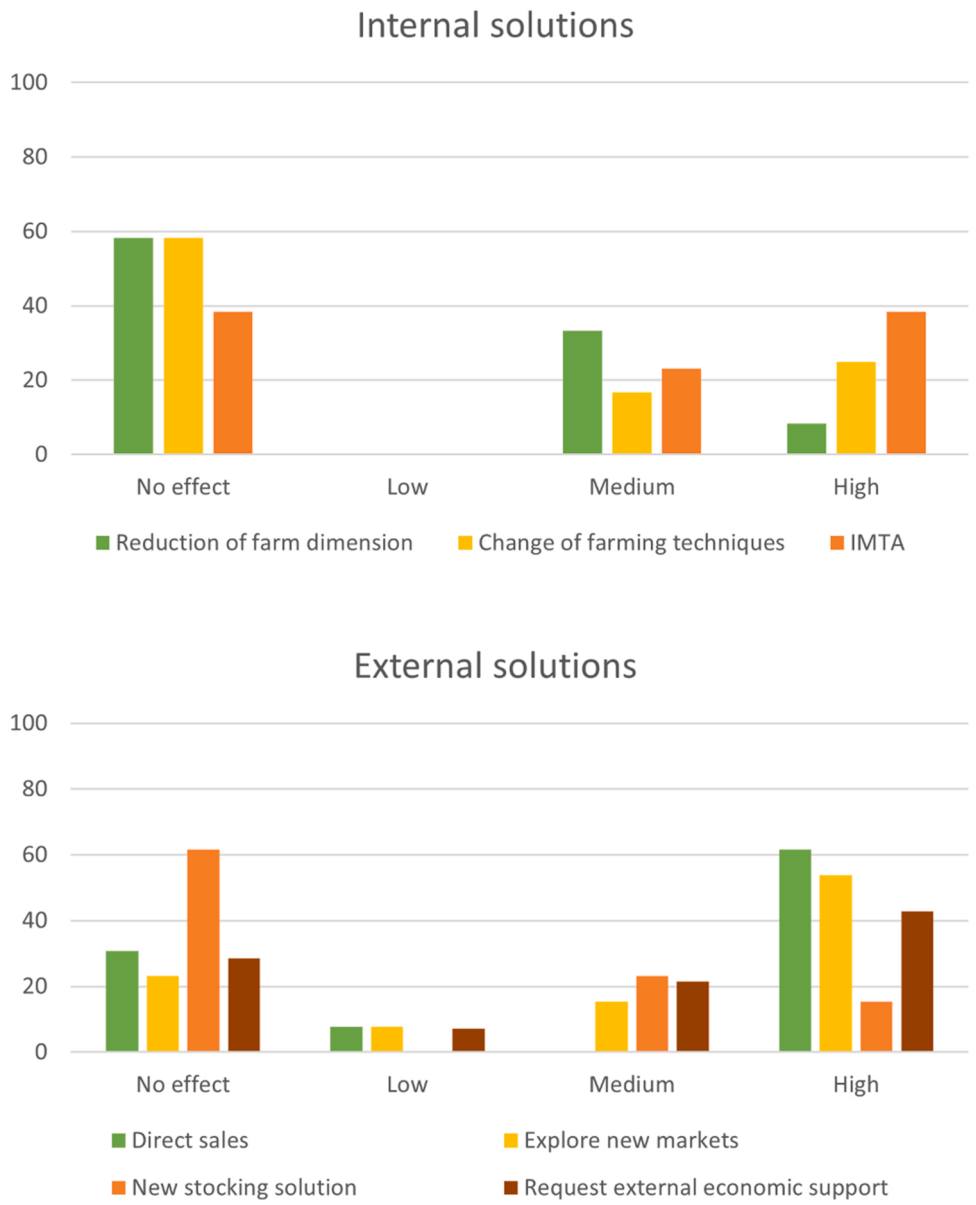

Fig. 7. Internal (site- / farm-based) and external mitigation measures adopted/suggested by stakeholders to cope with COVID-19 pandemic effects on bivalve farming, based on online survey.

3.2.2.1. European sea bass and gilthead sea bream. In south Croatia, cage-reared European sea bass (stocked in previous years) exceeded market sizes (300–400 g) and in April 2021 had already reached 500 g or more while waiting to be sold. Although it was not recorded in the short term, such an increase in the biomass of farmed finfish could exceed recommended values for the given farms and, paired with reduced availability of labour due to COVID-19 and associated health management measures, could result in severe animal welfare issues as well as negative environmental impacts [24].

The majority of Croatian European sea bass and gilthead sea bream farms obtain fry from abroad, as there are no local hatcheries that openly sell fry. While this meant there were no negative effects observed a hatchery level, farms reduced stocking densities as a response to low sales of market-sized fish during the COVID-19. Thus, the low impact of fry/juvenile availability observed through the online survey did not change in the remainder of 2020 before the field survey was performed; the supply of fry from abroad was enough to meet the lower demand.

On the other hand, the largest aquaculture company in Croatia, located on the central coast, seemed to be exempt from most listed negative impacts. This was likely due to large company size in comparison to other market competitors in the region, established local and international market position, as well as integrated business processes that allowed them a high level of independence from the availability of economic resources used in finfish production. These processes included: hatchery production of fry exclusively for in-company needs, on-growing in cage farms, dedicated aquafeed production, processing and packaging, distribution logistics and research and development.

3.2.2.2. European flat oyster and Mediterranean mussel. Low sales of bivalves, especially oysters, meant that market sized individuals with accompanying biofouling organisms remained in the sea and were weighing heavy on floating longlines, which required increased maintenance to prevent snapping of ropes, loss of harvest and equipment and/or mortalities of the cultured organisms. Thus, farmers were forced to adapt existing production processes to handle the large quantities of unsold bivalves. Fortunately, mussels require minimal maintenance during harvest and subsequent restocking on longlines and a lot of these processes are easily automated, but oysters require significant manhours

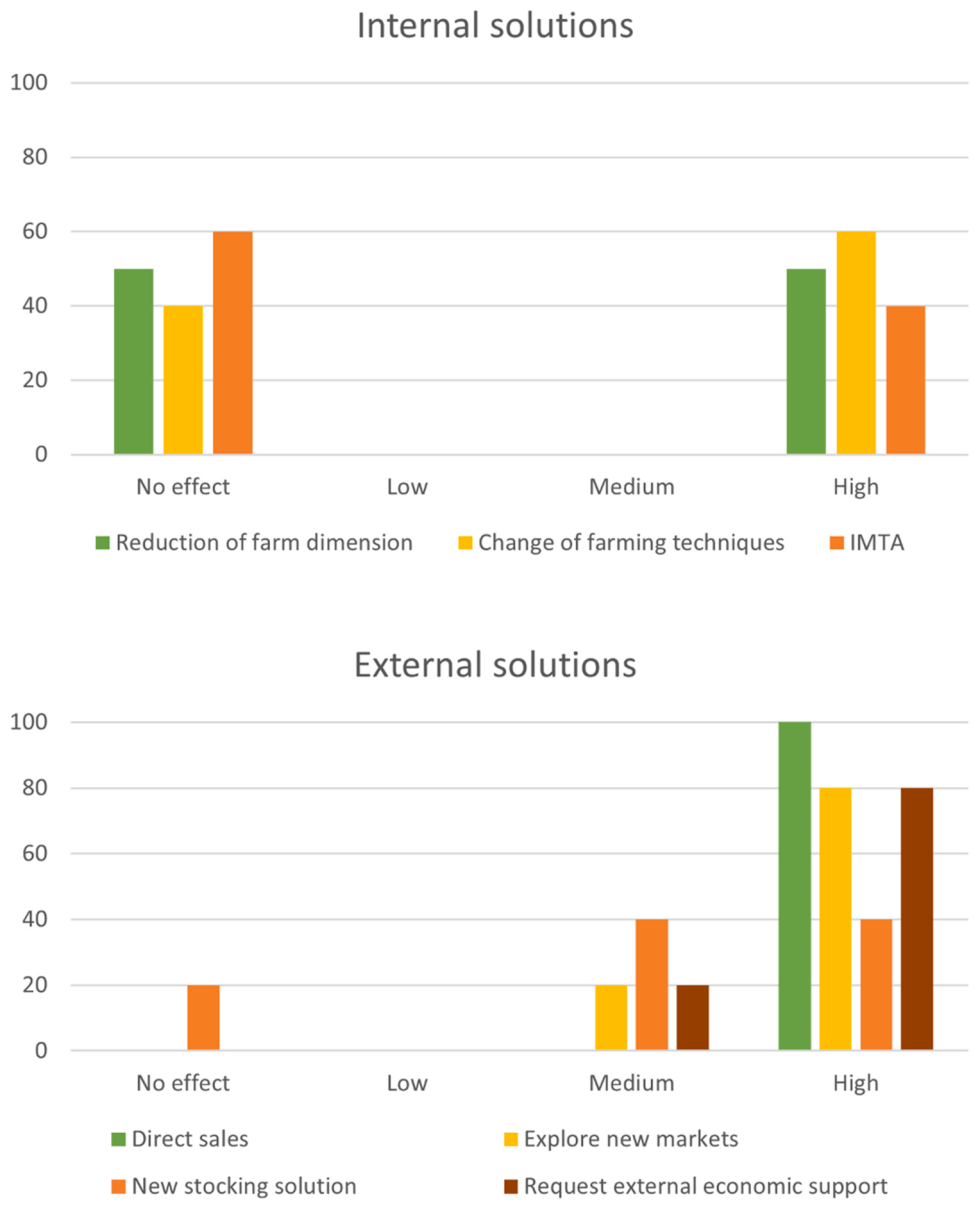

Fig. 8. Internal (site- / farm-based) and external mitigation measures adopted/suggested by stakeholders to cope with COVID-19 pandemic effects on finfish farming, based on online survey.

for sorting and cleaning of biofouling organisms before restocking. To reduce maintenance-related manual labour, one farmer placed oysters at a higher depth which had been observed to coincide with decreased biofouling during certain seasons [27]. Lower farm incomes caused by reduced market demand for aquaculture products led some farmers to reduce employment to just the permanent staff and not hire part-time or seasonal workers, which was a change to what was observed earlier that year by the online survey (low job loss). Some farmers took the opportunity of having more spare time due to reduced production to reorganise their production flow and/or catch up on backlogged activities. This allowed them to focus on increased maintenance and testing of different equipment and materials used in the production process, like protective nets for mussels (from gilthead sea bream predation), different types of collectors for oysters and regular maintenance of previously stocked bivalves that remained in the water from previous seasons, which can sometimes be overlooked during times of increased demand. A silver lining to the negative impacts caused by COVID-19 was that farmers were able to re-evaluate and optimise the business processes of their farms which could potentially result in future gains due to a more streamlined production. Some farmers addressed the additional maintenance required during this time by placing cultured organisms as close as possible to the docking space of the service vessel(s), reducing both travel time and fuel consumption for reaching their concessions. Others traded and sold other marine food products, which allowed them to be less dependable on the core production of their farm and mitigate the decline in sales.

3.2.2.3. Bluefin tuna. Similarly, the decline in tuna sales caused an increase in biological assets and consequently workload and expenditures. A loss of the market shares, a more difficult supply of fish feed and an increase in associated costs were also observed. The increased workload was exacerbated by drops in workforce due to illness and restrictions, requiring the companies to invest in increased safety measures which led to additional expenditures pertaining to the purchase of protective equipment, the use of numerous smaller vessels to compensate for the inability to use larger vessels if key personnel were not available and reduced labour capacity due to working double shifts. Personnel on Croatian bluefin tuna farms were most affected by the COVID-19

Table 2
Farm profiles and sales of 6 aquaculture SMEs from the Mali Ston area in south Croatia before (2019) and one year after (end of 2020) the COVID-19 pandemic, based on field survey.

SME	Cultured species	Farm size (1000 m^2)	Number of employees		Sales (tons)					
			2019	2020	2019			2020 (change relative to 2019)		
					O	M	SB	O	M	SB
1	O	9,5	1	1	2	–	–	0.15 (7 %)	–	–
2	O, M	15	1	1	2	5	–	1 (50 %)	2.5 (50 %)	–
3	O, M	88	1 + 2 *	1	7	15	–	0 (0 %)	2.25 (15 %)	–
4	O, M	100	5	5	10	60	–	2.5 (25 %)	15 (25 %)	–
5	O, M, SB	10	1 + 3 *	1	15		15	7.5 (50 %)		7.5 (50 %)
6	O, SB	230	11	4	6	–	30	0 (0 %)	–	1.5 (5 %)

O – European flat oyster, M – Mediterranean mussel, SB – European sea bass.
*part-time/seasonal.

Table 3
Numbers of employees and total sales of Cromaris - the largest Croatian aquaculture company, located in the central Adriatic - for the period from 2017 to 2020 (www.cromaris.com).

Year	2017	2018	2019	2020
Number of employees	396	479	519	554
Total sales (t)	7862	8871	9557	10,367
Growth (%)	13	8	9	20

pandemic during the period from May 2020 to May 2021, when vaccination began. The biggest concern for the management during this period was the organization of work on the farms and fishing vessels. Since these working environments require work in closed and confined spaces, a COVID-19 positive result of one crew member would result in quarantine of the whole crew.

As tuna farming is based on catching wild juveniles and is strictly supervised by ICCAT, increases in production depend on the quota available. However, capture quotas did not have an effect on production of tuna in 2019 and 2020, as these fish were caught 2–3 years prior to the COVID-19 pandemic. Furthermore, the pandemic has not had a negative effect on quotas which have been steadily increasing since 2015. What was affected however were sales, which were delayed for most of 2020, and finally achieved at lower prices. This resulted in companies having to adapt to new activities –processing and selling the small pelagic fish that had previously been caught to use as feed for the farmed tuna.

In comparison to other acute negative impacts on production that farmers are faced with during regular production, such as mortalities caused by predation [28–30], loss of equipment and harvests to tidal wave events or temporary market lockdowns due to rare incidences of human pathogen presence around the farms [9], the COVID-19 pandemic as a standalone stressor has had the worst effect on production and sales to date. Furthermore, its effects on aquaculture have been exacerbated by existing chronic stressors, which by themselves have already had significant ecological, social and economic impacts on a global scale [4]. On a more local scale, negative impacts that had been described as chronic in Croatian aquaculture were more or less continuous and had become acceptable economic losses during the production process. As described by surveyed farmers, these were more frequent in the case of bivalves and pertained to unchecked growth of biofouling organisms (>20 % reduction in production) and in some cases even to gilthead sea bream predation, especially in the case of mussels where predation can result in a 20–30 % reduction of production quantities. These effects have been mitigated through proper spatiotemporal management of bivalve farms in terms of timing production processes to seasonal variations in chronic stressors. For this reason, bivalve farms that were not versatile enough to adapt to new conditions caused by the COVID-19 pandemic, can likely expect further long-term negative effects as a result of synergistic effects of COVID-19 and existing stressors,

Table 5
Farm profiles and sales of five bivalve farms from the north Adriatic after the COVID-19 pandemic, based on field survey.

SME	Cultured species	Number of employees in 2019	Sales (2020 relative to 2019)
1	M + O	3 + 2*	70 %
2	M + O	2 + 1*	65 %
3	M	2 + 1*	50 %
4	M	2	30 %
5	M + O	2 + 1*	50 %

*part-time/seasonal.

Table 4
Farm profiles and sales of four tuna farms from the central Adriatic before (2019) and one year after (end of 2020) the COVID-19 pandemic, based on field survey.

Farm	Cultured species	Farm size (1000 m^2)	Number of employees		Sales (tons)		Change in sales (2020 relative to 2019)
			2019	2020	2019	2020	
1	T	460	100	95	500	676	135 %
2	T	220	80	80	900	883	98 %
3	T + SB	130	329*	329*	898 + 495	488 + 560	54 %/113 %
4	T	190	80 + 70**	80 + 70**	760	761	100 %

T - Atlantic bluefin tuna, SB - European sea bass and gilthead sea bream.
*a number of employees work on bass/bream culture and pre-market processing.
* *part-time/seasonal.

mainly due to the pandemic-caused disruption of established production processes and timings.

3.2.3. Short- and long-term mitigation of negative COVID-19 effects on Croatia's mariculture industry

On 19th March 2020 (amended on 3rd April 2020), the European Commission adopted Croatia's Scheme to support the fishery and aquaculture sector in the context of the coronavirus outbreak in the amount of approximately €4 million, provided several types of aid, including, but not limited to: direct grants, equity injections, selective tax advantages and advance payments (of up to €120,000 for companies in the fishery and aquaculture sector), guarantees and subsidies for loans as well as support in the form of deferral of tax payments and wage subsidies for employees [31].

As was to be expected from the results of the online survey, almost all farms applied for and received some form of government aid to compensate for decreases in production and/or salaries, although it was mainly in the form of wage subsidies for employees. Although not a sustainable long-term solution, these measures were used to cover numerous standard and new expenditures (mostly emerging from requirements for increased maintenance of farms) in the short-term in order to compensate for decreased incomes from sales. While most farms did not profit from these subsidies, at least they were able to break even.

Potential solutions to mitigate negative effects of the COVID-19 pandemic put forth by some of the interviewed farmers during the field study were mainly related to securing and increasing sales and included: (i) export under better conditions; (ii) local home deliveries, although time would be needed to reorganise individual businesses to accommodate new distribution chains; (iiI) national restrictions on imports (primarily for the case of finfish), while there is an abundant supply of locally available produce. However, even with the best intentions, it would be impossible to implement ideas related to international trade due to free market regulations within the EU. These responses did not vary greatly from the mitigation measures proposed through the initial online survey, but proved to be more difficult to implement than was originally thought.

4. Conclusion

Micro enterprises (family farms) were able to survive the brunt of the pandemic mainly due to their part-time nature, low capital investments and running costs, while small to medium enterprises were under the most pressure. On the other hand, large enterprises were also barely affected as they had very secure local and/or international distribution chains and dominated the market. Several factors determined whether the larger SMEs would sink or swim through the crysis. Producers that relied on the HoReCa market for product placement and/or were in a transitional period of their business, either investing in capital, expanding and upscaling production or exploring new markets/distribution lines, were hit the most. Bivalve producers generally experienced a higher drop in sales than finfish farms. Moreover, companies with a highly specialised production were not able to adapt to market changes to the degree that more versatile and diverse businesses seemed capable of.

To conclude, the most affected were small to medium bivalve farms that relied on the HoReCa sector for market placement. Governmental aid in the form of subsidies for employee wages was the only thing keeping these SMEs afloat.

CRediT author statement

Marijana Pećarević: Conceptualization, Methodology, Formal analysis, Writing - Original Draft, Supervision. **Kruno Bonačić**: Conceptualization, Methodology, Formal analysis, Writing - Original Draft. **Tatjana Dobroslavić**: Investigation, Visualization, Writing - Original Draft. **Branko Glamuzina**: Investigation, Writing - Review & Editing. **Leon Grubišić**: Investigation, Visualization. **Josip Maleš**: Investigation, Visualization. **Igor Ćelić**: Investigation, Visualization. **Gianluca Sarà**: Research conceivement, Methodology, Formal analysis. **Maria Cristina Mangano**: Research conceivement, Methodology, Formal analysis, Visualization.

Data availability

Data will be made available on request.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2022.105395.

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