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A stakeholders' perception: Turkish aquaculture sector under COVID-19 pandemic effect with consideration of anthropogenic stressors

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ABSTRACT

The Turkish aquaculture sector is growing very rapidly, yet the impacts of the pandemic on both sea and inland water operations remain unclear. To provide a knowledge baseline based on stakeholders, we carried out a rapid assessment in the present study. The primary objectives were to evaluate the stakeholder perceptions regarding economic loss attributed to the COVID-19 pandemic, the effectiveness of implemented mitigating measures, and the overall impact on health and wellbeing. The study also asked respondents about the disruption and loss they felt as a result of the consequences of anthropogenic stresses over the previous ten years. Out of 195 survey participants, only 107 completed and were assessable (73 from land-based farms and 34 from sea-based farms). Ninety percent of those surveyed said they had suffered various levels of financial loss as a result of the COVID-19 epidemic, especially in land-based systems. Loss of market and clients appeared to be a major issue, particularly for land-based farmers. To deal with the problem, sea-based farmers tried to develop integrated aquaculture systems, change farming systems and increase the link with scientists, whereas land-based operations preferred changing marketing methods such as direct sales to consumers, substitute market and processing methods to deal with the problem. The respondents reported higher loss associated with anthropogenic stressors, namely diseases and heat waves. Our results suggest that the decision-makers should be more prepared for such unexpected crises and take anthropogenic stressors into account when designing future recovery strategies for this productive sector.

1. Introduction

The aquaculture sector in Türkiye has grown very rapidly, with an annual growth of 7.8 % during the last decades [1]. While marine aquaculture systems focus on European sea bass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) with smaller shares of meager (*Argyrosomus regius*), rainbow trout, and bluefin tuna (*Thunnus thynnus*), land-based aquaculture is typically based on rainbow trout (*Oncorhynchus mykiss*) with a small share of brown trout (*Salmo trutta macrostigma*) and common carp (*Cyprinus carpio*) (Table 1 and Fig. 1). The sector has become a substantial industry in food production with an economic value of 1.96 billion USD by providing direct and indirect jobs of about 250,000 [1,2].

The COVID-19 pandemic has caught the world off guard locally and globally, affecting all productive sectors, including aquaculture, with varying degrees of repercussions [3–5]. Attempts have been made to determine the effects of the pandemic on different perishable food production systems, including agriculture, fisheries, and aquaculture [4–13]. Former studies investigating the effects of COVID-19 on aquaculture farms have reported remarkable disruption in areas such as the

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Table 1
Production, economic value and total employment of aquaculture systems in Türkiye in 2019 [2].

	Land based[a]	Sea based[b]	Total
Total production in 2019 (tonnes)	116.426	256.930	373.356
Average economic value (million U$)[c]	318,222	1.038,767	1.356.988
Total direct employment in aquaculture farms	10.750		

[a] Cultured species include Rainbow trout (*Oncorhynchus mykiss*), common carp (*Cyprinus carpio*), European catfish (*Silurus glanis*), brown trout (*Salmo trutta macrostigma*), sturgeon (*Acipencer sp.*), tilapia (*Oreochromis sp*), frog (*Rana sp*).
[b] Cultured species include European sea bass (*Dicentrarchus labrax*), gilthead sea bream (*Sparus auarata*), rainbow trout (*Oncorhynchus mykiss*), meagre (*Argyrosomus regius*), bluefin tuna (*Thunnus thynnus*), mussel (*Mytilus sp.*), red porgy (*Pagrus major*), shi drum (*Umbrina cirrosa*), common dentex (*Dentex dentex*), sharpsnout seabream (*Diplodus puntazzo*), pink dentex (*Dentex gibbosus*), redbanded seabream (*Pagrus auriga*), bluespotted seabream (*Pagrus caeruleostictus*).
[c] Calculated from Turkish Lira using the average exchange rate of the Central Bank for 2019.

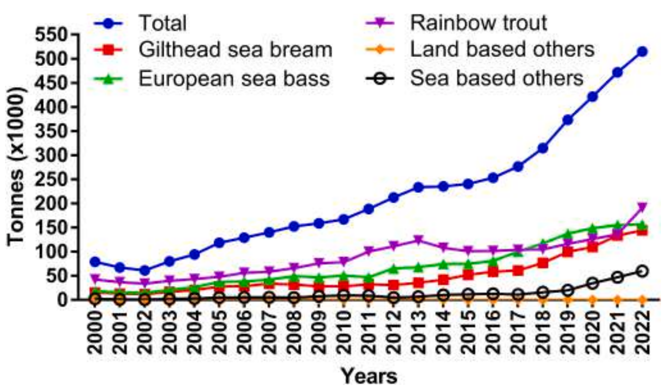

Fig. 1. Total and main species aquaculture production of Türkiye by years (2000–2022) based on data reported by BSGM (2023). Other species are detailed in the footnote of Table 1.

economy, employment, and welfare [5–7,12]. However, only a few studies have investigated the ancillary effects of COVID-19 on the cumulative stressor framework [14–19]. A knowledge gap that needs to be filled remains to be disentangled for future unplanned interruptions.

The aquaculture sector is characterized by a great degree of heterogeneity in technology and strategies used, and many species are farmed using different technologies for dissimilar purposes around the world. Different nations engage in aquaculture to address hunger and

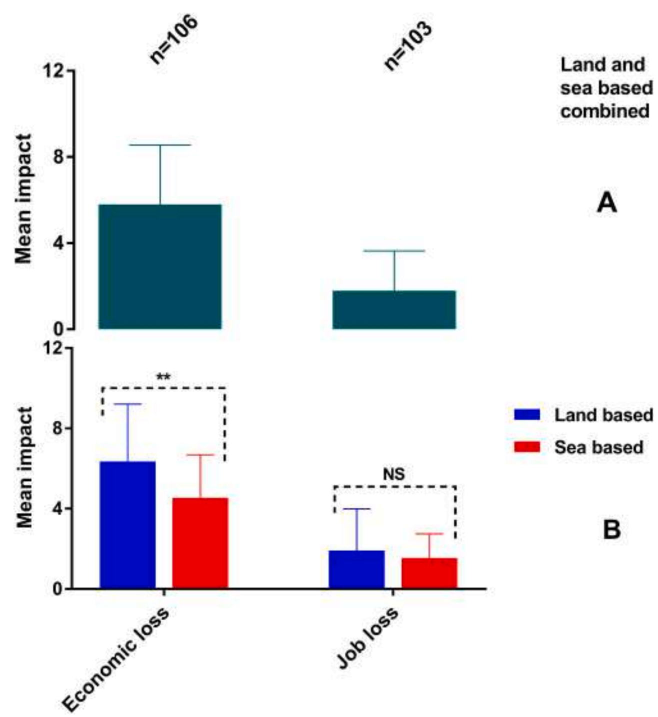

Fig. 3. Influence of COVID-19 pandemic on economic losses and job losses in aquaculture farms (A) and presented by aquaculture systems i.e. land-based and sea-based systems respectively (B). Values were reported between 1 (no loss at all) and 10 (very high loss). Values are shown as mean ± SD. ** denote a significance level of $p < 0.01$ based on the Wilcoxon test.

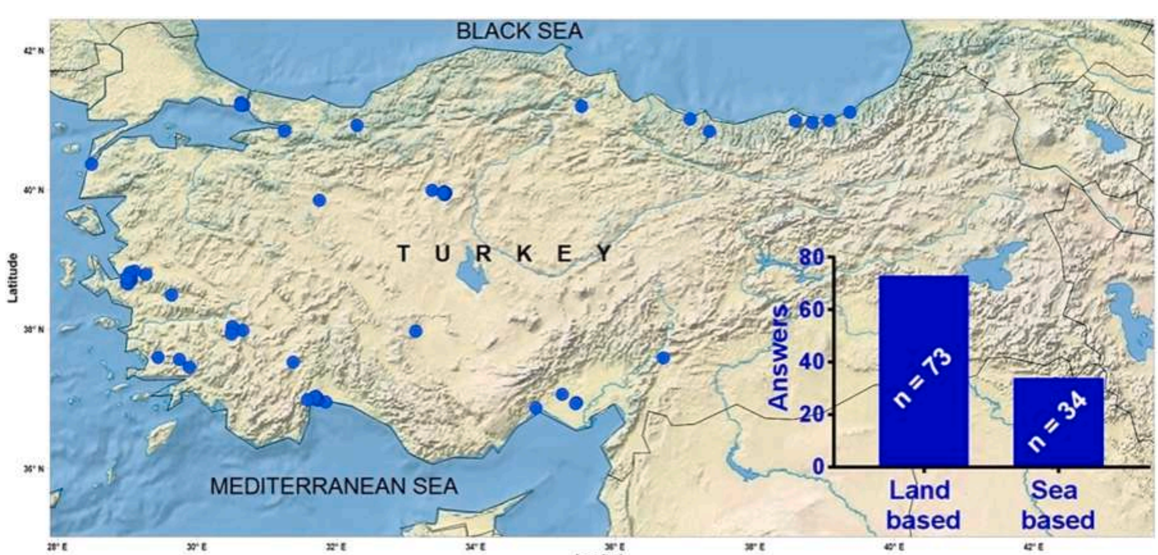

Fig. 2. Geographic distribution of respondents (blue spots) to the questionnaire planned to estimate the influence of COVID-19 on aquaculture sector in Türkiye (Note: The spots show the place where the respondents filled the online survey, meaning that they do not necessarily represent the specific locations of production farms) N=107.

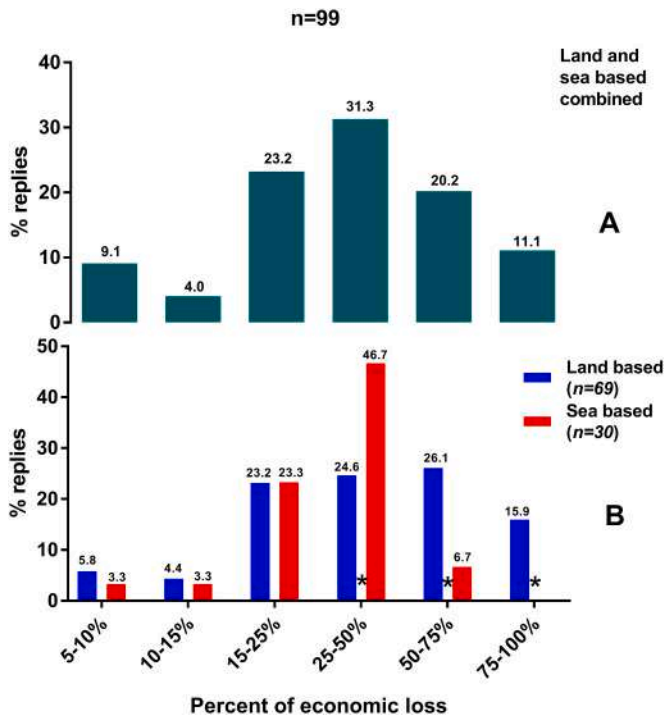

Fig. 4. Influence of COVID-19 pandemic on percent economic losses in aquaculture farms (A) and presented by aquaculture systems i.e. land-based and sea-based systems respectively (B). * denotes a significance level of $p < 0.05$ based on contingency analysis (Chi-Square value = 10.318, DF = 6, P = 0.0021). Comparison revealed significant differences between land and sea-based aquaculture; *Fisher's exact test; *p* value for 25–50 % = 0.0362; *p* value for 50–75 % = 0.0302; *p* value for 75–100 % = 0.311).

subsidence or to enhance efficiency and economic profitability [20]. Consequently, a country-level examination of pandemic impacts is recommended. Against this backdrop, our focus was to assess stakeholder perceptions within the context of Turkish aquaculture. Limited efforts have been made to investigate how COVID-19 has affected Türkiye's aquaculture and fisheries sectors on local and national levels [21–24]. These studies revealed a reduction in trade volume, prompting a shift toward less perishable product categories such as frozen, canned, and smoked versions. A recent study by Erol [25] dealt with the financial and economic impacts of the pandemic on the sector using consolidated financial statements in 2020 and reported that despite a remarkably higher net profit margin in 2020 than in 2019, the pandemic severely influenced the sector in terms of the rate of cash ratio and short-term assets. The present study aimed to provide more insights into the effects of COVID-19 on aquaculture farms, mitigation strategies farmers preferred or implemented and the welfare conditions they encountered, and how the effects of the pandemic were compared to anthropogenic stressors that occurred during the last ten years until the pandemic.

2. Materials and methods

This study focused on investigating stakeholder perceptions in Türkiye as a part of a broader global survey [4,9], which was designed and conducted to assess the impact of COVID-19 on aquaculture systems. The study received ethical approval from the Ethical Committee at the University of Palermo, Italy; UNPA-183 - Prot. 767–05/05/2020 n. 1/2020 29/04/2020.

2.1. Survey distribution and data collection

The survey questions, translated from English to Turkish, were disseminated online using the Qualtrics platform (https://www.qualtrics.com) to reach a wide audience of farmers, particularly during a period of social distancing. The online survey was available for about 4 weeks, from May 5, 2020 to June 1, 2020, and could be completed on various devices such as smartphones, tablets, and computers. During this period, there were intermittent lockdowns and restrictions, especially on weekends, and national and religious holidays in Türkiye. The target respondents were aquaculture farm managers or representatives involved in production at the farm or within the company. The survey distribution channels included the branches of Fisheries and Aquaculture, the Provincial Directorate of the Ministry of Agriculture and Forestry, and local and national farmers' organizations. A brief presentation of the investigation and authors was added on the first page, mainly to explain the reason for collecting information and the potential outcomes, as well as to obtain the informed consent of the respondents.

2.2. Questionnaire structure

A semi-structured questionnaire was designed to assess stakeholder perceptions of the direct or indirect economic challenges associated with COVID-19. The challenges measured were the level of economic losses, loss of usual costumers and retailers, loss of international markets, market loss due to consumer reduction, loss of middlemen, transportation cost increase, logistical restrictions, difficulties of seafood buyers, price decrease, difficulty of auction selling, liability problems of insurance companies, raw material reduction, difficulty of broodstock trade, lack of infrastructures, and difficulty in accessing remote farm sites. We also collected information about the mitigation measures adopted to cope with COVID-19 disruption. These strategies included modifications in working rules, employment of integrated aquaculture approaches, direct sales to final customers, increased cooperation with scientists, adoption of stocking solutions (i.e. freezing or smoking), new markets and buyers, request for economic support from the government, adoption of new farming techniques, reduction of farm dimension, hiring new staff, and staff dismissal. We further collected farmers' perceptions about how COVID-19 has affected their well-being, including the increased need for family care as a priority (children, elderly, handicapped, etc.), their concerns about the virus infection, any increase in working efficiency, any improvement on the connections with other actors in the supply chain, the lack of personal protective equipment (PPE), inadequate working conditions, and the risk perceptions associated with farmers working at sea. A final set of questions was created to assess disruption patterns in a multiple-stressors context, and a final set of questions was designed to survey the economic loss associated with climate change-related stressors, (i.e. 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) reported during the last decade.

Responses were scaled from 1 = no loss or no importance at all to 10 = very high loss or very high importance. A multiple-choice test was allowed for the last questions related to the anthropogenic stressors, being conscious that multiple stressors may affect farm sites over time.

Crucial information related to the type of aquaculture systems *i.e.* land-based, consisting mainly of rainbow trout production in ponds, raceways, and cages in freshwater dam lakes or sea-based, including cage farming of marine fish species and large trout.

2.3. Statistical analysis

Three different approaches were applied to data reported as numeric values between 1 and 10. First, all responses were treated as a whole without separating data as land-based and sea-based and analyzed with the Kruskal-Wallis test followed by Dunn's multiple comparison test to evaluate the degree of impact of COVID-19 on farms from the perspectives of socio-economy, health, and well-being, and adaptation measures against the pandemic. Second, the data were evaluated by breaking down the farms into two groups land-based and sea-based farms to

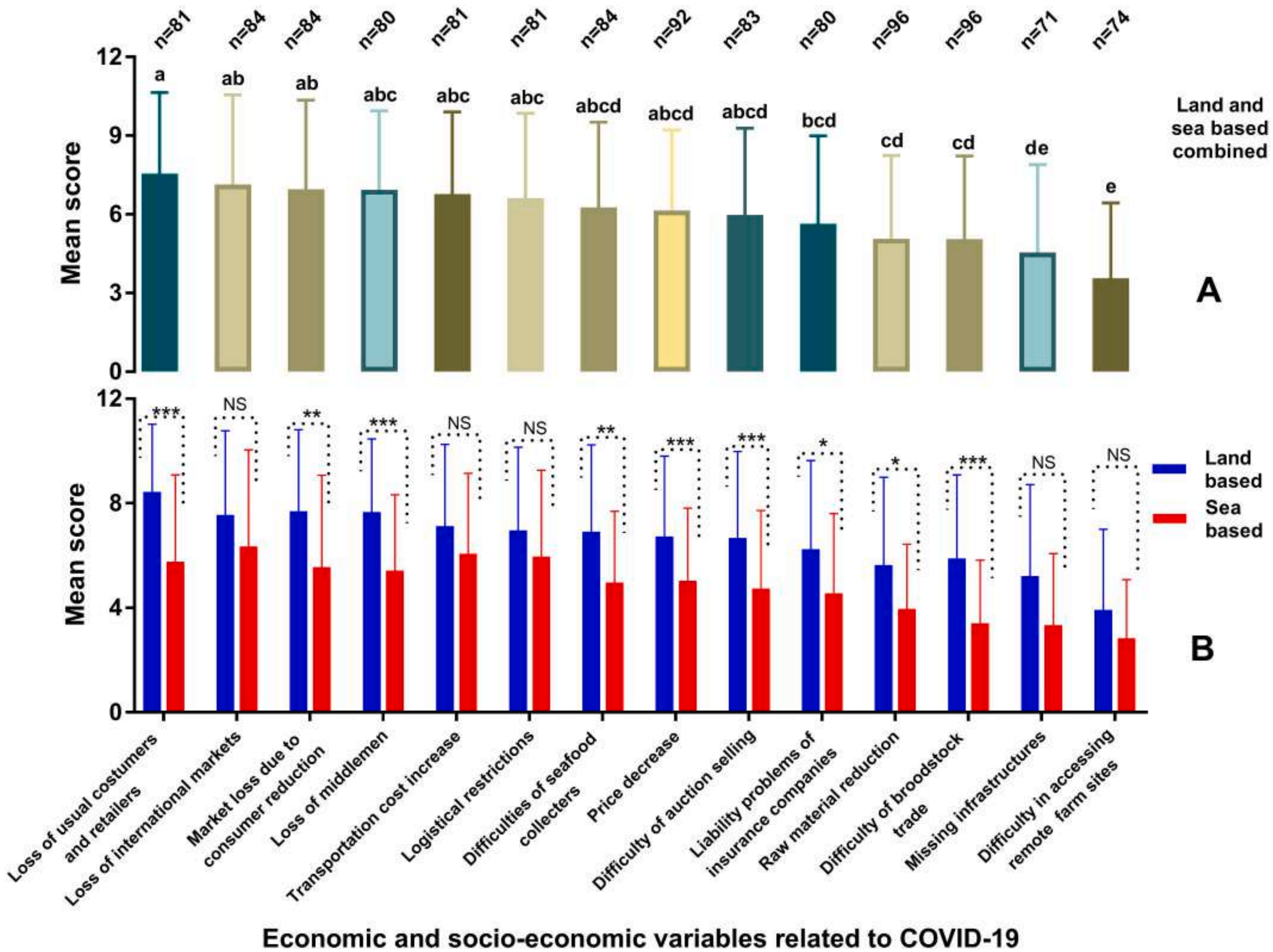

Fig. 5. Socio-economic challenges faced by aquaculture farms (by all data, A and culture systems, B) in Türkiye due to COVID-19. Values were reported between 1 (no loss) and 10 (very high loss). Values are shown as mean ± SD. Bars in graph A with different superscripts are significantly different from each other at a level of P=0.05 according to Dunn's test. Significance levels of differences shown by *, ** and *** are P<0.05, P<0.01 and P<0.001, respectively, in graph B based on the Wilcoxon test. NS denotes no significance.

compare the responses using the Wilcoxon test. Third, the impacts of the pandemic on the farms and the mitigation measures were further analyzed using a confirmatory factorial analysis (CFA) based on the Maximum Likelihood estimation approach. Factor path diagrams of indicators on the selected latent variables were created to display loadings between manifest and latent variables and covariance between the manifests. The CFA was iteratively conducted to improve the model fit by considering several fit indices as well as higher indicator, composite, and construct maximal reliabilities [26–28]. Three CFA models for the impacts of COVID-19, mitigation measures, and well-being were constructed by grouping the land and sea-based. The anthropogenic stressors experienced by the farms and their comparison with the influence of the COVID-19 pandemic in terms of negative effects were tested by contingency analysis. To this aim, the reported economic impacts due to COVID-19 were divided into four categories as the main factor: no loss (1), low (2−4); moderate (5−7) and high (8−10). Statistical analyses were conducted using JMP v.17.0 and GraphPad Prism 7 softwares.

3. Results and discussion

Out of the 195 responses that were received, 107 questionnaires from the survey (73 from land-based farms, 34 from sea-based farms) were deemed legitimate for statistical analysis because the respondents provided answers to basic questions about their farming system and COVID-19-related economic losses (Fig. 2).

The 107 stakeholders reported two primary culture systems and a range of production levels, from a minimum of 2 tons/year to a maximum of 30.000 tons/year. The findings of the impact of the COVID-19 pandemic on the Turkish aquaculture sector from different perspectives are presented and discussed further.

3.1. Socio-economic challenges

The majority of responders (n = 106; 99.1 % of replies) commented on their economic losses due to COVID-19 (Fig. 3A). Participants reported a mean loss score of 5.79 ± 2.77 on a scale of 1–10, where 1 indicates no loss and 10 indicates a very high loss. A comparison of farm systems revealed a significant difference, with land-based aquaculture systems experiencing higher losses (mean: 6.36 ± 2.85) compared with sea-based systems (mean: 4.55 ± 2.14) (Fig. 3B) (P<0.05). A slightly lower percentage of respondents (n = 99) responded when asked to express the percentage of economic losses experienced (Fig. 4). The majority of farmers (about 79 %) reported their losses between 10 % and 15 % and 50–75 % (Fig. 4A), while 11 % reported losses as high as 75–100 %. This indicates that 90 % of Turkish farmers reported

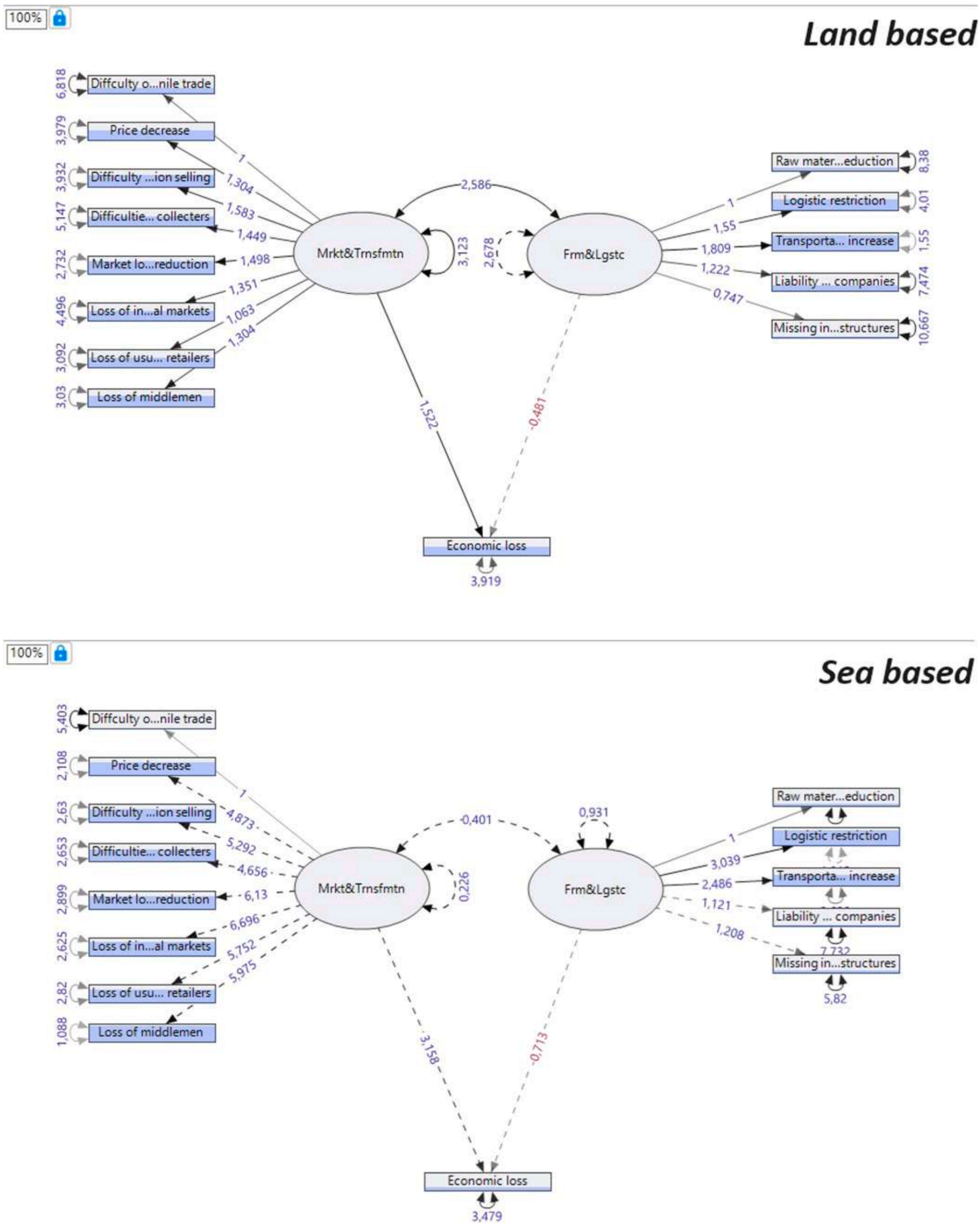

Fig. 6. Illustration of path diagram of CFA developed for analyzing the impacts of COVID-19 on fish farms. Observed manifest variables were collected under latent variables of Marketing & Transformation (Mrkft&Trnsfmtn) and Farming & Logistics (Frm&Lgstc). Covariance was added between the latent variables to search for a significant relationship. To estimate the role of latent variables on economic loss, regressions were included in the model from latent variables to economic losses. Dashed lines indicate insignificant loadings.

Table 2
The results of Goodness of Fit for the CFA models developed to analyze the impacts of COVID-19 on land-based and sea-based aquaculture farms, mitigation attempts and health and wellbeing situations.

Model Fıt Indexes	Absolute Fıt Measures							Incremental Fit Measures			Parsimony Fit Measures			
Models	χ^2	DF	Prob>χ^2	SRMR	RMSEA	GFI	AGFI	CFI	TLI	NFI	PGFI	PNFI	PCFI	χ^2 /DF
Recommended criterion				≤0.08	≤0.08	≥0.90	≥0.90	≥0.90	≥0.90	≥0.90	≥0.50	≥0.50	≥0.50	≤3
Issues due to COVID-19	309	150	<0.0001	0.101	0.141	0.823	0.720	0.789	0.745	0.670	0.679	0.552	0.651	2.060
Mitigation	154	67	<0.0001	0.148	0.179	0.821	0.652	0.700	0.600	0.595	0.611	0.444	0.521	2.299
Health & Wellbeing	27.9	22	0.1785	0.072	0.085	0.978	0.929	0.962	0.928	0.859	0.512	0.450	0.504	1.268

CFA; Confirmatory Factorial Analysis, DF; Degrees of freedom, CFI; Comparative Fit Index, MSEA; Root Mean Square Error of Approximation, TLI; Tucker Lewis Index, NFI; Normed Fıt Index, GFI; Goodness of Fıt, AGFI; Adjusted Goodness of Fit, SRMR; Standardized Root Mean Square Residual, PGFI; Parsimony Goodness of Fit Index, PNFI; Parsimony Normed Fit Index, PCFI; Parsimony Comparative Fit Index

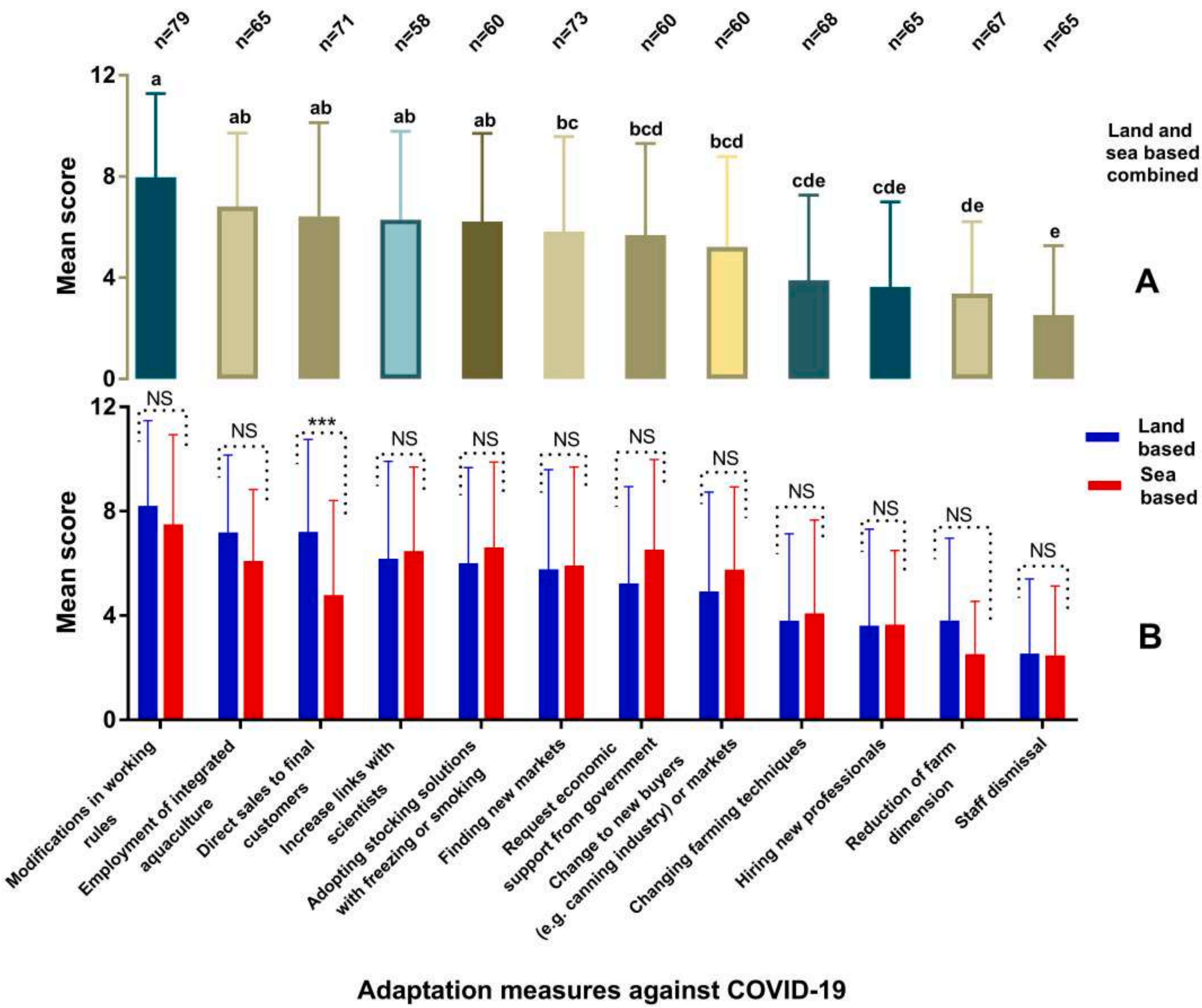

Fig. 7. Adaptation measures taken by stakeholders to alleviate the effects of COVID-19 (all data combined, A and by farm systems, B). Values were reported between 1 (no importance at all) and 10 (very high importance). Values are shown as mean ± SD. Bars in graph A with different superscripts are significantly different from each other at the level of $p = 0.05$ according to Dunn's test. A significance level of the difference shown by *** is $p < 0.001$ in graph B based on the Wilcoxon test. NS denotes no significance.

economic losses due to COVID-19, albeit with considerable regional variations. A closer look at the loss by farm typology revealed that land-based farmers reported a larger percentage of economic loss, 75–100 % (Fisher's exact test; P<0.05). Land-based farms also reported a significantly higher percentage of loss of 50–75 %, while the majority of sea-based farmers reported a percentage of loss of 25–50 % class (Fisher's exact test; P<0.05) (Fig. 4B). In other words, land-based farms reported significantly higher economic losses because of COVID-19, which is consistent with the findings of the land-based aquaculture sector on a global scale [9] or country level [29]. This outcome may be elucidated by the prevalence of small-scale land-based farms compared with sea-based systems in Türkiye (Supplementary Table 1) [2,30].

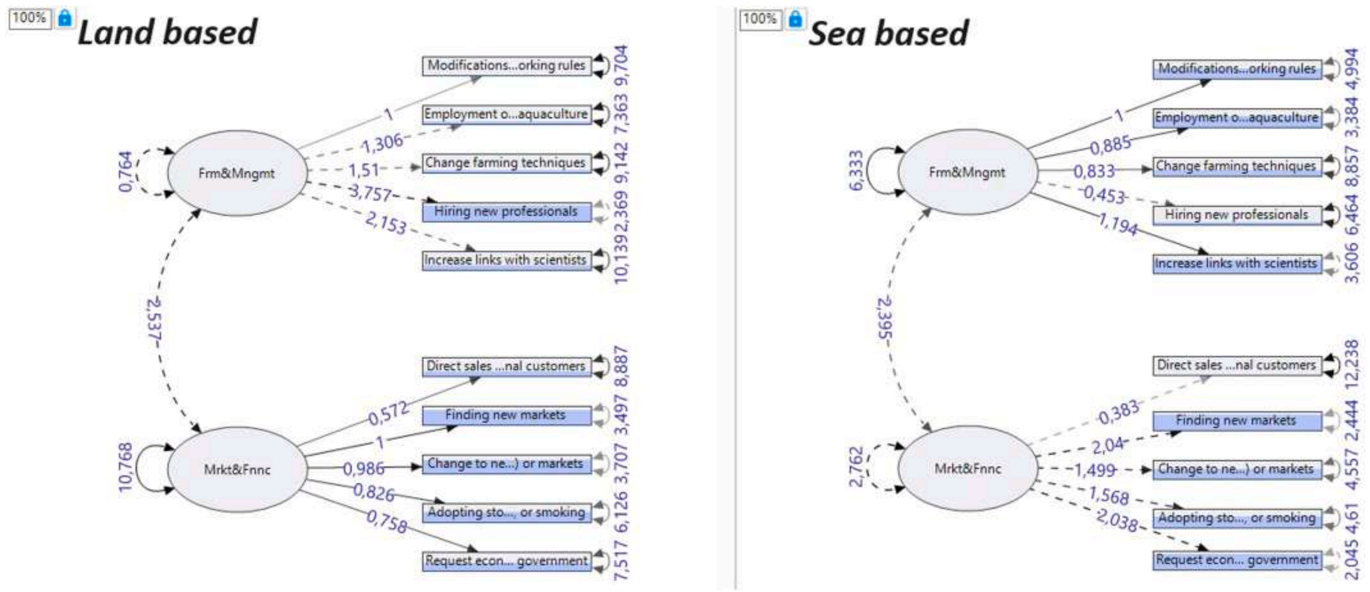

Fig. 8. Illustration of path diagram of CFA developed for analyzing the adaptation measures taken by the farmers to remedy the impacts of COVID-19. Observed manifest variables were collected under latent variables of Farming & Management (Frm&Mngmnt) and Marketing & Finance (Mrtk&Fnnc). Covariance was added between the latent variables to search for a significant relationship. Dashed lines indicate insignificant loadings.

Specifically, during the study period, there were 1178 land-based farms with an annual capacity of 0–50 tons, compared with just 154 farms in sea-based systems [2]. This result is consistent with those in the literature reporting that fisheries and aquaculture enterprises, whether small or family-run, are likely vulnerable to sudden shocks [31–33].

The more thorough impacts of COVID-19 on the socioeconomic variables of aquaculture farms are shown in Figs. 5 and 6. The most significant socioeconomic issue reported by most farmers was the loss of customers and retailers. These were followed by, in descending order, loss of international markets, loss of market due to consumer reduction, loss of middlemen, an increase in transportation cost, logistical restrictions, difficulties of seafood collectors, price decrease, difficulty of auction selling, liability problems of insurance companies, raw material reduction, difficulty of broodstock trade, missing infrastructures, and difficulty in accessing remote farm sites (Fig. 5A). Marketing appeared to be the main challenge to aquaculture farms in Türkiye during the early phase of the pandemic, posing a far greater risk to land-based farms (Fig. 5B), which is clearly separated by CFA in Fig. 6. Once again, this may be related to the smaller production capacities of land-based farms that mainly supply for domestic consumption [30].

Although the fit indices of the CFA model of COVID-19 impact on the farms were slightly weaker than those recommended levels except for those parsimony fit indicators (Table 2), the model still provided important information. The model showed that sea-based farms were less affected by COVID-19 than land-based operations. For instance, all selected manifest variables significantly loaded on the latent variables (marketing & transformation and farming & logistics) ($P<0.05$) but none of the marketing & transformation-connected variables were significant, and only loadings of logistic restriction and increase of transportation costs were significant in sea-based farms. Furthermore, a significant positive covariance was observed between the latent variables in land-based farms (Wald $Z = 2.62$; $P<0.05$), implying that a deterioration in one area could worsen in other areas. The disruption of the marketing chain was the main cause of economic loss in land-based farms when a significant regression of marketing & transformation was considered (Wald $Z = 2.55$; $P<0.05$).

Fish consumption per capita in Türkiye is extremely low (between 6.2 – 7.2 kg in 2019 and 2022) [1,2] compared with the world average, and the main consumption is in restaurants. According to farmers, a partial or complete lockdown can therefore seriously limit the mobility of usual customers and consumers ($P<0.05$) (Fig. 5B, Fig. 6). Furthermore, a cascading effect of consumers' access to fresh fish at markets or auctions on customer losses cannot be ruled out due to the indiscriminate impacts of COVID-19 on adjacent sectors. For this reason, land-based operations experiencing marketing trouble and cash flow switched to direct sales to customers (Fig. 6A; 6B) at lower prices to circumvent the problem and increase profit margin. This claim is consistent with the findings, at least partly, of Erol [25], who reported that the Turkish aquaculture sector experienced liquidity and financial difficulties due to pressure from lenders despite a high profitability performance in 2020.

Türkiye exports most of its production, especially marine fish species, to the EU [2,25,30,32]. A decrease in fish consumption in those buyer countries due to the worldwide effect of COVID-19 would inevitably result in a marketing bottleneck. Turkish aquaculture stakeholders, particularly land-based farmers, responding to our survey reported large losses in international markets, middlemen, and seafood collectors (Fig. 5B, Fig. 6) as well as related problems (please see Supplementary Table 2). Indeed, when the data inventory of BSGM and statistical figures [34] were used to measure the impacts of the pandemic in 2020 figures as done by Erol [25], the increase of per capita domestic consumption of national aquaculture production in 2020 compared to 2019 was much higher than that of per capita aquaculture exportation with 14 % *vs* 5.6 % (Supplementary Table 3) [34].

3.2. Mitigation measures adopted during the pandemic

Aquaculture stakeholders were also asked to specify the mitigation measures they would prefer to relieve the effects of the pandemic (Figs. 7A, 7B). The most important recognized mitigation measure, regardless of farming systems, was the change of working rules in the farms, adopted mostly to reduce the risk of disease infections among staff and to ensure the continuation of farm activities. Moreover, to ensure continuity of production, manufacturing, supply and logistics chains, health, agriculture, and forestry activities, the government exempted the people and places from all COVID-19 restrictions [35].

The CFA pathways for mitigation measures taken by the farmers are shown in Fig. 8. The fitting indices of the best model did not perfectly perform the desired thresholds except for parsimony values (Table 2), but the model still yielded reasonable results with some differences from

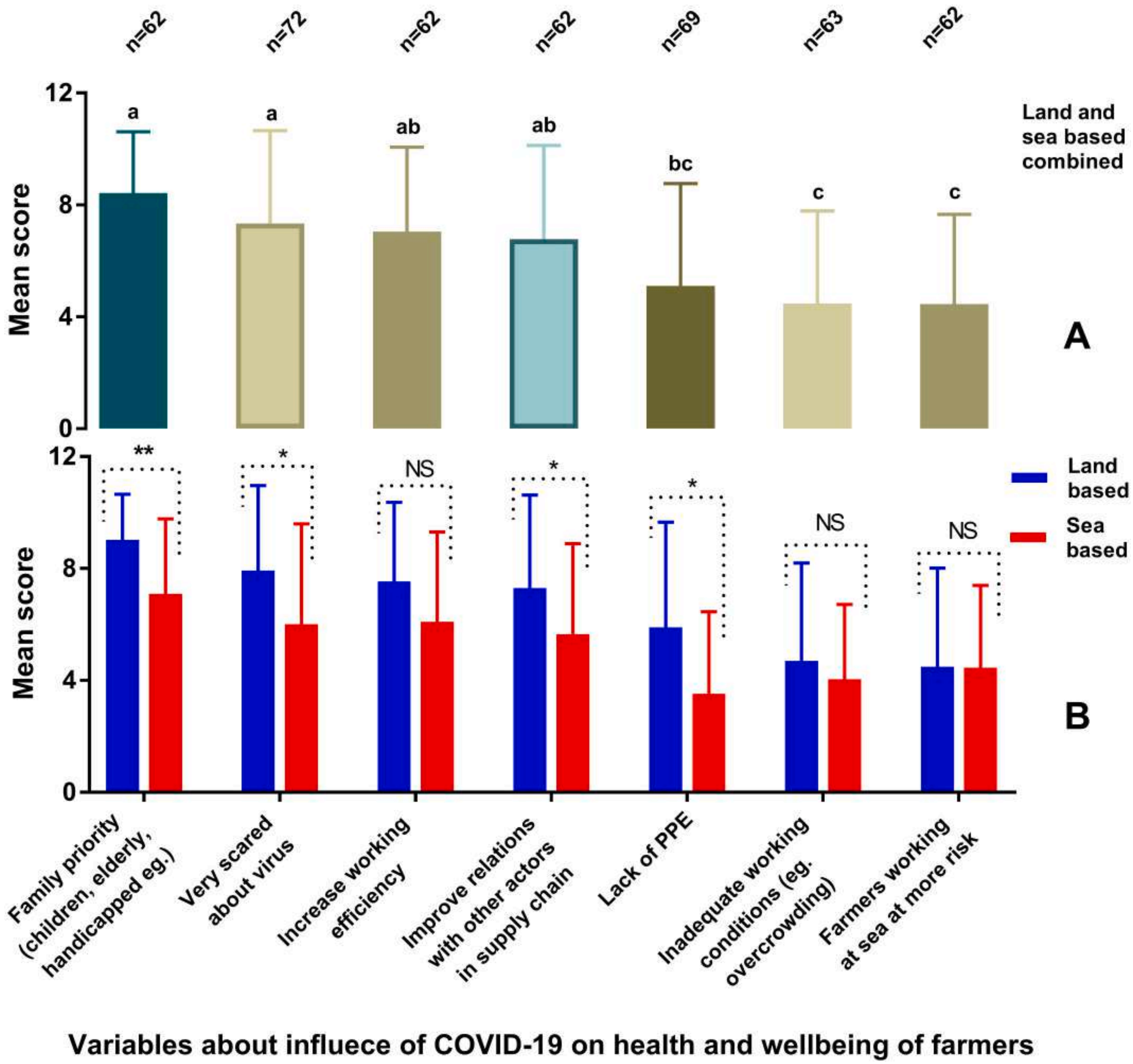

Fig. 9. Influence of COVID-19 health and well-being measures to alleviate the effects of COVID-19 (all data combined, A and by farm systems, B). Values were reported between 1 (no importance at all) and 10 (very high importance). Values are shown as mean ± SD. Bars in A with different superscripts are significantly different from each other at the level of $p = 0.05$ according to Dunn's test. Significance levels of differences shown by ** and *** are $p < 0.01$ and $p < 0.001$, respectively, in graph B based on the Wilcoxon test. NS denotes no significance.

nonparametric methods. The CFA showed that the approaches of land and sea-based operations to avoid the negative impacts of COVID-19 were different. In other words, land-based farmers tried to overcome the problems associated with the impacts of COVID-19 with measures related to marketing strategies, including direct sales to consumers, searching for new markets and buyers, adopting alternative storage methods, and being more ready for financial support from the government. Conversely, sea-based farmers opted to change farming and management methods such as employment of IMTA (Wald Z=3.23; P<0,05), changing farming techniques (Wald Z = 2.18; P<0,05), and increasing their links with scientists (Wald Z=3.39; P<0,05). The notable interest of farmers in exploring alternative farming practices and systems such as integrated multitrophic aquaculture (IMTA) (Fig. 8) is supported by the applications of three aquaculture farms to the General Directorate of Fisheries and Aquaculture to revise their existing systems by incorporating IMTA. Furthermore, numerous other operations expressed willingness to adopt this approach (Fig. 7A). The IMTA system appears to be a superb approach for lessening the impacts of COVID-19 and increasing the resilience of aquaculture operations because of the cultivation of more than one species [4]. IMTA farmers can benefit from larger market options of diversified species to overcome the disruption of the supply chain during COVID-19 [9]. As can be seen from the pathway diagram (Fig. 8), sea-based farmers preferred to collaborate with scientists to adapt the IMTA and other farming technologies, which was not the case with land-based farmers. The interest for IMTA in this study is probably related to reducing the economic risks associated with operating with a single species, increasing profitability, and environmental-social sustainability. This assertion aligns with the

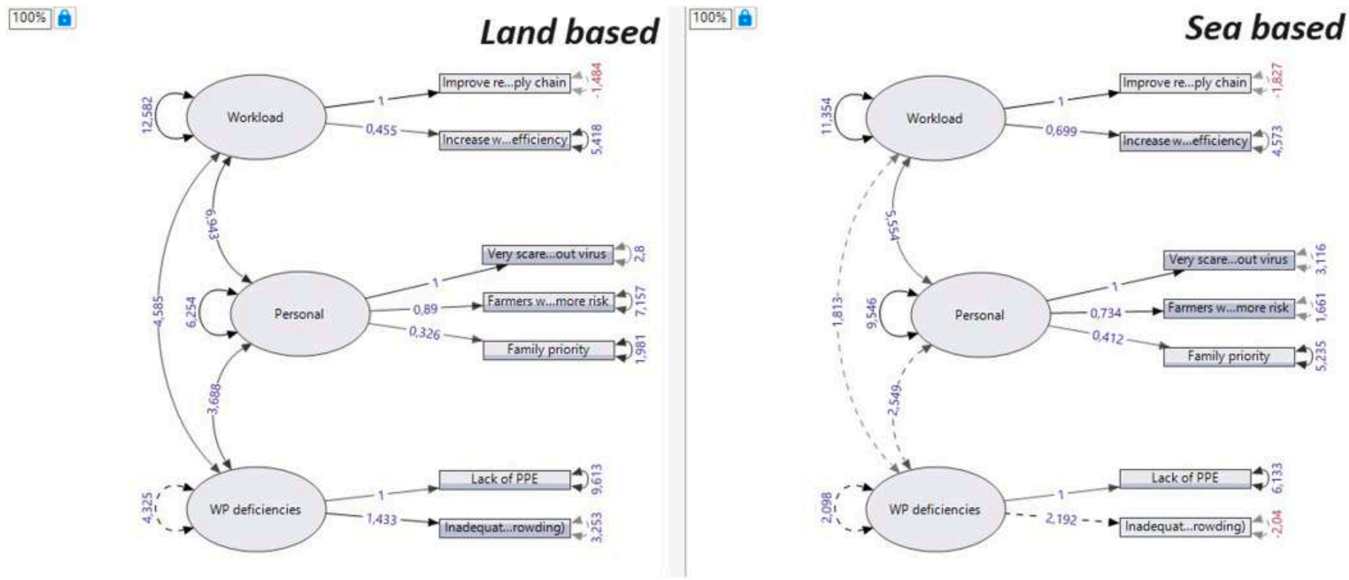

Fig. 10. Illustration of path diagram of CFA developed for analyzing the impacts of COVID-19 on the health and well-being of the farmers. Observed manifest variables were collected under latent variables of Workload, Personal and Work Place Deficiencies (WP deficiencies). Covariance was added between the latent variables to search for a significant relationship. Dashed lines indicate insignificant loadings.

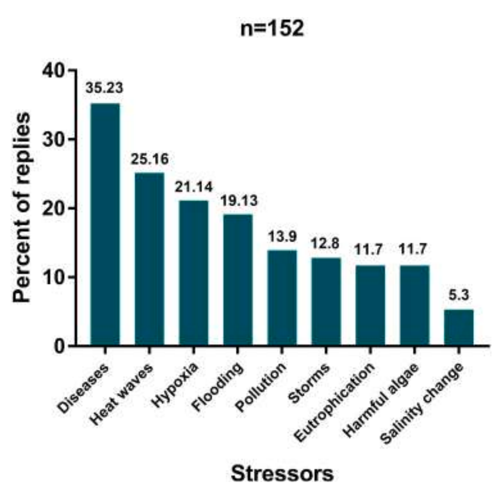

Fig. 11. Anthropogenic stressors experienced during the last ten years in aquaculture farms reported as more negative relative to COVID-19 pandemic.

findings of [4,17], who found that the diversification of product ranges from an aquaculture operation can increase resilience with the management of wastes via sequential utilization by diverse valorisable organisms.

Stakeholders, namely land-based farmers, implemented additional adaptation measures to cope with the impacts of COVID-19, including direct sales to consumers, storage of harvested fish as frozen or smoked, exploring new markets, and adapting processing for new products (Fig. 8 and Supplementary Table 4). Comparable responses have been reported in the aquaculture sectors of various nations, including the USA, Malaysia, India, Spain, and the countries in the Mekong Region [5,6,11, 17,36–38]. Although the study did not specifically inquire about strategies to reach the final customer, securing the marketing appeared to be favored over reducing production or changing farming techniques (Fig. 7), potentially because farmers found themselves amidst their regular production cycle during the pandemic. In 2020, the Ministry of Agriculture and Forestry, along with the Central Association of Aquaculture Farmers, organized three nationwide marketing campaigns to boost fish sales in chain markets, aiming to mitigate market disruptions caused by the pandemic. The campaigns allowed farmers to sell their fresh products and consumers to access high-quality food [24]. An increasing trend in the abundance of frozen or processed aquaculture products from domestic production was also reported, an indication of alternative mitigation measures, as observed in Türkiye [21,22] and elsewhere [9,37,38]. Furthermore, stakeholders described the state's direct financial support as a welcome adaptation measure, and the state has provided fish farms with financial support of approximately 0.25 US $/kg (for processed products, with a maximum limit of 100 tons per year) to compensate for part of the export losses in the year 2020 [39]. Interestingly, the respondents expressed a low preference for changing farming techniques by either recruiting new professionals or reducing production. The impact of the COVID-19 pandemic on job loss (Fig. 3) and staff dismissals in response to the pandemic was reported as very low (Fig. 6), which is in line with the findings of Erol [25]. Notably, as a COVID-19 mitigating measure, the government mandated that no company be able to fire employees for three months beginning on April 17, 2020 [40]. According to the regulation, during the ban, the employer had the right to put the employee on unpaid leave. If this was the case, they could benefit from short-time working allowances at roughly 60 % of their daily income. The extension of the ban period was under the authorization of the President [40], and the ban was terminated on 30.06.2021 (Official Newspaper, 30.03.2021, n.31470).

3.3. *Influence of COVID-19 on health and well-being*

The biggest concern resulting from the COVID-19 emergency was identified as the need to provide care for more vulnerable family members (e.g. children, elderly and handicapped; Fig. 9A). Stakeholders operating on land-based farms expressed this concern more prominently than their counterparts operating on sea-based system ($P<0.05$) (Fig. 9B). This discrepancy can be attributed to the fact that respondents from land-based farms employ a smaller number of staff overall, often limited to a few individuals within family-owned farms [30]. Furthermore, it is not possible to discount the impact of a curfew that was implemented in March and April 2020 [41] for individuals who are with chronic illness, older than 65 and younger than 20 to reduce the spread of the disease. Many farmers reported feeling apprehensive about the virus, acknowledging that the pandemic compelled them to increase their working efficiency. However, the specific strategies employed to

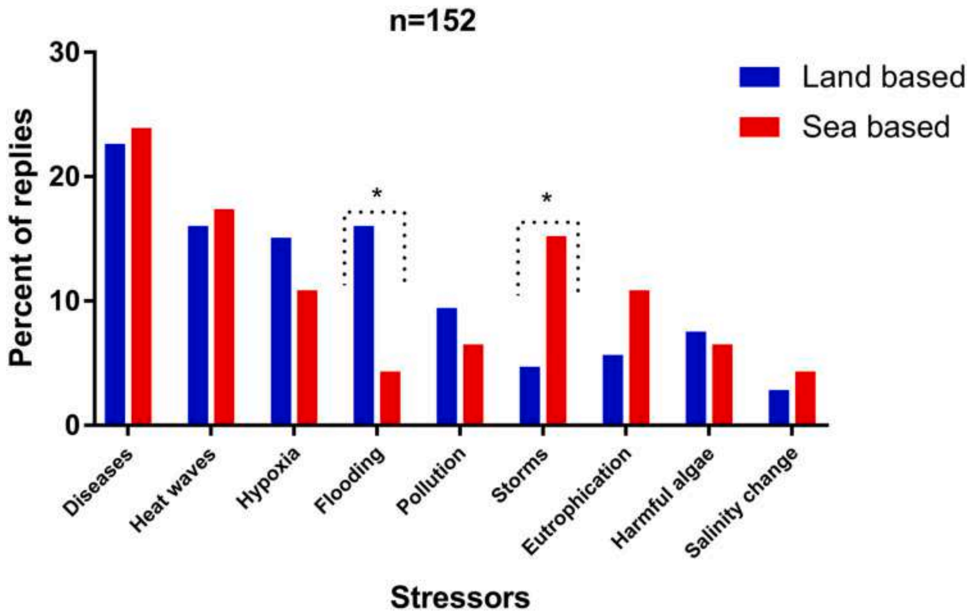

Fig. 12. Comparison of reported stressors (Contingency analysis showed no significant differences between the farm typology in terms of experienced stressors; Chi-Square value = 10.493, DF = 6, p = 0.232). Comparison of each cell revealed significant differences between land and sea-based aquaculture for flooding and storms; *Fisher's exact test; p value for flooding p = 0.0294; p value for storms p = 0.0354).

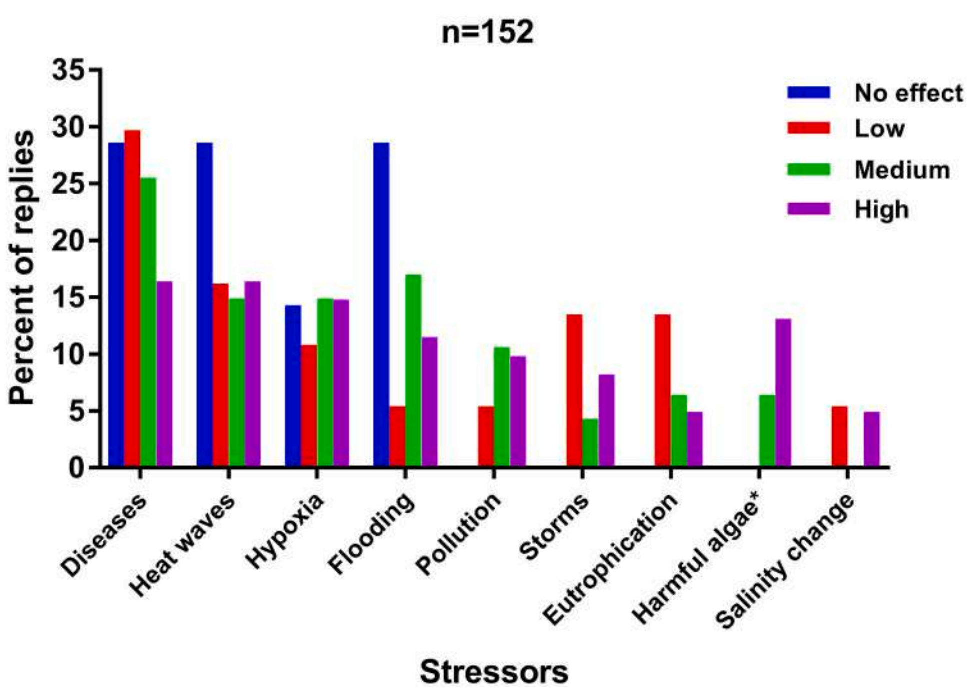

Fig. 13. Occurrences of COVID-19 related economic losses in relation to anthropogenic stressors. No significant differences among the levels of economic losses and reported stressors (p = 0.2426). However, a comparison among each cell revealed that a significance for high and low economic losses in terms of harmful algae was the case (*Fisher's exact test; p value for harmful algae p = 0.0046 between High and Low economic losses).

achieve this increased efficiency remain unclear. Due to more serious marketing and financial difficulties, most farms also had to improve relationships with other actors in the supply chain, with a greater level in land-based farms ($P<0.05$) (please see Fig. 5 and Fig. 9). All loadings of variables on the latent variables were significant ($P<0.05$) in terms of the influence of COVID-19 on the well-being of the farmers (Fig. 10). The CFA model developed for well-being supported the above findings and showed that the pandemic increased their workload. The path diagram displayed some differences between land- and sea-based systems in terms of intercorrelation among the latent variables. All the latent variables were positively correlated with each other in land-based farms ($P<0.05$) but only workload and personal well-being were covaried in sea-based systems (Wald Z = 2.13; $P<0.05$), implying that the pandemic disrupted the well-being of land-based-operators more seriously.

3.3.1. Environmental stressors and COVID-19

Fully comprehending the effects of environmental stressors on aquaculture is difficult due to the complexity of this system [14,42]. A global-scale survey revealed that environmental stressors negatively influence aquaculture farms and related supply chains, and the impacts are compounded when combined with the COVID-19 pandemic [4]. Here, we collected data on the environmental stressors that farmers have faced during the last decade in Türkiye (Fig. 11). Environmental stressors have been reported 152 times, either in isolation or in combination, in descending order as follows: diseases, heatwaves, hypoxia, flooding, pollution, storms, eutrophication, and harmful algae and salinity change. Climate change is thought to play a major role in increased pathogen challenges in Mediterranean countries [19,43]. Vaccination has become a routine practice in Turkish aquaculture to prevent widespread diseases [44,45], and there is a growing interest in the use of medicinal plants in fish diets to enhance immunity [46]. A comparison of the environmental stressors reported by farm typology is given in Fig. 12. Although the contingency analysis did not reveal a significant difference between the farming typology in terms of the reported stressors, Fisher's exact test suggested that flooding events were reported more frequently by land-based farms, whereas higher storm events were reported by sea-based systems ($p < 0.05$). Since rainbow trout is overwhelmingly farmed around streams and dams, it is reasonable to assume that an increase in the frequency of flooding cases on land-based farms may be related to unexpected sudden and heavy rainfalls in those streams and lakes. However, respondents reported that more storm incidents occurred in marine aquaculture, which is consistent with the findings of a previous study [45]. Turkish marine aquaculture is mainly conducted in off-shore cages located in the Aegean Sea and the Mediterranean Sea, but storms are common in these waters [9,47,48].

There was no significant difference in the level of COVID-19-dependent economic losses based on the selected anthropogenic stressors (Fig. 13). However, reported cases within economic loss groups displayed notable variations, warranting attention despite the somewhat limited data. For instance, 14–29 % of stakeholders who reported no economic losses due to COVID-19 suffered from disease, heatwaves, hypoxia, and flooding events. Among the respondents from the low-economic-loss group, 5–30 % have suffered from almost all stressors, with the highest level from disease outbreaks. Environmental stressors affecting farms within the class of moderate economic loss from COVID-19 ranged from 4 % to 26 %, with the highest incidence of diseases in the present study (Fig. 13). Additionally, 5–16 % of operations reporting high economic loss experienced all the stressors. These results implied that human stressors, either alone or in combination, are a very common problem in Turkish aquaculture. Moreover, the link between disease and economic losses in farms may result from a lack of timely and accurate pathogen detection during the pandemic. Another implication from the current study is that anthropogenic stressors recently experienced by the Turkish aquaculture sector remarkably reduced the resilience of farmers against sudden shocks, as commonly observed in many countries [4,17,29]. This issue should be seriously considered by national decision-makers when designing economic support for this vulnerable productive sector. Moreover, further studies are required to discern and specify the relationships between the stressors and the Turkish aquaculture sector, which is expanding toward the Eastern Mediterranean, Black Sea, and inland freshwater dams to increase resilience in case of future unexpected troubles.

3.4. Conclusions

The findings of this study indicated that the COVID-19 pandemic caused economic losses in all farms and their businesses, but that land-based rainbow trout aquaculture systems were more clearly and severely affected due to their small-scale prevalence. Supply chain issues, including logistical restrictions and transportation cost increase, marketing, and cash flow were the main issues due to the loss of international and domestic customers. Disease problem was the main implication as a prevailing stressor regardless of the magnitude of the economic losses. Furthermore, despite the serious impacts of COVID-19 on the sector, Turkish aquaculture production continued to increase by an average of 11.3 % annually in 2020, 2021, and 2022 [1,34], since none of the farmers attempted to reduce their production as a mitigation measure. Policy-makers should be more prepared to protect aquaculture producers and ensure food safety in the event of an unexpected global crisis by taking into account different scenarios. In such cases, small-scale producers should be prioritized. Further studies are required to gauge the pandemic impacts on the aquaculture sector with more emphasis on the supply chain, marketing, and related business branches by considering the resilience capacity of the sector to be better prepared for such crises.

CRediT authorship contribution statement

Daniela Giannetto: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Gianluca Sara**: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mustafa Altuğ Atalay**: Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis. **Hüseyin Sevgili**: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Data curation, Conceptualization. **Maria Cristina Mangano**: Writing – review & editing, Writing – original draft, Validation, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mahir Kanyılmaz**: Writing – original draft, Validation, Methodology, Investigation, Conceptualization. **Serkan Erkan**: Writing – original draft, Validation, Investigation, Formal analysis.

Declaration of Competing Interest

The authors declare no conflict of interests.

Data availability

The authors do not have permission to share data.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106153.

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