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An assessment of health management and biosecurity procedures in marine fish farming in Spain

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ABSTRACT

Marine fish farming in Spain has experienced problems of performance due to losses caused by infectious diseases. Biosecurity and health management are identified by the Food and Agriculture Organization (FAO) as current priorities for proper aquaculture governance. However, they both transcend the responsibility of farmers and require significant resources, concerted action and cooperation. This study presents the analysis of biosecurity practices on marine fish farms, through a questionnaire-based survey on biosecurity procedures and an analysis of health management practices for different stakeholders. The Strengths, Weaknesses, Opportunities, and Threats (SWOT) technique was implemented, which identified the important threats and weaknesses faced by the sector, such as the risk of direct disease transmission between farms, the high likelihood of importing diseases through juvenile shipments, the chronic lack of communication between stakeholders, and the deficient coordination of health strategies. Strengths included awareness of prevention measures and the availability of expertize of health experts at most levels. On the other hand, the availability of experts together with the need to adapt governance to the current production systems were seen as opportunities. Health management measures themselves were actually already found to be adapted to the type of production but they varied between companies (i.e. categorization and diagnosis of mortalities). Nevertheless, the quality of expertize along the value chain provided by private and public laboratories, research institutes, Health Protection Groups, companies and veterinarians was noteworthy. However, there was still a need for all stakeholders involved in marine fish health to improve diagnostics, provide epidemiological information, biosecurity and prevention measures, as well as to promote transparency for better health governance.

1. Introduction

In Mediterranean countries, marine fish farming is mainly focused on the production of European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*). The production of farmed seabream and seabass in 2016 was 376,984 tonnes, which was valued at 2066 million USD (Llorente et al., 2020). The seabass and seabream sector is a wide-spread industry that satisfies a highly internationalized demand. Its production takes place in as many as 20 countries, with Spain as the fourth producer of seabass and seabream in the region, which in 2019 produced 36,988 tonnes of seabass and seabream (MAPA (Ministerio de Agricultura, Pesca y Alimentación), 2020). The value chain is also well represented across the region, with the presence of seabass and/or seabream hatcheries, aqua-feed manufacturers, and many other providers of goods and services, including health providers (i.e. vaccines, treatments, diagnostics, etc.).

Traditionally, fish health management has focused on a disease-reaction approach (pathogen-disease-diagnosis-treatment), whereas currently it is recognized that it should focus on a more integrated system approach, where surveillance, biosecurity, risk assessment, prevention, sustainable treatments and welfare are key aspects that should also be included (Bernoth, 2008; World Bank Group, 2014). Biosecurity has been defined by the Food and Agriculture Organization (FAO) (2018a) as "*a strategic and integrated approach that encompasses both regulatory and normative frameworks whose objective is to analyze and manage risks that affect human, animal and plant life and health, including*

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related environmental risks". Moreover, biosecurity and health management are identified by FAO as current priorities for proper aquaculture governance (FAO, 2018a), as they transcend the responsibility of farmers and require significant resources, concerted action and cooperation.

The legal basis for such governance is currently defined by regulation EU 2016/429 (European Union (EU), 2016), which repealed Directive (EU) 2006/88/EC from 21 April 2021. This legislation sets the basis for the prevention and control of the listed and emerging diseases in aquatic animals in the European Union (EU), and demands European countries apply biosecurity standards in their aquaculture zones and establishments, under the direction of the competent national and local authorities. The aquaculture enterprise owners have the responsibility for biosecurity within their premises and, consequently, each facility needs an ad hoc biosecurity plan. Key elements of such biosecurity are: i) adequate diagnostic and detection methods for infectious diseases; ii) disinfection and pathogen eradication methods; iii) reliable high quality sources of animal stock; and iv) optimal health management practices. It should be noted that neither seabass nor seabream were included as susceptible host species for the notifiable pathogens listed in the recently repealed EU legislation through Council Directive 2006/88/EC (European Commission, 2006), and the new animal health law Regulation (EU) 2016/429 still does not have a list of susceptible species (European Union (EU), 2016). Moreover, the relevant pathogens affecting seabass and seabream identified in the EU are not listed as notifiable by the World Organisation for Animal Health (OIE) either (OIE, 2018, 2020). Consequently, because of the lack of regulation for specific diseases, the surveillance requirements for seabass and seabream diseases are lower than for other aquaculture fish species, such as trout, salmon or carp.

However, currently, Spain does not have an Aquatic Pathogen List at the national level. The regions (Autonomous Communities) can implement their surveillance programs according to the most important diseases for the sector. Such regional surveillance programs are coordinated by the regional Aquaculture Health Protection Groups (ADS by their Spanish name), which carry out specific active and passive surveillance. The pathogen lists included in the regional programs, although quite similar, may vary.

Good health management procedures are fundamental for correct husbandry and welfare. In addition, biosecurity and health management are identified in the State of World Fisheries and Aquaculture (FAO, 2018a) as one of the current priorities for proper aquaculture governance, which states that "*Taking action on biosecurity requires significant resources, concerted action and international cooperation. National strategic planning for aquatic animal health and biosecurity is vital*" (FAO, 2018a).

Good biosecurity plans must be adapted to the specific characteristics of the reared species and their production systems. Studies concerning health management in aquaculture have been reported for different important cultured species, such as white shrimp hatcheries in Latin America (FAO, 2003) or Norwegian salmon aquaculture (Lillehaug, 2015). More recently, for seabass and seabream, the MedAID H2020 project has published a report concerning "*Biosecurity and risk of disease introduction and spread in Mediterranean seabass and seabream farms*" (Tavornpanich et al., 2020).

Following the publication of the Strategic Guidelines for the Sustainable Development of EU Aquaculture (European Commission, 2013), member countries were requested to set up multiannual plans to promote aquaculture. Thus, Spain developed its Aquaculture Strategic Plan (MAGRAMA (Ministerio de Agricultura, Alimentación y Medio Ambiente), 2015c) that, in its Strategic Objective 3, calls for strengthening the competitiveness of the sector through R&D, the reinforcement of relationships between the scientific community and the sector, as well as proper health management and welfare issues.

This current study is part of the EU H2020 MedAID project, and was implemented as a case study to assess the health management and biosecurity procedures in the marine fish farming sector in Spain. Its main objective was to gain further knowledge on these key issues throughout the whole value chain of the marine fish farming sector in Spain and to propose broad-based recommendations for biosecurity procedures at the farm level, which were supported by a SWOT analysis based on a stakeholder consultation exercise.

2. Materials and methods

2.1. Analysis of on-farm health management and biosecurity procedures

The information used for the analysis came from a questionnaire designed in one of the tasks of the MedAID project to "*Improve disease management by risk assessment tools for relevant new and emerging pathogens in the Mediterranean basin*". It contained 160 questions regarding the general characteristics of the farm, its production statistics, production management, health management, disease reporting, diagnostic capacity and biosecurity measures; the questionnaire used for this study and the results of that study are available in MedAID's report Deliverable 4.1 (Tavornpanich et al., 2020). Prior to its implementation, the questionnaire was internally reviewed and pilot tested with stakeholders for subsequent further improvement. Interviews were conducted, mainly face to face, during the period between August 2018 and July 2019. One person/team was responsible for interviewing all farms in the same country. A total of 88 farms were consulted from eight Mediterranean countries with MedAID partners, covering the whole of the Mediterranean basin with the purpose of including as many farms as possible for all types of production stages, and also the main seabass and seabream producing countries (Croatia, Egypt, France, Greece, Italy, Spain, Tunisia, and Turkey). In the case of Spain, 27 farms were surveyed that were represented by two hatcheries (7.4 %), four pre-growing sites (14.8 %) and 21 on-growing (77.8 %) farms. The 21 on-growing units together represented 27,903 tonnes, 80 % of the 2018 Spanish seabass and seabream production (MAPA (Ministerio de Agricultura, Pesca y Alimentación), 2020). This data set allowed a complete descriptive study to be generated for the health management and biosecurity procedures in Spain.

The information obtained was processed, always maintaining the principle of confidentiality in order to guarantee the use of the data, without compromising the data protection rights of the personnel in the MedAID project.

The Mann-Whitney statistical test was used to compare differences between two independent groups when the dependent variable is either ordinal or continuous, but not normally distributed, as is the case for stocking densities. For the rest of the parameters, a descriptive analysis was chosen.

2.2. Mapping of stakeholders along the value chain

Along the entire marine aquaculture value chain, a broad range of stakeholders are, directly or indirectly, involved in the design and implementation of health management and biosecurity procedures in Spain. The mapping of stakeholders not only helps to ensure an adequate consultation process, but also provides information about the existence and quality of human and institutional resources. For the purpose of this study, the value chain of the Spanish marine fish farming sector was stratified into the following five categories: i) Production, ii) Input providers, iii) Service providers, iv) Knowledge providers, and v) Governance. This classification was made in accordance with the concept of the FAO's sustainable food value chain (SFVC) framework (FAO, 2014).

Stakeholders from the five categories were identified. The profiles included farmers, veterinarians and health managers, veterinary services from ADS, veterinary services from aqua-feed companies, providers of diagnosis, vaccines and treatments, research and academia, insurance companies, and public officers from central and subnational administrations.

In total, 36 stakeholders, from the five categories of the value chain related to health aspects in the Spanish marine fish farming sector were consulted according to the following distribution:

- Production: Veterinarians and health managers from fish farms (8).
- Input providers: Technical advisers/veterinarians from aqua-feed, probiotic and functional food companies (4), vaccine (3) and disinfectant (2) producers.
- Service providers: Aquaculture insurance (1) and diagnostics laboratories (4).
- Knowledge providers: R&D centres (2), universities (3), and aquaculture media (1).
- Governance: ADS (3), national administrations (2), subnational administrations (1), national reference laboratories (1), and certification (1).

2.3. SWOT analysis

The SWOT (Strengths, Weaknesses, Opportunities and Threats) analytical tool provides a contextual rational scheme that can be developed in order to carry out an analysis of the competitiveness of the aquaculture health management aspects of the sector from both external and internal perspectives. The external aspects were related to the **T**hreats and **O**pportunities that existed in the sector, which must be either overcome or exploited, respectively. On the other hand, the internal aspects analyzed the **S**trengths and **W**eaknesses of the sector, according to the current context, and the analysis was always based on objective facts. The SWOT analysis was implemented by following four steps: step 1 – Selection of stakeholders; step 2 – Consultation of stakeholders; step 3 – Analysis of the information and elaboration of a draft SWOT matrix; and step 4 – Group consultation and ranking. These steps were defined as follows:

2.3.1. Step 1 – selection of stakeholders

Stakeholders representing the above-mentioned five categories of the value chain were selected, contacted, informed about the assessment objectives and finally invited to participate. A confidentiality agreement was sent to all participating stakeholders, together with the MedAID commitment of non-disclosure of individual information.

2.3.2. Step 2 – consultation of stakeholders

Veterinarians and health managers from fish farms were interviewed either face-to-face on their own farms or during the MedAID's regional survey concerning "Biosecurity, management practices, and diagnostics capacities of Mediterranean marine fish farms", whereas 17 stakeholders from other sectors of the value chain were interviewed by different means, including face-to-face meetings, phone or videoconference calls. Interviews were purpose designed, with questions tailored according to the stakeholder professional profile, their experience and position in the value chain. All the interviews started with a series of introductory questions regarding the general view that stakeholders had on the health situation of the marine fish farming sector in Spain, as well as mortality and disease prevalence data, which was also included in this study. Thereafter, questions were focused on attaining the information on the sector's strengths, weaknesses, opportunities and threats. The interviews were carried out from July 2018 to February 2019. Each interview lasted 45 min on average, and it was recorded and a report was made for each one.

2.3.3. Step 3 – analysis of the information and elaboration of a draft SWOT matrix

The recorded information was compiled, organized and synthesized in order to elaborate a draft SWOT matrix for later discussion with stakeholders. The Spanish Administration had conducted an analysis of the aquaculture sector at national and subnational (Autonomous Communities) levels, also using SWOT. The results were used for the elaboration of the Spanish National Aquaculture Strategic Plan (MAGRAMA (Ministerio de Agricultura, Alimentación y Medio Ambiente), 2015a, 2015b). The aspects related to health management and biosecurity, such as source of live fish, water sources and treatments, vaccines and vaccination procedures or rearing management, were considered in this step of the current study.

2.3.4. Step 4. Group consultation and ranking

The conclusions drafted from the interview process and the draft SWOT matrix were reported at a workshop organized by the project MedAID which was held at the IAMZ-CIHEAM Mediterranean Agronomic Institute site in Zaragoza (28th March 2019). Participants were asked to score each of the identified items by assigning a value of 0–5. This was carried out by means of the interactive consultation tool Mentimeter (www.mentimeter.com). Then, the final SWOT matrix was compiled, after refining the draft with the feedback from the stakeholders during this exercise. Moreover, the results of the study on disease prevalence in Spanish fish farms were also presented to the attendees for further discussion.

Since the Mentimenter tool only provides the average score given by the experts, not the individual scores of each participant, a deeper statistical analysis was not feasible.

3. Results and discussion

Various aquaculture production systems exist in the Spanish aquaculture sector, which have highly variable sizes and different degrees of intensification. In terms of the size of the production units, inland tank facilities cannot be compared with marine cages or extensive production systems in estuaries; therefore, the differences between the specific husbandry parameters of each production system (e.g. densities, water renewal), must be taken into account by comparing only equivalent systems when the analysis is made. The contextual production data on the Spanish seabass and seabream systems comes from MedAID's WP4 survey in 2018.

Moreover, from the MedAID surveys, an increasing trend in the production scale of seabass has been seen in recent years (almost double in 2018); when compared to that of seabream, which, according to the producers, is due to their ease of production and rusticity (Tavornpanich et al., 2020). Therefore, the seabass production system is more highly represented in the analysis due to its size.

3.1. On-farm health management and biosecurity procedures

The context of the Spanish seabass and seabream production was considered as a starting point for the SWOT analysis. The 27 production units surveyed represented 80 % of the on-growing and 45 % of the hatcheries of both seabream and seabass production sites in Spain. While the hatchery and pre-growing sites were in land-based facilities, most of the on-growing sites were sea cages. The units examined were mostly dedicated to seabass, with an average annual production of 1146 tonnes, although they had a wide variability, given the different sizes of the on-growing sites, which ranged from an annual production of 90 tonnes to a maximum of 4000 tonnes.

The maximum stocking densities in the hatcheries and on-growing facilities were both lower and more homogeneous than in pre-growing facilities, which showed a great dispersion of the data (Fig. 1). The maximum stocking density reported in on-growing farms had an average of 16 kg/m^3 in the case of seabass, and 20 kg/m^3 in the case of seabream, with no significant differences between them ($p = 0.111$; Mann-Whitney statistical test).

For the analysis of the health management measures implemented at the sites, it was essential to take into account the different production systems, since many measures for inland farms would be different and impossible to implement in sea cages. Thus, the health management measures were analyzed by stratifying them according to the production system (hatchery, pre-growing and on-growing), taking into account the

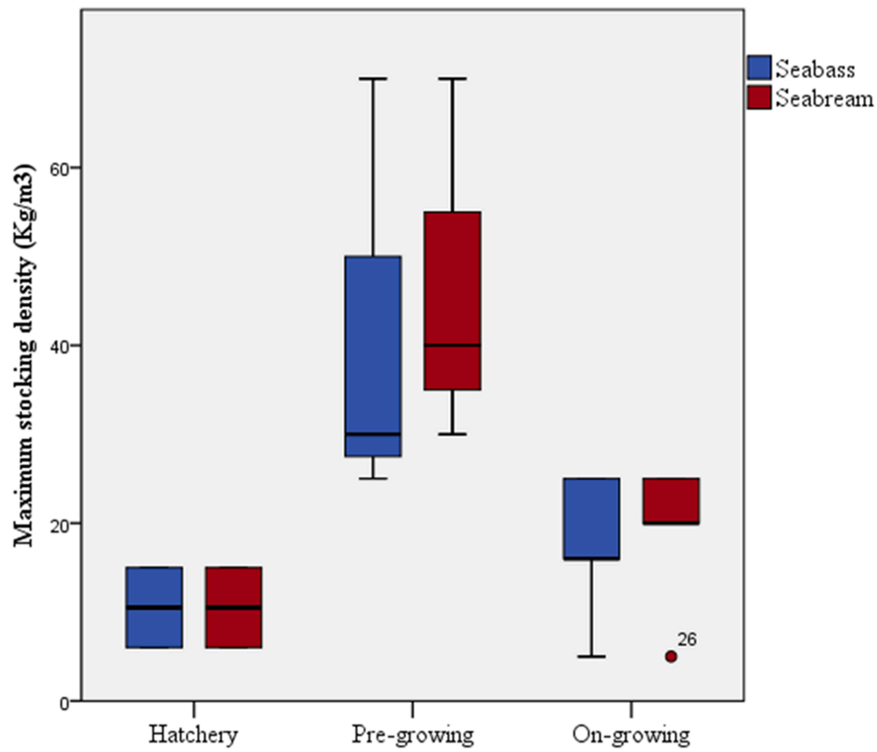

Fig. 1. Descriptive analysis of the maximum stocking density (kg/m^3) by species in each production phase. Central bars indicate the median. The extremes of the boxes represent the first (Q1, lower) and third (Q3, upper) quartiles. Boxes represent the interquartile range (IQ = Q3 – Q1), which indicates 50 % of the data. Whisker bars were calculated from the IQ (Upper: Q3 + 1.5 × IQ; lower: Q1 – 1.5 × IQ), and reflect the variability of the data outside Q1 and Q3.

economic, logistical and operational casuistic of each company.

3.1.1. Mortalities and diagnosis

Some on-growing sites did not routinely remove dead fish, leaving them as food for birds or mammals that coexisted with the facilities, in contrast to the farms that went to great efforts to remove the dead fish daily. Paradoxically, despite facts such as 33 % of the on-growing farms surveyed did not categorize their mortalities, and more than 90 % replied that they did not send dead/sick fish for diagnosis, none of them performed routine necropsy, although only two on-growing sites replied that they lacked disease surveillance systems on the facility. This can be regarded as a warning indicator with respect to the lack of biosecurity self-awareness of this sector. However, as many as 74 % of the production units were able to perform on-site diagnosis, with 4 % recording parasitic diseases, 18 % parasitic and bacterial diseases, and 52 % parasitic, bacterial and viral diseases.

3.1.2. Control of visits and movement of workers

All facilities had restricted visits, always escorted by company staff, and they were requested to comply with the biosecurity measures. Conversely, approximately 85 % of the workers routinely moved between facilities. Moreover, for most farms, work clothing was routinely washed by the workers in their own homes. Furthermore, approximately 85 % of the staff interviewed used the same unmarked clothing around the farm, regardless of the production unit. Only 63 % of the production units had disinfection stations for their workers, which decreased to 50 % in the on-growing phase.

3.1.3. Fallowing

The nature of the production systems made fallowing and disinfection of the facilities difficult and, even though most land-based sites applied these measures, it was usually for a very short period (2–3 days) before new fish stocks were allowed in. This was worse for off-shore facilities, where only 35 % of them conducted fallowing for any length of time, and depending on the season.

3.1.4. Vaccination

Regarding vaccination, there was a difference between on-growing sites, where fish were mostly vaccinated by the supplier at source, and pre-growing sites where vaccination was more extended than the farm sites. This needed to be taken into account when interviews were carried out, specifically where vaccination was performed by the supplier for on-growing sites. A total of 100 % of seabass were vaccinated against *Vibrio* sp. and *Photobacterium damselae*, followed by 52.4 % that were also vaccinated against *Aeromonas* sp. and 9.5 % for *Streptococcus* sp., whereas only 4.8 % of the production units included nodavirus vaccination (Table 1).

On the other hand, for seabream, on-farm vaccination was higher

Table 1
Spanish vaccination in 2018 of fish at source (by supplier) or on-farm categorized according to the production phase and species.

	By supplier		On-farm	
	Seabream (%)	Seabass (%)	Seabream (%)	Seabass (%)
On-growing (21)				
Photobacterium damselae	57.1	100.0	33.4	33.4
Vibrio sp.	61.9	100.0	28.6	28.6
Nodavirus	0.0	4.8	0.00	0.00
Aeromonas sp.	0.0	52.4	0.00	0.00
Streptococcus sp.	0.0	9.5	0.00	0.00
Pre-growing (4)				
Photobacterium damselae	25.0	50.0	75.00	100.00
Vibrio sp.	25.0	50.0	50.00	100.00
Nodavirus	0.0	0.0	0.00	25.00
Aeromonas sp.	0.0	0.0	0.00	25.00
Streptococcus sp.	0.0	0.0	0.00	25.00

than vaccination at source, thus 75 % of seabream were vaccinated at the pre-growing phase against *Photobacterium damselae* and 50 % for *Vibrio* sp., which represented three times and double the percentage compared to vaccination at source, respectively. Seabream were vaccinated against *Photobacterium damselae* and *Vibrio* sp. only, regardless of the growth phase and location, whereas seabass received a wider range of vaccines in their earlier growth stages, both at the farm site during pre-growing or for fish that received vaccination at source (Table 1).

In the case of seabass, it was noteworthy that approximately 50 % of fingerlings arrived at the pre-ongrowing facilities already vaccinated by the suppliers (hatcheries), and were thereafter all vaccinated before being transferred for on-growing (Table 1).

Regarding vaccination (both licensed and autologous vaccines), the answers to the questionnaire indicated that it was an extended practice, with *Vibrio* sp. and *Photobacterium damselae* vaccines being the most commonly applied to both fish species (Tavornpanich et al., 2020). Nodavirus vaccines were actually approved during the implementation of this study; therefore, the extent of their current use could not be addressed properly.

When the vaccination used was compared with the most prevalent diseases (Muniesa et al., 2020), it was shown that, in the case of seabass, the diseases and the vaccines used matched completely. Accordingly, there was a very large proportion of vaccination against *Photobacterium damselae* and *Vibrio* sp. in all phases and by both types of suppliers, although this was mainly in the early growth stages. This may be due to several causes, such as the fact that early growth stages in land-based facilities have higher prevalence of these pathogens and, therefore, more incidence of their diseases. Moreover, specific disease notifications might have allowed/promoted the development and licencing of auto-vaccines. However, vaccination in sea cages is a very complicated and stressful activity that has lower efficiency than land based vaccination, due to multifactorial phenomena; therefore, it should be avoided wherever possible. Although there were no reported photobacteriosis or vibriosis outbreaks in seabream, this species was vaccinated against these pathogens, according to the production phase (Table 1). This may be due to the fact that most farms produced both seabream and seabass, and they considered vaccination necessary in both species for better control of the potential spread of these diseases. In addition, seabass were vaccinated against *Aeromonas* sp. (25 % of pre-growing sites vaccinated on-farm and 52.4 % of on-growing sites vaccinated by the supplier), even though no outbreaks related to this pathogen were recorded in either the MedAID or ADS data. This vaccination strategy was most likely designed to maintain the bacterial load at a low level in farms/areas where these diseases had been present previously.

The impact of *Aeromonas* sp. affecting mainly very large seabass would justify extra vaccination cost and a quick response in order to fight this very worrying emerging pathogen in the Mediterranean. Moreover, *Aeromonas salmonicida* subsp. *salmonicida*, has been isolated from farmed seabass in Spain (Fernández Álvarez et al., 2016). A similar situation was found for *Streptococcus* sp., where on-farm vaccination was 25 % (Table 1), even though there were no reported outbreaks in the studied period. Regarding nodavirus, it should be pointed out that commercial vaccines were made available during the development of this study. Thus, the extent of their application should be considered as preliminary. Although nodavirus incidence was apparently low for both species (Muniesa et al., 2020), vaccination of on-farm seabass was 25 %, indicating the perceived need in the sector to vaccinate against this relevant pathogen.

3.1.5. Pathways of entry for pathogens

One of the main pathways of entry for pathogens in a facility is represented by introductions of live fish via the fish themselves and/or the transport vehicles (Hedrick, 1996). The analysis showed that biosecurity measures could vary according to whether incoming fish came from the facilities of the same or a different company. When they came from the same company, most of the surveyed facilities only requested a health certificate and health history record. However, when they were from a different company, the results of diagnostic tests for the main pathogens were also required and, in some cases, an on-site inspection of the animals was carried out before shipment.

Other important biosecurity procedures had previously been the practice of quarantine and an "all-in, all-out" policy that were important health management measures in use until a few years ago. Nevertheless, currently, such practices have been relegated to a methodological approach based on the surveillance of new fish stocks, due to a lack of a specific holding unit for quarantine and the lack of synchronization for fish entries (Table 2).

Various measures are available to prevent birds from entering aquaculture facilities in order to reduce the damage they may cause. Of the surveyed farms, 88.89% took specific measures, usually based on nets, to prevent the entry of birds and scavengers. However, only 18.5 % of the companies also had control programs in place for rodents.

Regarding water treatment, most land-based plants applied filtration and UV treatment to the intake water, whereas their outflow water was only decanted.

3.1.6. Biosecurity measures/factors associated with mortality outbreaks

Concerning seabass and seabream production, Tavornpanich et al. (2020) found several biosecurity measures/factors associated with farms experiencing major mortality outbreaks. These included the concept of the lower the contact between fish, either within the farm or with wild fish, the lower the mortality rates related to pathogens. This also applied to farms of the same company preventing movements between their sites. In addition, other factors included hygiene related to feed storage in protected containers, ad hoc equipment for different husbandry practices and vehicle disinfection (Table 2).

The trade and movement of live fish is well known as one of the main disease transmission mechanisms (Rodgers et al., 2011), not only for notifiable diseases but also for "*non-target species for which health examinations may not be required, or for which criteria for pathogen inspections have not been developed*" (Hedrick, 1996), as is the case for seabream and seabass. Cidad et al. (2018) provided some information concerning the trade of seabass and seabream in the Mediterranean region, which was a key issue that required further research. Apart from live fish movements, other disease dissemination causes also play a role, such as water currents, surrounding wild fish and boats, all of which are very relevant for marine cage farming.

3.2. Mapping of stakeholders

The design and implementation of adequate aquaculture health governance requires consultation with stakeholders and participation through the whole sector value chain (FAO, 2019). Their engagement is

Table 2
Summary of the main on-farm health and biosecurity procedures requiring improvement in Spain.

- Enhancement of on-farm diagnosis (necropsy, parasitology, etc.) by improving diagnostic accuracy and standardization using diagnostic SOP protocols and inter-comparative exercises.
- Control of staff movements between facilities and related hygiene prevention measures (corporate clothing for exclusive on-site use, disinfection stations).
- Improvement of quarantine procedures and facilities (specific ad hoc locations/ facilities/cages or tanks) and stamping out procedures, scheduled in coordination with production.
- Mitigation of the risk of disease introduction associated with fish movement by ensuring updated information and transparent communication protocols from and for the stakeholders. Critical information should also cover relevant disease prevalence in neighboring facilities, regions of origin of fish, etc.
- Harmonized epidemiological data collection and information sharing. This should include categorization of mortalities, analysis of prevalence and mortality, related environmental data and effectiveness of vaccination.
- Training in biosecurity and hygiene for all farm workers should be considered using continuous in-house programs by the companies themselves.

essential, and should also include governments, public research institutions, industry and all interested parties, in order to protect and improve aquatic animal health (Subasinghe et al., 2019).

The basis of the current study was the mapping of all the value chain segments and stakeholders involved in health management and biosecurity of marine fish farming in Spain. This exercise not only facilitated the process of selecting stakeholders and ensuring that the needs and views of the whole sector were considered, but it also provided an important understanding of the existing or missing human and institutional resources throughout the whole value chain, which was used to assess the strengths and weaknesses of the system.

The veterinarians and health managers from fish farms came from companies representing 80 % of the seabass and seabream production in Spain, and 45 % of the fingerling production. No stakeholders from the supranational level were included in this analysis.

The professional level and the critical mass of health experts/stakeholders in Spain along the value chain, both in public institutions and private companies, were seen as an important strength and a competitive asset. Currently, Spain has a high level of diagnostic capacity dedicated to fish diseases. Seabass and seabream are the main species produced in Mediterranean marine fish farming, however, they, as other marine farmed species (e.g. meager, sole, tuna), have not been listed as susceptible host species for the notifiable pathogens listed in the EU legislation (Council Directive 2006/88/EC) (EU, 2006), thus, generating a lack of systematic reporting for this sector. The new European animal health law has not listed susceptible species to date. Moreover, Spain has no internal legislation regarding either listed diseases or susceptible species.

According to a survey conducted by the EU Horizon 2020 projects MedAID and PerformFISH, Spain has 28 fish disease laboratories and was among the Mediterranean countries with the highest resources. Moreover, they were all characterized as advanced to specialized, with laboratories focused on the diagnosis of all pathogen groups (parasites, bacteria, and viruses), as well as having collateral techniques available (Zrnčić et al., 2021). Another important asset was the presence of biotechnological companies specialized in vaccine development and production, such as Hipra and Aquatreck Animal Health.

However, the same mapping study showed stakeholder weaknesses within the different segments of the chain. Thus, the analysis identified the existence of veterinarians and health experts in medium/large sized companies, but not in small/medium companies, where diagnosis is normally externalized. Moreover, certain important biosecurity tasks are not undertaken (e.g. correct recording and identification of mortalities). At the governmental level, there is a National Fish Diseases Reference Laboratory, whose main objectives are focused on the surveillance of notifiable diseases of fish and, consequently, no supervision is undertaken for marine fish, due to the lack of any listed pathogens.

3.3. Assessment of health management procedures using a SWOT analysis

A SWOT analysis is a tool recommended in foresight exercises for fisheries (FAO, 2020). There are numerous examples of its application to fisheries and aquaculture (Rimmer et al., 2013; Sam Siril Nicholas et al., 2015; FAO, 2018b) and a few on the analysis of biosecurity for livestock (Noordhuizen, 2005; FAO, 2018c). As the analysis is undertaken in consultation with different stakeholders, one key step is to ensure that the process involves stakeholders with differing perspectives and backgrounds that can provide insights into each area, since the analysis focuses on both internal (strengths and weaknesses) and external (opportunities and threats) factors in order to determine their competitive advantages and disadvantages.

The analysis of resources and capacities evaluated a large diversity of factors related to health management. The SWOT technique consisted of analyzing the competitive context in order to facilitate the establishment of the necessary strategic lines to improve the situation in the near future. The recorded information from all interviewed stakeholders was compiled, organized and synthesized in order to elaborate a draft SWOT matrix, which was finally discussed and weighted by 36 invited stakeholders, in a seminar on Health Management and Biosecurity held at IAM-CIHEAM, Zaragoza (28th March, 2019) using the Mentimeter app/software. The SWOT items identified were ranked using scores according to the importance considered by the experts in order to help prioritize the categories, and the resulting matrices are shown in Figs. 2 and 3.

From the internal analysis (strengths and weaknesses), the greatest strength according to the stakeholders interviewed was the "increasing awareness on prevention" that had an average score of 4.3 out of 5, followed by trust in the health experts (score 3.9, 2nd position and 3.3, 4th position), diagnostic capacities in fifth (score 3.1) and seventh positions (score 3.1), indicating the valuation of a technically well-equipped system. On the other hand, the greatest weakness was precisely the "lack of awareness in some segments of the value chain", scoring 4.1 out of 5, whereas the concern for a lack of decision making capacity of health experts was in 7th position (score 3.2). The difficulties in implementing ADS to meet their objectives was not considered a specific weakness (score 2.7, 11th position), and neither was the lack of veterinary experts in small companies (score 3.1, 10th position). These discrepancies indicate an apparent lack of efficiency in the implementation of a health management system in Spain, including governance, since lack of communication between producers and administrators was in 4th place (score 3.6) in the weaknesses analysis. Regarding the structure of companies, their modernization (score 3.8, 3rd position) and concentration (score 3.1, 6th position) in the sector were considered strengths. One the other hand, the high-density of units in production areas was considered as the second weakness (score 4 as opposed to a score of 3.1 when the concentration of companies was considered as a strength). This apparent contradiction seems to point towards a company driven sector, with deficient spatial planning, which is again a governance issue. The weakness list was more extensive than that of the strengths, with issues related to the scarcity of authorized treatments (score 3.9, 3rd position) and a poor legislative framework in marine aquaculture (score 3.4, 6th position), with difficulties obtaining prescriptions (score 3.1, 9th position) additionally being considered (Fig. 2).

Taking into account the external situation (opportunities and threats), it was very interesting to note that seven out of nine descriptors were health-related issues, including the first five on the threats list (scores 4.1–3.5, respectively), indicating the concern for disease problems. The two main threats found throughout the value chain were a "lack of coordination of health strategies in the same production area" followed by "high disease transmission possibilities, due to high culture densities" that both obtained an average score of 4.1 out of 5. Interestingly, these two threats were in line with two weaknesses related to the high density of production units and the lack of communication (score 4.0, 2nd position and score 3.6, 4th position, respectively); therefore, these similar factors were considered both an internal and an external problem, thus, strengthening their relevance. This was followed by the concern for the impact of fish stock movements with limited control (score 3.9, 3rd position and score 3.8, 4th position, respectively). Climate change appeared as a threat on its own (score 3.1, 6th position) and was implicit together with new diseases resistant to treatment (score 3.5, 5th position). The lack of Mediterranean regional coordination (score 3.0, 7th position) was also in line with an equivalent weakness identified at the internal level. The concentration of production in large companies was considered to be the lowest threat (score 2.3, 9th position) in an external context, although it had also actually been considered an internal strength (score 3.1, 6th position).

On the other hand, the most important opportunity (among only four identified) was defined as "experts in companies and in all the segments of the value chain is a competitive advantage, in contrast to other countries" that scored 4 out of 5, in line with the strengths of well-trained health experts (score 3.9, 2nd position) and the existence of

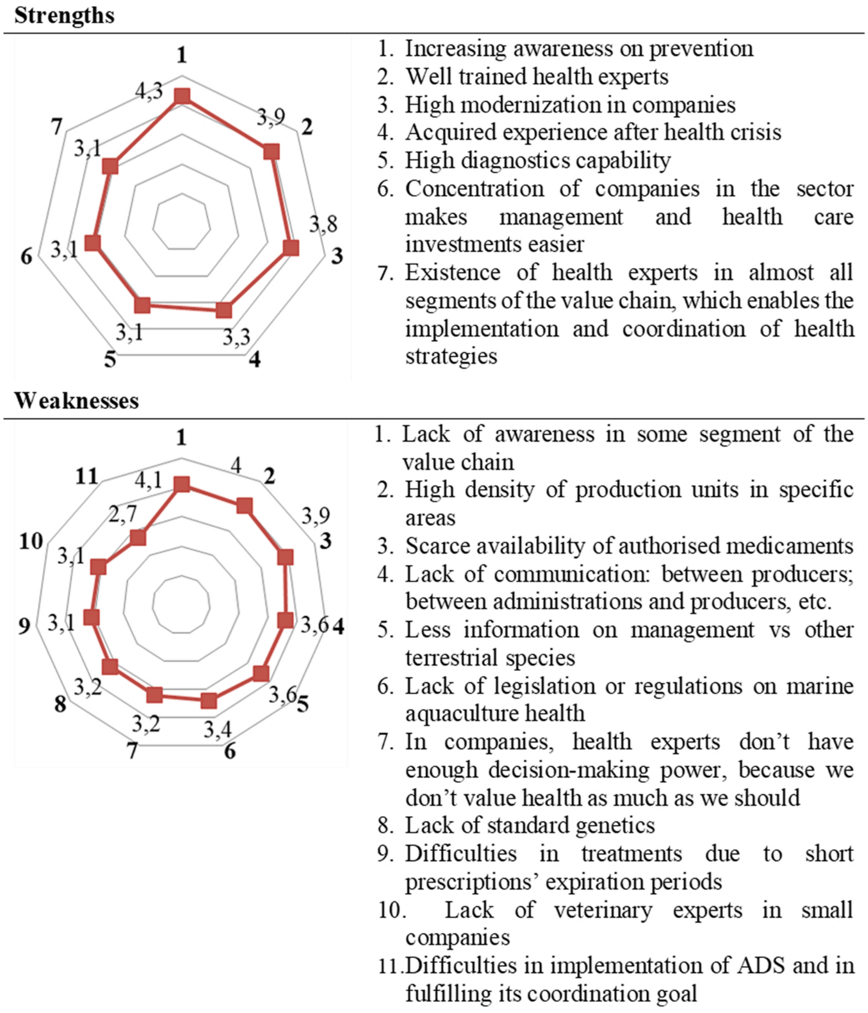

Fig. 2. Quantification of the internal characteristics (strengths and weaknesses) using Mentimeter (n = 33). The result of the scoring by ranking, from the highest to the lowest, is presented in a clockwise direction. The descriptors are listed on the right-hand side of the graph.

health experts in almost all segments of the value chain (score 3.1, 7th position). Interestingly, internal weaknesses related to lack of communication/coordination (scoring 3.6–2.7, positions 4th, 7th, 9th, 10th and 11th, respectively) were seen as opportunities (3.4, 3rd position) for further development of ADS. Finally, improved genetic lines for disease resistance were considered an opportunity (score 3.2, 4th position), whereas concomitantly their lack also appeared as a weakness (score 3.2, 8th position) (Fig. 3).

When the health management SWOT analysis carried out for this study was compared to that implemented in the Spanish National Strategic Plan for fisheries and aquaculture (MAGRAMA (Ministerio de Agricultura, Alimentación y Medio Ambiente), 2015c), it was shown that there was a lack of transfer of information and technology between the agents involved, as well as insufficient institutional coordination, which were common weaknesses found in both analyzes. In addition, the various strategic plans for the different autonomous communities reflected the dispersal of competencies and increased regulation at all levels (both thematic and hierarchical).

The laws that apply to fish health management and disease surveillance in Spain are based on European regulation and Spanish legislation. At the national level, the Central Government is in charge of the legal framework for animal health, the coordination and communication (mainly of notifiable and emerging diseases) with Europe and other international organizations (i.e. OIE), and coordination with the autonomous communities for the surveillance systems. The autonomous communities are the responsible administrations for the implementation of the Spanish legislation on animal health and they can also develop their own legal regulation for surveillance. Whereas at the national level there is no national aquatic pathogen list, the autonomous communities may have surveillance programs that include specific diseases, which are normally implemented in coordination with the ADS. The existence of ADS must be highlighted because they do not exist in most Mediterranean countries. The ADS are animal health associations, regulated by Spanish Royal Decree 842/2011 (MAGRAMA (Ministerio de Agricultura, Alimentación y Medio Ambiente), 2011), and created by related producers in order to establish coordinated surveillance systems that would bind together aquaculture companies, at the level of the autonomous communities, according to the European regulations. The ADS's objectives are to implement prophylaxis (prevention) programs, fight against diseases and improve the sanitary status of associated facilities/companies in order to improve the productivity and sanitary level of their products.

The ADS are funded by the Ministry of Agriculture, Fisheries and Food (MAGRAMA) through the Spanish Autonomous Communities, with additional support that can be requested from the European Fisheries Fund for specific actions addressing animal health issues and environmental protection. In Spain, the main marine fish farming production regions (Autonomous Communities) that have ADS are Murcia (ADS-Región de Murcia), Valencia (ADS-ACUIVAL), Canary Islands (ADS-ACCAN), and Andalusia (ADSAQUA). These associations, together

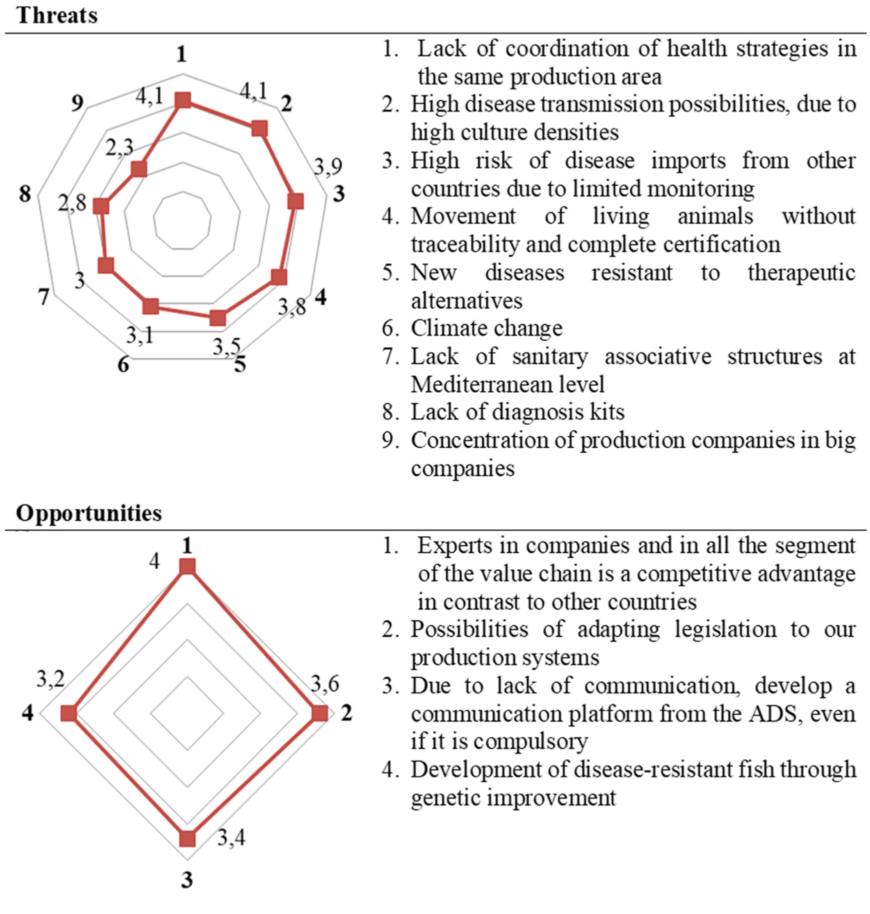

Fig. 3. Quantification of the external situation (opportunities and threats) using Mentimeter (n = 33). The results of the scoring by ranking, from the highest to the lowest, are presented in a clockwise direction in the figure. The descriptors are listed on the right-hand side of the graph.

with other ADS dedicated to freshwater fish farming (e.g. ADS-Aragón), are integrated into a National Federation (FEADSA: Federación Española de Agrupaciones de Defensa Sanitaria de Acuicultura).

Although the existence of the ADS is an evident strength and a competitive advantage for a country, membership of farms is not compulsory. Thus, whereas in Murcia and the Canary Islands all companies are members of their regional ADS, this is not the case in the Valencia region, which results in an incomplete surveillance program that also hampers the possibility of implementing common biosecurity programs. In the current SWOT analysis, some companies from this region (not ADS members) refused to participate in the analysis, justifying confidentiality reasons, which is another example of how holding back information hampers good analysis and avoids provision of a perspective of the sector.

The SWOT analysis in this study identified the main threats as the lack of coordination of health strategies in the same production area, high possibilities of disease transmission due to high culture densities and the high risk of importing diseases from other countries due to limited monitoring, including movement of animals without traceability and certification.

Health management at the farm level and its coordination with nearby production units has a direct consequence on lowering mortality, which provides cost savings, lower variability in production, better planning and risk mitigation, thus resulting in a better return on investments and decrease of inputs (e.g. treatments). This, in return, provides a better quality product, improved welfare and decreased environmental impact. Altogether, these approaches facilitate the achievement of product labels that improve the image and social acceptability of the product and the marine fish farming sector.

In summary, this SWOT analysis showed how the Spanish marine aquaculture sector relies on highly specialized stakeholders along the value chain, which deal with health management and biosecurity procedures (e.g. laboratories, health associations, health companies, veterinarians). However, the sector needs to improve the communication channels at all levels, as well as the systematic collation of information on disease prevalence and their economic impact in order to provide better aquaculture health governance. Updated knowledge concerning relevant pathogens, standardized diagnosis and key performance indicators (KPIs) are essential for implementing a complete health management system.

4. Conclusions

The analysis performed showed that the Spanish marine aquaculture sector could count on highly specialized stakeholders dealing with health management and biosecurity procedures. Training was a critical component of biosecurity for all stakeholders along the value / sector chain and should be included in the syllabus of professional colleges and faculties, as well as in the continuous in-house programs organized by the companies themselves. There is also a lack of communication amongst stakeholders that needs to be improved for better sector health management.

All the threats found in the SWOT analysis would be partly solved with the development of a regulatory frame that would ensure adequate information is gathered and shared, and that the sector cooperates in a coordinated way.

CRediT authorship contribution statement

Muniesa, Basurco, Furones and Rodgers: Conceptualization. **Muniesa, Basurco, Furones and Rodgers:** Methodology. –: Software. **Muniesa, Basurco and Furones:** Validation. **Muniesa:** Formal analysis. **Muniesa, Basurco and Furones:** Investigation. **Muniesa, Basurco and Furones:** Resources. **Muniesa and Basurco:** Data curation. **Muniesa and Basurco:** Writing – original draft. **Furones and Rodgers:** Writing – review & editing. **Muniesa, Basurco and Furones:** Visualization. **Basurco:** Supervision. **Basurco and Furones:** Project administration. **Basurco and Furones:** Funding acquisition.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Bernardo Basurco reports financial support was provided by Horizon 2020.

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