Aquaculture Reports 25 (2022) 101257

Contents lists available at ScienceDirect

Aquaculture Reports

journal homepage: www.elsevier.com/locate/aqrep

An assessment of disease occurrence and mortality in marine fish farming in Spain

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ARTICLE INFO

Keywords:
Disease occurrence
Mortality
Health surveillance
Mediterranean marine fish farming

ABSTRACT

Marine fish farming in Spain, as in most Mediterranean countries, focuses on the production of European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*). The sector has experienced performance problems that affect the industry's competitiveness, and infectious and parasitic diseases have been described as being among the main causes of losses. Whereas companies are aware of the need to assess the impact and causes of such losses, the analysis of disease occurrence and mortality in seabass and seabream has received scarce attention from the sector and official administrations. Through information obtained from interviews and surveys, it has been possible to carry out an assessment of disease occurrence and mortality in marine fish farming in Spain. The median survival rate data for seabass and seabream was shown to be slightly higher in seabream, although no significant differences were found between species. It was not possible to further differentiate the causes of diseases or losses, as they were generally not standardized into categories and they also varied between companies. Nevertheless, the aim was to prompt producers and health management stakeholders into discussing how to improve the collection and analysis of data for relevant disease outbreaks and mortalities. Moreover, EU Regulation 2016/429 (the 'Animal Health Law') calls on Member States to implement disease surveillance programmes to investigate 'increased mortality' events in order to be alert for possible emerging diseases. Good knowledge of a disease situation and its impact on production represents a base mechanism for designing health surveillance. Therefore, the standardization of health data collection and its analysis will help countries in the implementation of surveillance programmes and rapid alert mechanisms in order to combat emerging diseases at an early stage.

1. Introduction

Diseases are considered to be among the main causes of economic losses in farmed fish (Israngkura and Sae-Hae, 2002). However, it is difficult for farmers to discriminate between the underlying causes of diseases and mortality (i.e. pathogens, management, environment, etc.), and even more so when these factors could be interrelated. Proper recording of mortality, diagnosis of pathogens causing outbreaks, and the analysis of correlated causes can facilitate health management actions for treating and thus preventing further losses. Long-term mortality rates and their comparison with baseline mortality can be used as a key performance indicator (KPI) for evaluating the impact of changes in management and production strategies (Bang Jensen et al., 2020). Short-term mortality rates (abnormal mortalities) can be used as a surveillance alert indicator (Soares et al., 2011, 2012). Moreover, mortality rates have been proposed for use as welfare indicators: either as a retrospective welfare performance indicator (WPI) (long-term mortality rates) or as an operational welfare indicator (OWI) (short-term mortality rates) (Ellis et al., 2012).

The application of these data as indicators (KPI, WPI, OWI) will depend on the availability of reliable baseline mortality and mortality threshold values, which are also essential in relation to the identification of abnormal mortality.

In Mediterranean countries, marine fish farming is mainly focused on the production of European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*). The Mediterranean seabass and seabream

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https://doi.org/10.1016/j.aqrep.2022.101257
Received 17 August 2021; Received in revised form 18 May 2022; Accepted 7 July 2022
Available online 11 July 2022

sector is widely spread across the basin itself, with production taking place in as many as 20 countries, although it is led by Turkey and Greece (FAO, 2018). Spain is the fourth producer of seabass and seabream in the region that, in 2019, produced 36,988 tonnes (24,543 tonnes of seabass and 12,445 tonnes of seabream), with most of its production being in Murcia (29.4 %), Valencia (29.35 %), Canary Islands (21.3 %) and Andalusia (19.7 %) (MAPA, 2020). In addition, Spain produced almost 100 million fingerlings in 2019 (36 million seabream and 69.5 million seabass).

It should be noted that neither seabass nor seabream are among susceptible host species for the notifiable pathogens listed in Council Directive 2006/88/EC; EC (2006). This Directive, which was valid until 20/04/2021, is currently being derogated and substituted by Regulation (EU) 2016/429 (EU, 2016) on transmissible animal diseases that amends and repeals certain articles in the area of animal health (‘Animal Health Law’). Article 18 of Regulation (EU) 2016/429 states that operators should notify abnormal mortalities and other signs of serious disease or significant decreased production rates for further investigation. Article 26 in the same regulation states that the competent authority shall conduct surveillance to detect not only the presence of listed diseases, but also relevant emerging diseases.

The Mediterranean seabass and seabream sector has faced certain zootechnical and profitability issues, and it has been affected by important infectious and parasitic diseases. From among these have been identified, viral nervous necrosis (VNN), caused by Betanodavirus nodavirus, (Vendramin et al., 2016; Muniesa et al., 2020) both in seabass and seabream, tenacibaculosis, caused by *Tenacibaculum maritimus*, and vibriosis, caused by *Vibrio* sp., in seabass, photobacteriosis, caused by *Photobacterium damselae* subsp. *piscicida* both in seabass and seabream, and sparicotylosis, caused by *Sparicotyle chrysophrii* (a gill fluke) in seabream. These relevant pathogens, however, are not listed as notifiable in either Council Directive 2006/88/EC or by the World Organisation for Animal Health (OIE) (OIE, 2021). Consequently, because of the lack of regulation for specific diseases, the surveillance requirements for seabass and seabream are lower than for other aquaculture fish species, such as salmonids.

Currently, Mediterranean aquaculture is lacking or has fragmented knowledge relating to the occurrence, prevalence and impact of diseases on production, which represents a baseline mechanism for designing health surveillance, risk analysis and biosecurity systems.

This current study is part of the EU H2020 MedAID project, and was implemented as a survey in order to assess the disease occurrence and mortality in on-growing marine fish farming in Spain, as well as to gain further understanding of these issues and propose sound recommendations.

2. Materials and methods

2.1. Source data

Data were obtained from two main sources of information: (i) two surveys conducted by the MedAID project from a fish farming assessment (WP1) and a health survey (WP4), and (ii) directly from the veterinary services of the Aquaculture Health Protection Groups (ADS by their Spanish name) in the main seabass and seabream producing regions (Autonomous Communities) of Murcia (ADS-Murcia), Canary Islands (ADS-ACCAN) and Valencia (ADS-ACUIVAL). The information obtained was processed, always maintaining the principle of confidentiality.

2.2. Disease occurrence

In MedAID’s WP1 (Holistic sustainability assessment of Mediterranean aquaculture and governance) a first survey was conducted directly with fish farms in 2018 (covering the period from 2015 to 2017; calendar years) in order to assess their zootechnical, environmental and economic performance, including health management aspects. Prior to its implementation, a questionnaire was designed, pilot tested and revised. Interviews were mainly conducted in person on the fish farms involved, with additional data also being received by email. A total of 50 production units, including on-growing, pre-growing and hatchery facilities, located in 10 Mediterranean countries (Croatia, Cyprus, Egypt, France, Greece, Italy, Portugal, Spain, Tunisia, and Turkey) were surveyed (Cidad et al., 2018). From the 50 European sites, a total of eight production units were surveyed in Spain.

For a more complete analysis of the occurrence of infectious and parasitic diseases in seabass and seabream in Spain, a comparative analysis was conducted with the information provided by the ADS of the Canary Islands, Murcia and Valencia, which accounted for 80 % of the Spanish seabass and seabream production. The ADS’s veterinary services provided information concerning outbreaks obtained from the active (quarterly) and specific surveillance that these services conduct for their associated farms.

The diseases were diagnosed either by a company health specialist or external veterinary services and laboratories. For recurrent outbreaks, the diagnosis was frequently based on clinical signs or necropsy, and historical farm records,which are common procedures in aquatic veterinary medicine that can provide a precise diagnosis when considered together.

Regarding disease occurrence on seabream and seabass on-growing farms in Spain, two sources of information were used: MedAID WP1 surveys (2015–2017), and the ADS veterinary services, covering data from 2016 to 2018. Since the periods covered were not the same, it was therefore decided to compare the data only from the same calendar years (i.e. 2016 and 2017). This cross-sectional study was deemed sufficient for the methodological objective of the study.

2.3. Mortality

A second farm questionnaire was designed for MedAID’s WP4, Task 4.1 (Improved 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 a farm, its production statistics, production management, health management, disease reporting, diagnostic capacity, and biosecurity measures (Tavornpanich et al., 2020). Prior to its implementation, the questionnaire was reviewed, pilot tested and further revised twice. Interviews were conducted, mainly in person, during the period between August 2018 and July 2019, covering 2018 data. One person/team was responsible for interviewing all farms in the same country. A total of 88 farms from eight different Mediterranean countries (Croatia, Egypt, France, Greece, Italy, Spain, Tunisia, and Turkey) were consulted.

However, for this current study, 27 production units located in Spain were surveyed, and the questionnaire included specific questions concerning mortality. The survival rates of 20 of the 21 Spanish on-growing farms surveyed were analysed for each species (seabream and seabass) by stratifying mortality due to pathology and mortality related to non-pathological causes. Furthermore, these parameters were compared for each species using the Student’s t test for independent samples.

3. Results and discussion

3.1. Fish farm characteristics

A total of 27 seabream and seabass production units were surveyed in Spain with the WP4 survey (Table 1). Their total production represented almost 80 % of Spain’s on-growing production (28,183 tonnes) and 43 % of its hatchery facilities (54.5 million fry); therefore, it was considered that the sample surveyed was representative of the Spanish sector.

Hatchery and pre-growing sites were located in land-based facilities. Almost all the on-growing sites were sea cages located off-shore, frequently within a distance of 10 km from other sites.

Table 1
Characteristics of the Spanish production units during the period 2016–2017 surveyed in 2018.

Characteristics	Hatchery	Pre-growing	On-growing
Land-based	2	4	1
Open sea water	0	0	20
Company owned farm	2	4	20
Family owned farm	0	0	1
Facilities within 10 km of this facility	0	2	17
No facilities within 10 km of this facility	2	2	4
Total	**2**	**4**	**21**

Source: MedAID's WP4 survey (2018).

Most on-growing units produced both seabass and seabream, however, seabass was the main product with an average annual production of 720 tonnes/unit. There was a wide variability in production, given the different sizes of the on-growing sites, with a minimum annual production of 90 tonnes/unit and a maximum of 4000 tonnes/unit (Table 2).

3.2. Disease occurrence

The results obtained in this study were based on surveys conducted at the fish farm level, including directly from both on-site staff (eight production units) and the three ADS groups (Canary Islands, Murcia and Valencia).

Overall, the reported data showed that bacterial disease outbreaks dominated for seabass, whereas parasitic outbreaks were the most frequently reported infections in seabream (Table 3).

There were large similarities between the disease/pathogen profiles found in Spain and those found across the Mediterranean (Vendramin et al., 2016; Muniesa et al., 2020), which may have been due to the high level of interaction in the sector at the basin-regional scale (Cidad et al., 2018), highlighting the need to study the disease transmission routes between different countries.

The main difference, regarding fish host outbreaks profiles, between the WP1 MedAID surveys and the ADS data, was the presence of tenacibaculosis in seabass and seabream and VNN in seabream, which were reported in the MedAID survey but not by the ADS. Regarding the number of outbreaks reported in both MedAID and ADS, photobacteriosis in seabass was largely reported in the MedAID survey (25) whereas only 7 farms reported it in the ADS survey. Additionally, seabream parasitosis outnumbered in the ADS data (51) to MedAID (2). This difference could be due to dissimilarities between surveyed farms and different data collection methodologies. The MedAID-surveyed (WP1) farms were not geographically distributed (as the selection criteria was based more on farm/company typology, and in the case of Valencia (the main producing region) not all farms belonged to the ADS.

The disease outbreaks reported for seabream and seabass were different (Tables 3 and 4), both in aetiology (pathogens) and number of outbreaks, therefore, it was necessary to assess the disease outbreaks for each fish species separately. Moreover, the disease profiles can vary depending on the production system and the farming phase, therefore, these two variables should be taken into account when studying the prevalence of diseases (Muniesa et al., 2020). Winter syndrome, a disease which develops during periods of cold temperature in seabream (Tort et al., 1998), has also been reported both by MedAID and ADS.

Bacterial diseases were mostly reported from hatcheries, with photobacteriosis being the most common for seabass, although the reports from MedAID outnumbered those from the ADS (25 vs 7). However, photobacteriosis was reported from all stages throughout the production cycle of seabass, while vibriosis seemed to be more problematic for hatchery and pre-growing sites, with the most frequently reported bacterial infection in seabass being in the pre-growing phase. Current commercial vaccines for seabass are produced to combat their main bacterial pathological burdens, photobacteriosis and vibriosis, and they are widely used by producers. However, their efficacy in the field is difficult to assess, since many factors are involved in the final survival

Table 3
Comparison of disease outbreaks in seabream and seabass in Spain gathered by ADS (Valencia, Canary Islands and Murcia) and the MedAID WP1 surveys in 2016 and 2017.

Disease	Seabass		Seabream	
	MedAID	ADS	MedAID	ADS
Vibriosis	14	10		
Tenacibaculosis	4		3	
Photobacteriosis	25	7		
Winter syndrome			2	7
VNN	3	3	5	
Parasitosis			2	51
Other*		8	2	5

* This include other bacterial and viral diseases as well non-pathological causes: not reported in any other way.

Table 4
Mapping of disease outbreaks in seabream and seabass farms in Spain by production systems (2016–2017).

Production system	Disease	Seabass	Seabream
Hatchery	Tenacibaculosis	4	3
	Photobacteriosis	12	
	Vibriosis	2	
	VNN		5
Pre-growing	Photobacteriosis	1	
	Vibriosis	12	
On-growing	Photobacteriosis	12	
	VNN	3	
	Red rash		2
	Sparicotylosis		2
	Winter syndrome		2

Source: MedAID's WP1 surveys 2018.

Table 2
Spanish seabass and seabream on-growing unit characteristics during the period 2016–2017: production (tonnes), length of production cycle (months) and maximum stocking density (kg/m^3) by species.

	Production (tonnes)		Length production cycle (months)		Maximum stocking density (kg/m^3)	
	Seabass	Seabream	Seabass	Seabream	Seabass	Seabream
n	21	19	21	19	21	19
Mean	1146.05	201.89	23.79	16.39	18.90	20.79
SD	1081.80	120.18	16.59	3.09	5.21	4.49
Median	720.00	186.00	16.50	16.50	16.00	20.00
Interquartile range	1798.25	126.00	6.25	2.50	9.00	5.00
Minimum	90.00	70.00	15.00	14.00	5.00	5.00
Maximum	4000.00	522.50	70.00	28.00	25.00	25.00
p (MW)	0.001		0.282		0.111	

Source: MedAID's WP4 survey (2018).

outcome. It would be, therefore, very relevant to perform a vaccine performing study in the Mediterranean basin, in order to assess the real impact of vaccination on the sector's health performance. Therefore, we have not been able to segregate the data regarding vaccination's applied. Interestingly, the only reported bacterial infection affecting seabream was tenacibaculosis, which occurred in the hatchery phase (Table 4). VNN was the only viral disease reported, occurring mainly at the on-growing stage for seabass and in the hatchery phase for seabream (Table 4).

According to the data set, VNN was less frequent than most bacterial diseases. However, its economic importance, together with the scarcity of available prevention tools, such as few vaccines and reliable non-lethal testing for broodstock, suggested that this pathogen should be a priority agent in surveillance programs. The risk of VNN is related to probability (i.e. the incidence in this case may be low) and the damage/impact that the disease can cause (in this case very high). They were no commercial VNN vaccines in use at the time when the study's surveys were being performed, therefore, the results presented are not biased by vaccination applied on the farms. However, currently, there are two commercial vaccines now available, and a very promising experimental VNN vaccine is under study (Barsøe et al., 2021), which in due course should allow their benchmarking at the field level.

Parasitic infestations, such as sparicotylosis, were only common in the on-growing phase of seabream (Table 4). Unfortunately, the current restrictions on authorized disinfectants and the lack of vaccines are compromising the seabream sector.

To our knowledge, most Spanish seabass and seabream farms perform correct etiological diagnosis of diseases, which is a critical aspect in health management (Bondad-Reantaso et al., 2021). Spain counts on an important number of specialized public and private laboratories for diagnosis of all groups of pathogens -parasites, bacteria, and viruses (Zrncic et al., 2021). Most farms are members of their regional ADS, which provide surveillance and diagnostic support, and they also receive health technical support from aquafeed companies. Moreover, medium-large companies have veterinarians and health experts on their farms, and we want to highlight the importance of applying the biosecurity plan to prevent and limit the appearance and impact of diseases, such as photobacteriosis in seabass farms.

3.3. Mortality

In sustainable aquaculture production, monitoring and minimizing mortality must be a top priority. Systematic measuring of mortality over time can be used to evaluate the impact of changes in management and production strategies (Bang Jensen et al., 2020) or to assess reporting thresholds as a tool for detection of potential disease concerns (Salama et al., 2016). The mortality pattern of farmed fish populations is an important performance indicator of their health status and welfare. The survival rate data for seabass and seabream (median 94.58 % and 95.40 %, respectively; Table 5) in Spain for 2018 were higher than the average obtained for the Mediterranean with the MedAID surveys for the years 2015–2017, with a median survival percentage for seabass and seabream of 85 % and 80 %, respectively (Muniesa et al., 2020). Although mortality in seabream was higher than mortality in seabass, no significant differences were found when analysing the parameters studied using the Student's t-test (Table 5).

However, this was a single year reference and further studies are needed, since it is known that high variations can exist between years. In 2019 and 2020, there were important bacterial disease outbreaks (pers. comm. Murcia ADS) and severe storms in the Spanish Mediterranean that caused very important escape rates and mortalities (MisPeces, 2020). Therefore, mortality, due to both diseases and other causes, can be highly variable from one year to another.

Due to the nature of the data gathered in this study, there is a need to conduct further studies to determine better what is understood by normal (baseline) mortality/survival rates, which should also consider different production systems and/or growth phases. It is also important that companies gain better knowledge concerning the causes and links of mortality with specific pathogens, as well as the environmental and management factors that may be related to disease outbreaks.

Seabream and seabass farms should record their mortalities in their production logs, which are available for the official administration to inspect. However, the way that mortality should be recorded in production logs is not standardized and it varies according to the region considered. Moreover, the ADS groups do not keep detailed records of mortalities, therefore, it was not possible to calculate the actual survival rates from their records, only the mortality during different periods, aggregated for all batches and for both species on the farms.

Variability between farms was observed related to the systematic way of record keeping for mortalities, which highlighted the need for standardization of such important data. Firstly, it is necessary to define how to register both long-term and short-term mortality, which should correlate with abnormal mortality and mortality event rates. Secondly, at a farm-level scale, records should distinguish between whole-farm data versus batch- and time-scale data that need to be included in the record keeping in order to associate seasonality with mortality events.

3.4. Health management implications

The data collection concerning outbreaks and prevalence of diseases and mortality was a difficult challenging task. Some seabass and seabream companies were reluctant to participate in the MedAID study, whereas other fish farms did not keep and/or report sufficient quality data. Thus, some farms recorded total losses, without differentiating mortalities due to pathogens or other causes, which compromised the data treatment, emphasizing the importance of harmonizing data collections and treatment in order to be able to obtain a clearer picture of the different farm scenarios. In this current study, data obtained from ad hoc surveys (MedAID) were compared with data collected by the ADS directly from their associates. The similarities found from both sources

Table 5
Survival and mortality rates in seabream and seabass for on-growing sites in Spain during 2018.

Parameter	%Survival		%Mortality Disease		%Mortality Other causes*	
	Seabass	Seabream	Seabass	Seabream	Seabass	Seabream
n	13	8	13	8	13	8
Mean	89.23	94.04	4.28	2.57	6.49	3.39
Standard deviation	10.30	3.61	3.52	1.72	8.17	2.47
Median	94.58	95.40	3.20	2.78	2.21	2.68
Interquartile range	18.41	3.80	6.83	3.28	12.71	2.34
Minimum	72.08	85.20	0.44	0.55	1.30	1.01
Maximum	97.90	97.70	9.85	5.70	21.69	10.40
p (t-test)	0.237		0.229		0.239	

* This include non-pathological causes (escapes, environmental, nutrition, management, etc.
Source: MedAID's WP4 survey.

suggested that relevant health information (i.e. main diseases affecting the sector, baseline mortality rates) could be obtained through epidemiological surveys, which could be used as a proxy when gathering data from all farms is not feasible. It is, however, interesting to note that, although the qualitative information gathered in MedAID and from the ADS was similar for the most relevant pathogens (Table 3), neither VNN in seabream nor tenicibaculosis in both species were reported by the ADS. Qualitatively, MedAID reported more outbreaks than the ADS, and it would be important to know the causes of such differences, such as whether there were due to the data gathering approach or to confidentiality concerns from the farmers.

The great difficulties found in this study for collecting data highlighted the existing reticent position within the Spanish marine fish sector for sharing this type of information. Farmers were afraid that such information might have negative commercial implications for them, or could be used to impose restrictive sanitary legislation, despite the fact that there are no listed notifiable diseases for their sector. Therefore, it is crucial to convince fish farmers of the importance of sharing data, in order to carry out epidemiological studies for a better understanding of the causes of disease occurrence. It is obvious that without systematic and reliable information on disease prevalence and mortalities, the establishment of effective health management plans would be compromised.

Systematic collecting of epidemiologically valuable data (e.g. pathogen prevalence, co-infection rates, morbidity and mortality rates vs date, temperature time-series, fish size, sites affected, fish movements, etc.) would be of unquestionable value both for companies and the ADS. Such structured analysis, shared with the stakeholders involved in health management along the sector's value chain, would allow an integrated management approach allowing the anticipation of problems and leading to cooperation in fighting diseases, which is not achievable when companies operate unilaterally. Although complete detailed data collection and analysis may be difficult to achieve, and the benefits might not seem obvious at first, the experience from countries where integrated and transparent aquatic health management are already in place, shows that efficient health management is only possible with good reliable transparent data (Mowi, 2018).

The existence of Health Protection Groups (ADS by their Spanish name) 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, 2011), created by connected producers in order to establish coordinated surveillance systems that would bind together aquaculture companies according to the European regulations. However, it should be pointed out that, whereas in Murcia and the Canary Islands all companies are members of their regional ADS, this is not the case in the Valencia region, where 25 % of them are not members, which makes the implementation of common surveillance programs difficult.

The Spanish ADS implement surveillance programmes and keep records of mortality events and their aetiology. They report to both their associates and their corresponding regional administrations. However, no annual reports are published concerning the aquaculture health situation in these regions or at a wider national level. As the collection of disease information is not standardized, it may require important administrative investments (data collection systems and human resources) and would face some reticence from farmers that consider this information is still "confidential". Therefore, we believe that priority should be given to the standardization of the collection of disease occurrence and mortality information, while initiating the implementation of epidemiological studies based on surveys covering the different producing areas rather than on complete farm census analysis. As most seabream and seabass farms in Spain are concentrated in specific areas, such studies should be representative and could help to implement data collection systems properly. Information concerning disease outbreaks can also be regularly collected from other relevant sources, such as public and private diagnostic laboratories, vaccine producers and health experts. Similar approaches have been successfully put in place in other countries, for example, in Norway since 2003 (Hjeltnes et al., 2018).

The Spanish Aquaculture Producers Association (APROMAR) publishes a well-known and recognized yearly report, concerning the situation of the Spanish aquaculture sector. Unfortunately, the APROMAR report does not include a health report, thereby missing an opportunity to improve transparency and communication at the national level. In contrast, in salmon aquaculture, "Mowi" (formerly Marine Harvest), the world's largest salmon aquaculture company, as proof of transparency and open communication, released its first annual report in 2018 (Mowi, 2018) that covered fish health and welfare issues (e.g. mortality rates and main causes, escapees, sea lice management, medication use).

Large multinational companies use management software to maintain control over areas such as production, feeding, health and management operations. In these systems, daily mortality is registered and the most probable cause of death is assigned (Soares et al., 2011). The main Spanish producing companies belong to multinational companies and they keep good records of their production and health operations; however, most of this information is only used internally and is never shared with the sector, which hinders a better understanding of baseline mortality, disease prevalence and their impact on a larger scale. Therefore, the need to improve and standardize the collection of data on pathologies in Spanish aquaculture, the absence of epidemiological field studies, together with ignorance of the risk factors that affect the prevalence of diseases has led the authors to develop the project ARISA (Network Analysis of Health Information in Aquaculture) in order to improve the methodology for obtaining information from the Spanish aquaculture sector.

ARISA has the main objective of improving the methodology for obtaining information in Spanish continental and marine aquaculture in order to facilitate the analysis of the health situation of the sector, the standardization of health indicators (i.e. prevalence, mortality, well-being) and the identification of related parameters. This will support quality epidemiological studies in order to demonstrate the possible correlation of these health and production parameters with environmental factors. Furthermore, they will enable the study of the effect that climate change may have on the ecology of aquatic animal diseases.

4. Conclusions

There is limited knowledge concerning the prevalence and impact of diseases for seabream and seabass in Spain. This situation hampers the development of health management plans, which should be implemented taking into account the species, the production system and the growth phase, since disease profiles have been shown to vary accordingly, both in aetiology (pathogens) and occurrence. According to the data set in this study, VNN, due to its economic importance, together with the scarcity of prevention tools, such as few vaccines and reliable non-lethal testing for broodstock, should be a priority agent in surveillance programs, although it is less frequent than other diseases.

Standardized diagnostics and KPI are essential for communicating properly the incidences of disease occurrence; therefore, compiling a list of relevant pathogens is critical in order to identify the specific diagnostics needed and the associated indicators involved. The fish mortality patterns (long-term and short-term mortality rates) of farmed fish populations are important indicators of their health and welfare status. Consequently, it is highly recommended that companies and ADS collect information related to disease outbreaks and mortality, in a standardized way, in order to be able to compare them between different farms and, in addition, study their evolution over time in each production unit and at the sector level in order to draw adequate conclusions and recommendations for the improvement of health management plans.

CRediT authorship contribution statement

Muniesa, Basurco, Furones and **Rodgers:** Conceptualization, Methodology, Software, 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.

Acknowledgements

This study received funding from the European Commission Horizon 2020 (H2020) Framework Programme through the MedAID project (Mediterranean Aquaculture Integrated Development) with grant agreement no. 727315. Funds were also received through the Pleamar Program (Fundación Biodiversidad) co-financed by the European Maritime and Fisheries Fund 2014–2020 through the ARISA project (Collaborative Analysis of Health Information in Aquaculture). The authors acknowledge the aquaculture companies that have participated in this study by providing data and that took part in the consultation exercise. Special recognition is paid to the veterinary services of the ADS from Valencia and Murcia.

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