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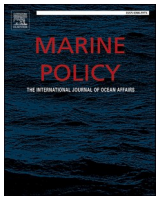

A conceptual framework for risk management in aquaculture

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ABSTRACT

Aquaculture is considered a high-risk industry in which the heterogeneity of the productions hinders the development and application of risk management. However, risk sources have still received little attention in aquaculture research. The present study aims to provide a framework of the main risk sources perceived by aquaculture producers. Firstly, we conceptualize the different dimensions and typologies of risks. Then, we integrate the main risk sources into a comprehensive framework based on a review of the literature providing empirical evidence on aquaculture producers' risk perceptions in different countries and aquaculture productions. Finally, the opinion of a panel of independent experts provides the vision of other relevant stakeholders in the value chain. This process allowed us to present a picture of risks in the aquaculture industry, consisting of eight risk categories, 19 risk types and 40 risk sources. The most relevant sources of risks for producers in the internal dimension are those related to operations (fingerlings, feeding, seeding and harvesting). In the external dimension, market risks (price variability, inputs price, and changes in demand) and production risks (climatic shocks and diseases) stand out. The perceptions of the stakeholders consulted highlight that producers tend to underestimate important risks, such as regulatory or financial ones. This picture provides a useful risk framework for policy makers, producers, scientists and other stakeholders to address such an essential first step in risk management and governance, the identification of risk sources.

1. Introduction

Aquaculture is an industry that has experimented a rapid growth during the last three decades. It is currently the fastest growing food production industry, driven by an increase in the seafood demand caused by population growth. The stagnation in wild captures has increased aquaculture's contribution to total seafood supply and nowadays, it provides 52% of seafood for human consumption [15]. Despite the rapid growth in production and demand, aquaculture firms inherently face more variability in their results than other food production industries, as repeatedly concluded by several researchers from Geurin and Geurin [48] to Flaten et al. [45].

In terms of systematic risk management, aquaculture lags behind comparable industries [94,51] and only a fraction of the potential losses are insured [22,84]. On the one hand, the production process presents a high complexity and uncertainty due to the broad range of technical, biological, environmental, and economic factors that influence its results [62,66,68]. On the other hand, the aquaculture industry is heterogeneous [61,76] as it comprises companies that vary greatly in size, production systems, species, environmental conditions and locations. This characteristic makes especially difficult the generalization of risk models. Thus, aquaculture companies have had to deal with the main sources of risk based on individual analyses, combining, when possible, the use of different risk management strategies [79]. However, the vast majority of aquaculture producers are small and medium-sized companies, which in general do not have the resources or the knowledge to develop their own risk management systems. At the same time, research contribution to risk management in aquaculture is limited [4] and also unbalanced. The majority of the contributions are concentrated around certain specific risks while others remain practically unstudied [23].

In this context, several studies have already pointed out the necessity to address this problem. Zajicek et al. [98] highlighted the need of presenting an "accurate picture of risks" and improving risk management tools in aquaculture. Holmen et al. [52] stated the potential benefits of developing a standardized approach to risk analysis for the

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Norwegian aquaculture industry. To do so, studies in risk management highlight the importance of addressing the fundamentals of risk and its conceptualization, before focusing again on the operative "how-to" [89,17].

In the same vein, the most important standards on risk management, such a COSO [36] or ISO 31000 [53], indicate that the appropriate risk management should always start by the identification of the main risk sources, on which then is based the development of the assessment methodology. Furthermore, they recommend starting with the theoretical description of the factors that could impact the firm results, and then, determining the industry-specific risk sources comprising such factors in each case, based on stakeholders' consultations.

The main objective of this study is to provide an integrated and comprehensive risk framework for aquaculture firms and stakeholders. With this aim, we start by a theoretical conceptualization of the general risk categories that can impact on firm results, founded on the proposals of the main agencies and institutions specialized in risk management. The second step is the analysis of the industry-specific sources of risk for the different types of risk emerging in aquaculture. This task is based on a review of the literature providing empirical evidence on aquaculture producers' risk perceptions. Once the types of risk and their sources have been identified, an analysis is carried out in order to compare the results of the different studies and determine the most frequent risks and those that are most relevant for the producers surveyed in the different works reviewed. Finally, the analysis and discussion are completed with the opinion of a panel of independent experts who represent stakeholders other than the producers, and who provide their views on the identified risks and the importance given to them.

This article is structured as follows: Firstly, this section has introduced the reasons justifying the development of a comprehensive risk framework. Accordingly, Section 2 details the methods and materials employed. Subsequently, the conceptual risk framework is developed and presented in Section 3. Lastly, the main findings of the work carried out are discussed in Section 4, with special emphasis on the policy implication, and its main conclusions and limitations are summarised in Section 5.

2. Materials and methods

This work is based on the idea that technical knowledge concerning risk has to be combined with specific industry information to address risk comprehensively and coherently for all the company's risks [29]. In this regard, this section describes the materials and methods used to conceptualize the types of risks faced by aquaculture farms and to review and discuss the main sources of risk behind them.

2.1. Theoretical conceptualization of risk factors

It is particularly difficult to establish broadly accepted and consistent definitions of key terms related to fundamental risk concepts [91]. This can be explained by the great range of different types of risks and the importance of some internal aspects, while not forgetting the existing ambiguities and gaps in their assessment [29,42]. For this reason, it is necessary to ensure that the fundamentals of risk are addressed in their broadest sense and following common rules and models, in order to allow the future development of efficient risk assessment and management techniques, as had already been proved in other sectors [89].

In this case, the identification of risk categories has been carried out based on several sources, among which the following stand out. On the one hand, we have followed the main standards on risk management provided by ISO [53], COSO [36], CIMA [14] and the Basel Committee [20]. On the other hand, we have also used the reports of the main rating agencies and consulting firms, as they are the leading experts in risk assessment and risk management through advanced models [21,16,83,88].

Table 1
Composition of the panel of experts.

Expert	Area of Expertise / Occupation	Current Institution
1	Marine biology Policy-making	Food and Agriculture Organization (FAO)
2	Applied Economics Policy-making	University Institute in Maritime Studies - University of A Coruña
3	Marine studies Scientific Research	Spanish Institute of Oceanography (IEO)
4	Veterinary Sciences Scientific research	International Center for Advanced Mediterranean Agronomic Studies (CIHEAM)
5	Engineering Cybernetics Scientific research	Norwegian University of Science and Technology
6	Technology and Data Science Scientific research	Getulio Vargas Foundation - Sao Paulo School of Management (FGV-EAESP)
7	Corporate Finance Scientific research	University of Cantabria (UC)
8	Business Management Scientific research	University of Cantabria (UC)
9	Business support Asoc. in distribution and wholesale	Fish Wholesalers Association of Asturias (AMPPA)
10	Business support center for technical processes	Aquaculture Technological Centre (CTAQUA)

2.2. Aquaculture producers' risk perceptions

The heterogeneity of the aquaculture industry makes it difficult to extrapolate farmers perceptions from one country-specific survey to the whole industry. We decided to conduct a review of the publications on aquaculture farmers' risk perceptions, with particular attention to the similarities in terms of risk sources and their importance. To do that, firstly, the main search engines for scientific publications were used to find all those articles containing the keywords "Risk perception" or "Perceived risk", together with "Aquaculture" or "Fish Farming". Secondly, an exhaustive search was carried out among the articles found to select those that contained a survey conducted directly with aquaculture producers.

In this regard, all the selected publications include a survey regarding the importance of each perceived risk and, therefore, the results are basically related to the subjective perception of aquaculture producers. However, they help us to obtain more information on the risk sources of particular concern and the main risk management needs in different countries, production systems and species.

The use of different scales to measure importance does not make possible a direct comparison of the results of the different studies. For these reasons, we have developed a standardized Importance Rating (IR) by following two steps. Firstly, we have converted the importance values (xi) assigned in each publication, which follow Likert scales of different lengths (e.g., 1–5 and 1–7), to the percent of maximum possible score (POMP). This allows for direct comparison of different studies, providing useful additional information, as explained by Cohen et al. [34].

$$POMP = \frac{x_i - \min\_score}{\max\_score - \min\_score} * 100 \quad (1)$$

Secondly, we have applied the theory of fuzzy sets [97] to assign an aggregated final measurement of importance to each risk source from the different producers' perceptions. In particular, we applied one of the most popular types of fuzzy numbers, the triangular fuzzy number, which is defined by three real numbers, the mean, the minimum and the maximum scores. Thus, they are especially useful in this case as they allow us to integrate in the final aggregated measurement of importance other aspects beyond the average of the importance assessments, such as the existence of a high variability in the overall producers´ perceptions or a specific survey that presents substantially different measures of importance for the countries or species under study. This process was

Table 2
Risk categories.

Origin	Category	Description	Source
External	Market risk	Possibility of a loss due to unanticipated market or price movements, based on the fluctuation of supply and demand, including uncertainty surrounding equities, interest rates, commodities and foreign currencies.	[54]
	Reputational risk	Already highlighted as a major risk by the CIMA[14], can be defined as the economic impact, actual or potential, arising from the negative perception on the part of different stakeholders of the company's or the sector activity.	[20, 83].
	Regulatory risk	Uncertainty and the potential costs of not complying with regulations or the impact of changes in laws concerning some environmental or social aspects or even from potential changes in governments [90], which has been systematically documented in regulated industries and explicitly recognized in the law.	[16, 44].
	Technological risk	Understood as the effect generated in the company by changes or disruptions in the technology used in the sector. Especially the impact due to artificial intelligence and big data in production and decision-making processes and digital commerce.	[36]
	Production risk	Also known as environmental risk, stem from the activity being exposed to unforeseen events related to climate (storms, floods, droughts, etc.) or technology (machine breakdowns, inaccuracies, etc.), as well as from health or epidemic threats.	[71]
Internal	Financial risk	All those risk sources derived from the capital structure of a company and the financial flows that determine its solvency and liquidity. They are based on the likelihood that one party of the different financial instruments' contract will fail to meet its contractual obligations on the grounds of insolvency or inability to pay.	[83,21]
	Strategic risk	Losses or damages derived from strategic decisions, or their poor implementation, which affect the medium and long-term interests of the company's stakeholders. Strategic decisions concern both the internal context (including scale, degree of integration and diversification) and the external context (location, products and markets). Company's interaction with the context is instrumented through strategy and is materialized in the short term in operational actions	([36, 41]).
	Operational risk	Losses due to inadequate or failed internal processes, people and systems. In some studies, the uncertainty about external events is also included in this category. In this case, external events have been analyzed separately - either as a production or regulatory risk - due to its very importance and exogenous origin. Despite being quite recent, operational risk has proven to be a key factor in the survival of companies and in avoiding downgrading by rating agencies[77].	[19]

Source:Source: Authors elaboration based on literature.

also applied to calculate the average Importance Rating of the sources belonging to the same category, considering not only the average IR, but also the minimum and maximum ones.

Table 3
Publications on fish farmers' perceptions of risk.

ID	Authors (Year)	Tittle	Location	Species	Sample Size
A	[80]	Perceived Risk and Risk Management Strategies in Pond Aquaculture	Bangladesh	Pangas, Tilapia	645
B	Alam and Guttormsen [3]	Risk in aquaculture: farmers' perceptions and management strategies in Bangladesh	Bangladesh	Multiple	350
C	Lebel, Lebel and Lebel[60]	Impacts, Perceptions and Management of Climate-Related Risks to Cage Aquaculture in the Reservoirs of Northern Thailand	Thailand	Tilapia, Catfish	97
D	Le Bihan, Pardo and Guillotreau (2013)	Risk Perception and Risk Management Strategies of Oyster Farmers	France	Oyster	97
E	Ahsan[1]	Farmers' Motivations, Risk Perceptions and Risk Management Strategies in a Developing Economy: Bangladesh Experience.	Bangladesh	Shrimp	300
F	Ahsan and Roth[2]	Farmers' Perceived Risks and Risk Management Strategies in an Emerging Mussel Aquaculture Industry in Denmark	Denmark	Mussel	14
G	Le and Cheong[58]	Perceptions of Risk and Risk Management in Vietnamese Catfish Farming: An Empirical Study.	Vietnam	Catfish	270
H	Bergfjord[23]	Risk Perception and Risk Management in Norwegian Aquaculture	Norway	Salmon	38

2.3. Expert opinions on risk

As shown in different studies, farmers present very different attitudes towards risk for a wide variety of reasons [74]. Producers' perceptions are highly determined by the perceiver's previous knowledge [70] and some socioeconomic factors [92,87]. Furthermore, some non-expert respondents tend to mix the probability of a specific type of risk event and the subsequent awareness of its consequences [86].

In order to complement the information obtained from the producers' perceptions, we conducted an independent discussion with a panel of ten experts, both from industry and academia (scientist, technologists, wholesalers, and policymakers, excluding producers at this step) (Table 1). The expert opinion gathering process was performed using one-on-one in-depth interviews. In particular, we carried out various rounds of conversations during the second half of 2021 where the experts were asked to analyse two main aspects: (I) the completeness of the sources of risk identified and its adequacy to the reality of the

Table 4
a and b Risk framework – External and internal context.

Risk framework				Importance[a]				Rating by publication[b]							
Origin	Category	Types	Source	Times	IR	Rank	EP	A	B	C	D	E	F	G	H
External Context	**Market/Price Risk** (IR 55%)	**Selling Prices**	Price Variability	8	72,88	2		69	73	74	56	68	78	87	83
		Market Related	Changes in demand/ preferences	7	59,26	10		54	37	39	72	64	83		65
			Access to different markets	4	62,53	9			37			76		76	73
		Interest Rates	Interest rate	6	45,08	28		54		34		49	23	64	51
			Exchange rates	2	34,00	37							11		58
		Input Price / supply	Fingerlings	6	53,94	16		64	44		*53*	78		*74*	23
			Feed And Chemicals	7	62,82	7		61	56	80	*53*	60		*74*	50
			Labor cost	6	47,77	23			41		*53*	43	36	*74*	29
	Production Risk (IR 68%)	**Climatic shocks**	Climate producing losses	6	63,56	6			72	88	72		63	64	33
		Bio-sanitary	Death rate due to disease	8	73,77	1		69	77	80	91	88	53	74	66
	Technological Risk (IR 29%)	**Technological**	Technical Failure	3	32,84	38							36	32	31
			Technological disruption	1	25,00	40	+								25
	Regulatory Risk (IR 47%)	**Legal Requirements**	Trade policies	4	56,54	11					*69*		38	62	65
			Environmental/social Regulation	5	62,73	8				56	*69*		82	53	48
			Product safety and Health	5	55,98	12	+			70	*69*				36
			Certification requirements	3	50,62	31							48	46	44
			License system	3	39,07	21	+					20	42		57
		Governmental Aid	Subsidies	4	35,45	35	+	52				33	34		21
			Taxes	2	34,33	36				74			27		42
Risk framework	**Importance**[c]	Rating by publication[d]													
Origin	**Category**	**Type**	**Source**	**Times**	**IR**	**Rank**	**EP**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Internal Context	**Financial Risk** (IR 48%)	**Credit**	Guarantees from buyers	3	42,64	29						59	39		29
		Liquidity	Financing availability	7	46,42	25		59	34	30		60	29	66	44
		Structural	Capital Structure	5	53,99	15		63	67				42	69	35
	Strategic Risk (IR 46%)	**Location**	Site selection	4	46,19	26			47		28			47	64
		Infrastructures	Facilities	4	47,42	24		59	48					50	34
			Equipment	5	39,73	30		60	43			31	40		22
		Other													
(integration, scale…)	Negotiating power	4	52,03	20		47	30			73	61				
	Operational risk (IR 52%)	**Production system**	Seeding and harvesting	8	53,46	17		58	33	56	*82*	*53*	*41*	55	*34*
			Fish welfare (Overstocking…)	7	54,12	14		54	40		*82*	*53*	*41*	62	*34*
			Feeding	7	55,68	13	+	55	50		*82*	*53*	*41*	68	*34*
			Use of chemicals and medicines	8	52,58	18	+	55	42	41	*82*	*53*	*41*	52	*34*
			Logistics and transportation	3	36,47	34						20	54		34
		Control													
Processes	Fingerlings (Quality, Health, Origin…)	4	71,13	3		65	72	76				73			
			Feed Stuff Quality	4	68,71	4		64	73	73				66	
			Water Quality	2	66,75	5			63					71	
			Security	4	45,46	27				70		35	48		25
		Human Resources	Lack of qualified labor force	2	36,67	33	+						40		33
			Work-related accidents	3	52,09	19					84		48		23
			Moral risk	2	29,50	39						45			15
	Reputational Risk (IR 44%)	**Reputational**	Social, Environmental	4	38,83	32	+					33	36	49	36
			Quality and Health product	3	50,01	22						27	78		42

[a] The numbers in italics indicate that various consecutive sources come from a unique perception in the original publication.

[b] In order to assess the importance of each source of risk, we provide three variables: the number of times they are cited out of the 8 papers reviewed ("Times"), their importance rating calculated as explained in the Materials and Methods section ("IR"), and their position in the ranking, according to their "IR", within the 40 risk sources ("Rank"). Furthermore, we have marked with a "+ " the risk sources that the expert panel has concluded that should have greater importance than they hold.
[c] In order to assess the importance of each source of risk, we provide three variables: the number of times they are cited out of the 8 papers reviewed ("Times"), their importance rating calculated as explained in the Materials and Methods section ("IR"), and their position in the ranking, according to their "IR", within the 40 risk sources ("Rank"). Furthermore, we have marked with a "+ " the risk sources that the expert panel has concluded that should have greater importance than they hold.
[d] The numbers in italics indicate that various consecutive sources come from a unique perception in the original publication.
Source:Source: Authors elaboration.

industry and (II) the importance rating, with particular emphasis on any possible undervaluation in producers' perceptions.

3. Results

3.1. Conceptualization of risk factors for aquaculture production

First of all, the present work has focused on identifying and structuring the main risk types that later serve as a basis for the identification of the specific sources of risk in aquaculture. In this regard, we start by the most general criterion to typify risk, which differentiates between external and internal context risks. Generally speaking, external context risks can be defined as those factors over which the company has no control, but nevertheless they do affect the company results, situation or trust [36]. By contrast, internal risks originate in the decisions and processes of the company's internal agents [69].

Within each of these contexts, it may be distinguished eight risk categories, five external and three internal (Table 2), that encompass all those risks that are part of or have an influence on the company's economic-financial situation. In this way, we have tried to adhere to the definitions and classifications of risks most commonly used in the literature and practice.

Once the risk categories have been defined, the identification of those risks that compose them, as well as the sources that potentially originate these risks, can no longer be carried out in a theoretical and generalized manner for all economic activities, but requires an individualized analysis to identify those that have an impact on the industry under analysis, as presented in the following section.

3.2. Perceived risk in aquaculture production

To date, only a few empirical studies concerning the identification of the main risk sources based on the perception of aquaculture producers, have been developed [80]. The review covers eight articles from the past 15 years, that contain the perceptions of more than 1500 producers from a wide range of species and countries (Table 3). The results analysed cover some of the most relevant producing countries (such Norway or Thailand) and species (salmon, catfish, tilapia, pangasius, shrimp, oyster or mussel).

These papers explore the farmers' risk perceptions through surveys and interviews with producers who belong to the same country of production and, most of the time, produce the same species. Through these questionnaires they obtain a sample of the most important sources of risk and their relative importance, always based on the perceptions of the producers. In addition, the authors discuss the situation of the country or the species in terms of risk and the risk management strategies that are currently used to deal with different groups of risk sources.

The review led us to find some differences between countries, species, and production systems. The results show that European countries, such as Norway (Bergfjord, [23]) and France (Le Bihan et al. [59]), show a greater than average concern for changes in consumer demand or preferences. Furthermore, the licensing system is also highlighted as a key source of risk, unlike in the case of developing countries. Alternatively, South Asian producers are more affected by financial aspects. An example of this is the high importance of both the guarantees from buyers in the publication of Ahsan [1] and capital structure in Le and Cheong [58], Alam and Guttormsen [3], or Rahman et al. [80]. Another example is the concern regarding work-related accidents observed in the shellfish production industry, which is a more labour intensive segment of the industry Le Bihan et al. [59].

Although the review of the works evidences the existence of differences in producers risk perceptions, the differences in the methodologies used in the eight articles reviewed make no possible a direct comparison of the results. On the one hand, the units of measurement of the importance of the different sources of risk are different. On the other hand, several of the works group the types of risks using "principal component analysis and multivariate regression", which implies that they are not classified by their typology from a conceptual point of view, but rather by similarities in terms of producers´perceptions.

In order to integrate the findings of all these studies in a common framework, we started by identifying all the producers' statements pointing to a specific risk source. Then, we included in this risk framework those risk sources that are referred to in at least two publications. Lastly, we standardized and aggregated their measures of importance in a unique importance rating, as explained in the Materials and Methods section.

This resulted in the identification of 40 risk sources (see Tables 4a and 4b). Between them, 19 belong to the external context while the other 21 are part of the internal context. Results indicates that in average, production, market, and operational risks comprise the most important risk sources, while the technological risk appears to be the least relevant for producers. These results are in line with traditionally conducted research, as production and operational risks have been studied jointly in several papers, such as Llorente and Luna [63], World Bank [11] or Khan et al. [56], while market-related risks have been the focus of much of the research effort in recent years (Tveteras and [7,38,49,32]). Within the most important risk categories, disease, price volatility, and quality control have been ranked as the most worrying risk sources for producers. By contrast, producers usually perceive the uncertainty surrounding technology and human resources as not being very significant.

3.3. Stakeholders perceptions

The analysis of the results of the previous literature is complemented and completed with the opinion of a panel of independent experts representing a variety of stakeholders in the aquaculture value chain.

There was a total consensus among the experts when pointing out that the risk framework resulting from the literature review collects the most frequent risk types and risk sources in aquaculture production. They also add that the specific analysis of each aquaculture activity will later determine if it is necessary to dispense any type of risk and sources of risk, or on the contrary, some not considered in this framework must be added. But again, they point to this framework as a useful starting point from which to identify the types of risk present in an aquaculture activity, as well as their sources.

Furthermore, there was a general concern regarding several aspects. It should be clarified that the classification by the internal or external context of each risk is not absolute, and in some cases could be misleading. Decision-makers should consider that, while some risk sources originate outside the company, as already explained in the previous section, there are attitudes or decisions that promote their emergence or aggravate their negative effects. This is particularly important in the case of mortalities due to disease or the losses caused by

climatic shocks. In should be also noted that potential risk sources and their magnitude are not permanent and static, but rather continuously changing due to different factors that have a direct impact on them. For example, the emergence of new production countries is having a direct effect on price volatility, while global climate change is causing some farms to face risks they have never faced before.

The importance rating generated considerable discussion in the expert panel, during which it came to light that some sources of risks should be more highly ranked than they are. In this respect, although they found the ranking heavily dependent on the characteristics of each farm (size, location, species, etc.), experts pointed to some sources of risk that seem to be frequently underestimated, as shown in Tables 4a and 4b.

In the case of exogenous risks, experts highlighted the need to give greater importance to regulatory risks. They argue that the industry is increasingly subject to continuous change, but also the considerable differences in the regulatory framework between countries are hampering the farmers' ability to compete. In particular, many experts placed special emphasis on the importance of licensing systems since these have led to the relocation, merger or even closure of many companies in recent years. Moreover, there was wide consensus on the importance of government aid going beyond economic factors by promoting actions to, for example, reduce excessive bureaucracy, stimulate local industries or increase the availability of open data and tools. Experts have also pointed to the potential impact of the emergence of technological disruptions that could render the current form of production obsolete. This is a source of risk that was considered in only one of the publications reviewed, which suggests producers being little aware of this factor.

With regard to the endogenous factors, operational risks have engaged most of the attention of the experts as they are a source of high uncertainty. Among these, more importance should be given to the production system and, especially, to the use of feedstuff and chemicals, as they constitute not only one of the greatest financial challenges for the company in order to maximize biomass increase, but also the main sources of waste and pollution. Moreover, the aspects related to human resources should also be given due importance in the classification, since this is an industry highly influenced by the need for more qualified labour to avoid unnecessary risks for the company and the workers themselves.

An important limitation was also detected in the identification and valuation of strategic and financial risks, as factors that affect the solvency and liquidity of the company to meet payments. For example, the importance of scale, market diversification or the degree of integration. This situation could be corrected by including in the surveys economic stakeholders linked to aquaculture, such as banks and financial directors of large companies.

Lastly, consensus was achieved on the need to raise awareness of the importance of reputational risks, which, from their point of view, are seriously underestimated by producers. More and more, society is valuing social and environmental issues, so companies should not only take the regulatory consequences of their actions into account, but also the reputational ones. In addition, the expert panel also highlighted diversification strategies – regarding species, markets, processing, etc. – as an effective way of reducing risks, as it has already proven to be an effective way to reduce risk, not only in aquaculture but also in other food production industries [95].

4. Discussion and policy implications

The lack of knowledge about the risks faced by aquaculture companies represents a problem for aquaculture farm management, but also for policy makers, regulatory institutions and other stakeholder such as financial and insurance agents. Risk management in an economic activity starts by addressing the fundamentals of risk and identifying the main risk sources. Only after the main risk and their relative importance are known, it is possible to develop models, methodologies and tools for risk management. However, only a few empirical studies, based on the perception of producers, have been developed concerning the identification of the main risk sources in aquaculture.

In response to that problem, this study collects, review and compare the results of previous works identifying the main risk sources that could adversely affect aquaculture producers´ performance. As a result, we have compiled 40 risk sources from the perceptions of more than 1500 producers from eight different studies, as well as the opinions of a panel of independent experts in aquaculture not involved in production. Moreover, we estimated an importance rating of each risk source from the producers' valuations gathered in each of the publications reviewed. In this way, we were able to compare the results of the different studies and identify the most common and relevant sources of risk.

We found that production (external), market (external), and operational (internal) risks are deemed of greatest importance, respectively. Production risks are mainly related to environmental conditions and disease, two factors that in most of the cases are beyond the control of producers, but that strongly influence and impact production. There is an extensive literature that highlights the influence of climatic conditions on aquaculture production. However, in recent times, there are more and more uncertainty due to the effects of climate change and the impact of extreme climatic events [35,40,46,57,81] on production. The concern of producers is caused by the multiple impacts that climate change has on their activity, including losses of production and infrastructure arising from extreme events such as floods, diseases, parasites and harmful algal blooms, reduced availability of wild seed as well as reduced precipitation leading to increasing competition for freshwater [37]. This is particularly relevant for small scale fish farmers and communities which are especially vulnerable to climate change because of both their geographical locations and their economic status, since generally depend on the sector for their livelihoods [55]. The concern of the producers should be translated into a greater investment in the study and mitigation of the risks associated with the effects of the climate on aquaculture. However, the generation of this knowledge requires an enormous amount of resources, and a multi-sectorial and multi-stakeholder approach [55]. This is why public and regulatory institutions have a key role supporting producers to mitigate this growing source of risk through research funding, governance initiatives, aid and innovation programs, and regulatory frameworks, among other measures [18,81].

In terms of bio-sanitary risk, diseases are one of the main causes of mortality in aquaculture production. There is a strong field of research in animal health, especially for disease prevention and vaccine development. However, few authors address the implications and positive impacts of integrated health management programs to reduce uncertainty and improve economic results in aquaculture Muniesa et al. [73]. Animal health management goes beyond the measures adopted by companies, and requires the support of institutions that foster research and promote governance initiatives. Governance in this field would make it possible to standardize procedures and generate data collection and information systems that make it possible to coordinate disease management and reduce their impact. The recent study by Muniesa et al. [73] provides recommendations in this direction. These authors point the way to policy makers and regulatory institutions when considers of primary importance the need for harmonized diagnostic procedures and a standardized reporting of disease data in order to get a representative picture of the disease situation in the Mediterranean aquaculture. Improvements in this line would facilitate timely diagnosis and responses, which are crucial aspects to reduce spreads and mitigate diseases impacts.

The threat of changes in inputs cost, prices, demand, consumer preferences, and the appearance of new competitors, make the competitive environment of aquaculture companies very dynamic and volatile. The importance given to market risks derives perhaps both from the intensity of the shocks and from the frequency with which they take

place. There is a large number of works that contribute to a better understanding of the functioning of the seafood value chains and markets [5,6,10,7,30,39,43,47]. However, this type of research frequently faces difficulties in accessing information, which limits their scope and the methodologies applied [43]. Those countries in which there are open access public databases coincide with the seafood markets on which there is more research and the producers have a greater knowledge of the market, especially the USA and Europe. The work carried out in data collection by institutions such as FAO or the European Union, as well as by numerous national governments, has a direct and positive impact on the knowledge about seafood markets. In the same way, those institutions and research centres funding and coordinating research programs such as USAID, CGIAR or Worldfish, help to improve the knowledge in those areas where there are no standardise data collection systems. The creation, financing and sustainability of data collection systems emerges as a key measure to provide companies, scientists and policy makers with the necessary information to analyse and make the appropriate decisions to reduce the uncertainty associated with evolution of seafood markets and thus help aquaculture producers to improve their competitiveness.

In the internal dimension, the operational risk is directly related to decision-making in aspects such as seeding, harvesting, or feeding. Once again, companies, scientists and public bodies have made an enormous effort to improve aspects such as feeding, fingerlings and production technologies and systems. However, there is a field directly related to uncertainty, such as decision making, in which little progress has been made compared to risk sources discussed above. Since the 1990 s, various authors have developed innovative decision support models [8,25,24]. The evolution of the research in this field have been reviewed in Pomeroy et al. and Llorente and Luna [64,78]. In the last ten years, simulation replaced the cost–benefit analysis as the main decision support methodology, while classical optimisation methods such as lineal programming have been substituted by powerful methodologies based on algorithms Shamshak and Anderson [85]. However, farm size and uncertainty within markets are increasing, which makes the existing bioeconomic models less useful in decision-making processes. The latest advances in artificial intelligence and computing techniques already applied in other economic activities represent a revolution in terms of decision support models in aquaculture ([63], 2014; [33,66,68,67]). Supporting these advances will provide a significant leap forward in the management efficiency of aquaculture companies and the reduction of uncertainty associated with strategic and operational decisions. Currently, the biggest challenge is the integration of the models developed in decision support systems (DSS) tools. The development of open access software and tools would facilitate the transfer of this knowledge in a friendly way to aquaculture companies, especially medium and small ones.

We also found significant differences within the countries and types of productions evaluated in the papers considered. Results show that European countries, such as Norway and France, show a greater than average concern for changes in consumer demand or preferences. This can be partly explained by two reasons. On the one hand, Europe, along with the United States, are the two main destination markets for fishery products. In them is the greatest demand for products and the most sophisticated consumers, who not only demand healthy and nutritious products, but also introduce many other factors in their purchase decision such as quality, degree of transformation, or the sustainability of production. In contrast, there are many other markets in which the production priority is to meet the population's demand for protein, so consumer orientation is not the producers' priority.

Similarly, the licensing system is also highlighted as a key source of risk in global north, unlike in the case of global south[2] countries. There are several studies that recently point to regulation as a limitation for the competitiveness of producers in the USA [12] and Europe [13,65], which would explain the greater relevance of this risk in these countries. On the other hand, South Asian producers are more affected by financial aspects, particularly lack of access and insufficient funding [93].

With regard to the panel of independent experts, they added the necessary points to enhance the aquaculture risk framework arising from the literature review. They reached a total consensus on the completeness and usefulness of the sources of risk identified from the perceptions of the producers consulted in the different studies. However, they pointed out the insufficient relevance assigned to some risk sources, seriously underestimated by producers. In this regard, they highlight the need to give greater importance to regulatory and reputational risks, as well as to some operational aspects. Regulatory issues have proven to be almost as important as technical innovation for the development of the aquaculture industry [9,12], to the point of becoming a determining factor for the development of sustainable aquaculture in Europe [13,31,50,65]. The regulatory framework also affects producers in exporting countries to the main markets such as Europe or America. Trade and food regulations, as well as other not tariff measures may arise as a source of uncertainty for aquaculture producers in exporting countries. Limitations are also observed in the perception of strategic and financial risks, which are given limited importance. Similarly, the expert panel expressed concern about the technological development of some farms and the risk of becoming out-of-date due to new disruptive technologies.

From the policymakers' perspective, risk sources identification is needed to develop policies that favour the development of the aquaculture industry. Different studies had already pointed out to the importance of improving the understanding of the specific context of decision-making in the agricultural sector prior to develop new policies in order to prevent them from becoming a source of more uncertainty [27]. In this way, anticipating potential circumstances and identifying realistic economic objectives for aquaculture farms have been also highlighted as key factors to define more appropriate aquaculture policies [26]. In addition, several studies, such as Yu and Yu [96], have highlighted the importance of insurance policies issued by governments to improve risk management capacities, for which an effort by policymakers is necessary to improve some aspects of this sector such as the legal system or the supervision and control systems.

With regard to the financial agents, it should be noted that as much of the expansion of the aquaculture industry is been carried out in the direction of large-scale capital-intensive aquaculture [28], companies demand more and more funding. Thus, a better understanding of risk sources in aquaculture may facilitate entry in the sector of new financial agents, such as rating companies and investment funds, who require more homogeneous standards and readily available risk information [23]. This translates into powerful competitive advantages as fully-insured farmers can focus more on profit-maximization [82] and unconstrained-credit farmers are usually led to use better quality inputs and make better management decisions [72].

5. Conclusions

This work provides a comprehensive picture of risks in aquaculture production that farmers perceive based in the research done so far. The literature review developed has shown how the sources of risk perceived

[2] Global north represents the economically developed societies while global south includes the economically backward countries. Most of global north and global south countries are geographically located in the northern and southern hemispheres, respectively. However, these terms do not always inherently refer to a geographical area [75].

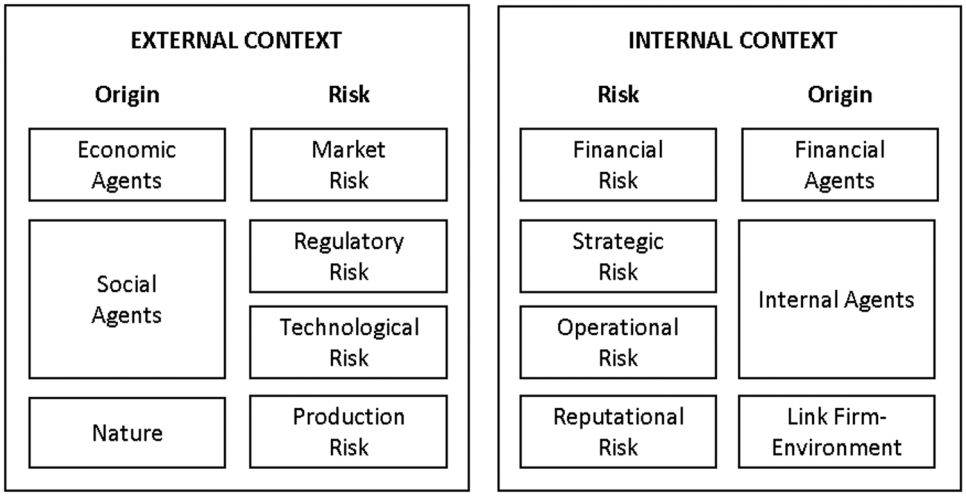

Fig. 1. Risk Classification.
Source: Authors elaboration.

by producers change depending on the country and the type of production. Global north countries show a greater than average concern for changes in consumer demand or preferences. Similarly, the licensing system is also highlighted as a key source of risk, unlike in the case of global south countries, where producers are more affected by financial risk. Differences in the relevance of risk sources highlights the need to generate ad hoc risk management systems for different species, production systems and regions.

The analysis of the 40 risk sources identified also shows certain common characteristics regarding producers´ risk perceptions. Production, market, and operational risks are those of most relevance, respectively, while the technological aspects stand out among those with less relevance.

Consideration of the perceptions of stakeholders other than the producers has led to the conclusion that there are sources of risk to which the producers do not attach importance, and which are actually relevant when not crucial for the result of their activity, including regulatory and reputational risks. This suggests that studies on the perception of risk in aquaculture would improve if they included not only producers, but also other relevant actors in the global value chain, such as policy makers, feed producers or financial entities, among others.

All this provides a clear picture of risk sources in aquaculture and more information and knowledge pointing to some blind spots in producers' perceptions which could result in inappropriate risk management decisions. In this way, the present work presents a reliable framework that aims to be useful to the whole aquaculture industry. It does not only help aquaculture producers to manage the uncertainty surrounding the main company decisions, but also support policy-makers, financial agents and other stakeholders in their governance initiatives and decision-making process. Finally, we encourage future works in this line of research that consider experts from other relevant aquaculture production regions. This would help to on the one hand validate common sources of risk across regions, and on the other hand identify key specific risk sources for a better governance of aquaculture in those regions. (Fig. 1).

CRediT authorship contribution statement

Manuel Luna: Conceptualization, Investigation, Methodology, Writing – original draft. **Ignacio Llorente:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Ladislao Luna:** Conceptualization, Investigation, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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