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Barriers and Facilitators to Shellfish Cultivation

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Running Title: Shellfish Cultivation in Northern Ireland

Abstract

A literature review was conducted to determine the barriers and facilitators to shellfish cultivation using Northern Ireland (NI) as a case study. This review included 23 papers, published in 14 journals, indexed in the Web of Science database. The eligibility criteria included (i) peer reviewed articles or websites from key government or agency stakeholders in the aquaculture supply chain; (ii) had a primary focus on shellfish production and; (iii) made reference to the United Kingdom, Ireland or Northern Ireland. Six key categories were identified as impacting the aquaculture sector; Economic, Environmental, Technical, Welfare, Political and Consumer factors. The most commonly cited codes within these categories included: regulations, management decisions, environmental welfare, weather conditions, consumer needs and water quality. Within the scientific literature the study designs were variable and NI specific data was limited. However, the recommendations were relatively consistent. More evidence-based data collection is needed to better establish the status of the aquaculture industry in this region and to provide more effective management practices and recommendations. The information gained from this review allowed the identification and discussion of the challenges and opportunities for shellfish production worldwide; an insight into production in NI; and preliminary recommendations for improving this industry. As a result, the review offers important foundations and lessons for other aquaculture production units across the world to assess their industry.

Keywords: Aquaculture Production, Bivalve Mollusc, Food Quality, Food Safety, Supply Chain and Risk Management

1 Introduction

Aquatic food makes an important contribution to human health and nutrition, particularly as an animal protein resource, and is enjoyed by consumers for cultural and gastronomic reasons (Jennings et al., 2016; Clegg et al., 2014). It is sourced from the wild fisheries (capture of aquatic animals from the wild for commercial value) or aquaculture (farming of aquatic organisms such as fish, crustaceans or molluscs) (DAERA, 2018). This aquatic food must be safe, sufficient, and nutritious to fulfil the needs and wants of the consumers, whilst achieving environmental, social and economic sustainability to provide for the long term (Jennings et al., 2016). These requirements can be challenging due to: the growing global human population, expected to grow from 7.6 billion to 9.8 billion by 2050 (United Nations, 2017); the increased demand as a result of a growing 'middle class' sector who have greater spending power and typically consume more animal protein than people with lower incomes (Kharas, 2010); and the state of the wild stocks which are approaching their maximum sustainable potential (Clegg et al., 2014; Read and Fernandes, 2003). In order to achieve these increasing requirements the aquaculture industry has become a vital source of production over the last 30 years, increasing from less than 1 million tonnes per year in the early 1950's to 60 million tonnes in 2010 (FAO, 2010). Consequently, this sector has become one of the fastest producing industries worldwide and an essential source of food, nutrition, income and livelihood for billions of people around the world (FAO, 2016, Clegg et al., 2014). A further 140million tonnes of aquaculture produce is predicted for 2050 if demands for aquatic food are to be met (Waite et al., 2014). At present, production primarily occurs in the developing countries, particularly Asia, whilst, the annual growth rates of developed and industrialised counties have stagnated. (FAO, 2017a; European Commission, 2016; Jennings et al., 2016).

Northern Ireland (NI) appears to have a comparative advantage, in terms of temperature regime and suitable sites for the production of shellfish species, namely Pacific oysters (*Crassostrea*

gigas or *Magallana gigas*), Mussels (*Mytilus edulis*) and Native oysters (*Ostrea edulis*). In this region, these species benefit from a good health status with the absence of notifiable diseases, except for localised cases of *Bonamia ostreae* and *Marteilla Refringens* (DAERA, 2018). There is currently 46 farms licenced for the cultivation of shellfish directly employing 91 full time and 78 part time employees (DAERA, 2018). These are mainly small-medium or micro enterprises based around the five sea loughs in Northern Ireland providing jobs and revenue to the local economy (Fig. 1). This sector often compliments employment in inshore fishing, tourism and small-scale agriculture especially at times when income from these other activities may be insufficient to consistently sustain a livelihood, making an important contribution to social cohesion (BIM, 2008). Motivations range from meeting immediate subsistence needs to gathering substantial income for multinational companies trading in export markets (Jennings et al., 2016). Shellfish cultivation has the potential to make an important contribution to the environment through their filter feeding features which can benefit water quality and ecosystem integrity (Marquis et al., 2015; Coen et al., 2007). Despite these distinct benefits of shellfish cultivation, production in the region remains relatively stationary at 3,438 tonnes worth £4.3million in 2016 in comparison to 3,469 tonnes worth £3.6 million in 2015 (Table 1) (DAERA, 2018; FAO, 2017). Although, these figures do not account for production in Lough Foyle (circled in red in Fig. 1) where there is an estimated 30,000 unlicensed oyster trestles (BBC News, 2016). This Lough shares a border with the Republic of Ireland and both regions are in a political dispute over ownership. As a result neither authority has the power to regulate or control the spread of oyster farmers. There are some signs that shellfish cultivation in NI may be entering a growth stage (Habrey and Evans, 2016; Murray et al., 2012), but major constraints such as seed, site availability, water quality, pathogens and consumer perceptions continue to inhibit the industry (Alexander et al., 2015; Oidtmann et al., 2011; Simard et al., 2008; Kaiser and Stead, 2002). As a result NI has underperformed in comparison to the

worldwide growth rates over the last three decades (Habrey and Evans, 2016). It is therefore essential to identify and address the current barriers to shellfish production in NI and illustrate the unrealised potential in this region. The aim of this study is to determine both the barriers and facilitators to aquaculture production in NI and provide recommendations for the construction of a strategic approach to address such issues and allow this sector to capitalise on the worldwide markets and opportunities for shellfish production.

Figure 1: Shellfish production sites in NI.

The map of Northern Ireland (created using google maps) shows the water bodies where mollusc sites authorised for aquaculture production businesses are located in the region. The red circle indicates production in Lough Foyle which shares its border with the Republic of Ireland. Neither the UK or ROI governments has the ownership or power to regulate or licence shellfish production in this water body.

2 Trends in Shellfish Research

The barriers and facilitators to Shellfish Cultivation in the United Kingdom, Northern Ireland and Ireland was initially discussed in the literature in 2003. These studies were conducted in 15 different years over a 47 year time period (1970-2017) (Fig. 2a). Studies specific to the United Kingdom, Northern Ireland and Ireland are relatively sparse and variable with the majority (83%) published from 2010 onwards (Fig. 2a). The literature is published over 14 different journals, predominately in the journal 'Aquaculture' (26%), jointly followed by Marine Pollution Bulletin (9%), Preventative Veterinary Medicine (9%), Journal of Sea Research (9%), and Parasitology International (9%). The remaining journals had one publication each (4%). The aims of the studies ranged from a review of the existing literature to investigations of the challenges and consequences of shellfish production. Within these publications a number of factors were cited which impact the success of the aquaculture industry. These factors could be categorised into Economic, Environmental, Technical, Welfare, Political and Consumer aspects (Table 2). The most commonly cited factors included regulations, management decisions, environmental welfare, weather conditions, consumer needs and water quality (Fig. 2b). There were a number of deficiencies and limitations within the scientific data for shellfish cultivation in NI. Firstly, data specific to NI describing the challenges and opportunities for shellfish cultivation is trivial. This is a limiting factor as many of the barriers and facilitators cited in the literature have regional differences and are not uniform to aquaculture sites across Ireland and the UK. Thus, in order to fully determine the challenges and opportunities specific to Northern Ireland, there is an urgent need to explore the factors which aqua culturists in this region experience during cultivation.

131

132 **Figure 2a: The number of publications on the barriers and facilitators to shellfish**
 133 **cultivation in United Kingdom and Ireland from 2003 to 2017.**

134 The number scientific studies relating to the barriers and facilitators to shellfish cultivation in the United Kingdom,
 135 Northern Ireland and Ireland.

136

137 **Figure 2b: The number of times each factor which influenced shellfish production in**
138 **Northern Ireland was identified in the literature.**

139 The scientific literature has cited 27 different factors which influence shellfish cultivation in Northern Ireland.

140 The factors cited the most included regulations, management decisions and environmental welfare whilst animal

141 welfare, human welfare, physical contaminants, political dynamics and radiation were the least cited factors.

142 **Table 2: Emerging themes related to the barriers and facilitators to aquaculture production in Northern Ireland**

Category	Theme	No. papers cited in	Illustrative Quote	References
Economic	Financial Viability	8	"Risks to social and economic sustainability result from low financial viability of production systems and low resilience to shocks"	Jennings et al., 2016; Marquis et al., 2015; Clegg et al., 2014; Nunes et al., 2011; McCoy et al., 2015; Hannon et al., 2013; Callaway et al., 2012; Oidtmann et al., 2011
	○ Income			
	○ Expenses	7	"EU wide, the major costs are feed (31%), stock (18%), other operational costs (18%) and labour costs (15%) but there is considerable variation between sectors and countries"	Jennings et al., 2016; Marquis et al., 2015; McCoy et al., 2015; Clegg et al., 2014; Hannon et al., 2013; Callaway et al., 2012; Oidtmann et al., 2011;
	State of the Economy	3	"The economic down turn has had a knock on effect on the prices of marketable species both in Europe and worldwide..."	Jennings et al., 2016; Hannon et al., 2013; Callaway et al., 2012
	Food Fraud	3	"There are opportunities for deliberate misrepresentation and mislabelling of product in most supply chains. If these are taken, they can increase income and meet demand for fish that cannot be met through legal routes"	Crovato et al., 2017; Jennings et al., 2016; Giangaspero et al., 2009
	○ 9 sins of Seafood			
Environmental	Biological	8	"...diseases are a key risk" "[NI] Production benefits from a good health status with the absence of notifiable diseases..."	Jennings et al., 2016; Marquis et al., 2015; Peeler et al., 2012; Callaway et al., 2012; Nunes et al., 2011; Oidtmann et al., 2011; Murray et al., 2012; Read and Fernandes, 2003
	○ Disease			
	○ Pathogens of consumer concern	8	"Bivalve molluscs are internationally recognised as a potential vehicle for foodborne diseases especially when consumed raw or improperly cooked"	Crovato et al., 2017; Jennings et al., 2016; Winterbourn et al., 2016; Marquis et al., 2015; Dabowski et al., 2014; Callaway et

			al., 2012; Giangaspero et al., 2009; Read and Fernandes, 2003
○ Water Quality	9	“Bivalve molluscs are filter-feeding animals that may accumulate particles present in the surrounding water including viruses and pathogenic micro-organisms” “The seafood-harvesting areas (category A, B, C) are classified (by the regulations) according to an <i>Escherichi coli</i> indicator. This classification determines whether shellfish can be sent for direct consumption or must be treated previously to commercialisation.”	Crovato et al., 2017; Jennings et al., 2016; Winterbourn et al., 2016; Marquis et al., 2015; Dabowski et al., 2014; Callaway et al., 2012; Nunes et al., 2011; Giangaspero et al., 2009; Read and Fernandes, 2003
○ Nuisance Species	4	“Most marine aquaculture enterprises are vulnerable to nuisance and harmful species, which can have direct negative effects on the cultured species to the extent that they kill entire stocks within days”	Jennings et al., 2016; Tidbury et al., 2016; Callaway et al., 2012; Kraan, 2008
○ HAB's	7	“Globally, harmful algal blooms (HABs) cause major environmental problems...and through the consumption of contaminated shellfish, can potentially impact human health”	Crovato et al., 2017; Jennings et al., 2016; McCoy et al., 2015; Callaway et al., 2012; Nunes et al., 2011; Lopez-Rivera et al., 2010; Read and Fernandes, 2003
○ Weather Conditions	11	“The health of both finfish and shellfish is heavily dependent on environmental conditions, such as temperature, salinity, oxygen solubility...” “Aquaculture facilities are often located in areas which are likely to bear the brunt of climate change impacts”	Jennings et al., 2016; O'Carroll et al., 2016; Marquis et al., 2015; Clegg et al., 2014; Dabrowski et al., 2014; Callaway et al., 2012; Murray et al., 2012; Peeler et al., 2012; Nunes et al., 2011; Giangaspero et al., 2009; Ferreira et al., 2008
Chemical	3	“Chemicals in the environment, including pesticides, heavy metals and persistent organic pollutants can accumulate in fish and shellfish and can pose a public health issue”	Crovato et al., 2017; Jennings et al., 2016; Read and Fernandes, 2003

	Physical	1	"any foreign matter in food can cause injury or illness during human consumption"	Jennings et al., 2016
	Radionuclides	1	"Monitoring programs have demonstrated that radioactivity in aquatic food is within safe limits and that exposure to members of the public from authorised discharges is well below the UK national and European limit"	Jennings et al., 2016
Technical	Availability of resources ○ Sites ○ Species ○ Equipment	8	"Production is controlled by the number and size of facilities, choice of cultured species" "It has been suggested that the large scale growth of the industry has been constrained by a shortage of suitable sites and the ecological carrying capacity of existing sites."	Jennings et al., 2016; Alexander et al., 2015; Hannon et al., 2013; Callaway et al., 2012; Murray et al., 2012; Nunes et al., 2011; Ferreira et al., 2008; Read and Fernandes, 2003
	Management Decisions	15	"Inconsistent animal husbandry practices increases stress, slows growth and increases mortality." "One of the key needs of the aquaculture industry is the implementation of effective management methods to ensure the sustainability, economic viability and minimization of negative impacts on both human and ecosystem wellbeing"	Crovato et al., 2017; Jennings et al., 2016; O'Carroll et al., 2016; Forde et al., 2015; Clegg et al., 2014; Hannon et al., 2013; Peeler et al., 2012; Dabrowski et al., 2013; Callaway et al., 2012; Murray et al., 2012; Nunes et al., 2011; Oidtmann et al., 2011; Krann, 2008; Ferreira et al., 2008; Read and Fernandes, 2003
	Training and experience	7	"Although member countries should work to the same level of standards, in reality this is not the case. This is a result of several factors: limited experience and training in surveillance or diagnostic methods for listed diseases, lack of knowledge of international trade standards, and lack of resources..."	Forde et al., 2015; Hannon et al., 2013; Callaway et al., 2012; Nunes et al., 2011; Oidtmann et al., 2011; Ferreira et al., 2008; Read and Fernandes, 2003

	Research	17	<p>“Information is sparse for the aquaculture sector”</p> <p>“It is essential that such safeguards are formulated from the best available science and technology...”</p> <p>“Validation of these models, however, remains critical if they are to be adopted...”</p> <p>“To this end it is proposed that provision should be made for more and better research...”</p>	Crovato et al., 2017; Jennings et al., 2016; O’Carroll et al., 2016; Winterbourn et al., 2016; Forde et al., 2015; McCoy et al., 2015; Dabrowski et al., 2014; Dabrowski et al., 2013; Hannon et al., 2013; Callaway et al., 2012; Nunes et al., 2011; Oidtmann et al., 2011; Lopez-Rivera et al., 2010; Giangaspero et al., 2009; Kraan, 2008; Ferreira et al., 2008; Read and Fernandes, 2003
	Collaboration	6	<p>“Some relevant data on...is held by individual enterprises, but little of this is publically available, nor is it collected systematically”</p>	Forde et al., 2015; Hannon et al., 2013; Callaway et al., 2012; Oidtmann et al., 2011; Ferreira et al., 2008; Read and Fernandes, 2003
	Storage and distribution	2	<p>"As perishable food commodities, fish and fish products and the markets they support are rapidly affected by...breakdown of production or storage facilities or transport networks..."</p>	Crovato et al., 2017; Jennings et al., 2016
Welfare	Animal	1	<p>“In aquaculture, welfare is an issue throughout the life cycle as well as the point of slaughter. Stocking density, diet, feeding technique and management procedures all affect welfare prior to death. In part, welfare is a focus of aquaculture operations because it affects the health and flesh quality of fish”</p>	Jennings et al., 2016
	Human	1	<p>“Aquatic food production, relies on industries where workers can be, and/or are exposed to higher risk of injury, death and human right abuses than in many other jobs”</p>	Jennings et al., 2016

Political	Environment	13	<p>“The environmental impacts are wide ranging from aesthetic aspects to direct pollution problems.”</p> <p>“However, the CBD also recognises that aquaculture may have positive effects on biodiversity...”</p>	Tidbury et al., 2016; O’Carroll et al., 2016; Alexander et al., 2015; Forde et al., 2015; Marquis et al., 2015; Dabrowski et al., 2013; Callaway et al., 2012; Nunes et al., 2011; Murray et al., 2012; Oidtmann et al., 2011; Kraan, 2008; Ferreira et al., 2008; Read and Fernandes, 2003
	Regulations	17	<p>“Regulation in this sector addresses registration of aquaculture production businesses (APB), aquatic animal health, managing the environmental impact of discharges, and planning and managing interactions with other users”</p> <p>“The legislative framework must include a clear delineation of responsibilities and therefore accountability for the application of the statutory requirements”</p> <p>“The regulatory framework is complex and extensive and this may be a barrier...”</p> <p>“Monitoring programmes are in place to ensure effective regulation”</p>	Crovato et al., 2017; Jennings et al., 2016; O’Carroll et al., 2016; Tidbury et al., 2016; Alexander et al., 2015; Forde et al., 2015; Clegg et al., 2014; Dabrowski et al., 2014; Dabrowski et al., 2013; Hannon et al., 2013; Callaway et al., 2012; Nunes et al., 2011; Oidtmann et al., 2011; Lopez-Rivera et al., 2010; Giangaspero et al., 2009; Ferreira et al., 2008; Read and Fernandes, 2003
	Certification Schemes <ul style="list-style-type: none"> ○ Voluntary ○ Expensive ○ Competitive advantage 	3	<p>“Institutional measures such as Codes of Conduct and Codes of Best Practice have been and are being established at international, national and Aquaculture Producer Association level as mechanisms of self-regulation”</p> <p>“Certified products tend to be more expensive, but suit buyers and consumers who want assurances and can afford to make a choice.”</p>	Jennings et al., 2016; Ferreira et al., 2008; Read and Fernandes, 2003
	Political Dynamics	1	<p>"Supply chains may be impacted by strikes, trade restrictions or embargoes and political unrest"</p>	Jennings et al., 2016

Consumer	Market Demand	9	“Many other sources of nutrition are available, and ‘sufficient’ is usually treated as sufficient to meet demand” “To meet future demands...aquaculture production will need to more than double to 140million tonnes by the year 2050.”	Jennings et al., 2016; Alexander et al., 2015; McCoy et al., 2015; Hannon et al., 2013; Dabrowski et al., 2013; Nunes et al., 2011; Oidtmann et al., 2011; Ferreira et al., 2008; Read and Fernandes, 2003
	○ Consumer Needs			
	○ Consumer Wants	4	“Demands for fish and shellfish as products are increasing” “The choices made by the average consumer are quite conservative” “Consumers tended to respond to rises in fish prices by ‘trading down’ or reducing the amount they buy” “Other barriers to eating fish included lack of knowledge about how to prepare them, lack of availability of fresh fish locally, preparation time, dislike of fishy smell and the need for meal planning”	Crovato et al., 2017; Jennings et al., 2016; Alexander et al., 2015; Callaway et al., 2012
	Consumer Perception	8	“There is a significant commercial risk for companies when it is highlighted in the media and elsewhere that they are producing or trading aquatic foods that do not meet the expectations of consumers and society” “Supply chains may be impacted by...health scares, consumer or supplier boycotts, campaign groups...” “...implementation of risk communication activities is fundamental to promoting the responsible consumption of bivalve molluscs.”	Crovato et al., 2017; Jennings et al., 2016; Alexander et al., 2015; McCoy et al., 2015; Dabrowski et al., 2014; Dabrowski et al., 2013; Nunes et al., 2011; Ferreira et al., 2008
	○ Campaign Groups			
	○ Health scares			
	○ Risk communication			

3 Barriers and Facilitators to Shellfish Production in Northern Ireland

The barriers and facilitators to aquaculture production in Northern Ireland can be categorised into six distinct but linked categories. These include Economic, Environmental, Technical, Welfare, Political and Consumer Factors. Within each of these categories a number of key elements exist which act as a barrier, facilitator or both to aquaculture production. These are outlined within this section and illustrated in Figure 3.

3.1 Economic

Economic factors are those which influence the profitability of an aquaculture production business (APB). Economic factors include three key elements: Financial Viability, The State of the Economy and Food Fraud.

3.1.1 Financial Viability

In order to be profitable and facilitate shellfish production, income must exceed expenses. Income comes in the form of finance, i.e.: access to bank loans, grants, compensation or insurance schemes; sale of products and; savings. Expenses are any cost or outflow of money from the APB.

The primary economic return and facilitator for aquaculture production is the sale of its commodities. This is dependent on the retail price coupled with the quantity of sales. It should incorporate the cost or expenses required for production, (e.g. raw materials, labour, transportation etc.) whilst allowing a profitable return for the business. This price will be influenced by supply and demand, i.e. how willing and able the consumers are to purchase the commodity (consumer factors) and how the business is able to make available what the consumer wants (technical factors). A greater price can be commanded with greater market demand and provided this demand remains higher than supply. As an example, oyster herpes virus in France led to a decrease in the French supply and increased the demand for disease-

free oysters. This allowed disease-free areas, such as NI, to capitalise on the increased demand (Peeler et al., 2012). Shellfish products from NI are perceived as a quality product attracting a high price. This is evident from the fact that although shellfish production has decreased substantially from 2010 to 2016 (-165%) the value of production has actually increased 3% (Table 1). This indicates a considerable increase in value (168%) within a 6 year time frame.

Table 1: Production and value of the aquaculture sector in Northern Ireland

	2010		2016	
	Tonnes	£('000)	Tonnes	£('000)
Finfish	1155	3100	1136	6300
Shellfish	11081	7700	3468	7900
Both	12236	10800	4604	14200

Savings is another crucial facilitator of sustainable shellfish cultivation. This sector is subject to a range of current and emerging barriers to its production (discussed throughout this paper). The greater the level of savings a business can accumulate, the more resilient it will be to overcome such risks and thus the more likely it is to remain viable for the long-term (Jennings et al., 2016). Grants are non-payable funds gifted to an APB to facilitate production. In the European Union the European Maritime Fisheries Fund (EMFF) supports projects that deliver on sustainable economic growth in the sea fisheries and aquaculture sectors. EMFF funding available in NI is currently €13.73m plus a national allocation of €4.58m (Total: €18.31m) (DAERA, 2018). Shellfish farmers can apply for 50% grant aid on the cost of aquaculture equipment through this fund. A review of the EMFF in the UK was carried out in 2014 and illustrated how funding is a driver of sustainable development boosting economically viable and competitive aquaculture businesses who can adapt to changing needs (Gov.uk. 2014). Nevertheless, this only provides a financial aid for equipment and represents a small contribution to the overall expenses of a business. A number of critical economic barriers in

terms of income and expenses continue to exist for shellfish production within NI. Bank loans are a form of finance. However, banks are not keen to finance an APB because shellfish are a vulnerable species and therefore not a fixed asset (Bostock et al., 2010). Similarly, compensation schemes limit financial loss when damage or mortalities have occurred. However, there is currently no such scheme offered by the Government in England, Wales or NI (Oidtmann et al., 2011). The lack of investment to the aquaculture sector is not unique to this region. Poor access to credit has been described as a key constraint at the global level, particularly for small and medium scale aquaculture producers in both developing countries such as Egypt and developed countries such as the United States (Kleith et al., 2013; Bostock et al., 2010). In terms of expenses, the greater the expenditure of a business, the lower profits it generates. Jennings et al., (2016) described the major costs to aquaculture production, EU wide, as: feed (31%), stock (18%), operational (18%) and labour costs (15%) but stated there is considerable variation across sectors and countries. These statistics were not differentiated into finfish, shellfish or seaweed and thus are not directly transferable to shellfish cultivation. Other costs have included: securing a suitable site; conducting an environmental impact assessment; purchasing raw materials (e.g. equipment, species etc.); production losses; labour; mitigation and control measures; and transportation costs (DAERA, 2018; Jennings et al., 2016; Callaway et al., 2012). Research undertaken by Kleith et al., (2013) revealed lenders should be encouraged to develop more credit and saving products targeting the aquaculture sector, particularly small-medium enterprises (SME's). To facilitate this, a key requirement appears to be more emphasis on better financial management by aquaculture businesses; equipping APB's with the skills to fully articulate their ventures to funders; and improved information flows to reduce negative perceptions about the riskiness of aquaculture investments (Muir, 2005).

3.1.2 The State of the Economy

The financial viability of a business is contingent on the state of the economy, i.e. the economic environment in a country or region. The condition is considered a facilitator to production when the economy is expanding and a barrier when it is in decline.

At present, an APB is facilitated by the fact the UK has a strong economy and claims one of the highest GDP's in the world, only behind Germany within Europe. It continues to have Foreign Direct Investment and jobs tend to be plentiful. In this state, consumers have a greater confidence to spend more which provides greater market opportunities and allows businesses to prosper. However, the state of the economy is dynamic and the economic conditions can change as a result of monetary policy decisions, a process known as the monetary policy transmission. If the economy declines consumers don't have excess income and tend to spend less. Consequently, this may force businesses to cut costs to maintain profits and act as a barrier to an APB. For example, the economic crisis which hit the UK in 2008-2009 reduced the purchasing power and attitude of consumers and forced companies to drop their prices or clear smaller volumes. As a result, many of the economically inefficient APB's collapsed. This had devastating effects on the shellfish farmers involved and the livelihoods and communities they supported. However, it has also resulted in a more efficient industry as the more proficient businesses survived and acquired the sites which collapsed (Jennings et al., 2016; STECF, 2013). In NI, the shellfish species cultivated are primarily exported. Thus, this industry also relies heavily on the state of the economy in the countries it supplies. It is therefore vital to be aware of economic trends in such countries in order to react ahead of any potential reductions in demand. The economic factors which affect the monetary policy transmission, and thus act as a barrier or a facilitator, include: the country's political situation, banking policies (interest rates and borrowing capacity), exchange rate, inflation and competition. The political position of a country (see political factors) can influence taxes and government spending within the

region. Taxes are a direct payment for an APB, and the businesses and consumers in the supply chain. Any change can affect the disposable income, consumer demand and asset value. In terms of government spending a greater level of spending often stimulates the economy and vice versa. Political decisions also have a role to play (discussed further under political factors). For example, the decision for the UK to leave the EU resulted in a drop in the GDP of the sterling. Banking policies can impact the ability of a business to attain the necessary funds to become established and sustainable. In particular, the aquaculture industry is associated with a high capital cost at the onset or during development work and a delayed period of production before any economic return. Moreover, aquaculture in NI is characterised by small-medium enterprises (SMEs) which rely heavily on access to loans from banks or other financial institutions as a source of funding. Worryingly, it has been cited that aquaculture has not been recognised as a viable business venture for such funding. When loans are attained, interest rates become an additional expenditure and any changes to interest rates can affect the total expenses for a company with debt, or, the extent of savings for a profitable business. Exchange rates are another concern, particularly as importing and exporting materials and commodities is a key characteristic of shellfish cultivation in NI. A change in exchange rates may affect the cost or return of an item and affect how a company should pay or receive money from its international suppliers and buyers. Inflation is another economic factor. Inflation is the rate at which prices within the economy are increasing and causes increases in the businesses expenses, including rent, utilities and cost of materials used in production. This may force an APB to raise the cost of their commodities in order to maintain profits. Concurrently, inflation can reduce the purchasing power of consumers (unless employers increase wages based on the level of inflation) as demand of goods is directly dependent on its availability and price. Moreover, competitive factors such as imitation products and price wars can have consequences to the price, sale and thus profitability of a business. These elements under the state of the economy

exist for aquaculture production businesses worldwide. Ultimately, it is vital to consider and understand the economic environment and the factors which influence it or this may prove to be a major constraint to the profitability and growth of this sector (Habrey and Evans, 2016).

3.1.3 Food Fraud

Food fraud is an intentional act for economic gain and thus introduces another economic barrier into the food supply chain. In particular, aquatic products have been described as extremely vulnerable to fraudulent activities. This is because they are highly traded and often involve food passing through an internationalised and complex supply chain. Moreover, it includes: a very diverse range of species, often closely related and visually similar; production by aquaculture or the wild fisheries; may involve processing where appearance or flavour are modified; and, can involve the use of common names on sales notes and labels. This creates opportunities for an increase in income or supply that cannot be achieved through legal routes (Jennings et al., 2016). The types of fraud which can occur in the seafood supply chain have been termed the ‘9 sins of seafood’, namely species substitution, fishery substitution, chain of custody abuse, species adulteration, illegal, unreported and unregulated (IUU) substitution, catch method fraud, undeclared product extension, modern day slavery and animal welfare (Elliott, 2014). In terms of shellfish cultivation in NI, the industry predominately involves the sale of shellfish live in the shell for further on-growing or human consumption. Thus the opportunities for species substitution, species adulteration and undeclared product extension are minimal. In addition, if shellfish are stressed this negatively affects the productivity, quality and price of the shellfish. Therefore, animal welfare concerns are not warranted. However, opportunities for fishery substitution, catch method fraud and IUU substitution do exist. Fishery substitution is the substitution of a product from a fishery with an inferior reputation to a superior reputation. It can be carried out by aqua-culturists who mislabel the farming site, e.g. labelling shellfish from a Class C site as a Class A site to increase market opportunities,

but, it is more commonly associated with distributors, middlemen and food service companies. For example, most of the oyster cultivation in NI is exported to French markets. There, food service companies may label the oysters as French to receive a greater market. IUU substitution includes shellfish which have been farmed in areas closed for harvest, the use of unlicensed vessels or farms, or illegal movements of shellfish. For example, shellfish from a disease area cannot be legally moved to a disease free area. However it is suspected an illegal movement of oysters from West Galway to Lough Foyle occurred in 2005. Consequently, *Bonamia ostrae* was introduced into Lough Foyle and meant the area lost its disease free status. Catch method fraud involves the mislabelling or advertising of the type of production or harvesting method to increase financial return. The consumer views ‘wild’ species as a superior standard than farmed species and thus this fraud allows greater financial return particularly outside of their wild season and when in lower supply (Fox et al., 2018; Jacquet and Pauly, 2008). Food fraud has vexed the food industry globally and throughout history. It is not known conclusively how widespread food fraud is because those who commit the act seek to avoid detection (Johnson, 2014). However, it acts as a barrier in the supply chain as it has consequences to: animal health and productivity; traceability and food safety; consumer confidence; meeting legal requirements; ensuring fair competition among producers and processors; allowing consumers to receive what they pay for; and ensuring the benefits and risks of products are known (Jennings et al., 2016). In order to tackle food fraud, the opportunities must be reduced through vulnerability analysis critical control point (VACCP) principles. This will make fraudulent commodities much harder to market and reduce the incentive (Fox et al., 2018; Heylar et al., 2014).

3.2 Environmental

Bivalve molluscs are sessile creatures. Although they appear robust they are perishable when harvested and prone to temperature stress and physical shocks. They are also filter feeders,

feeding from the surrounding water. As a result molluscs are highly dependent on their natural environment and may greatly concentrate certain contaminants (Jennings et al., 2016). This coupled with the fact bivalves are characteristically tender, easily digested and are often eaten raw or only lightly cooked poses a direct threat to human health (Crovato et al., 2017; Murchie et al., 2015; Lees, 2000). It is therefore crucial to consider environmental features to ensure a safe and successful industry. These features can be categorised into biological, chemical and physical factors.

3.2.1 Biological Factors

Biological factors are those relating to life or living organisms. They can either act as both a facilitator and barrier to shellfish cultivation. The biological factors include: Weather and Climate Change; Water Quality; Disease; Pathogens of Consumer Concern and Harmful Algal Blooms.

3.2.1.1 Weather Conditions and Climate Change

Bivalve molluscs are poikilothermic organisms. Their metabolic rate, energy requirements and growth potential are highly dependent on environmental conditions such as temperature, salinity, wave regime, storm frequency or sea level (Callaway et al., 2012; Murray et al., 2012). In addition, bivalve farming may rely on wild spat and broodstock for stock, plankton for food and water quality for health, all of which are impacted by climate. In NI, the weather and temperature regime is generally within the optimum range for shellfish production and may actually facilitate spat fall, growth rates, food conversion efficiencies, growing seasons, range expansion and use of new areas (FAO, 2016; De Silva and Soto, 2009). However, there have been a number of extreme weather events which are a barrier to production. For example, low pressure, tidal surges and record wave heights recorded in Ireland and UK during December 2013-February 2014 resulted in considerable damage to coastal infrastructure (O'Carroll et al.,

2016), whilst flooding events have increased pressure on sewage structures and resulted in increased microbial load of coastal and harvesting waters (Winterbourn et al., 2016). In particular, bivalve larvae naturally exhibit high mortality rate (>98% in the wild) during their transitional phase from free swimming larvae juveniles. Thus any additional stress from the weather conditions can significantly reduce the number of individuals recruited (Callaway et al., 2012). As a result, weather conditions, particularly seasonal differences, can have a positive or negative effect on the growth of bivalves and may be largely responsible for any differences in growth between sites and other production regions, e.g. France and China.

The reliance of bivalve molluscs on the weather conditions is particularly worrying as the threat of climate change looms. Climate change is the large scale, long-term shift in global or regional climate patterns. In Ireland, this change is predicted to incorporate longer growing seasons, milder winters, a further 1.5⁰C increase in January temperatures and a 2.5⁰C increase in July temperatures by 2050. The annual precipitation is to remain relatively unchanged, but with an increase of rainfall predicted in the winter by 10-25% and a reduction in summer precipitation by 25-40% (Dunne et al., 2009). These changes are not expected to be uniform across the Island of Ireland resulting in regional differences. Other patterns, including: increased pH; sea level rise; extreme climatic events; and modified ocean circulation patterns, monsoon cycles and hydrological regimes have been described (Doubleday et al., 2013; De Silva and Sotto, 2009; Handisyde et al., 2006). These environmental changes are associated with barriers to shellfish production, including: stress; increases in invasive species, pests and disease (Bock et al., 2011; Burgiel and Muir, 2010; Halpern et al., 2008; Ramsay et al., 2008; Coutts and Forrest, 2007; Thompson and MacNair, 2004; Byers et al., 2002; Stachowicz et al., 2002); changes in farm husbandry practices (e.g. cleaning of infrastructure); altered species physiology (e.g. changes in growth rate and development); changing trends and distribution of toxins (e.g. introduction of Tetrodotoxin) (Turner et al., 2015; Baker-Austin et al., 2013); impaired farm infrastructure

and escapees (Callaway et al., 2012); diminished sustainability of current farming locations and; changes to day to day farm operations (Tewabe, 2015; Gilbert et al., 2014; Safefood 2014; Doubleday et al., 2013; Callaway et al., 2012; De Silva, 2012; Murray et al., 2012; Karvonen et al., 2010; Cochrane et al., 2009; Hobday et al., 2008; Brander 2007; Handisyde et al., 2006; Focardi et al., 2005). Climate change is also predicted to impact negatively upon the wild fisheries and its supply of feed and seed to the aquaculture industry. Thus, a heavier reliance on hatchery produced seed, selective species or changes to the species cultivated is predicted for the future (FAO, 2016; Callaway et al., 2012; Cooley and Doney, 2009). Conversely, new opportunities may arise by shifts and changes in wild stocks in response to climate change, i.e. greater demand for aquaculture as wild fishery production declines and hatching shellfish for restocking wild populations (Callaway et al., 2012). To date, there has been limited data to substantiate that aquaculture has suffered from climate change (Jennings et al., 2016; Barange et al., 2014; Cheung et al., 2010). Consequently, it has been difficult to differentiate climate change effects from natural environmental variability and the pace of technological development.

In NI, Ferreira et al., (2008) developed an ecosystem model (SMILE) which was used to predict the effects of climate change on aquaculture. This model indicates that an increase in water temperature would reduce aquaculture productivity and the mean weight and length of individuals, particularly for blue mussels. An increase of 1⁰C, as proposed by DAERA fisheries for NI, would lead to an approximate 50% reduction in mussel production and less than 8% in Pacific oyster production. An increase of 4⁰C, the maximum increase predicted by the year 2100 by the UN Intergovernmental Panel on Climate change, would result in a reduction of 70% in mussel production and less than 8% in Pacific oyster production. The model also indicated changes to nutrient inputs due to modifications in the hydrological regime and land use of the catchment. It is therefore important to establish and monitor the critical limits for

environmental conditions and assign mitigation and control to counteract undesirable conditions. Changing weather patterns is not a situation unique to NI (Bostock et al., 2010). Global warming is recognised as a global challenge and part of the United Nations 17 Development Goals (United Nations, 2015). Climate change is predicted to have the greatest consequences in higher tropic regions and developing countries, where a large proportion of aquaculture production occurs (Corlett, 2012). Research and adaption will be vital for sustainable production in these regions.

3.2.1.2 Water Quality

Water quality is a measure of the condition of the water relative to the requirements of shellfish production. Good water quality is important to facilitate the growth of high quality and safe shellfish, whilst poor water quality acts as a barrier to production (DAERA, 2018; Dabrowski et al., 2014). EC Regulation (2004) classifies water quality of shellfish harvesting sites into one of three categories (A, B or C) based on the concentration of the faecal indicator organism *Escherichia coli*, present in shellfish flesh. The latest classification in February 2018 revealed only one classified shellfish bed had an A classification; thirty had a class B; whilst five had a class C. The remaining four sites experienced seasonal changes, moving between a B and C classification (FSA, 2018). This classification system defines the level of post-harvest treatment prior to sale for human consumption (Crovato et al., 2017). Thus, only one site is capable of sale for direct human consumption without further on-growing or purification (Table 3). The monitoring for the presence of phytoplankton, marine biotoxins and chemical contaminants in samples of shellfish flesh is also undertaken. Any deterioration in water quality or site can result in an increase in ambient levels of opportunistic pathogens (e.g. *Trichodina* sp.) and promote secondary infection by bacteria (Callaway et al., 2012). Consequently, the harvesting site may drop a classification level which has economic repercussions due to

increased treatment and production time and reduced reputation and market demand for the shellfish. Water bodies can be impacted by pollution and reduced quality from various sources, including run-off from agricultural land or discharges from sewage treatment works (DAERA, 2018). Other water users pose the greatest threat to water quality (Winterbourn et al., 2016). This is evident during summer when there is greater effluent loading into water bodies located near popular tourist destinations (Dabrowski et al., 2014). Similarly, at times of increased run-off, e.g. flooding events, the water body suffers from increased turbidity, nutrient loads and contaminant loads to the near shore environment as a result of sewage overflows (Winterbourn et al., 2016; Callaway et al., 2012; Kay, 2008). Nitrogen-related pollution of coastal waters has caused widespread hypoxia and anoxia, habitat degradation, alteration of food-web structure and loss of biodiversity (Callaway et al., 2012; Howarth, 2008). The situation will only worsen as population, industry and climate changes grow.

Table 3: Classification system for water in shellfish harvesting areas (Pocknell, 2017, o. 974)

Bed Classification	E. Coli presence/100g flesh	Effect upon the bed
A	230 or less	Live bivalve molluscs can be harvested and marketed directly for human consumption
B	231-18000	An area which live bivalve molluscs can be gathered but only placed on the market for human consumption: a) After treatment in a purification centre or after relaying (followed, where necessary, by treatment in a purification centre); or, b) After heat treatment by an approved process in an approved establishment.
C	18001-46000	An area from which live bivalve molluscs can be gathered only after: a) A relaying period of at least 2 months, followed, where necessary by treatment in a purification centre; or b) Heat treatment by an approved process in an approved establishment
Prohibited	46001+	No shellfish can be placed on the market of such beds.

427

428 3.2.1.3 Disease

429 Disease is the single biggest risk to the maintenance and growth of aquaculture production
430 (Carnegie, et al., 2016; Jennings et al., 2016; Marquis et al., 2015; Murray et al., 2012;
431 Oidtmann et al., 2011). At present, NI has a high health status and it is declared free of a number
432 of shellfish diseases. This provides the region with a unique marketing opportunity to capitalise
433 on the demand for disease free oysters. However, notifiable diseases are known to be present:
434 *Bonamia ostrea* in Lough Foyle and Strangford Lough, Oyster Herpes Virus (OsHV-1- μ Var)
435 (only Lough Larne is free) and as of 2017, *Marteillia Refringens* in Belfast Lough and
436 Dundrum bay (DAERA, 2018). These diseases can have huge economic repercussions to these
437 areas through mortality and movement restrictions (IFREMER, 2017; DEFRA, 2014; Murray
438 et al., 2012; Arzul et al., 2011; Oidtmann et al., 2011).

439 *Bonamia ostreae* is an intracellular haplosporidian protozoan parasite which causes
440 Bonamiosis, a lethal infection to the haemocytes of flat oysters, *Ostrea edulis*, and the native
441 oyster. An infected oyster typically appears normal but clinical signs may occur up to 5 months
442 after infection Worldwide, the prevalence of *Bonamia ostreae* in infected populations is
443 variable (0-80%) (OIE, 2018). Whilst in NI, they are typically 1-3% in wild areas and 20-30%
444 in farmed areas with relatively low levels of mortality (IFREMER, 2017). Epidemiological
445 studies indicate seasonal, size, age, stress, and environmental conditions all impact on the
446 prevalence and intensity of infection observed (OIE, 2018; DEFRA, 2014; Flannery et al.,
447 2014). Typically, the parasite is active at temperatures of 12⁰C and higher salinities, although
448 warmer temperatures may also increase disease outbreaks (OIE, 2018; DEFRA, 2014; Murray
449 et al., 2012). It has been associated with winter mortality in France and Ireland. In NI, the host
450 for *Bonamia* is the native oyster, whilst the Pacific oyster has been described as a carrier of the

disease (Murray et al., 2012; Lynch et al., 2010). There is no known treatment for Bonamiosis and the only effective control is to prevent the introduction of the disease through restricting live movements from infected areas. This can introduce barriers to importing seed and exporting finished bivalves to a disease free region(DEFRA, 2014).

Martelia refringens is another protozoan parasite which causes Marteiloiosis in Blue mussels (*Mytilus edulis*) (40-100% mortality) and Native and Pacific oysters (80-90% mortality) (OIE, 2017). It requires temperatures in excess of 17⁰C for sporulation and transmission (OIE, 2017) and survives best at reduced salinities (Murray et al., 2012; Robelo and Figueras, 1995). *M. Refringens* was first detected in NI in 2017 during routine testing in Belfast Lough and Dundrum Bay (DAERA, 2018). There was no clinical signs of disease in the Blue mussels, but, the infected area is under confirmed designation notice and movement restrictions are in place (DAERA, 2018; OIE, 2017). Marteiloiosis evolves concurrently with *B. osteae* but displays a different dynamics pattern, probably due to the fact both diseases deplete the host's resources and thus affect the development of the other parasite during co-infection (Arzul et al., 2017; IFREMER, 2017). In combination with *B. ostrease*, *M. refringens* has been associated with >90% decline in *O. edulis* population in France illustrating its devastating effects in a region (Murray et al., 2012; Arzul et al., 2011) Recent phylogeny work on these parasites suggest that *Marteilia refringens* should be considered as two distinct species, called types M and O (IFREMER, 2017). *Marteilia refringens* type M also known as *M. pararefringens*, infects *Mytilus edulis* in the UK, Norway, Sweden and NI but is not present in flat oysters farmed in the same zones (IFREMER, 2017; Murray et al., 2012). *Marteilia refingines* 'O-type' is genetically and biologically distinct from 'M-type' and has not yet been recorded in NI.

Oyster Herpes Virus is a virulent disease of both the Pacific oyster, *Crassostrea gigas* and native oysters (Degremont et al., 2013). It has been associated with the sudden and high

476 mortality of *C. gigas* (up to 100% in a few days) reared in France, Ireland and England,
477 particularly in the summers of 2008 and 2009 (Murray et al., 2012; Oidtmann et al., 2011;
478 Renault, 2011; Peeler et al., 2010; Segarra et al., 2010). Though, the cause of mortality events
479 in *C. gigas* are believed to be multifactorial with OsHV-1 infection (with OsHV-1 μ Var now
480 predominating) a necessary but not sufficient cause (Clegg et al., 2014; Samain, 2011). Other
481 suspected risk factors include viral load of the bay (Clegg et al., 2014; Garcia et al., 2011;
482 Schikorski et al., 2011; Sauvage et al., 2009; Pepin et al., 2008); a sudden change or increase
483 in temperature (Clegg et al., 2014; Degremont et al., 2010; Peeler et al., 2012) husbandry and
484 farm management practices such as introduction of possibly infected spat (Clegg et al., 2014;
485 EFSA, 2010; Samain and McCombie, 2010), the movement and mixing of populations, age
486 and condition of oysters when first infected and no prior exposure of the seed or the related
487 broodstock to the virus (Clegg et al., 2014; Pernet et al., 2012; Garcia et al., 2011; EFSA, 2010;
488 Huvet et al., 2010; Sauvage et al., 2009; Degremont et al., 2007). In particular, the European
489 Food Safety Authority (EFSA, 2010) noted that no outbreaks have been reported when the
490 water temperature was below 16°C. Oyster herpes virus is not yet a listed disease but it is
491 considered of relevance and notifiable in NI as it was associated with high levels of mortality
492 of both adult (25%) and larval (mean 55%) Pacific Oysters in Ireland during May to August
493 2009 (Clegg et al., 2014; Murray et al., 2012; Peeler et al., 2012; Malham et al., 2009). Since
494 2009, this mortality has been linked to the presence of OsHV-1 μ Var (Clegg et al., 2014;
495 Murray et al., 2012; EFSA, 2010; Segarra et al., 2010). Larne Lough is the only disease free
496 area in this region and an ongoing surveillance and sampling program is required to retain this
497 disease free status. The virus has not been detected in Dundrum Bay but it has been removed
498 from the surveillance program due to an industry request stating sourcing and operational
499 difficulties (DAERA, 2013). There is a number of other diseases associated with shellfish
500 cultivation in NI. In 2015, *Haplosporidium costale* was detected in *C. gigas* in UK and

501 *Mikrocytos mimcus* was reported in two small farms, although, it has never been seen again
502 (IFREMER, 2017). Surveillance is no longer implemented for *M. mimicus* as the infection
503 causes some specific heavy clinical signs sufficient for detection. This parasite is associated
504 with very low temperatures (IFREMER, 2017). In Ireland, the bacterium *Vibrio hemicentroti*
505 is screened as it was described during mussel mortality events in France. However, at the 2017
506 Annual meeting of NRLs for Mollusc Disease it was stated that additional work carried out in
507 2016 on the mussel mortality samples concluded that *hemicentroti* was a false alarm for mussel
508 mortality in France; after full sequencing they found that it was actually *Vibrio splendidus*
509 present (IFREMER, 2017). This NRL meeting also commented on the trends in shellfish
510 disease, stating that the mortality levels in the past couple of years has been very low with only
511 two events investigated in 2016. These events involved Pacific oyster, *C. gigas*, but the origin
512 or the aetiological agent responsible for the mortality was unknown (likely environmental). It
513 was also commented that there has been no conclusive explanation found to explain the
514 significant decrease in mortality except differences in rain (IFREMER, 2017). Thus, disease
515 still poses uncertainty to aquaculture especially as the industry is predicted to grow further in
516 response to plateauing wild stocks. This growth is likely to be accompanied with intensified
517 systems, new cultured species, expansion into new geographical areas and the development of
518 new systems. Historically, major aquatic disease incidents throughout the globe has occurred
519 in parallel with such developments (see examples in Oidtmann et al., 2011). Therefore, the
520 introduction and spread of disease must be mitigated. There is a number of typical routes for
521 disease into a shellfish harvesting site. The principle route involves the movement of waters,
522 fomites, live vectors or aquatic animal products contaminated with disease (Murray et al., 2012;
523 Dube et al., 2011; Oidtmann et al., 2011; Brown et al., 2006; Keeling and Eames, 2005). Other
524 routes have been suggested. These include infection from lorries which carry live shellfish
525 (although these enter empty so risk should be low if disinfection is carried out), import of

pathogens within ballast water and shellfish attached to hulls during shipping and ornamental fish trade (Murray et al., 2012). Pathogens may also be transported naturally due to water currents or wild vector species from zones of infection in adjacent territories, depending on their survival in seawater (Jennings et al., 2016; Murray et al., 2012; Bridges et al., 2007). In NI, the small isolated nature of the bivalve farming industry may restrict pathogens becoming more than a local problem. However, the presence of a number of farms in the one lough may mean that all sites within that lough are at risk of being infected as a result of management decisions made by a near-by farm (Murray et al., 2012). Once established pathogen eradication may be impossible (Oidtmann et al., 2011) and the intensity of the disease will increase dependent on the size of the population (Jennings et al., 2016; Murray et al., 2012; Bridges et al., 2007). Ultimately, disease has proved to be a major constraint to efficient production throughout global aquaculture systems. New disease problems are emerging. Continued vigilance and solution development is vital (Bostock et al., 2010).

3.2.1.4 Pathogens of consumer concern

Bivalve molluscs are filter feeders that can greatly concentrate protists, bacteria and viruses from their surrounding environment, particularly in areas impacted by sewage. As these species are often eaten raw, they pose a public health risk if the pathogens are not cleared or inactivated by the bivalves (Crovato et al., 2017; Jennings et al., 2016; Dabrowski et al., 2014). To ensure consumer safety, shellfish harvesting sites are subject to a monitoring program. Any site above safe limits will be closed down temporarily or long term posing a direct barrier to production (Marquis et al., 2015). Despite these controls, a number of outbreaks of human pathogenic viruses associated with bivalve shellfish continue to occur. In the EU, shellfish were responsible for 8.1% of strong evidence outbreaks and 2.3% of weak evidence outbreaks (EFSA and ECDC, 2015). This has repercussions to the reputation and profitability of the farmer and industry. According to the EFSA (2015) norovirus was the predominant cause.

Other pathogens of concern include: pathogenic protists, such as *Cryptosporidium* spp. and the microsporidian *Enterocytozoon bienesusi*; members of the bacterial genus *Vibrio*; and viruses such as hepatitis A and E. The particular genus of concern is dependent on the species and location factors (Jennings et al., 2016; Lowther et al., 2012; Le Guyader et al., 2010).

Norovirus is a single stranded RNA virus and is recognised as the largest aetiology linked pathogen group found in bivalve molluscs in Europe (Jennings et al., 2016; Winterbourn et al., 2016; Dabrowski et al., 2014; Lees, 2000). It is shed in great quantities by infected individuals, is present in high copy numbers in sewage waste, has a relatively low infectious dose, is environmentally stable, can mutate rapidly and is only slowly removed from shellfish by commercial depuration practices (Jennings et al., 2016). Consequently, norovirus is a persistent and significant shellfish-associated human pathogen causing outbreaks of acute gastroenteritis to people of all ages (Winterbourn et al., 2016). Shellfish are at particular risk during periods of heavy rainfall or snow meltwater when tertiary water treatment works are passed and effluent is discharged in a highly contaminated state. A systematic analysis of norovirus contamination in commercial oyster sites in the UK revealed that norovirus is highly prevalent, present at all sites with 76.2% of 844 samples positive (Jennings et al., 2016). Worryingly, these outbreaks have occurred when shellfish are compliant with *E.coli* standards (Dabrowski et al., 2014). This is because *E. coli* and norovirus can originate from different sources, are susceptible to different stresses and accumulate differently in shellfish (Winterbourn et al., 2016). Moreover, depuration methods that are effective against bacteria of faecal origin do not ensure the elimination of certain species of *Vibrio* or enteric viruses in the product (Crovato et al., 2017; Suffredini et al., 2014). It is therefore unsurprising that The Shellfish Association of Great Britain has seen an increase in the number of incidents of norovirus associated with bivalves with current estimates for the UK population revealing 1 in 219 individuals are infected each year, with gross underreporting of clinical cases suggested (Jennings et al., 2016).

576 This warrants the need for a greater research effort, innovative technology and education and
577 training in order to overcome the threat from human pathogens.

578 There is increasing evidence of other viral pathogens linked to bivalve shellfish (Jennings et
579 al., 2016). **Hepatitis A virus (HAV)** is an established human pathogen which infects the
580 liver. It was responsible for the largest ever shellfish associated food-borne outbreak in
581 history, affecting almost 300,000 people in the late 1980's (Potasman et al., 2002). The virus
582 continues to cause approximately 1.5 million cases annually (Jennings et al., 2016). Several
583 characteristics of HAV make it a significant shellfish pathogen: it is relatively stable in the
584 environment, it can remain in shellfish matrices for long periods and it is only slowly
585 removed from shellfish by depuration practices (Jennings et al., 2016). **Hepatitis E virus**
586 **(HEV)** is a single stranded RNA virus which causes human infections via the faecal-oral
587 route. Available epidemiological evidence for Western Europe indicates that the virus is
588 responsible for around 5% of cases of acute hepatitis and there is evidence of a large increase
589 in reported cases in the UK in the last decade (Jennings et al., 2010). These pathogens are
590 highly prevalent in swine wastewater and manure (McCreary et al., 2008) and can enter water
591 courses and bio-accumulate in bivalve molluscs. However the evidence for HEV in shellfish
592 is not conclusive (Grodzki et al., 2014).

593 Bacteria of the genus *Vibrio* are another pathogen responsible for severe infections in humans
594 and animals. These are gram-negative bacteria which inhabit surface waters at coastal and
595 estuarine sites and are responsible for a number of severe infections in humans and animals
596 (Vezzulli et al., 2013). Only two *Vibrio* species, *Vibrio vulnificus* and *Vibrio*
597 *parahaemolyticus*, are significant human pathogens that can occur in aquatic food (Baker-
598 Austin et al. 2009, 2010; Dechet et al. 2008; Altekruuse et al. 2000). *Vibrio cholerae* is also a
599 food pathogen, but it is rarely associated with seafood from the UK (Baker-Austin et al.,
600 2009). The *Vibrio* species grow preferentially in warm (>15 °C) and low-salinity (<25 ppt

NaCl) seawater (Baker-Austin et al. 2010, 2013). The number of *V. vulnificus* and *V. parahaemolyticus* infections is steadily increasing due to climate change and the associated warming of low salinity marine environments (Lindgren et al., 2012; Burrows et al., 2011; Martinez-Urtaza et al. 2010). Surveillance and monitoring of these infections are poor and disease burden of *Vibrios* from shellfish consumption is likely underestimated (Jennings et al., 2016).

3.2.1.5 Nuisance and Harmful Species

Nuisance and harmful species are a barrier to the shellfish industry. These are animals which negatively impact the cultured species, to the extent they can kill entire stocks within days (Callaway et al., 2012). These species can be native or non-native. Non-native species are those that have been intentionally or unintentionally introduced outside their native range (Callaway et al., 2012; Maggs et al., 2010). If these species become established and threaten biodiversity or cause economic damage, they are known as ‘invasive’ (Callaway et al., 2012; Wilcove et al., 1998). In the UK and Ireland, the annual cost of invasive species to the aquaculture industry is estimated to be £1.7 billion a year. Although this is probably an underestimate as there is little distinction between native and non-native species during pest control operations (Williams et al., 2010). The cost associated with invasive species occurs through the fouling of nets, cages, buoys, moorings, boat hulls and the cultured species themselves (Callaway et al., 2012; Williams et al., 2010), competition for resources such as space and food, or, predation and parasitism (Callaway et al., 2012). In particular, the invasive marine microalgal *Sargassum muticum* has been noted in the literature as a nuisance species to shellfish cultivation in NI. It was first detected in Strangford Lough in 1995 (Kraan, 2008) and possesses characteristics that allow it to outcompete local species including; tolerance to a wide range of salinities and temperatures, a high growth and reproduction rate and a diplontic and monoecious life cycle. It is thought *S. muticum* was unintentionally introduced into Europe via the import of oysters

into France from Canada or Japan for aquaculture. Thereafter, natural transmission, boating activities and movements of oysters facilitated its spread throughout Europe (Kraan, 2008). The likelihood of colonisation rate is dependent on factors such as currents, prevailing winds and geography. But, once established *S. muticum* competes for hard substrate and space, alters the ecosystem in shallow waters and has been associated with fouling of equipment, boat propellers and oyster beds. Moreover, the species cannot be eradicated and its control involves seasonal harvesting in problem areas which can be repetitive and laborious. Other species which have become established in the UK and Ireland have had an impact on aquaculture industries in other countries through fouling include: *Didemnum vexillum* (Coutts and Forrest, 2007), *Ciona intestinalis* (Ramsay et al., 2008), *Styela clava* (Thompson and MacNair, 2004) and *Botrylloides violaceus* (Bock et al., 2011), although similar consequences are yet to be reported in this region.

3.2.1.6 Harmful Algal Blooms

A Harmful Algal Bloom (HAB) is a rapid increase or accumulation of phytoplankton (also known as microalgae) in the water which causes injury to animals or the ecology. It is recognised by a discolouration in the water from their pigments and often only represents a small proportion of the total phytoplankton biomass (Callaway et al., 2012). However, if large enough the algal bloom can cause problems and become a barrier to shellfish cultivation (Hinder et al., 2011). Phytoplankton can become indigestible when they are nutrient starved, probably due to accumulation of noxious secondary metabolites, and act as ecosystem disruptive algal blooms (EDAB's) (Callaway et al., 2012; Mitra and Flynn, 2006). Such phytoplankton block the natural flow of energy and elements through the food chain (e.g. *Phaeocystis*). Consequently, bivalves are food deprived and, when dying, EDABs cause further damage through decay (e.g. hypoxia). More commonly, HAB's are associated with shellfish poisoning (McCoy et al., 2015; Anderson et al., 2012; Lopez-Rivera et al., 2010;

651 Hallegraeff, 2003; Smayda, 1990). This is the result of the natural toxin production of algae
652 and the subsequent accumulation in the shellfish through filter feeding. These toxins are
653 associated with a number of serious and potentially fatal human illnesses (EFSA, 2009; FAO,
654 2004) and include: dinoflagellates such as *Alexandrium* associated with the production of
655 paralytic shellfish poisoning (PSP); *Dinophysis* producing lipophilic shellfish toxins (LST)
656 responsible for Diarrhetic Shellfish Poisoning (DSP) and Azaspiracid Shellfish Poisoning
657 (AZP); and diatoms such as *Pseudonitzschia* linked to amnesic shellfish poisoning (ASP)
658 (Bresnan et al., 2010; Lopez-Rivera et al., 2010; Read and Fernandes, 2003). Unlike marine
659 pathogens, these toxins cannot be eliminated through food processing techniques and
660 depuration is inefficient (Jennings et al., 2016). Instead, surveillance testing and maximum
661 permitted levels exist in order to reduce the human health risk. If toxin levels are detected above
662 the maximum permitted levels the site will be closed down (EC, 2004). This poses a substantial
663 barrier to shellfish production. A barrier exacerbated by the fact HAB's are difficult to predict
664 and challenging to avoid. Fortunately, NI harvesting areas have been only slightly impacted by
665 HAB related events. Although, they are recognised as having increased in distribution, intensity
666 and frequency over the last 40 years (Hallegraeff, 2003) with sites in Scottish and Irish waters
667 closed as a consequence (Bresnan et al., 2010). These trends are believed to be due to, in part,
668 increasing temperatures and climate change effects. It is therefore important to become
669 proactive, gaining an understanding of HAB's and preparing the industry should they become
670 prominent in this region. In general HAB related events occur near the shore. However, they
671 may originate off-shore through seeding and advection. They are primarily associated with
672 sunny, warm and stable water conditions (Callaway et al., 2012) but have also been linked to
673 terrestrial processes following anthropogenic activity including: nutrient inputs; changes to
674 local marine ecosystems affected by land use and human population growth; and changes in
675 sea water and environmental parameters (Baker-Austin et al., 2013; Callaway et al., 2012;

Bresnan et al., 2010). Climate change may also create opportunities for new analogies of toxin groups currently present in UK waters and the introduction of new species of toxin-producing phytoplankton (Turner et al., 2015). Another risk factor for toxins is an imbalance of N:P rations within phytoplankton, which can occur due to the use of P-fertilizer, sewage systems and heavy rainfall (Bresnan et al., 2010; Youlian et al., 1998). Whilst Si stress, which can occur due to limited run-off during reduced rainfall, is linked with toxicity for the diatom *Pseudo-nitzschia australis*, a common species off the UK (Youlian et al., 1998). Another recognised contributing factor is ocean acidification (Callaway et al., 2012). This is because alkaline waters are detrimental to algal growth (Hansen, 2002) and as algal blooms consume CO₂, nitrate and phosphate (alkalisation of the water), the lower the starting pH, the longer species succession can occur (Callaway et al., 2012).

3.2.2 Chemical

Chemical hazards are chemical substances that cause harm or injury to the health of living organisms. They are a barrier to shellfish production as they can accumulate in the flesh of shellfish following uptake in food or water in the cultured area (Jennings et al., 2016). Chemicals in the aquatic environment include: dichlorodiphenyltrichloroethane (DDT); dioxins; endosulfan; heavy metals such as methyl-mercury, cadmium, lead and arsenic; persistent organic pollutants; pesticides; polybrominated di-phenyl ethers; polychlorinated biphenyls (PCBs); and polycyclic aromatic hydrocarbons (PAHS) (Jennings et al., 2016; Soon and Baines, 2012). The variation in chemical concentration is dependent on: the location; shellfish characteristics (i.e. host type, fat content, size, age, growth rate and gender); and other physical, chemical and biological factors (Jennings et al., 2016). Chemicals act as neurotoxins and can have carcinogenic effects, posing a threat to public health. In areas or consumers which consume high quantities of shellfish, chemicals have a bio-accumulative effect. Health risks are associated with chronic (long-term) exposure, whilst vulnerable individuals can be at risk

from acute short term exposure (Jennings et al., 2016; Grandjean and Landrigan, 2014; Oken et al., 2012; Mahaffey et al., 2011; Nesheim and Yaktine, 2007; Sunderland, 2007; Knowles et al., 2003). However, the nutritional benefits from shellfish are thought to outweigh any potential risks (Crovato et al., 2017; EC, 2001). Regulation EC/1881/2006 defines the maximum levels for contaminants in live bivalve molluscs. In 2011, the European Food Standards Agency (EFSA) set a new, more stringent and combined limit of 30µg/kg (as opposed to the previous individual limit of 10µg/kg) for four key PAHs, known as EFSA4, (Benzo(a)pyrene, Chrysene, Benzo(a)anthracene and Fluoranthene) in live bivalve molluscs. In NI, DAERA and Food Standards Agency (FSA) operate a joint monitoring program for a suite of chemicals in shellfish flesh. This determines whether shellfish are harvested or not (DOENI, 2016). Monitoring is carried out annually, usually in February or March, as this represents pre-spawning when the burden of contaminants on the shellfish body is at its highest. Generally, contamination of shellfish by chemical contaminants is low in most production areas. However, since the new limit was set for EFSA4, monitoring in Narrow Water has demonstrated levels of PAHs at or above the EFSA4 therefore continued surveillance is prudent (DOENI, 2016).

3.2.3 Physical

Physical hazards are foreign objects in food which can cause choking, injury or other adverse health effects when eating. In NI, shellfish cultivation is typically exported to foreign markets live in the shell. As a result, physical hazards are generally well controlled but can include shell in the flesh and metal or plastic from equipment or environment. Recently, plastic particle contamination, principally micro and nanoparticles of plastic in marine and fresh water systems have raised concerns regarding their impacts on shellfish, human health and potential to aggregate and spread pathogens (IFREMER, 2017; UNEP and DESA, 2013). Plastic is durable, can accumulate in marine habitats (accounting for up to 90% of all marine debris) (IFREMER,

2017; UNEP and DESA, 2013), and can break down to smaller fragments and exist as micro-plastics (MPs) (<1mm) or nanoplastics (NPs) (<1µm). At this smaller size, plastic can accumulate and persist in the bivalve mollusc for 48hours (IFREMER, 2017; Browne et al., 2008) where it has been linked with a strong inflammatory response (granulocytomas) and presentation of destabilisation of the lysosomes (IFREMER, 2017; Von Moos et al., 2012). Recent research also shows an affinity of polystyrene particles for contaminants such as flouranthene (Paul-Pont et al., 2016) which could potentially cause accumulative effects.

3.2.4 Radiation

Radiation is energy given off by an unstable nucleus. This radiation is in the form of rays or high-speed particles and is a waste product during the normal operations of a nuclear site. The amount of radioactive waste is controlled however, it can contaminate shellfish and enter the food chain when released into the sea acting as a barrier to production (Jennings et al., 2016). In the UK, a number of nuclear sites exist, however none of these are located in NI. Nevertheless, the NI Environment Agency (NIEA) carry out food, environmental and dose rate monitoring to confirm the safety of the food chain from radionuclide pollutants and establish long-term trends. This is necessary due to the continued use and proposed increase of nuclear sites (CEFAS, 2016; Jennings et al., 2016). At present, consumer doses in NI are less than 1% of the annual limit of 1 mSv for members of the public and thus not of significant concern (Fig. 3) (CEFAS, 2016).

3.3 Technical

Technical factors are those which have an impact on how a business operates. They include: Management Decisions; Training and Experience; Research; Collaboration; Availability of Resources; and Storage and Distribution systems.

3.3.1 Management Decisions

An APB must achieve sustainable rates of production in order to remain operational. This is managed at site level and is contingent on the management practices and ability of the business to counterbalance any risks to the production, e.g. disease (Dabrowski et al., 2013). These management practices are the decisions the APB makes with regards to the species, cultivation method, growing conditions, time of production, harvesting method, handling practices and surveillance and mitigation measures implemented (Jennings et al., 2016; Callaway et al., 2012; Seafish, 1997). Fox et al. (2018) outlines the production methods and supply chain structure in the UK, predominately involving on-bottom mussel culture and trestle oyster culture. All these decisions can facilitate or act as a barrier to production as they affect: the robustness, quality and safety of the bivalve mollusc; productivity and economic viability of the harvesting site; and the ability to meet regulatory requirements (Oidtmann et al., 2011). For example, mussels are a robust species but stress and multiple small impacts can have a cumulative effect, damaging the shell and resulting in death. Thus, it is important to consider handling operation, equipment design and workforce discipline in order to increase productivity (Seafish, 1997). Similarly, a failure to investigate optimum levels of cultivation for a harvesting site can result in increased competition for resources, over-exploitation of an area and decreased productivity and profitability of an APB (Nunes et al., 2011; Ferreira et al., 2008). These management decisions are not isolated to that of the aqua-culturist, but also to other stakeholders in the supply chain. For example, the period and location of sampling carried out by surveillance agencies can impact the likelihood of detecting pathogens and contaminants, especially those with seasonal dynamics. The management decisions made in the supply chain are dependent on a number of other technical factors, including: their training and experience to allow them to make knowledgeable and effective decisions; the mitigation options developed and advocated through data; and research shared with the industry.

3.3.2 Training and Experience

Aquaculture is a relatively young industry, re-commencing in the 1970's in Ireland. This is a barrier to shellfish cultivation as there is very few second generation farmers passing down their knowledge and experience about the best management options. This is not ideal as shellfish are a very sensitive species which require particular cultivation and handling methods and knowledge of production threats in order to achieve high quality and productive harvest. Moreover, the industry relies on passive surveillance whereby it is the duty of an aqua-culturist to report increased or unusual mortality or suspicion of a notifiable disease. Thus, the sensitivity of the system is vulnerable to a reluctance of reporting due to fear of financial or reputational loss and a lack of understanding of the importance of this responsibility (Oidtmann et al., 2011). Whilst the industry in NI is young, other locations have mastered the production of shellfish species. For example, Bostock et al. (2010) described this as one of the key facilitator's for aquaculture production in Asia as the pre-existing aquaculture practices. Best practices and lessons learnt should be sought and communicated to our aquaculture industry. Moreover, in many locations, most aqua-culturist farmers have attained a university degree in aquaculture. This is not provided or common in NI. Typically aqua-culturist have progressed from working in the wild fisheries and have learnt the trade through a process of trial and error. There is space to increase the productivity of shellfish cultivation in NI by greater knowledge understanding, training and sharing of experiences alone.

3.3.3 Research

In the EU, the use of scientific research to investigate the current risks, potential threats and effective solutions is advocated (Nunes et al., 2011). It is critical this research is communicated to the end user in a meaningful matter, providing effective training and optimising management decisions. It has been cited that the lack of conclusive data in aquaculture research, particularly on a region by region basis is a barrier to aquaculture (Read and Fernandes, 2003). For example, the recent emergence of OsHV-1 μ var and *Vibrio aestuarianus* questions our ability to predict

and prevent the spread of potential new emerging pathogens (IFREMER, 2017). In addition, the eradication of *Marteilia refringens* and *Bonamia ostreae* is not possible. Thus, a better understanding of the dynamics of these parasites is required to identify their impact on shellfish cultivation and construct relevant stock management, conservation or restoration measures (IFREMER, 2017). Another barrier to the industry is the lack of systems in place to report and share data. For example depuration centres need to comply with requirements related to mollusc disease. However, we currently lack data defining disinfection and water treatment efficiency. Similarly, data regarding mortality and biosecurity measures is missing for mollusc production. Moreover, the current predicative models and mitigation measures utilised in the industry vary in complexity, scale and scope of application with many not sufficient to manage risks (Covato et al., 2017; Nunes et al., 2011; Ferreira et al., 2008). The control system is reactive and the ‘just-in-time’ approach causes barriers and concern for the profitability of the APB and continuity of supply for consumers (Jennings et al., 2016). Ultimately, a greater effort on aquaculture research, specifically dedicated to key threats and data deficiencies specific to each aquaculture production region, is crucial to sustain and grow shellfish cultivation. Provisions need to be made for more and better research (Read and Fernandes, 2003).

3.3.4 Collaboration

Research is key to gain an understanding of bivalve production, the risks and solutions. However, for this research to become effective and provide solutions to the industry it must improve the understanding of the end user. The current level of engagement and dissemination has been described as inadequate and ineffective (Turnball et al., 2011). Stakeholders are an important source of information providing critical perspectives and new insights on production risks and solutions. Thus, the integration of the stakeholder’s perspective is vital for defining meaningful research goals. Similarly, discussing the resultant findings with the end user will optimise scientific research results. The end user (e.g. farmers, retailers, government etc.) have

the best understanding of the farming system and are key to establishing the aspects which can be manipulated to reduce such threats (Turnball et al., 2011). In addition, governance of the aquaculture supply chain involves many stakeholders which carry out individual testing (regulatory and voluntary). At present, these data results are not shared between proprietor and other stakeholders. This information could be used to analyse trends, identify opportunities and establish an Integrated Coastal Zone Management (ICZM) approach which combines the objectives for various resource users within the coastal zone (Read and Fernandes, 2003). A number of collaborative projects have been undertaken to help achieve this goal and illustrate their important role in establishing effective scientific guidelines for aquaculture, e.g. AQUASPACE, ICES, MARAQUA and OAERRE. More collaborative work in this area can only be beneficial.

3.3.5 Availability of resources

Resources is the stock or supply of raw materials which are required for an APB to function. For shellfish cultivation an aqua-culturist requires species, facilities and equipment. In NI, species availability has been described as a barrier mussel farmers, whilst French hatcheries provide a consistent supply seed to facilitate the oyster industry (Habrey and Evans, 2016; Jennings et al., 2016). In particular, spat recruitment and growth described as a greater risk than disease to mussel farmers in Scotland (Murray et al., 2012). This problem could increase due to climate change and may require a greater reliance on hatchery produced seed or a more resilient species (Callaway et al., 2012; Cooley and Doney, 2009). Facilities are another crucial resource. Shellfish cultivation requires a suitable location which provides optimum conditions for growth. In NI, shellfish cultivation makes use of suitable and naturally existing coastal habitats (Callaway et al., 2012). However, a shortage of suitable sites; competition for that space from other users which take precedence e.g. tourism; and the ecological carrying capacity of existing sites have been identified as limiting factors to the developments of the kind seen

in Asian countries (Jennings et al., 2016; Alexander et al., 2015; Bostock et al., 2010). The carrying capacity of an area is defined as the standing stock at which the annual production of marketable cohort is maximised. It takes account of physical, ecological and social aspects of production (Ferreira et al., 2008). In terms of bivalves, this includes primary production, detrital inputs and exchange with adjacent ecosystems at the ecosystem scale; and, substrate, shelter and food transported by tidal currents and density-dependent food depletion at the local scale (Ferreira et al., 2008). It is vital to determine the carrying capacity of an area to ensure a sufficient supply of food, prevent over-exploitation and to minimise any ecological impacts. There is potential for shellfish cultivation to expand offshore, particularly as cultivation structures develop and other un-used models exist e.g. wind farms, however this has not been explored in NI (Lacoste et al., 2018; Nunes et al., 2011; Kapetsky et al., 2010). Another important resource to cultivate, harvest and protect shellfish is equipment. It is vital the material used to construct equipment does not transfer harmful substances to the molluscs and it is resistant to seawater. However, such specialised equipment and storage containers add expense and may never return from distant destinations. Normal agricultural equipment are relatively inexpensive but, they are generally unsuitable for molluscs as they can be difficult to clean, susceptible to corrosion and have reduced protective abilities. Thus, the reduced cost may be compensated for through unnecessary losses during production, handling, storage and transport (Seafish, 1997).

3.3.6 Storage and Distribution Systems

Bivalve molluscs are sensitive animals, prone to temperature stress, physical shocks and contamination. Thus any breakdown or delays during storage or distribution act as a barrier to shellfish production (Crovato et al., 2017; Jennings et al., 2016). This is particularly concerning for shellfish cultivation in NI as it is embedded in a global market involving import of seed and export of live shellfish and relies heavily on the function of supply chains that involve transport

by air or sea. An example of the uncertainty and risk this can introduce into the supply chain was illustrated in July 2015 when delays in the Channel Tunnel had devastating consequences to the Scottish seafood production and export business as their customers were rejecting or cancelling their orders due to deterioration. In addition, it's recommended that the live product is held in the protected and clean environment of a transport vehicle or a storage room in cool (2-5⁰C with the exception of blue mussels which should be iced) and moist conditions (Seafish, 1997). Throughout this stage, the product must remain packaged and sealed until offered for sale to the retailer, caterer or consumer, although it may be repackaged (and subsequently, relabelled). It is critical that the finished product is protected and remains traceable throughout this process. Moreover, any stresses on the shellfish, e.g. over-heating, physical drop or other damage, has a cumulative effect. Repeated incidents of relatively minor mishandling can result in the death of the animal and reduced economic return to the APB. Should the shellfish be held out of water, their eating quality deteriorates over time to the extent that their flavours become sour and undesirable to the consumer well before any physical response indicates death (Crovato et al., 2017). The smooth running of transport, storage and distribution systems are therefore critical for shellfish quality and safety, and also to the supply chains and consumers it supports (Jennings et al., 2016).

3.4 Political

Political factors are those relating to government policies and administrative practices that can have an effect on an APB. They include Legislation or Certification schemes which can prove to be both a barrier and facilitator to production.

3.4.1 Legislation

NI is part of the UK and Europe. The region has been a member of the European Union (EU) for 45 years. However, in June 2016 the EU referendum took place and the people of the UK

899 voted to leave the EU. The departure date is scheduled for Friday 29th March 2019. The post
900 Brexit regulations and issues around the NI border remain unclear. This brings huge uncertainty
901 and potential to an APB in terms of regulations and trade agreements in the near future. At
902 present, the sector is subject to legislation laid out at International, European, National and
903 Regional levels which considers a variety of demands including: environmental pressures,
904 animal welfare, food safety, productivity and innovation (Alexander et al., 2015). At European
905 level, a common policy and legal framework for aquatic health has been developed. The
906 aquaculture sector comes under the remit of the Common Fisheries Policy (CFP). These
907 regulations stipulate that member states (MS) must adopt provisions which comply with the
908 objectives, conservation, monitoring, resource management, environmental and technical
909 controls, and, reporting of aquaculture statistics stated in EU Directives (Read and Fernandes,
910 2003). Along with the 2013 revision of the CFP (EC, 2013), the Common Aquaculture policy,
911 Blue Growth agenda (EC, 2012) and the strategic guidelines for MS (EC, 2013), the EU
912 Commission intends to recognise and facilitate aquaculture in a sustainable and
913 environmentally sound way (Ferreira et al., 2008). Additionally, the EU is committed to the
914 principles of the precautionary approach, including guidelines for aquaculture in the FAO Code
915 of Conduct for Responsible Fisheries, in which Article 9 covers aquaculture development, and
916 other international initiatives including the ICES Code of Practice on the Introductions and
917 Transfers of Marine Organisms (Ferreira et al., 2008; ICES, 2005). In NI, regional legislation,
918 codes of conduct and codes of practice defines the responsibilities and procedures required to
919 adhere to EU Directives and international agreements, whilst focusing its effort on regional
920 and national needs (Read and Fernandes, 2003). In practice, compliance with these measures
921 requires registration of an APB, adherence to a biosecurity plan and inspection and monitoring.
922 In NI, registration of an APB is authorised by the Department of Agriculture, Environment and
923 Rural Affairs under EU Directive (2006/88/EC) (EC, 2006) and the Aquatic Health Regulations

(NI). The authorisation process is required to ensure the APB has the rights to the resources being cultivated, including the protection of these resources (Oidtmann et al., 2011). It typically has a number of conditions attached, including: species, location, production rates, water and waste discharges, interactions with other users, movement and disease control, drugs and pesticides, feed and food safety, monitoring and record keeping (Alexander et al., 2015; Oidtmann et al., 2011; Read and Fernandes, 2003). In order to attain registration of an APB registration, the APB must secure a licence and gain access to the land and water. A licence is issued under Section 11 of the Fisheries Act (1996) by the Environmental Marine and Fisheries Group (EMFG) within DAERA. There are two types of licence applicable to shellfish cultivation in Northern Ireland (1): Fish culture licences which are compulsory for all fish and shellfish farms. It is an offence to operate without this licence or in breach of any conditions attached, and; (2): Shellfish fishery licences which are optional additional licences for shellfish farmers which gives the licence holder the exclusive right to cultivate a particular species of shellfish within a specified area (and so the exclusive right to take that shellfish from an area) whilst protecting their operations (DAERA, 2018). The EMFG evaluates the proposed shellfish production; carrying capacity and suitability of the site; and potential environmental impacts. They will grant a licence based on the outcome of this assessment. This approval process is necessary to comply with the Water Framework Directive (EC, 2000), Marine Strategy Framework Directive (EC, 2008) and The Water Framework Directive Regulations (NI) 2003 governing water and waste water (Alexander et al., 2015; Dabrowski et al., 2013). Access to land and water is a necessary stage to ensure an APB has access to and occupation of the sea bed and coastal land areas for a long period of time to allow cultivation. It is governed by the EU Habitats Directive and planning regulations. In NI, coastal zones and the seabed (where shellfish cultivation takes place) is classified as state property and are owned by the Crown Estate, an independent commercial business created by an Act of Parliament to maintain and

949 enhance the value of the crown estate. Thus, a Crown Estate Lease is necessary to exercise the
950 planning permission or licence granted for aquaculture developments (DAERA, 2018; Seafish,
951 2016). An APB must also construct and submit a documented BMP to the Fish Health
952 Inspectorate (FHI) for approval. This plan identifies the veterinarian for the farm, risks from
953 importing disease via shellfish movements, other activities which may spread disease on site,
954 mitigation and monitoring procedures and the accidental introduction of non-indigenous
955 species, coupled with a list of actions to take in such events. Once this BMP has been approved
956 aquaculture operations can commence. Thereafter, a number of governing bodies are
957 responsible for monitoring and inspection to ensure licence conditions and legislation are
958 adhered to. The FHI is part of DAERA and they are responsible for compliance to the EU
959 Directive 2006/88/EC which stipulate requirements for animal health. This legislation makes
960 it an offence to place aquaculture species on the market unless they are clinically healthy and
961 an offence to spread disease (Alexander et al., 2015). Council directives also require health
962 certificates and veterinary checks for animals when moved in and out of the EU. The FHI audit
963 farms at least once a year to ensure compliance to their BMP; take samples for laboratory
964 analysis; and ensure movement and mortality are maintained for three years, health surveillance
965 records are maintained for 5 years (requirement of the veterinary medicines regulations) and
966 information on animal transport retained for a minimum of 2 years (Oidtmann et al., 2011).
967 The Food Safety Authority (FSA) ensures food safety and carries out the monitoring of
968 requirements in The EU Shellfish Growing Water Directives for the health and quality
969 standards of shellfish for human consumption. This legislation stipulates the level of
970 contaminants and algal toxins permitted in shellfish for human consumption (Gingagaspero et
971 al., 2009). The monitoring, location and boundaries of production areas must be fixed and
972 classified according to the degree of contamination with faecal indicator bacteria, occurrence
973 of toxins and presence of causative organisms. The legislation gives the FSA extensive powers

974 to close or prohibit shellfish harvesting where microbiological standards or biotoxins levels are
975 exceeded (Read and Fernandes, 2003). Additional conditions are placed on APB's which are
976 located in Natura 2000 sites. These include Special Areas of Conservation (SAC) under the
977 Habitats Directive (92/43/EEC) and Special Protection Areas (SPAs) designated under the
978 Birds Directive (79/409/EEC) (O'Carroll et al., 2016). Other stakeholders also exist in the
979 aquaculture supply chain. The Agri-Food and Biosciences (AFBI) are a non-departmental
980 public body who carry out high technology research and development, statutory, analytical and
981 diagnostic testing functions for DAERA on the aquaculture sector. The Loughs agency is an
982 enforcement body for the Lough Foyle, Carlingford and Irish Lights Commission (FCILC)
983 which was established under the Good Friday Agreement to promote the development of the
984 Foyle and Carlingford Loughs for commercial and recreational matters, including aquaculture.
985 The aim of all this legislation and enforcement bodies is to protect the consumer and
986 environment whilst facilitating the maintenance and development of the aquaculture industry.
987 , However, the extent of regulations have been criticised for constraining the industry in Europe
988 and North America. This concern is heightened by the fact legislation and monitoring adapt
989 and grow as a result of the ever increasing debate about the effect aquaculture has on the
990 environment (Alexander et al., 2015; Dabrowski et al., 2013; Hannon et al., 2013; Nunes et al.,
991 2011; Read and Fernandes, 2003). Interestingly, Asia dominates the worldwide aquaculture
992 production. The relaxed regulatory framework, in comparison to that in other regions, e.g. the
993 European Union, has been described as one of the driving factors for the rapid increase in
994 production in this region (Bostock et al., 2010). Conversely, NI retrieves a high economic
995 return for its products and its disease free status allows entry into lucrative markets. The
996 regulatory regime has been deemed as one of the most important factors is achieving the
997 reputation of quality and safe products. This reinforces the important and pivotal role

998 regulations and political factors can play in production output and value. It is important to get
999 the balance right.

1000

1001 **3.4.2 Certification Schemes / Self-Regulation**

1002 Self-regulation is the act of regulating oneself without intervention from external bodies.
1003 Institutional measures which are linked to legislative requirements, such as codes of conduct
1004 or codes of best practice, have been recognised as useful mechanisms of self-regulation at
1005 international, national and aquaculture producer association levels. Typically, codes of conduct
1006 (e.g. the FAO of the UN adopted a Code of Conduct for Responsible Fisheries in 1997 which
1007 includes aquaculture development) comprise of a set of general rules and principles that should
1008 lead to the responsible and sustained development of the industry, whilst codes of best practice
1009 provide guidelines for aquaculture to avoid causing pollution and optimise the environmental
1010 management of operations. Both take account of the best available methods, techniques,
1011 strains, feeding regimes, environmental sustainability and welfare of animals and other issues
1012 relating to aquaculture (Read and Fernandes, 2003). These measures, if used responsibly by
1013 Producer Associations, can facilitate the shellfish industry through voluntary restraints which
1014 lead to significant quality control and allow competitive advantage. Moreover, they instil
1015 sectoral responsibility and allow members to demonstrate their attitudes towards the
1016 environment and the consumer. Typically a code of conduct is accompanied by proactive
1017 actions within the sector, such as certification schemes (Read and Fernandes, 2003).
1018 Certification schemes define, inform and assure buyers and consumers on a particular certified
1019 attribute of a product. It goes beyond the requirements within legislation. They typically use a
1020 logo on product packaging or advertisement to illustrate the certified attribute which represents
1021 provenance, environmental sustainability and/or human or animal welfare standards. For

example, a Chain of Custody Standard aims to ensure traceability and segregation of products throughout the supply chain. These attributes are increasingly important considerations for producers, buyers and sellers in societies where people want to make choices about how they produce and source food (Jennings et al., 2016; Ward and Phillips, 2008). Certified products tend to be more expensive, but the certified attributes matter enough to add value or reduce risk for producers or buyers who can afford to make a choice (Jennings et al., 2016). Different schemes have different standards and there is ongoing debate about appropriate benchmarks for sustainability and the relationship between selected benchmarks and societal expectations (Jennings et al., 2016). In aquaculture, a large proportion of production is certified. Consequently, some certification schemes have become a necessary customer requirement placing extensive working standards and a financial burden on the APB to remain in the marketplace. Although, no single player has yet achieved the same dominance as the MSC in wild-capture sector (Jennings et al., 2016).

3.5 Welfare

Welfare in aquatic food production falls under three key aspects: Animal, People and Environment. In NI, APB's must adhere to the legal standards for welfare and the ethical expectations of society (Jennings et al., 2016). However, concerns have been raised about the welfare of people involved in aquatic food production and supply; environmental sustainability of production systems; the use of genetically modified species and; animal welfare. These concerns are becoming increasingly highlighted by lobby groups and certification bodies who raise awareness and influence the choices made by a proportion of customers and consumers (Jennings et al., 2016).

3.5.1 Animal

Aquaculture operations affects the quality of life and health of animals and the industry must act in accordance to the Animal Welfare Act of 2006 (UK Government, 2006). Stocking density, diet, and management procedures all affect welfare prior to death. In shellfish cultivation, the more stress the species encounters the lower the quality of flesh. As a result, bivalves are typically treated and handled with upmost care and animal welfare is actually an advantage of shellfish production.

3.5.2 People

The welfare of people working in the fisheries, aquaculture and food processing sectors has received considerable media attention (Jennings et al., 2016). Internationally, reports on the aquatic supply chain have involved thousands of people relating to bonded, forced and child labour and other modern day slavery and health and safety violations (Jennings et al., 2016; International Labour Organisation, 2013). In this supply chain a large proportion of production relies on industries where workers can be and/or are exposed to a higher risk of injury, death and human right abuses than many other jobs (Fox et al., 2018; Jennings et al., 2016). Some of these supply chains are known to support UK consumption. For example, in Morecambe Bay in February 2004, 23 of 38 illegal immigrants from China died when they were cut off by a rising tide whilst collecting cockles (*Cerastoderma edule*, Cardiidae). The gang master showed no consideration for the health and safety of its workers and was sentenced to 14 years in prison for manslaughter (in practice he was deported back to China in 2012). This event prompted the Modern Slavery Act of 2015 which consolidated existing human trafficking and slavery offences. However, there are still continued reports of human welfare issues in the aquatic supply chain. These are primarily associated with the wild fisheries (SOCA, 2013). Whilst aquaculture does not have a similarly high offence rate, it does involve relatively high fatalities. For example, the Scottish aquaculture industry endured 5 fatal accidents from 2003-2013 (Health and Safety Executive, 2014), equating to a rate of approximately 25 per 100,000year

¹. Therefore, it is necessary to ensure aquaculture production continues to generate food whilst supporting the communities and providing socially acceptable working conditions for the people involved (Jennings et al., 2016).

3.5.3 Environment

Aquaculture production causes a range of concerns from aesthetic to pollution issues affecting the current and future state of the environment (Jennings et al., 2016; Nunes et al., 2011; Smith et al., 2011). In particular, shellfish cultivation typically requires large areas of space in coastal areas. The presence of structures can reduce the natural beauty of the area, cause conflicting demands for coastal resources with other users; changed habitat and hydrodynamics at the site; and public concern around the visual aesthetics of structures in coastal areas (McKindsey et al., 2011; Ferreira et al., 2008; Read and Fernandes, 2003). Similarly the aquaculture operations, e.g. the use of destructive gear for seed collection, heavy vehicles accessing cultivation areas and release of chemicals from machinery, can alter, destruct or contaminate the natural habitats (O'Carroll et al., 2016; Forde et al., 2015). In addition, shellfish cultivation has been negatively associated with the consumption of phytoplankton, which reduces the availability of food for wild populations (Ferreira et al., 2008), and results in the bio-disposition of faecal material (Forde et al., 2015). This material enriches the sediment below with organic material and increases the oxygen demand of the area. Observations generally follow the model of organic enrichment and oxygen deficiency (Darbowski et al., 2013; Pearson and Rosenber, 1978). Consequently, species tolerant to high organic loading replace stress sensitive individuals and the diversity in benthic communities is reduced (Nunes et al., 2011). Studies have reported varying levels of impact. Some report significant reductions in bottom oxygen concentrations, increases of tolerant species and the formation of extensive bacterial mats under cultivation structures. Whilst, others have reported no or minimal significant effect in the community structure (Nunes et al., 2011). The level of impact has been related to distance from

1095 the aquaculture structures (greatest effects seen in areas closet to cultivation structures); site
1096 location (impact is lower in offshore sites); the hydrographic conditions (areas with high tidal
1097 currents prevent the accumulation of organic material); and the size and frequency of
1098 production (greater production rates have greater effects) (Lacoste et al., 2018; Forde et al.,
1099 2015; Read and Fernandes, 2003). One potential mitigation measure to address aquaculture by-
1100 products is Integrated Multi-Trophic Aquaculture (IMTA). This method involves using the by-
1101 products including waste from one aquatic species as inputs for another. However, this practice
1102 has not been used for shellfish cultivation in NI. A report by Seafish (2016) outlines the need
1103 for a rigorous economic feasibility assessment and subsequent funding opportunities before the
1104 exploration of innovative projects such as IMTA in this region. Other ecosystem consequences
1105 include the dumping of mortalities, introduction of non-indigenous species which may escape
1106 to become invasive and displace wild populations or, cause genetic interactions with the wild
1107 (Nunes et al., 2011); introduction and increased intensity and frequency of pathogens and
1108 disease and their transfer from the farmed to wild species and; an increased frequency of
1109 harmful algal blooms (Nunes et al., 2011; Read and Fernandes, 2008). Each of these
1110 environmental effects have the potential to change the predator and competitor composition
1111 (Tidbury et al., 2016; Parker and Tyedmers, 2014; Werschkun et al., 2014). Shellfish
1112 cultivation also has positive effects to biodiversity and it is important to consider these whilst
1113 assessing environmental welfare. The cultured species can help preserve biodiversity as it
1114 reduces predation pressure on commonly harvested wild species; increases the local and total
1115 productivity of an area if site selection is good (related to flushing and dispersal of nutrients);
1116 provides biodiversity recovery by reducing pressure on commonly harvested species; helps
1117 increase light penetration in the water column; and; improves the ecological status of the area,
1118 i.e. shellfish are filter feeders and can extract nutrients and contaminants from the water
1119 column, and; provides the market with high quality farmed shellfish (Nunes et al., 2011;

Ferreira et al., 2008). Moreover, for any remaining environmental consequences or concerns, an environmental impact assessment is carried out and reviewed by DAERA and its associated bodies to prevent long term ecological effects. This is part of the licencing system in NI. In general, bivalve cultivation has a relatively small impact in comparison to semi-intensive and intensive aquaculture systems; production involves high productivity in a small area and; impacts tend to be localised around production sites (Jennings et al., 2016; Hall et al., 2011).

3.6 Market

The market is the customers who pay a sum of money to purchase and/or consume shellfish, returning profits to the APB. Their needs and wants play a crucial role in the supply, demand and success of aquaculture production (Callaway et al., 2012).

In terms of needs, NI is part of the UK, a relatively wealthy nation claiming the fifth highest GDP in the world (IMF, 2015). Consequently, many other sources of nutrition are available and the supply of aquaculture is often focused on meeting the wants and expectations of consumers. These demands typically include food quality, quantity, safety, welfare, nutrition and price (Jennings et al., 2016). Health is a key motivation for aquatic food consumption. However, it is relatively expensive and many people tend to eat what they can afford as opposed to food they prefer. This encourages consumers to ‘trade down’ or eat less, reducing the amount they buy. Other barriers to consumption include a lack of knowledge about how to prepare shellfish, lack of available fresh shellfish locally, preparation time, dislike of the smell and need for meal planning (Jennings et al., 2016). There is also fear a disease outbreak, health scares or campaign groups may lead to a consumer boycott and threaten the export market (Jennings et al., 2016; Alexander et al., 2015). Health concerns are a particular concern since these commonly arise from contamination during handling, processing or storage by distributors, retailers and the consumer and thus pose an uncontrollable risk to the reputation

1144 and safety of an APB and the shellfish industry (Croato et al., 2017). Similarly, campaign or
1145 lobbying groups may intensify pressure by increasing consumer awareness and perceived
1146 impact of environmental and public health issues related to shellfish. For example, such groups
1147 can confuse and scare consumers through focusing heavily on the potential presence of micro-
1148 organisms, bio-toxins and chemicals in shellfish rather than considering the likelihood and
1149 benefits of consuming aquatic food. Therefore, risk communication in the supply chain is a
1150 very important element which should be addressed, particularly as risky behaviours by
1151 consumers including inappropriate storage conditions from storage to home, lack of respect for
1152 the cold chain and unsafe handling behaviours during food preparation have been identified as
1153 major causes for food disease outbreaks (Croato et al., 2017). At present, consumer demand
1154 in NI is described as quite conservative, with the exception of a few species such as warm water
1155 prawns. As a result, cultivated shellfish are predominantly exported as the local market is
1156 insufficient and not commanding a high price in comparison to the buoyant export markets
1157 (Habrey and Evans, 2016). This is contrary to the report from WHO (2010) who stated
1158 international trades in bivalves is very much regionalised with many regions unable to penetrate
1159 distant markets outside their province mainly due to technical barriers such as strict regulations
1160 on imports of bivalve products. This is a distinct advantage for NI shellfish production which
1161 is able to access major markets due to their strong reputation for high regulatory standards and
1162 disease free status (DAERA, 2018). The growing population, income growth and urbanisation
1163 will continue to create market opportunities (Kharas, 2010). However, this may also prompt
1164 the global growth of the industry and create competition from regions where current production
1165 is low but lower production costs and regulation and ignorance to environmental consequences
1166 of non-sustainable production allow aquaculture to be offered at a much lower price (Jennings
1167 et al., 2016; Nunes et al., 2011). Nevertheless, in parallel to the trend for intensification in areas
1168 (such as Asia) there is a growing demand for improved high quality, nutritious safer to eat

shellfish products occurring within the region (FAO, 2017b). This provides vital opportunities to NI and puts it in a unique position with its disease free and strict environmental welfare attributes attractive to these markets. The balance between global growth of aquaculture; trends in demand for aquatic food, outside and inside the UK; and the value placed on NI shellfish will likely influence the likelihood of investment in expanding aquaculture production in NI (Jennings et al., 2016). In order to access these markets and gain a strong market position, it is vital NI develops marketing structures and strategies. This importance is evident from the fact the industry in Africa and parts of Latin America suffered due to the lack of well-developed markets and an ability to reach them (Bostock et al., 2010). It is also important to consider the impact of changing climatic conditions which may become unfavourable for current species and potentially create opportunities for other species. However, it is more likely mitigation measures to overcome such barriers, rather than substituting the species will occur due to the consumer demand in the local and export market (Callaway et al., 2012).

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Figure 3: Simplified diagrammatic traffic light illustration of the key barriers and facilitators to shellfish cultivation in Northern Ireland.

Aquaculture is affected by six key categories: Economic, Environmental, Technical, Welfare, Political and Consumer factors. Within these categories a number of factors have been identified and illustrated as a facilitator, barrier or both to shellfish cultivation within Northern Ireland.

4 Facilitating Growth of Shellfish Production in NI

The information gained from this review has exposed the current barriers to shellfish production. These factors are an important advancement to those revealed in global reviews published by Muir and Young (1998) and Bostock et al., (2010). As recommended by these authors, it is important to study individual aquaculture industries in relation to these factors. In NI, it is evident that the availability of suitable sites is a limiting factor. However, there is

opportunity to increase the productivity of our current production sites. Moreover, the higher requirements in terms of food safety, sustainability, and welfare has contributed to the high value placed on NI shellfish products. This paper argues that this is the key opportunity to increase the profitability of the sector for this region. To allow this increased productivity and profitability the following recommendations have been determined based on the results discussed throughout the review:

1. Carry out a comprehensive review of the current financial support available to the industry and establish suitable funding mechanisms for growth (e.g. Capital Investment Schemes, Aquaculture Loan Arrangements, Aquaculture Subsidies and Insurance Options; Departmental budget for continued surveillance; and Research Grants to relevant research and development projects).
2. Translate scientific research into meaningful policy, procedural best practices and an economically viable model that will achieve sustainable production; improved farm profitability and resiliency; and more efficient use of resources.
3. Establish a platform to report and share data and create a robust scientific base of key statistics, economic trends and production data for the aquaculture industry.
4. Facilitate stakeholder engagement and partnerships between all members of the aquaculture supply chain, other water users, academia, government and consumers to address current challenges in our system, establish key opportunities for growth and deliver a shared strategy which makes a significant contribution to our aquaculture sector, the economy and the environment.
5. Take a consumer centric approach to understand the consumer and establish a Northern Ireland brand based on key unique selling points (e.g. origin green, sustainability, organic, voluntary labelling and certification schemes of consumer interest).

- 1220 6. Create timely, feasible and evidence informed policy briefings following a major review of
1221 existing regulation and international best practice; research translation; and stakeholder
1222 engagement.
- 1223 7. Assess on-farm training needs and develop a holistic plan for skills development and
1224 knowledge transfer to improve production volume and value
- 1225 8. Carry out a complete assessment of the current marketing structures and promotional
1226 activities associated with shellfish cultivation in NI against other successful countries to:
1227 create a clear food promotion strategy; proactively promote our NI produce; negotiate
1228 market entry; grow sales and exports; pursue new opportunities and improve
1229 competitiveness.
- 1230 9. Encourage innovation along the aquaculture supply chain, inspire entrepreneurs and work
1231 in partnership with other bodies (e.g. engineering firms, R&D services and business) for
1232 the commercialisation of robust, easy to use, rapid and inexpensive automatic equipment,
1233 mitigation measures, analytical techniques and value added products.
- 1234 10. Speak as a truly co-ordinated representable body which lobbies and supports for the
1235 aquaculture industry; bridges the gap between each of the stakeholders in the shellfish
1236 supply chain; advocates changing course on shellfish legislation; develops the skills and
1237 entrepreneurship of the industry; takes a leading role in improving the quality of coastal
1238 waters and takes responsibility for innovation funding to ensure a consistent and shared
1239 approach across industry.

1240 A number of key stakeholders already exist in the NI aquaculture sector (see political factors).

1241 A potential structure to ensure a collaborative and effective effort to undertake these
1242 recommendations could involve the amalgamation of suitable personnel from each of these
1243 organisations into a working group or professional body. The responsibility for each action or

recommendation is then delegated among those personnel (and organisations). This structure is outlined in Fig. 4.

In conclusion, the opportunities which exist for aquaculture production are extensive and lucrative, particularly due to a growing population and plateauing wild fisheries. Shellfish cultivation is impacted by a complex set of economic, environmental, technical, welfare, political and market factors. Each of these factors interact differently dependent on the aquaculture producing country. In order to engage in a strategic partnership to optimise global aquaculture production it is important for each region to define the role each factor plays in their industry. In NI, the priority is to ensure increased productivity of the current licenced sites coupled with high standards of production across the region. This will allow niche marketing opportunities of premium shellfish products into major and profitable markets. In NI a greater appreciation and effort to address data deficiencies coupled with the provision of financial, procedural and legislative support is required. This will: stimulate investment; improve competitiveness and productivity; and allow the industry to maximise its potential contribution to our local economy. The creation of a working group or professional body may provide a suitable structure to facilitate this and assign responsibility and accountability for each of the recommendations defined.

Figure 4: Facilitating growth in the aquaculture sector in Northern Ireland.

In order to facilitate a sustainable and profitable aquaculture sector government funding is needed to continue surveillance and research and development projects. The funding should be allocated following a comprehensive review of the financial status of the sector. The ongoing work within the sector and the recommendations within this review should be allocated to the appropriate stakeholders. The creation of a working group would facilitate co-operations between academia, industry, government and consumers to identify and address barriers in the aquaculture supply chain; identify research gaps; provide a platform for data sharing and surveillance; translate research to enable the development of new culture practices, technologies and solutions for farmers and decision makers; provide education and training for effective knowledge exchange; advocate and lobby to update shellfish legislation; and deliver a clear customer centric marketing strategy.

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