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Deliverable D7.2

Value chain analysis of case studies

8/3/2021

Executive summary

To improve selected aquaculture production processes is the overall aim of AquaVitae. A large part involves biology and technology but understanding also economic aspects of production will also be important to achieve sustainable production. This first analytical contribution from this WP describes the value chains of preselected case studies. In this we improve understanding of the production process, distribution, markets for both finished products and inputs and input-output conversion factors. This provides a basis for the coming studies on profitability and socioeconomics.

The "value chains" of the respective case studies differ considerably. Some are well developed with many producers, suppliers, and buyers, while others have not reached commercial production. The end-product from the chains also varies. Some chains' products are ready for consumption, while others are used as inputs in other value chains. These differences contribute to a case-by-case approach being employed. Primarily the first aspect of the global value chain (GVC) analysis, input-output structure, is described. Where information permits, a description of supply and markets, value adding along the various stages of production is presented. A brief description of industry organization is provided where applicable. Each case study section concludes with identification of value chain improvement areas and critical factors for development. Aspects related to power and competition were of little relevance for most CSs, as the industries are less mature. These will be more relevant in upcoming deliverables on business plans.

<u>CS2 Offshore macroalgae – the Faroese macroalgae value chain and the company Ocean Rainforest</u>
Macroalgae have been cultivated for industrial purposes reportedly since the 16th century. The industry ranges from wild-harvested macroalgae used as feed and fertilizers, to farmed macroalgae used for high value chemical compounds, food and cosmetics, or even for biofuels and bioenergy. Macroalgae aquaculture production is largely dominated by China and other Asian countries, but there is increasing attention in the Western world.

Cultivation is space demanding and with other industries and activities competing for space, locating farms offshore appears most promising. Yet this has proven challenging, and only a few are operative, one of which is AquaVitae industrial partner Ocean Rainforest. The value chain of Ocean Rainforest has potential for growth, yet many challenges remain. To achieve more cost-efficient processes further technological development is needed, especially in automation of harvesting. Capital investment is needed to take advantage of economies of scale. During AquaVitae, the value chain will explore the application of new mechanised harvesting method, as well as improvements to the cultivation and landing logistics. Further, the adequate valuation and recognition of the ecosystem services that macroalgae provides can be fundamental to encourage entrepreneurship AquaVitae will contribute with methodologies to calculate such values.

<u>CS4 Sea-based multitrophic culture – abalone, France Haliotis SA and South African abalone industry</u>
Abalone world markets are now dominated by aquaculture production. The main markets are China and other countries in South-East Asia. Smaller markets also exist in North America and Europe. The primary value chain stages include broodstock and egg production, incubation, start-feeding, weaning, grow-out, harvesting, processing and distribution. Production generally takes 3-4 years and is relatively

labour-intensive, as sorting, density adjustments and feeding are not automated. Both macroalgae and formulated feeds are used. Sea-based production is large in China and Korea, and the EU case study firm is sea-based. South African farming is almost exclusively land based. Products sold are generally fresh, frozen, canned, and dried for consumption. Size and quality are important price determinants.

The EU industry has been reduced and now consists of approx. 5 small-scale on-growing operations. The case study firm is profitable and expanding. The firm is highly vertically integrated, with all production stages from broodstock to primary processing in-house and a strong marketing department. The South African industry, now about 12 firms, has grown and generally been profitable. Most are vertically integrated from hatchery to primary processing. The final marketing and distribution in the South-East Asian markets is however outsourced to independent so-called agents. These seem to capture a considerable share of the price to consumer, likely reflecting strong bargaining power.

Integrated multi-tropic aquaculture is in its infancy in both the EU and South Africa, while Chinese farmers have long been co-culturing kelp and abalone and scallops and abalone. Key related value chain improvements are the ability to utilize infrastructure and personnel more efficiently, as well as providing customers a wider range of products. Growing macroalgae can improve feed quality and availability. Critical aspects are improving survival of oysters and scallops and improving efficiency in macroalgae culture. AquaVitae will contribute by establishing production protocols for these species.

<u>CS6 Sea urchin roe enhancement</u>

Sea urchins are a highly valued seafood product. There is a substantial world market for sea urchin roe with the largest market (approximately 80% of worldwide consumption) in Japan. Supply has diminished and the sea urchin market is not considered saturated, especially in the off-season. Overgrazed seabed barrens provide low nutrition availability, resulting in smaller urchins with small gonads. This provides a business opportunity for urchin roe enhancement.

Holding systems, enhancement practices and feed have been developed for gonads to reach a satisfactory market size in 10-12 weeks. Feed has a significant impact on the efficacy of the enhancement and the resulting quality of the sea urchin roe. CS6 focused on value chains in Spain and in Norway, which were found to differ quite significantly. Most of the harvest from Spain is consumed domestically, live or processed, with only processed roe being exported. In Norway, the commercial harvest of sea urchins is less developed, and a very small domestic market. Several companies have run small-scale or trial production, some focusing on live urchins, some on processing and roe production and one on full-cycle sea urchin farming. AquaVitae will contribute knowledge on roe enhancement relevant for both value chains.

This VCA has identified areas for value chain improvement. Value chain coordination needs improvement as sales channels for exports are not well developed. Better understanding of markets, adaptation of feed and improved transportation can provide market and product development. Roe enhancement technology can be improved especially from more efficient catch, knowledge on feed and feeding protocols.

<u>CS9 Offshore blue mussels – Danish and Swedish value chains</u>

Mussels have been farmed for centuries in Europe. Mussels are farmed at a large scale globally and within the EU. Production has doubled in the last three decades, reaching 2.2 million tonnes in 2018. Most of the mussel production currently takes place in coastal areas, yet to increase food production offshore, technologies and cost-efficient methods must be developed. Accordingly, this case study focuses on a Danish enterprise operating in the Great Belt in Denmark and a Swedish firm that operates off the west coast of Sweden where prospects to move offshore are interesting.

There are currently 14 active mussel farms in Denmark, most are in Limfjorden where there currently are four large and some smaller mussel producers. Two of those are vertically integrated, as they are either partly owned by a processing company or have their own onshore processing plants, whereas other farms are either selling directly to e.g. Dutch buyers or collaborating with processing companies. The products of the Danish firm are either sold fresh in the domestic market or exported to the Netherlands where the mussels are boiled and placed in cans and then sold as high-quality products in Holland or France.

In Sweden, mussel production is dominated by two large firms, but there are also smaller firms. Production is primarily directed towards the domestic market, but fresh mussel is also exported to the Netherlands. Both the Danish and Swedish firm are small players in a large international market which is dominated by buyers in the Netherlands. Because the firms are price-takers in European markets, they need to find economic and technical ways of reducing costs, for instance by increasing the size of their operation and taking advantage of economies of scale or finding a niche market. This development could take place through further consolidation and vertical or horizontal integration and would strengthen the firms' position viz-a-viz Dutch buyers. Seeking alternative markets for their products, for instance, in the firms' respective home markets, would also reduce their dependency on Dutch buyers. However, that may be expensive and can take time.

CS10 Freshwater finfish aquaculture - tambaqui

Tambaqui is an omnivore and the second-largest scaly fish after pirarucu in the Solimões–Amazon Rivers. Tambaqui are fast-growing and can reach 2 kg in 12 months. They are relatively easy to farm and have a good commercial value. These factors contribute to it being cultivated widely in Brazil and other South American countries like Peru, Venezuela, and Colombia (but Brazil accounting for 98%).

The majority of tambaqui farming in Brazil is carried out in extensive or semi-intensive production systems as earthen ponds and reservoirs. Currently, it is sold in regionalized markets. However, it has a wider and international market potential, because of its low price and good taste. Nevertheless, the tambaqui value chain in Brazil presents some challenges to be overcome to assure a sustainable development. These challenges include the seasonality of fingerlings supply, the absence of genetically improved lineages, the lack of specific feeds, the presence of intramuscular "Y" bones, and their low productivity in net cages. Specific tasks in AquaVitae are directed at improving triploid juvenile production and the bone issue.

The industrial organization is diverse. Most small and medium size farmers only operate as farmers. Some large farmers exist, and there are five processing plants that are vertically integrated with farming. These generally supply value-added products to supermarkets and other retailers. The smaller farmers sell to local markets directly or via middlemen. This is problematic from a sanitary and legal perspective and the lack of primary processing for production from small-scale farmers represents an important bottleneck.

CS11 Marine finfish aquaculture – linguado flounder

Linguado is a flounder species common along the south-eastern coast of South America, that has long been considered a candidate for aquaculture. So far only research production has been carried out. Culture of other flatfish is considerable in Portugal and Spain, and a bioeconomic model of production is developed that describes potential production and resource use based on these experiences. Growth and mortality seem comparable to sole production in Portugal. Similar investment and input use also seem reasonable to assume. There is currently only a supply of wild fish, and price information along the value chain is scarce. Wholesale prices for wild fish are relatively low, at about 14 real per kg (3.1 EUR), but examples from other markets indicate segments willing to pay considerably more. This also indicates that there is high mark-up from fisherman and wholesalers further in the value chain. A value chain for farmed products may well be more efficient, with less intermediaries and less fish going to waste. Farmers are also likely to have stronger bargaining power versus retailers. For comparison, the mark-up in the distribution stages for turbot sales in EU is relatively small. A linguado farming value chain would need to find and sell to customers with high willingness to pay and with few intermediaries to be profitable.

Feed accounts for a relatively large share, as is common for marine finfish. Juveniles also account for a large share. This reflects both high production costs and a small harvesting size. Improving productivity and fish growth/harvest size thus represents a strong opportunity for value chain improvement. A stable supply of juveniles is also critical for capital intensive grow-out farming. These are aspects that the AV projects aim to improve.

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1 Introduction

The AquaVitae project aims to develop and improve on several aquaculture production processes. The most attention and resources are devoted to biological and technological aspects within the actual physical transformation process. However, establishing a successful production or making a sound decision to stop further development, requires a more holistic understanding of the process. Thus, a work package (WP) investigating socio-economic aspects was included in the project. This report is the first analytical contribution from this WP, investigating value chain aspects of preselected case studies.

The selected case studies are offshore macroalgae (CS2), sea-based multi-trophic aquaculture (CS4), sea urchin roe enhancement (CS6), offshore production of blue mussels (CS9), freshwater fish aquaculture (CS10) and marine fish farming (CS11). This chapter describes the research methods and limitations of the work, whilst the respective value chains will be considered in the following chapters.

For some of the value chains, good industry and production descriptions have been available. For others, this deliverable will supplement the literature with easily accessible and digestible structured information about the industry, production processes and value chains. The information provided here will also serve as a good foundation for other tasks within AquaVitae, most notably the deliverables related to the economic aspects of the production (Figure 1).

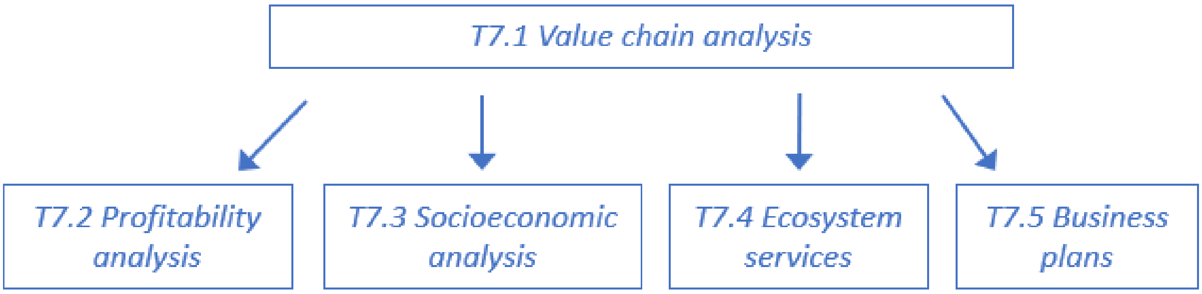

Figure 1 Information flow from T7.1

1.1 Research questions and delimitations

This report responds to task T7.1 "Value chain analyses of new LTS production and processes". Here the actual and planned production is to be described from raw material to consumer. This includes product and information flows, use of labour, investments, costs of production and revenues. Areas of improvement are also to be identified.

AquaVitae covers a total of five general "value chains" with 11 case studies, with each of these containing more than one species and production process. The description of action (DoA) narrowed the focus of this deliverable down to the six case studies mentioned above. Due to resource constraints, this is further delimited to cover one species or production process in each of the case study chapters.

The value chain description is in some cases delimited to stop before the traditional understanding of consumption. In some cases, process development has still not reached a stage where there is a product available or marketed to consumers and in one case the product from the AquaVitae production process is an intermediate product that can be employed as input in several other processes. The complexity and nodes in the value chain generally increase strongly during distribution and sale/retail. For resource reasons this cannot be covered in the same detail as the other stages.

The value chain encompasses several activities – a major distinction being made between primary and supporting activities. The latter includes areas such as research and development and general firm management. Although research is at the core of AquaVitae, in the value chain analysis, we focus on the primary activities.

1.2 Data and methods

To answer the research questions, value chain analyses were performed for the selected and delimited value chains. This methodology was described in AquaVitae deliverable D7.1, but a summary is provided here. As there is considerable variation between the case studies in important aspects such as industry maturity, data availability and value-chain areas of interest, the case study methodologies have necessarily been adjusted to context. Brief methodological remarks are provided in the introduction of each case study.

A value chain is the full range of activities that are performed to bring a product or service from conception to end-use. These can be undertaken by a single organization or more commonly distributed between several organizations. Between activities, business units and firms there are links that need to be coordinated. The processes are strongly influenced by several external factors such as competitors, institutions, and the general business environment.

There is no clear definition of value chain analysis. Here we employ aspects and methods from several of the perspectives that have been developed. The description of the production stages are inspired by the French systematic "filiere" method (Raikes, Jensen, and Ponte 2000) and where applicable, the description of competition within the industry is inspired by Porter's "five forces" model (Porter 1985) and the governance of an industry by the Gereffi "global value chain" perspective (Gereffi, Humphrey, and Sturgeon 2005). There is no clear definition of value chain analysis. Here we employ aspects and methods from several of the perspectives that have been developed.

Data and information are gathered through secondary literature and from interviews with value chain actors. These have primarily been sampled from the project partners and industry reference group, but also other sources of information have been interviewed. An interview guide was developed, and the actual semi-structured interviews have all, but one been carried out online. The COVID pandemic has caused problems for several of the informants, disrupting production, logistics and markets. Along with the travel restrictions, this again has in some cases made it problematic for us to get access to other sources of information and do farm and value chain visits. Hence, a larger share of the information presented has been derived from published sources than initially planned. This also implies that sections regarding value chain governance have been less developed than planned.

Especially areas concerning prices along the value chain, investment and production costs and organization of the value chain will be revisited in more detail in upcoming deliverables from this WP. These include business economic profitability analysis, socioeconomic impact assessment and business plan development.

1.3 Report structure

This chapter has introduced the research questions and methodologies employed. The report is further structured with separate chapters analysing the value chain for each of the six selected case studies. These are as follows from first to last: Offshore macroalgae, sea based multitrophic, sea urchin roe enhancement, offshore mussel, freshwater finfish, and marine finfish.

2 CS2 Offshore macroalgae

2.1 Case study introduction

Case study 2 analyses the production of the brown kelp species *Saccharina latissima* and *Alaria esculenta* in the North Atlantic, specifically the value chain (VC) in the Faroe Islands. Macroalgae cultivation in the Faroe Islands has successfully operated under offshore conditions (term is discussed in the next section) for almost 10 years and has reached commercialization stage. The cultivation methods used in the Faroe Islands have potential to be replicated in other offshore areas, hence this analysis can have broader relevance.

2.1.1 Methodological remarks

The value chain analysis for macroalgae production in the North Atlantic covers the basic dimensions of the Global Value Chain (GVC) framework such as input-output structure, geographical considerations, governance structure and institutional context. As macroalgae production in the western world is a new industry, focus was given to the first and second dimensions outlined in the GVC framework. For the governance structure and institutional context, a more general description of the macroalgae industry in Europe was provided, with focus on areas of improvement. Public sources were used to assess world production and main producers, as well as to describe the relevance of ecosystem services for the macroalgae industry. The value chain was described based on interviews with the case study leader and project partner. An interview guide was developed, and interviews were conducted as semi-structured based on this guide. As an expansion of the input-output structure, the production method for the project partner was analysed in detail based on these interviews. The market conditions for the macroalgae production in the North Atlantic was analysed based on information from literature and project partner information. The goal of this analysis was to identify pathways to improve competitiveness through increased efficiency and reduced costs along this value chain. Information on cost structure and value-adding was sparse to allow for a more formal analysis, which constitute a main limitation of the analysis. However, the analysis allowed for the identification of critical issues and areas of improvement in the value-chain.

2.1.2 Case study description

Case study 2 in the AquaVitae project studies the prospect for upscaling offshore macroalgae production. Aquavitae also contributes towards the adequate valuation of ecosystem services of macroalgae cultivation. Macroalgae[4] or seaweed cultivation, is a long-standing industry in Asia, where it has been produced at a massive industrial scale for over a century for food, animal feed, pharmaceutics and cosmetics. Over the last two decades interest in macroalgal cultivation has grown rapidly in the Western world (Bak et al. 2020; Buschmann et al. 2017; Kim et al. 2017; van den Burg et al. 2016). More product applications for macroalgae, increased consumer demand for natural and

[4] Macroalgae is a collective term used for seaweeds and other benthic (attached to the bottom) marine algae that are generally visible to the naked eye. Larger macroalgae are also referred to as seaweeds. They are distinguished from microalgae (e.g. diatoms, phytoplankton, and the zooxanthellae that live in coral tissue), which require a microscope to be observed (Diaz 2008).

organic products, potential for bioenergy production and growing interest in developing integrated Multi-Trophic Aquaculture (IMTA) practices are the main drivers. These new dimensions to macroalgal aquaculture have led to exploring the introduction and upscaling of macroalgal production also in offshore sites, even though this environment has proven to be very challenging (Bak et al. 2018; van den Burg et al. 2016).

The concept of "offshore production" was introduced with the electricity, oil and gas production activities in the open ocean. The term was later adopted by the aquaculture industry. Although the definition of "offshore" varies according to country and sector, a standardized definition was found for aquaculture cultivation where three categories were defined according to depth and distance to shore (Bak et al. 2020). The offshore site category is reserved for sites with a distance to shore of ≥3 NM; the nearshore exposed are sites with a water depth ≥50 m yet <3 NM from shore; finally, the nearshore sheltered sites are those with a water depth <50 m and <3 NM from shore, as summarized in Table 1.

Table 1 Three categories for macroalgae cultivation at sea defined by two site parameters: water depth and distance from shore (NM, nautical mile) (Bak et al. 2020)

Categories	Water depth	Distance to shore
Offshore	≥50	>3 NM
	<50	>3 NM
Nearshore exposed	≥50	<3 NM
Nearshore	<50	<3 NM

Several trials have been conducted to pursue large-scale offshore kelp cultivation, yet they have proven it is a challenging endeavour. (Buck et al. 2017; Roesijadi et al. 2008; Bak et al. 2020). Most of these trials were technically viable yet most of them are not currently operating or reached commercial stage (Bak et al. 2020). Among the few successful trials, AquaVitae (AV) partner Ocean Rainforest Sp/f (ORF) has successfully operated under nearshore exposed conditions since 2010. Their kelp farming structure is in a site with 70 meters depth and is 440-1,060 m from shore. The structure must withstand harsh weather events common in the Faroe Islands and therefore presents great potential for moving kelp farming further offshore (Bak et al. 2020). The structure is commonly referred to as Macroalgal Cultivation Rig (MACR) and has proven successful under these challenging conditions (Bak et al. 2018). Figure 2 describes the functioning of the MACR.

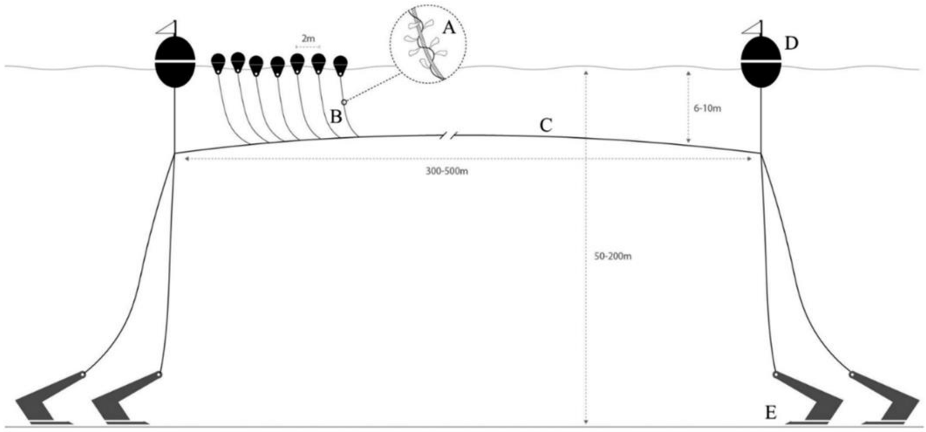

Figure 2 Schematic drawing of a Macroalgal Cultivation Rig (MACR) constructed by Ocean Rainforest Sp/f. The construction can be deployed for macroalgal cultivation at wave-exposed sites with a water depth of 50–200 m. Seed lines (A) are twined around growth lines (B) that are attached at 2-m intervals to the fix line (C) by a loop and held in a vertical position by a buoy. Two main surface floats (D) and four steel anchors (E) ensure the right position of the rig (Bak, et al. 2018).

The successful operation by Ocean Rainforest (ORF), has proven that the rig is robust enough under these highly energetic conditions, with potential to move the operation further offshore. With a scientific and innovative approach to macroalgal farming, ORF has tried for several years a non-destructive cultivation method that allows them to harvest up to 6 times from the same stock lines without re-seeding, called multiple partial harvesting. This method has produced the highest known harvesting yield per meter of seeded line[5] in Europe so far, with the potential to reduce the production cost by 75% according to Bak et al. (2018). However, this process still faces many challenges, reflecting the novel state of the macroalgae industry in Western countries. Even more cost-efficient methods are needed (from deployment to harvest). Further technological developments and an adequate and updated regulatory framework are necessary to enable profitable operation of macroalgae aquaculture in non-traditional producing countries to compete with a well-established and mature industry in Asia. Acknowledging the importance, this framework is discussed D8.1 of AquaVitae.

This section aims to provide relevant insights from the current value chain, processing and market conditions in the macroalgae production in the North Atlantic, with the goal to identify pathways to improve competitiveness through increased efficiency and reduced costs. The analysis will focus on the production method developed and applied by ORF in the Faroe Islands and their current value chain. This analysis will be the foundation for upcoming deliverables focusing on profitability, socioeconomic impacts and business plan development.

2.1.3 Industry description

Macroalgae have been used by humans, as food and feed, for centuries, whereas industrial uses have emerged more recently. Early utilization of macroalgae for industrial purposes was reported back to the 16th century, as component for medicinal treatments, transformed into gels or used as fertilizers.

[5] The highest yield is per seeded line, not the highest seasonal growth of brown kelp in the North Atlantic.

This industry has shifted over the years from utilization of beach-cast macroalgae as fertilizers in farming to high value uses, for example in the pharmaceutical industry (Buschmann et al. 2017).

Currently, most of the global aquatic algae output is produced in Asia for human consumption, while the remaining biomass is utilised as feed additives and in fertilizers. During the last decade, the macroalgae industry has experienced a significant expansion driven by growing demand in Western markets for contaminant-free macroalgae and for macroalgae-derived products for biotechnical and medical applications. Also, macroalgae is being used to mitigate environmental impacts of intensive fish farming through IMTA practices (Cook et al. 2016). The cultivation of aquatic algae is a relatively new industry in Europe and America. In the last two decades, brown kelp species have been increasingly cultivated in the North Atlantic Ocean (Kim et al. 2017) and as demand by western consumers continues to increase, the fast-growing macroalgae industry in the Northern Hemisphere is expected to continue expanding. Furthermore, macroalgae has been broadly acknowledged for its important environmental benefits, such as nutrient and carbon uptake and oxygen production. The public endorsement of macroalgae farming by popular environmental communicators such as Sir David Attenborough and Greta Thunberg, is very likely to have a positive impact on social license and public acceptance to macroalgae cultivation in Western countries.

2.1.4 Supply

The global aquaculture industry[6] has steadily increased its output since the year 1990. The world's production reached a record high of 114.5 million tonnes live weight in 2018. The cultivation of aquatic algae contributed to this output with 32.4 million tonnes wet weight. This accounts for approximately 27% of the global aquaculture production by weight and is estimated to be worth US $13.3 billion[7] (FAO 2020a). Figure 3 shows the growth of the global aquaculture industry output over the last decades. The contribution from aquatic algae to this growth is depicted in orange, and presents also steady growing output, with an important spike from year 2009, led mostly by the production of raw material for carrageenan extraction in Indonesia (FAO 2020b).

The importance that aquatic algae aquaculture has gained over the last two decades is clear when considering only marine and coastal aquaculture[8]. In 2018, aquatic algae (32.4 million tonnes) represented 51.3% of the global mariculture production, followed by molluscs (17.3 million tonnes, 27.4%), finfish (7.3 million tonnes, 11.6%), crustaceans (5.7 million tonnes, 9.1%) and other aquatic animals (0.4 million tonnes, 0.6%). Aquatic algae overtook molluscs production in 2000 and now represents more than half of the global marine and coastal aquaculture production (Chopin and Tacon 2020; FAO 2020b).

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[6] including both aquatic animals and plants in both sea water, freshwater, brackish waters and inlands saline waters,

[7] Farmgate sale value

[8] Also named mariculture, it excludes inland production of finfish

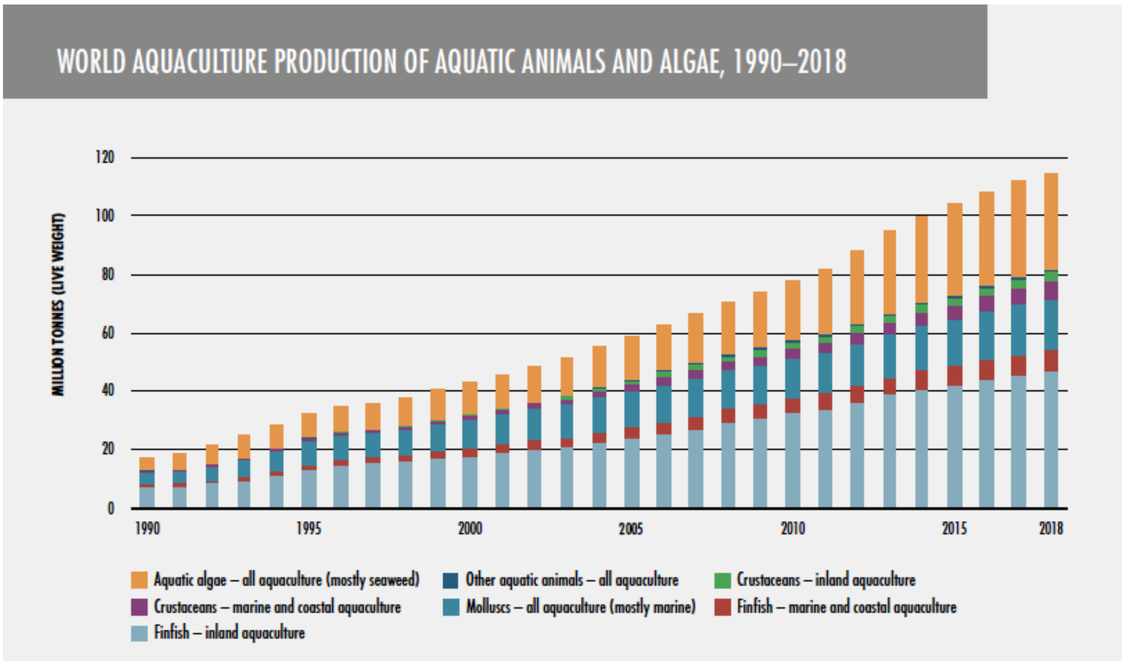


Figure 3 World aquaculture production of aquatic animals and algae from 1990 to 2018 (FAO 2020d)

Macroalgae production is dominated by a few species of brown kelps and red macroalgae[9] that account for over 81% of the industry's production (Kim et al. 2017). Cultivated kelp species accounted for 14.66 million tonnes wet weight, representing 45.3% of the global macroalgae production in 2018. The most cultivated species of the brown kelps is *Laminaria japonica* with a production of over 11.4 million tonnes in 2018, with China being its main producer, mostly for food (FAO 2020a). During the last two decades, kelp cultivation has extended to regions in Europe (Sweden, Norway, Iceland, Ireland and the Faroe Islands), North America (Canada and USA) and South America (Chile) (Grebe et al. 2019; Kim et al. 2017). In 2014, America and Europe produced approximately 54,000 tonnes valued at US $51 million (FAO 2016). Although the production of Europe and America is equivalent to 1.5% of the global gross production in 2016, it accounts for 4% of the production value (Grebe et al. 2019). This is due to the different conditions for macroalgae cultivation in Europe and America compared to those in Asia. On the one hand, kelp cultivation in Asia relies on low technology cultivation practices coupled with intensive labour at low costs. This cultivation method has been proven to be highly efficient and successful, as Asia has grown macroalgae at industrial scale for over a century for production of food, animal feed, pharmaceutical remedies and cosmetic purposes (FAO 2017). On the other hand, in Europe and America due to the economic, ecological and social framework surrounding macroalgae cultivation, commercial viability can only be reached through high value-added products with secured markets and reduced labour costs to balance significant technological investments and operational costs (FAO 2017; Grebe et al. 2019).

[9] From the brown kelps production focused on the species *Saccharina japonica* and U*ndaria pinnatifida* and, from the red macroalgae the species are *Pyronia* (in Japanese "nori"), *Kappaphycus alvarezii*, *Eucheumastriatum* (Carrageenophytes) and *Gracialiaria /Gracilariopsis* (agarophytes)

2.1.5 Products and markets

Macroalgae produce a versatile biomass with a wide range of applications, such as: (i) High-value and bio-based compounds used in edible food and feed ingredients, biopolymers, fine and bulk chemicals, agrichemicals, cosmetics, bio-actives, pharmaceuticals, nutraceuticals and botanicals; and (ii) lower-value commodity and bioenergy compounds used in biofuels, biodiesels, biogases, bio-alcohols and biomaterials. Macroalgae can be also processed into a broad variety of formats such as fresh, fermented, dried, powder or flakes, salted, canned, liquid extracts and as prepared foods for direct human consumption or processed into additives (Buschmann et al. 2017; FAO 2017; Hafting et al. 2015; Hishamunda et al. 2014). Due to this versatility, macroalgae have the potential to be processed under an integrated biorefinery concept, exploiting all the components of the raw material, and creating added value through processing (FAO 2017).

While the consumption of macroalgae as food in South-East Asia is common and traditional, with a market depending mostly on taste and price; their use as food in European and USA markets is more novel. There consumers consider additional parameters such as nutritional value with a strong preference towards organic, sustainable, and fairly traded products (Buschmann et al. 2017). In Europe, macroalgae are mainly used to produce hydrocolloids for the pharmaceutical industry, and in the food industry where alginate, agar and carrageenan are used as thickeners.

As this natural resource is still underexploited in Europe and America, efforts are in place to identify adequate production methods, processing, and market conditions to ensure a sustainable, competitive and profitable industry. This section and the future work in the AquaVitae project will contribute to increasing knowledge about these value chains, to the identification of opportunities to increase competitiveness, optimise processes and efficiently reduce costs, for a more profitable and sustainable commercial development.

2.1.6 Ecosystem services

When analysing the value chain of macroalgae, it is important to consider the ecosystem services that its cultivation provides. Natural macroalgae communities and aquaculture represent a significant sink for atmospheric CO_2 (Chung et al. 2017), they enhance primary production and thereby contribute to the global carbon, oxygen, and nutrient cycle. Algae production may contribute to several functions, such as wastewater management, nutrient recycling and even carbon capture. Both natural beds and cultivated farms of macroalgae provide nutrient cycling as well as waste purification and treatment services (Manninen et al. 2016; Buschmann et al. 2017; Chung et al.2017). In addition, algae contribute to reducing eutrophication and greenhouse gases, such as the release of methane associated with rearing herbivores (European Commission 2016). Figure 4 illustrates the possible applications of macroalgae cultivation and harvesting.

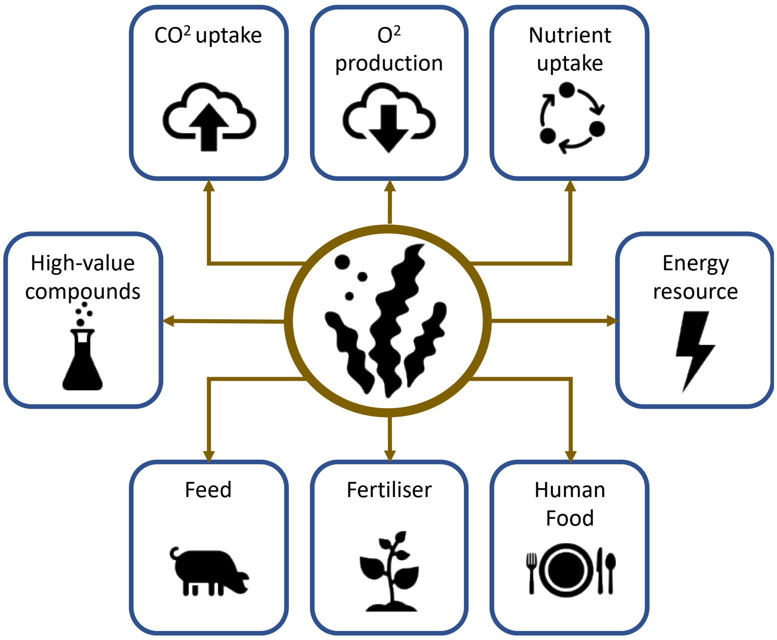


Figure 4 Possible applications of macroalgae harvesting and cultivation[10]

The ecosystem services role provided by macroalgae aquaculture often goes unnoticed by coastal managers, partly because the algae are hidden underwater, and partly because the services themselves are not yet accurately valued by markets (Barbier et al. 2009). The ecosystem services provided by macroalgae need to be recognized and valued appropriately (Chopin 2014; Buck et al. 2017). The recognition of the ecosystem services provided by extractive species and the implementation of financial mechanisms to trade these services, such as Nutrient Trading Credits (NTCs) and further regulatory incentives to encourage their application could provide benefits for the macroalgae farming industry, which currently faces the challenges of a new industry in a still immature market. Education and dissemination of the concept of ecosystem services will be key for their recognition by the general public, for their proper valuation by economic markets (Barbier 2012; Costanza et al. 2014), and appropriate use.

Finding methods to adequately valuate ecosystem services of LTS aquaculture, will be explored during the life of the AV project.

2.2 Case study specific value chain description

As mentioned, macroalgae produces a highly versatile biomass that can be processed in multiple forms for various and diverse uses. The present section focuses on analysing the production of two kelp species, *Saccharina latissima* and *Alaria esculenta* in the North Atlantic Ocean. Kelp has been cultivated during the last two decades in the in the United States, Canada, Iceland, Norway, Scotland, Ireland, Sweden, Germany, and the Faroe Islands. However, kelp cultivation in Western countries faces challenges related to regulatory complexities and social resistance to establishment of nearshore farm

[10] Adapted from https://www.submariner-network.eu/macro-algae-topic

sites. Hence, the prospect to cultivate macroalgae offshore has been suggested as an alternative to avoid stakeholder conflicts (Kim et al. 2017).

The company ORF has successfully cultivated kelp for almost one decade under nearshore exposed conditions.

This section presents a specific description of the macroalgae value chain as developed by ORF, which provides a general understanding of the value chain of the kelp industry in Europe and potentially North America, where ORF is currently collaborating with a scientific partner in the United States, the Bigelow Laboratory for Ocean Sciences, and since January 2020, a U.S. subsidiary of Ocean Rainforest - Ocean Rainforest Inc., started operating in Santa Barbara, California. Yield is the most important economic variable for seaweed cultivation, and ORF's novel multiple harvesting has shown very promising results as specified by ORF CEO Gregersen.

2.2.1 Stages in transformation process - Input-output structure

Macroalgae can be processed to two different main product types: as bulk and further processed products. The process used by ORF has been thoroughly described in Bak et al. (2018) and is main source of information for the following section. Yet, the processing methods have been updated and further described by company's CEO Gregersen. The updated production process and value chain are described below:

Biomass Production

The cultivation of the two kelp species analysed (*S. latissima* and *A. esculenta)* begins with the release of zoospores, then the mixture of gametophytes/sporophytes that develop from zoospores is seeded. Seeding methods differ between Asia where seeding frames are utilized, and the West where seed-spools are the most common practice, due to the nursery capacities and scale of the open water farms. Open water farms commonly use longlines where seed strings are deployed, and the kelp thali will grow (Stévant et al. 2017; Kim et al. 2017).

Seeding and breeding

- Seeding material was produced by a commercial partner of ORF located in the Netherlands until 2019, when ORF began to operate their own hatchery and nurse spores to sporophytes in their own facilities, they use a standard kelp sporulation process. The fertile macroalgae were collected from wild populations in the Faroe Islands in 2014.
- The breeding process is done in ORF hatchery. The company has a commercial agreement with Dutch company Hortimare BV to start a selective breeding program in the near future. Selective breeding is a key factor in macroalgae cultivation as it is critical for especially yield and quality.
- The selective breeding arrangement is expected to increase the yield of the farm by at least 30%.

Hatchery

- Spores are released under controlled conditions. The gametophytes were nursed in vitro for a period of 3 to 4 months in the company's laboratory facilities until sufficient biomass is reached. This process needs to be done once every year.
- The gametophytes develop into juvenile sporophytes in hatchery tanks within 2 to 4 weeks. Juvenile sporophytes are seeded directly into the growth lines with the sporophytes and a binder mixture and stored to be transported to the farm site for deployment.
- The hatchery requires trained personnel to conduct this process. The company currently has limited hatchery capacities and further investment in better facilities will be needed to upscale their production.

Deployment

- Seeded growth lines are transported by land from the hatchery facilities to the port, where they are transferred to a vessel, which transports them by sea to the farm location. A skipper and two operators are needed for this process.
- At the farm site, the growth lines (Figure 2, marked B) are attached along the fix line (Figure 2, marked C).

Farming

- The MACRs are inspected sporadically and according to the weather conditions they have endured. Inspection is done all throughout the year but is mostly needed during the growing season from January to March, where the harvesting season begins end of April.

Harvesting

- ORF uses the multiple partial harvesting method. Currently this is a manual process where the macroalgae is cut with a knife. This is a non-destructive harvesting method that aims to ensure regrowth of the thali[11].
    - Harvesting can be improved by mechanizing the operation, while keeping the non-destructive practice. Mechanizing this process can increase the harvesting capacity more than tenfold. This will require capital investment in vessels with tailor made equipment.
    - Mechanization is also relevant to control biofouling, which can constitute an issue when cultivating macroalgae. Biofouling can be controlled through adequate site selection, timing of harvesting periods and effective harvesting techniques (Visch, Nylund, and Pavia 2020). Mechanization is also relevant to control biofouling, which can constitute an issue when cultivating macroalgae. Biofouling can be controlled through adequate site selection, timing of harvesting periods and effective harvesting techniques (Visch, Nylund, and Pavia 2020).
    - Reducing harvesting time, decreases the storage time for unprocessed macroalgae which in line reduces the risk of deterioration.

Transport

- The harvested biomass is placed in plastic containers and transported by sea to the port and then by land to the processing facilities. Ideally, land transportation should be avoided,

[11] The production of *S. latissima* has been harvested twice a year, once during early summer and once during late summer. The multiple partial harvest of *A. Esculenta* is being tested and also aims to have two harvesting times a year (Bak, Mols-Mortensen, and Gregersen 2018).

when processing capacity is improved, the biomass could reach these facilities directly by sea, when landing infrastructure is available in the production site. As the quality of macroalgae biomass decreases quickly when extracted from the ocean, transportation to storage facilities should be swift and to ensure better quality the biomass should reach the storage stable stage as promptly as possible. The mechanization of the harvesting processes and improving transportation method, avoiding land transport to processing facilities, will contribute to this end.

Biomass Treatment

Macroalgae can be processed in multiple ways (e.g. dried, freeze, fermented, pellets, powder, etc.), where the key point is to achieve a storage stable state that preserves the qualities of the macroalgae according to the needs of the end-user. Macroalgae can be used for biofuels or bioenergy, where the biomass may require very little transformation and be sold in bulk. Further processing will be required for the food, feed, pharmaceutical and cosmetic industries, where additional requirements and quality controls might be needed. Freshly harvested kelp biomass needs to be treated according to the end-use to reach a storage stable stage in a short amount of time. The timing depends on the processing method.

In the case of ORF, they have the capacity to produce dried macroalgae with food grade apt for human consumption and to be added in cosmetics. Currently, most of the harvested biomass from ORF is ensiled and sold to be added to pig feed. The pig farming industry in North Europe is highly interested in macroalgae additives since they have proven to have several benefits for the pig's digestion, reducing the need for antibiotic treatment, piglet mortality rates and increasing weight at the time of slaughter, factors that have a major positive impact in the economic performance of pig farms (Morais et al. 2020; Corino et al. 2019; Ruiz et al. 2018; Øverland et al. 2019). This type of processing for animal feed additives can be expanded to the market of farmed cattle and other rearing herbivores; additional trials are undergoing. For this type of end-use, the macroalgae biomass is fermented and sold in bulk, to be incorporated into the pig feed. A small portion of ORF production is dried.

Pre-processing

- Washing and screening for debris. Remove rocks, snails and other entangled objects.
- Sorting. Biomass is sorted by hand for quality control immediately after harvesting. This process should also be swift to avoid biomass deterioration. Sorting is most relevant when the biomass is dried.

Secondary processing: Alternative 1 – ensiling

- Grinding. The washed macroalgae is ground into a 1mm pieces soup.
- Ensiling. Lactic acid bacteria and a sugar solution is added to the grinded macroalgae soup to bring pH levels down from 7 to 4 and make the product storage stable. The mixture is stored in airtight IBC containers of 1 tonne capacity to avoid contamination.
  - This process requires about 1 to 2 weeks and is not labour intensive
  - Ensiling does not require high energy consumption from the processing facilities.
- Transport. The macroalgae is ensiled and ready to transport to the buyer, in this case a pig feed processing company located in Denmark.

Secondary processing: Alternative 2 – Drying

- Spreading. The macroalgae material is spread in trays containing a food-grade mesh layer, approximately 1 kilo in each tray
- Stacking and drying. The trays are stacked up into towers of 15 trays and placed in a heated room equipped with dehumidifiers and fans. The process takes over 24 hours. The temperature of the dryer is 30-35 °C (86 F- 95 F). The macroalgae is dried to a water content of less than 30%.
- After-drying. Afterwards the racks are transferred into the after-drying room. This macroalgae is set to dry at 20-23 °C (68 F- 73.4 F) until <15% moisture content is reached – this takes 48 hours.
- Inspection. The drying macroalgae should be inspected and turned frequently to ensure the drying process is adequate and no section of the biomass are deteriorating.
    - The drying process takes approximately 3 days
    - This is a labour-intensive process, approximately 7 person-days for 800 kg wet weight of macroalgae. Dry weight is approx. 10% of wet weight.
    - Drying required significant energy inputs
- Packaging. The dried material is packed into food grade bags and boxes, in either mixed size (without milling) or after milling and sieving packed into particle sizes of <2 mm, 2-4 mm and 4-6 mm.
- Storage. Product is stored in a dry, cool storage room. Shelf life of the product is two years.

<u>Transport and distribution</u>

- Transport. The transformed biomass is transported by a hired transportation service to the port where the end product is shipped via sea. The ensiled macroalgae is sold to a pig feed producer located in Denmark, which is a natural market for the Faroe Islands. The dried macroalgae is sold to various customers mostly in the UK.
- Currently the product is delivered with transport and duty paid (DDP incoterms) to the buyer's factory.

The company ORF participates in the macroalgae value chain until this point. The product is sold as bulk to be further processed by the buyer. During the process little to no waste is expected, as the biomass is fully utilized in the fermentation process and no by-products remain. This type of processing does not require as much energy as drying or freezing of the biomass, and is less labour intensive, making ensiling a more cost-efficient process. By processing the macroalgae biomass through ensiling in bulk, ORF adds approximately 45% of the total potential value of the product. The value added throughout this processing method is described in Figure 5.

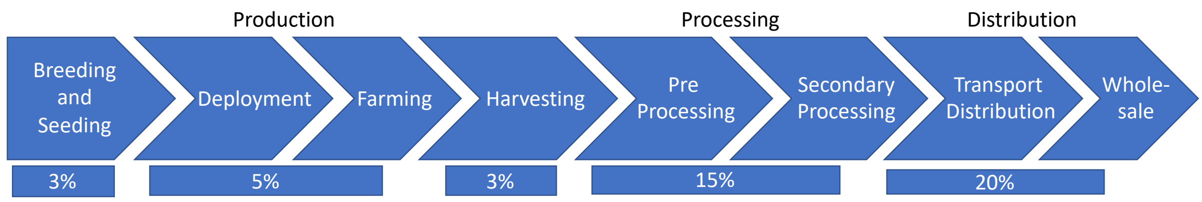


Figure 5 General diagram of the processing stages and value added along value chain for the macroalgae bulk industry

Figure 5 also shows the different stages for processing macroalgae in bulk, including also the value added to the macroalgae along the different stages. The biomass at this stage requires additional processing to be able to reach the end-consumer. For the specific case of the fermented macroalgae in bulk sold by ORF, the product will be added to pig feed at a 2% ratio, the pig feed will be then sold to the pig farming industry. At this level of transformation, the market of the fermented seaweed in bulk can expand into the cattle industry, where tests are undergoing to ensure animal safety and nutritional benefits of a seaweed component, says ORF representative.

<u>Additional processing – Processed macroalgae</u>

Tertiary processing and repackaging

- Reception and quality check. The containers of macroalgae arrive to the processing factory of pig feed. The product is inspected and is quality checked.
- Macroalgae addition to feed. The fermented macroalgae biomass is incorporated into the pig feed processing. The representative from ORF explains that the biomass is separated into a solid and liquid content, with a ratio of 1/3 seawater content, the separated biomass is mixed with rapeseed meal where the water content from the macroalgae moistures the canola content from the meal, which ferments to achieve the desired pro- and prebiotic dimensions of the pig feed.
- Quality control of final product. The final product with the macroalgae addition will require additional quality controls before packaging for distribution.
- Packaging. The final product is packed to be sold to the end-users
- Distribution. The pig feed will be transported to end-user

Retail - Sale to end user

- Retail. The product can be sold to wholesalers, specialized agricultural stores or the pig farmers directly.

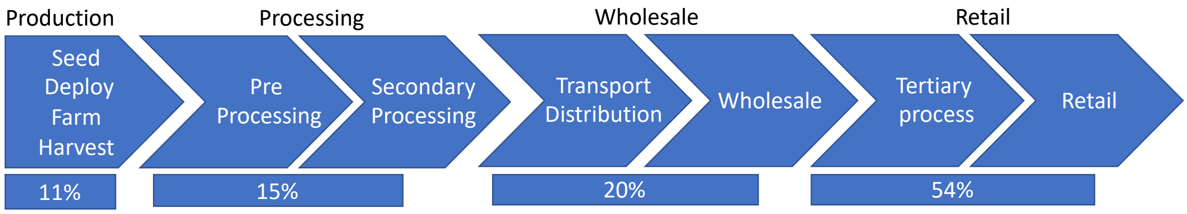


Figure 6 General diagram of the value chain for the macroalgae processing industry including percentage value added through the processing stages.

The value chain of macroalgae is completed when the product reaches the consumer. Figure 6 presents the last stages of processed or transformed macroalgae into a product ready for retail. The final stages to achieve retail add the remaining 65% to the final potential value of the product, as shown in Figure 6.

In order to summarize the value chain analysis presented above, Table 2 contains the description of the input-output structure of macroalgae processing at firm level, as presented above and according to the information provided by AV partner ORF.

Table 2 Themes for value chain input-output structure description – firm level

Inputs	Production	Harvest/primary processing	Secondary processing	Distribution and marketing
Types of inputs - Seeding material - Breeding - Hatchery - Bind seeded material to lines	Types of products - Fermented *S. latissima* in bulk - Fermented *A. esculenta* in bulk	Harvest process - Pulling growth lines - Manual harvest to containers - Transport to processing plant	Processing process - Washing - Milling - Fermenting - Quality check - Store stable	Transport mode and times Shipped by sea all duties paid (DDP)
Conversion rates - Seeding rates - Extraction rate: How much product from processing - Waste	Production process - Seeded growth lines - Deployment to MACR - Farming	Products harvested - *S. latissima* wet weight - *A. esculenta* wet weight	Products processed - Fermented S. *latissima* in bulk - Fermented A. *esculenta* in bulk	Sales channels Business to Business
Equipment/capital requirements - Licenses - MACR installation - Boats - Harvesting equipment - Processing facilities - Mill - grinder - Storage capacity	Scale - Full commercial scale in bulk	Labour involved - Biologist for seeding, breeding and hatchery - Technician for loading and transport - Skipper for transport to farm site - Harvesters	Labour involved - Technicians for washing, grinding and fermenting - Technicians for ensilage, storing and loading - Production manager - CEO	Storage Ensiled product
Scope of sourcing Equipment - National Seed material national	Labour requirements Three operators and one skipper in one vessel	Labour requirements Two operators and one skipper in one vessel	Labour requirements Three operators	Sales intermediaries Business to Business
Scarcity – commodities None - Recycled equipment	Waste Some macroalgae might be discarded at sea if severe fouling is found	Waste Almost no discards	Waste Almost no discards due to grinding and fermentation process	Markets, outlets and customers Pig feed producers
				Marketing activities Business to business

2.2.2 Cost structure and economic performance

Competition

Macroalgae is a well stablished market in Asia, yet a new industry for western countries. Yet, macroalgae farming in the North Atlantic is unable to use the same production practices. Asian algae production is labour intensive, in dense nearshore cultivating sites, where low-technological integrated aquaculture is practiced. Their cultivation and seedstock have been refined over the centuries and can now be highly sophisticated. This allows them to produce large amounts of macroalgae that are sold as a commodity, where the price is set based on quality and taste, in a highly mature market (FAO 2017). Western macroalgae production, in contrast requires capital investment for technological development, while reducing costs potentially through economies of scale. For this industry, it will be more likely to develop and expand to offshore cultivation sites to avoid stakeholder conflicts, as most of the nearshore waters are heavily used having both recreational (boating, fishing, swimming) and aesthetic (ocean and bay views from waterfront homes) values (Kim et al. 2017). Further, interest in macroalgae cultivation in the Western world has been mostly driven by the potential of the product for high value applications and for the value of the ecosystem services it provides. Therefore, western-produced macroalgae may need sufficient differentiation and a price premium to ensure economic viability. Yet, competition in the range of dried products for human consumption from China is expected as they are the largest macroalgae producers in the world, where the brown kelp *Laminaria japonica is produced,* and can directly compete with *Saccharinna latissima* and other brown kelp from the North Atlantic.

In the case of ORF, for the dried macroalgae segment, they do not expect immediate competition from Asia as they serve a market niche that prioritizes denomination of origin and handling of the product over low price. For the ensiled macroalgae segment, Norway is a more likely direct competitor. Norway is establishing its macroalgae industry, some of them in association with the fish farming industry, which also started providing fermented macroalgae to the North-European market. Yet, the production level in Western countries is still low, with supply limitation a price premium is still possible, as sufficient demand for this product exists and seems to be growing. As ORF's CEO manifested, his current productive capacity is fully sold, and he is constantly inquired about the availability of more production by potential customers. However, the actual customer base is still to be verified. At this early stage of a European macroalgae industry, rather than pursuing customers, competition is still focused mostly on establishing a strong investor base to upscale their production and increase their capacity to be able to steadily supply macroalgae biomass to a growing international market.

Costs of production

Reducing costs to achieve maximum return is one of the main goals for any enterprise. To be able to consolidate macroalgae production in the West, technological development and site selection are key factors. Technological development including selective breeding, cultivation, harvesting, transport, storage, processing, ecosystem services and product opportunities are needed to ensure productivity and long-term financial viability of these new endeavours, on the path to biorefinery of macroalgae and biofuels. Site selection is needed to ensure fewer restrictions to farm size and a greater economy of scale (Kim et al. 2017).

The above were some the factors mentioned by ORF's CEO, Ólavur Gregersen, when asked about the cost of ORF's operation and its economic performance. He mentioned that the costs of producing macroalgae at this early stage of their activity are still high. As the company and the market matures, the potential of taking advantage of economies of scale increases and hence, to reducing costs of operation while producing large volumes. As mentioned, technological development and site selection are key to producing large volumes of macroalgae in Western countries. The first challenge that ORF overcame was to achieve stable macroalgae production under nearshore exposed conditions. Since 2010, they operated under a license lent to them by a large salmon farmer which was not utilizing its right to farm in this site[12]. Since successfully operating over one decade, the company is ready to expand its operation and has already obtained license to farm in other sites in the Faroe Islands. As the company has the knowledge and capacity to operate under nearshore exposed conditions, they now could move further offshore, which enables them to farm in vast marine areas, if licenses and sufficient capital is obtained. Having more sites available allows them to increase their productive capacity and reduce operation costs. Mr Gregersen mentioned that if they can double their current productive capacity, they will reduce the operation costs by 10%. Mr. Gregersen explained that for

[12] ORF farm is currently located in the mouth of the fjord named Funningfjørður with a water depth of 50-70mts exposed to currents of 15-25cm s^{-1}, characterized as exposed area subject to significant wave height of 3-6 m (Bak et al. 2018)

them, the best scenario is to be able to deploy as much equipment as possible at once, which will imply the installation the maximum number of MACR possible in the authorized area, as the cost of this operation is high. Once the MACR has been installed cultivation can be done with little maintenance for around six years. Other materials need to be renewed during this life span, for example the growing lines need replacement every three years. Also, ORF utilises recycled equipment from the fishing industry, which is the largest industry in the Faroe Islands. They can use floats, buoys, anchors, chains and other equipment that are no longer used which enables large saving in the cost of installing the necessary infrastructure.

The next challenge is then to develop the necessary technology to operate the farm more efficiently. Technical development is currently needed especially for harvesting and processing the macroalgae. With the possibility to expand, the company needs to increase efficiency while preserving the processes that have proven successful over the years. For example, as described above the macroalgae is currently harvested manually, in a non-destructive manner that allow regrowth and hence multiple harvests during the productive season, which has proven to maximize the yield of the farm while reducing operating costs (Bak et al. 2018). To continue this practice, the company needs tailor-made equipment to be integrated to a new vessel with larger capacity. Mr. Gregersen has envisioned a vessel with all the necessary equipment for a fully mechanized harvest of macroalgae that will only require two operators on board. The equipment is designed to keep the kelp thali to the necessary length to allow for multiple harvests. Further, the harvested biomass could be stored and sailed directly to the processing factory onshore, without any human manipulation. This technological leap forward will scale up the productivity of the farm, currently limited by the manual harvest practice. Currently, harvesting requires three operators on board that can harvest 3 tonnes per 8 hours work. The automatization of the process can increase productivity to 60 kg per minute, while reducing labour costs.

A comparison between the investment structure of ORF according to the depth of the cultivation site and the length of the growth lines was provided by Mr. Gregersen. Figure 7 compares MACRs located nearshore sheltered and nearshore exposed. The nearshore sheltered area has 25 meters depth, 4 mainlines, 500 meters long mainlines, 5 meters long growth lines with 1 meter in between the growth lines. The exposed represents a MACR located in a nearshore exposed area with 50 meters depth with the same number of growth lines of 10 meters long each. The major investment is anchoring, lines and floats. Investment for the exposed site is about double, but the growth lines are also double in length. The relative share of the investments is changed. A higher share of investments are floats and lines, and less for the other components. Currently, ORF operates 8 mainlines, that is double the capacity described above.

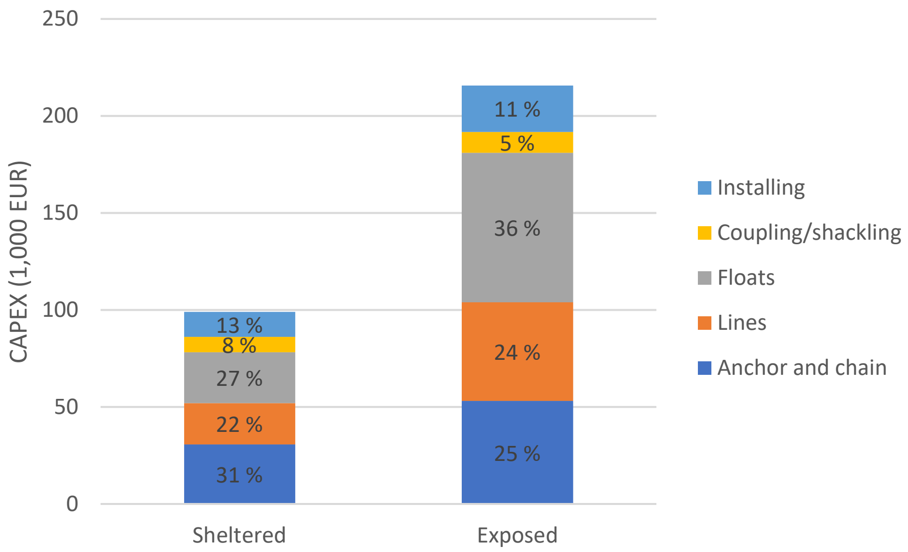


Figure 7 Total investment for one MACR type 2, 25 meters depth (nearshore sheltered), 4 mainlines, 500 m long mainlines, 5mt long growth lines with 1 meter in between the growth lines and MACR type 3, 50 meters depth (nearshore exposed), 4 mainlines, 500 m long mainlines, 10mt long growth lines with 1 meter in between the growth lines

Economic performance

The economic feasibility of macroalgae cultivation in the Western world is still an open question. Several studies portray an overly positive picture of macroalgae cultivation, yet there are important challenges to make this industry viable (Chopin and Tacon 2020; van den Burg et al. 2016). Integrative approaches such as IMTA and the synergy of offshore industries such a wind energy plants, appears to be an attractive strategy to increase profitability of the integrated production systems, plus they imply important environmental benefits. Yet, there are significant risks associated with the co-use of marine space which makes the concept difficult in practice. Mr. Gregersen considers that integrative approaches as still disconnected from the realities of ocean farming. The economic viability of the macroalgae industry in the Western world does not seem to depend on the integration of the operations. A specific study done in the North Sea concluded that the combination of a macroalgae farm with wind energy platforms did not improve the profitability of the macroalgae (van den Burg et al. 2016). Other studies comparing the performance of macroalgae farms aiming to farm offshore, further revealed that reaching commercial viability is still challenging and very few initiatives have been successful (Kim et al. 2019; Bak et al. 2020). The integrative aquaculture and industries synergy concepts are difficult, further knowledge is needed but most importantly, any further development must be addressed in close collaboration with macroalgae farmers, policy makers and scientists.

ORF is one of the very few successful cases of macroalgae farming under nearshore exposed conditions that have achieved commercial scale production. Their approach to reaching a profitable operation is upscaling instead of pursuing integrated aquaculture or synergies. As they advance in their incursion into a novel industry, they are still carrying most of the risks from the operation and commercialization themselves. Financial instruments and insurance policies are still very limited or inexistent, mentioned ORF CEO. They are part of a yet immature market, where the utilization of macroalgae additives has been only recently tested and approved for pig feed. Hence, their bargaining power is limited, having to take most of the risk of cultivating and selling the product until consolidating their market position. They cannot incur into the additional risks that the co-use of marine space, as the IMTA approach entails. Salmon farms have large nutrient emissions. IMTA with macroalgae could compensate for this and provide mutual benefits. However, Mr. Gregersen said the Faroese waters have sufficient nutrients for seaweed farming, so that this would not be necessary for them. The concept of regional emission balancing, where the activities are strategically located within a region but not necessarily in close proximity, is more interesting for him.

Mr. Gregersen states that the most important factor for seaweed farming is the yield. The higher the yield of the farm, the higher the return from capital investment. The company has worked to increase their yield per meter by conducting important research trials on their cultivation methods. The results from these trials were published by (Bak et al. 2018). Table 3 summarizes the results from these trials and together with their evaluations concluded, that by utilising the multiple partial harvest method, they could reach a 75% reduction of costs per kg cultivated if six harvests per growth lines are achieved.

Table 3 Cost calculations for cultivated kelp at an offshore and exposed site in the Faroe Islands using the special designed Macroalgae Cultivation Rig (MACR). This case represents one MACR seeded with 2500m of Saccharina latissima (Bak et al. 2018). *Costs in Euro and weight in kg dry weight.*

		Base scenario	Alt. scen. 1	Alt. scen. 2	Alt. scen. 3
Production	Total meters of growth line	2,500	2,500	2,500	2,500
	Years with same growth lines	1	1	2	2
	No. of harvests per year	1	2	2	2
	No. of harvests without re-seeding	1	2	4	6
	Average yield per m	0.29	0.32	0.37	0.29
	Cumulative yield per m	0.29	0.58	1.15	1.73
	Yield per MACR/ha	718.75	1437.5	2875	4312.5
Economic	Cost of MACR/year	6,800	6,800	6,800	6,800
	Cost of growth lines/year	14,900	14,900	7,450	4,967
	Operating cost/year	4,700	9,400	9,400	9,400
Costs	Cost of rig/kg macroalgae	9.46	4.73	2.37	1.58
	Cost of growth lines/kg macroalgae	20.73	10.37	2.59	1.15
	Operating cost/kg macroalgae	6.54	6.54	6.54	6.54
	Total cost/kg macroalgae	36.7	21.6	11.5	9.3

Mr. Gregersen explains that for ORF their ideal scenario will be to install as much infrastructure as possible at once, and from there continue cultivating a highly productive breed of seaweed that will be harvested several times during the productive season, without the need to reseed the lines after each harvest[13]. Further, to maximize the use of the resources, where the installed infrastructure and equipment can be fully utilized such as changing equipment, changing seeding lines, buoys, anchors and also reduced farming time and labour expenditures. Production volumes under current operating

[13] Multiple partial harvests

circumstances are on the range from 80 to 100 tonnes per year and they aim to reach 120 tonnes from one MACR.

Currently, production volumes are not enough to be economically viable, yet the company's investment value continues rising as they achieve important milestones and increase their knowledge and productive capacity.

2.2.3 Organization and governance

The macroalgae industry in Europe is at infant stages. The production of macroalgae in Europe is largely based on the harvesting of wild stocks. Commercial aquaculture of macroalgae is only found in France (Brittany, 6 farms), Spain (Galicia, 2 farms), Faroe Islands (Funningfjørður, 2 farms) and on an experimental basis in Ireland, Asturias (Spain), Norway and the United Kingdom. In France, where the most farms are located, almost 60,000 tonnes of macroalgae are produced annually, however only 50 tonnes come from aquaculture; the rest comes from wild macroalgae located offshore or onshore and from beach cast macroalgae. The main species produced is *Laminaria digitata*, with landings between 40,000 and 60,000 tonnes annually for a turnover of 1.7 to 2.7 million €. The total landings for *L. digitata* are dictated by the processing industry in relation with their capacity to process fresh algae (with treatment plant capacities ranging from 40,000 to 47,000 tonnes). The total amount of macroalgae required by the industry is divided among the boats, and a contract is established between the industry and individual fishers (Mesnildrey et al. 2012). Only two species are cultivated in France, *Undaria pinnatifida* and *Sacharina latissima,* for the latter only around 12 tonnes are produced a year.

The market for macroalgae produced in Europe is mostly destined to the food processing industry, chemistry and microbiology, followed by the agricultural supplies industry and in a small proportion for food distribution. The domestic production is not enough to meet the demand; hence imports are needed (Mesnildrey et al. 2012).

These numbers reveal the present status of the industry in Europe. The development of macroalgae aquaculture in Europe mainly depends on the success of new endeavours, as ORF and the expansion of existing ones. Trials are currently underway, which intend to vertically integrate the seafood production industry, by incorporating macroalgae and mussels to existing fish farms, though the implementation of IMTA processes. The Norwegian fish farming producer Lerøy is currently testing this type of operations[14].

Yet, for the new endeavours that are currently cultivating and commercializing macroalgae, their market position is still weak. Their bargaining power is limited as their presence in the market is new, as well as the knowledge about the product there are providing. Business relations are mostly dominated by the buyer, who can dictate the trade conditions. As is the case of ORF, which as mentioned earlier, is required to deliver the product with transport and all duties paid to the buyers' facilities. This entails higher costs of transportation and insurance, which further represent higher risks. Yet, in the case of ORF, they can charge a higher price for their product as the supply is very limited.

Furthermore, as the knowledge from this novel industry and its processes is still limited in the financial and insurance sectors, new companies are faced with the very limited and few adequate credit lines,

[14] https://www.leroyseafood.com/en/sustainability/ocean-forest/

financial instruments, and insurance to their product. Further research will be conducted in this aspect during future work in AV project.

Finally, in terms of legislation, the focus of government intervention must be to provide an enabling environment for aquaculture to prosper, while also ensuring that negative externalities that arise from the aquaculture activities are alleviated (Hishamunda, Ridler and Martone, 2014). Currently, macroalgae farmers are required to abide to regulations adopted from fish farming, which can be restrictive and strict. Yet, macroalgae aquaculture, provides an ecosystem balancing service to fish farming that should be considered. During his interview Mr. Gregersen mentioned that, at the local level he has met positive and understanding policy makers and the regulatory framework is positive changing to reflect the reality of macroalgae farming. Yet, this is not the case at the international level, where more restrictive laws can block entrepreneurship. As examples, Mr Gregersen mentioned that to abide to some of the rules to obtain the European organic certifications, which are crucial to reach premium price and a broader market, is nearly impossible in the small archipelago of the Faroes Island, as they impose a minimum distance to settled areas. Another example, he mentioned, is the requirement to conduct expensive surveys to obtain licenses to operate in North America. Developing a business-friendly, yet sustainable and adequate governance for macroalgae farming is a critical aspect to ensure the development of this value chain. Aquavitae is discussing the legal frameworks of low-trophic aquaculture in D8.1 and will further contribute to this topic in by analysing the impact of existing policy frameworks and provide recommendations to promote the development of macroalgae cultivation and other LTS aquaculture.

2.2.4 Value chain improvement areas

This section has presented an evaluation of the value chain of the macroalgae cultivation in the North Atlantic, with particular focus on the experience from AV partner ORF. The stages of the macroalgae production were described with focus on ensiled macroalgae for pig feed additive and dried macroalgae for food. Several issues have been raised and elaborated throughout this analysis, which will be summarized in this concluding section to highlight the key areas of improvement that this industry will need to focus on to grow and reach economies of scale. These key areas will be taken to further analysis in future deliverables from the AV project.

The first critical area of improvement is selective breeding. To produce resilient and highly productive macroalgae seeds selective breeding is fundamental. Adequate breeding enables maximum yield in to the cultivated macroalgae, which was identified as the most important factor for this operation. Furthermore, adequate breeding also ensures higher quality of the biomass which can contribute to marketability and higher price of the product. This is an undergoing process for ORF and is expected to show results in the future. Efforts to implement selective breeding in macroalgae farms is recommended.

The next area of improvement relates to the general lack of recognition of the ecosystem services that macroalgae farming provides through the uptake of nutrients in some of the sites. These can be translated into incentives and endorsement to companies like ORF. Improving the recognition and valuation of these services can promote further integration of macroalgae farms with existing fish farms to improve regional environmental conditions This will boost the expansion of the macroalgae industry by entering a well-established firm farming industry. The vertical integration of these industries will facilitate access to financial instruments and services, which are scarce today for macroalgae farms. These aspects are crucial areas of improvement for enabling macroalgae farming to grow in non-traditional producing countries. AquaVitae contributes towards this by developing GIS maps and describing the relevant parameters to be considered for site selection.

Also, the development of new technologies is necessary to progress this value chain. New technologies will contribute to reducing operational costs and take advantage of economies of scale. To develop new technologies for harvesting and processing equipment and vessels, capital investment is needed. Yet the industry is currently competing for investors instead of customers, as the market is still immature. During the AV project, the value chain will explore the application of new mechanised harvesting method which will reduce costs greatly, as well as improvements to the cultivation and landing logistics.

Further, for upscaling it is fundamental to acknowledge the attributes of macroalgae farming and the ecosystem services it provides for fish farming activities. A recognition of the ecosystem balancing service, could facilitate the site selection and adequate use of marine space with an emission-balancing approach at a regional level. AquaVitae will propose methods for valuation of the ecosystem services provided by low-trophic aquaculture and thereby hopefully encourage the valuation of such services to be used within the policy context.

3 CS4 Sea-based multi-trophic aquaculture

3.1 Background and value-chain selection

Case study four is concerned with different concepts of integrated multitrophic aquaculture. AquaVitae aims to design, test and evaluate different interventions in selected sea-based production concepts to provide a better basis for production in Europe using these methods and increase both production and diversification using these concepts. These include the following systems:

- Co-culture of mussels and macroalgae in South-Africa
- Using IMTA-grown macroalgae as feed for abalone
- Commercial-scale sea-based co-culture of abalone, sea-cucumber, queen scallop and macroalgae in France
- Effects of co-culture of mussels and macroalgae along with cage culture of salmon in Faroe Islands
- Potential for co-culture of oysters and lobster in sea-cages in Sweden

Resource limitations necessitate that the value chain analysis has to be narrowed down to cover a selection of the systems that are included in the case study. The mussel value chain will be described in other sections of this deliverable. Co-culture of mussels and macroalgae do not have the strongest linkages in terms of interdependencies, use much of the same infrastructure and is not considered particularly technically demanding. The same aspects also generally apply to the subcase co-culture with salmon, although this has stronger linkages that are more interesting to investigate from socioeconomic and ecosystem services perspectives.

Although there are linkages beyond utilizing the same infrastructure for oysters and lobster co-culture, the scale of production is relatively small. The abalone-related production is considered most interesting as it is a large and valuable industry, has strong linkage between the co-cultured species and currently limited production in Europe. IMTA abalone production is also a topic in CS3, so value chain research is relevant for this case as well. Further strengthening the choice of value chain is that a commercial producer is directly involved in the research in AquaVitae, thus securing good information and likely being able to utilize results in their production. Hence, we select this production system for value chain analysis. We will focus on abalone, but also provide some information about queen scallops and flat oysters.

3.1.1 Methodological remarks

The value chain analysis is primarily based on the Global Value Chain approach. It is limited to primarily cover one of the four main aspects of GVC; the input-output structure for the project partner, supplemented with information more relevant for the general abalone aquaculture industry. This information is obtained from published literature and interviews with the project partner and other industry informants. Supply and markets for the general industry are described utilizing public data from FAO, international trade data from ITC and Japanese customs in addition to published grey and peer-reviewed literature. The EU supply, distribution channels and end-markets are described using data and reports from EUMOFA. Firm-level input-output structure is extensively described based on information from interviews with project partner representatives. Geographic scope and organization and governance of the value chain, being other important aspects of GVC is to an extent described for the South African abalone industry, being a well-developed industry, but only briefly discussed for the European actors, where activity is relatively small. These aspects are described based on interviews with case study leaders and project partners and other informants.

Not part of the GVC framework, but still identified as relevant in D7.1, cost structure and value adding along the chain is described using a bio-economic model with variable information based on information from literature and project partner information. The identification of critical/improvement areas is based on information developed in the case study and through direct questions to the informants. An interview guide was developed and interviews were conducted as semi-structured based on this guide. As European abalone production is very limited, issues relating to the governance and competition within an industry are of little relevance and are not discussed. As the South African industry is considerably more developed, these areas could have been investigated further. However, access to informants was problematic both due to the COVID-19 pandemic and compounded by labour strikes at the industry partner.

3.2 Introduction of selected value chain and relevant innovations

France Haliotis SA is farming European abalone in sea-based systems, benthic cages attached to longlines. The company is the largest abalone producer in Europe, although being small compared to farmers in the rest of the world, currently producing about 4 tonnes. They currently use locally harvested macroalgae as feed. Products are sold primarily to restaurants in Europe.

The planned innovations in the company value chain is to combine aquaculture of different species within the same system that would increase both productivity and sustainability. Macroalgae culture alongside the farm is planned to supplement currently wild-harvested food, improving sustainability as well as reducing waste products. Including other low-trophic species, not competing with abalone for food, such as bivalves and sea-cucumbers, will potentially increase productivity in the system and resulting profitability. Growing more species for sale will also diversify the production revenues, potentially increasing resilience. Increasing the biomass may as a side benefit improve growing conditions for the macroalgae.

Macroalgae seed will be either purchased or produced in-house and deployed on longlines surrounding the current abalone cages. The same species of algae, *S. latissima*, is currently harvested and fed to the abalone. Some macroalgae are also colonizing the abalone cages during production. These will be managed to improve growth, primarily removing unwanted competitors, and be utilized as feed.

Queen scallops and flat oyster seeds will be bought and placed in the abalone cages. Flat oysters seem to require a phase where they are grown in a separate cage within the abalone cage. Sea-cucumbers will also be introduced in the cages depending on seed availability.

3.3 Industry level value chain

Abalone is the common name for a group of large sea snails in the taxonomic family *Haliotidae* containing only one genus, *haliotis*. There are about 56 different described species of abalone (Del Pino Viera Toledo 2014), distributed globally except in the North American Atlantic, South American Pacific coasts, the Arctic and Antarctic. The major stocks are found in the coasts of New Zealand, Australia, South Africa, North American Pacific and Japan. They are relatively slow-growing and with a natural habitat attached to rocks in inter- and subtidal sea zones. The snail's meat is a highly prized food in several cultures and markets. The shell can also be used for decorations and mother of pearls.

Figure 8 Adult abalone (Photo: M Naylor)

3.3.1 Supply

A generalized and simplified description of the abalone aquaculture value chain is illustrated in Figure 9 below. Broodstock are kept and provide fertilized eggs. Eggs are incubated and hatch, are start-fed and grown into spat. These stages are generally carried out in specialized facilities called hatcheries. A relatively long grow-out stage follows before the animal is harvested and processed into products ready to be distributed to sales outlets. Supporting activities such as administration, research and marketing is to varying degrees performed within some or all the stages in the value chain.

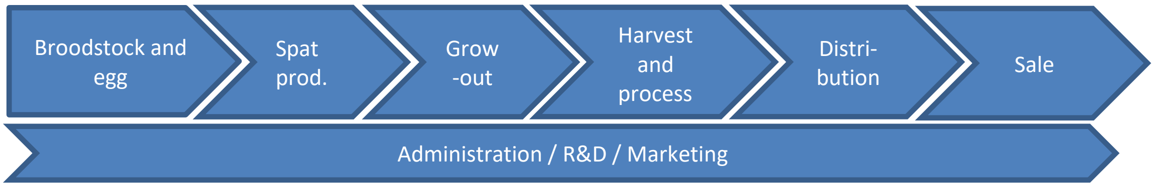


Figure 9 General value chain of abalone aquaculture

Abalone is both harvested from wild stocks and farmed in aquaculture. Wild harvesting is done primarily by divers collecting the animals from the bottom. Wild harvest has been reduced considerably from about 20,000 tonnes in the 1970ies to about 6,500 tonnes in 2016/17 (Cook 2019) and further reduced as shown in Figure 10. The main reasons behind this decline has been high fishing effort, both from legal and poaching fisheries, and disease. Many fisheries are now quota restricted or prohibited. The main current fishing nations are Australia, Japan, Mexico and New Zealand, constituting 93% of global registered catches in 2018. In addition, there are widespread illegal catches.

Based on anecdotal reports, Cook (2019) estimates these to about 7,000 tonnes. The reported harvest statistics are relatively little species differentiated, about 80% is reported as “Abalones nei”.

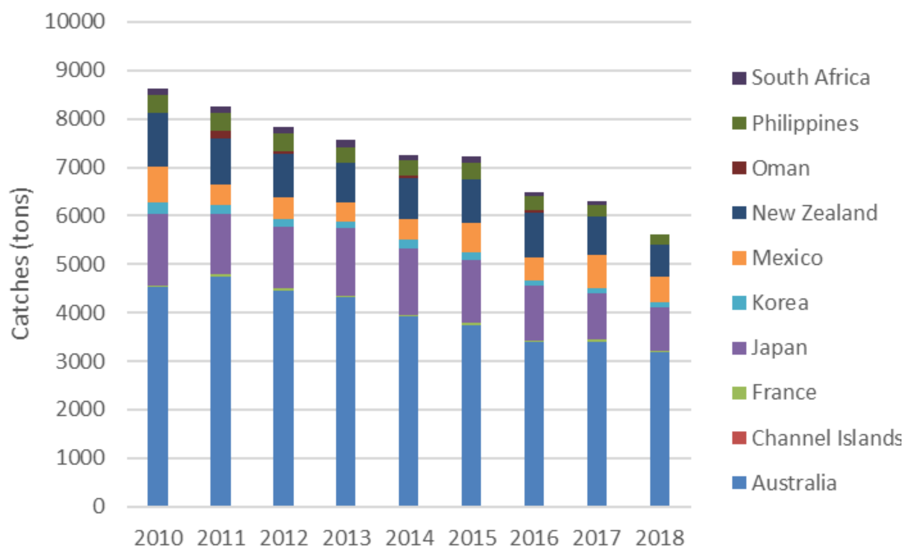


Figure 10 Registered catches of abalones (Haliotis) 2010 – 2018 (Source: FAO Fishstat)

Spurred by reduced wild harvest and strong demand, farming of abalone has grown from nearly negligible in the 1970ies to currently about 160,000 tonnes (Cook 2019), thus vastly outstripping supply from wild harvests. The major expansion of production occurred in the early 2000s, when China started expanding. China makes up the vast majority of production at about 87% in 2018.

In China, the species mix of production has changed considerably. In 2004, a significant share was made up of *H. diversicolor* that received less than 20 USD/kg. By 2010, about 95% of production is of the higher valued species *H. discus hannai* or a hybrid between this and *H. discus discus* (Cook 2014). According to Cook (2014), there were more than 300 Chinese farms in 2013, some producing over 1,000 tonnes. As production has expanded by about 50%, these figures are also likely to have increased.

Korea is the second largest producer with a share of production of about 11%. Here, there are about 3,000 farmers including both juvenile and grow-out producers.

Aquaculture production from 2000 to 2018 by country is shown in Figure 11. After China and Korea, South Africa, Chile and Australia are considerable suppliers with about 1,000 tonnes each. Several other nations contribute small quantities. Notably, the production in Taiwan has been considerably reduced. Supply from reported wild harvest represents about 3% of total supply, rising to about 7% if we add estimated illegal catches.

Almost all the aquaculture production is reported as “Abalones nei”, as there is little species differentiation in the FAO statistics. South African production is exclusively of the species *H. midae*, or “perlemoen”.

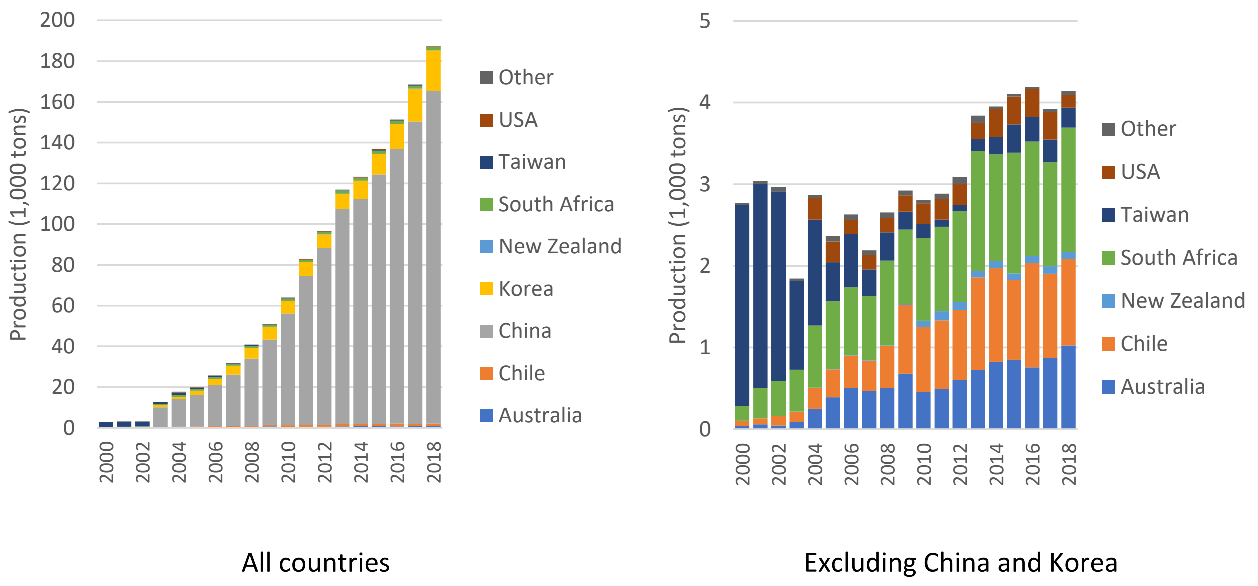


Figure 11 Aquaculture production of abalones (Haliotis) 2000-2018 (Source: FAO Fishstat). Left panel is all countries. Right panel excludes China and Korea.

Integrating production of different species has long been advocated as potentially providing economic and ecological benefits. Shi *et al.*, (2013) investigated ecological and economic implications of mono and co-culture of kelp and scallops based on actual farm production in Weihai, China, where both production methods were common. Co-culture was found to outperform monoculture both in terms of ecological sustainability and economic net present value. Positive effects from co-culture with abalone have also been reported (Ou and Yan 2011). However, Yu *et al.* (2017) found that farmers that had adopted such strategies were planning to change back to monoculture when visiting the area in 2013. This was likely due to prices for abalone having been considerably reduced, coupled with high wage growth. This made the infrastructure utilization benefits from co-culture relatively less and farming actually yielding negative profits, compared to a small profit from monoculture of kelp.

3.3.2 Demand – main markets and products

Abalone is primarily traded as fresh, frozen, dried and canned. In addition, shells are sold as decorations (Chigumira 2016), jewellery and furniture inlays. Fresh are transported live to the markets and are generally considered the best quality. These are often used in restaurants, and often showcased live there in aquariums. Canned abalone are more often used in home cooking. Dried products are often used for traditional medicine purposes. Demand for flavoured value-added products, beyond canning, are developing in some markets. There is differentiation based on brand, species and country of origin (Brown et al. 2008). Most of the consumption takes place in China, utilizing about 90% of domestic production, and importing from other countries (Globefish 2017). Although dwarfed by China, other main markets for abalone are found in Korea, Hong Kong, Japan and Singapore. There are well-established, but small markets in Mexico, USA and Europe as well.

Some of the Chinese production is exported to Japan, but despite the increasing supply domestic demand growth has seen exports declining. It is valued both for medicinal and food purposes. In China it is primarily sold fresh before holidays such as the autumn and spring festivals (Yu et al. 2017) and served especially on social gatherings such as weddings, family gatherings and banquets. Production has shifted towards the more valuable abalone, *H. discus hannai*. According to Urban-Econ Development Economists (2018), there are generally two main segments for abalone in the Asian markets. Small abalone produced in mainly China and Korea typically has a farm-gate price of about 15 USD/kg. Large, primarily imported abalone has a wholesale price of over 50 USD/kg and retail prices between 150 and 175 USD/kg.

Japan is after China the second largest market and where abalone generally receives the highest prices. Here they have native species and strong cultural traditions for eating abalone. Fresh products are also most common here and consumption is related to holidays and special occasions (Hoshino et al. 2015). A large share is prepared as sashimi in restaurants. Whole abalone is also cooked with fish broth and soy. Canned products are popular in the winter gift season. Abalone can also be sauteed in butter or marinated in vinegar. Dried abalone is used in Chinese cooking (Kelsky and Niemeyer 1989). *H. discus hannai*, being native to Japan, is particularly in high demand.

With depleted wild populations and reduced fishing operations, Japan imports most of its consumption. The market is well-diversified with imports from all the major producer areas as well as domestic supply. Imports are also of both wild and farmed products. Import data are easily accessible to illustrate quantity and price development. Imports from 2017 to present is shown in Table 4, illustrating well the large share of fresh products. Korea is the major supplier, supplying 1,500-1,800 tonnes, with Australia, China, Taiwan and USA supplying smaller quantities ranging from about 20-50 tonnes in 2019. South Africa has a relatively small market share, and France/EU is only registered with minimal sales back in 2017. The prices are highest for imports from Australia, with South Africa receiving the second highest prices. Products from China are paid considerably less than the others.

Table 4 Imports of abalone to Japan (Source: customs.go.jp)

	Quantity (tonnes)				Price (USD/kg)			
	2017	**2018**	**2019**	**2020 aug**	**2017**	**2018**	**2019**	**2020 aug**
Frozen, even in shell	666	523	651	287	**31,7**	**34,6**	**32,2**	**28,9**
Australia	141	150	125	58	38,9	40,7	37,9	35,1
Chile	141	84	134	49	20,8	21,3	20,9	20,8
People's Republic of China	250	188	310	153	35,6	39,9	36,2	30,6
Republic of Korea	64	39	21	2	31,0	35,1	30,9	31,4
South Africa				8				25,5
Taiwan	70	62	61	18	26,0	21,0	25,5	16,4
Live, fresh or chilled, even in shell	1,666	1,798	1,961	894	**30,4**	**27,9**	**27,8**	**25,3**
Australia	71	66	54	15	40,6	44,8	47,0	44,0
People's Republic of China	1	7	30	16	22,3	22,8	18,4	16,0
Republic of Korea	1,536	1,667	1,818	847	30,1	27,4	27,5	25,2
South Africa	3	4	2	0	31,4	31,8	32,4	
Taiwan	46	42	37	15	23,5	24,7	22,4	20,9
Thailand	2				21,7			
United States of America	7	13	21	1	37,0	28,3	24,4	35,3

Korean production is also primarily consumed domestically, but exports to China and USA have increased, along with Japan. Abalone is also here valued both as food and for health benefits. It is considered a premium food product. Table 5 summarises the production and trade of abalone and presents a simplified measure of the apparent consumption in the most important producing and importing countries. This consumption is calculated by summing the production and imports and subtracting exports. Of course, there are considerable differences in conversion factors between finished goods and production, and there may be differences in product mix between imports and exports. Hence, this only gives a rough illustration of the main consuming markets.

Table 5 Wild harvest, aquaculture, import and export of abalone 2018 (all in tonnes, wild and aquaculture are live weight and trade in product weight, Sources: FAO for production, www.trademap.org for trade)

	Wild	Aquaculture	Import	Export	App. consumpt.
China	0	163 169	1 458	11 470	153 157
Hong Kong			6 349	835	5 514
Macao			462		462
Taiwan		244	3 011	1 630	1 625
Japan	900		2 557	21	3 436
Korea	113	20 050	585	2 387	18 361
Singapore			1 899		1 899
Malaysia		12	1 018		1 030
Australia	3 175	1 027		2 300	1 902
South Africa	0	1 522		1 107	415
Chile		1 055		645	410
Others	1 425	283	1 744	3 117	335

3.3.3 EU and South African value chains

European production is limited, with France being the biggest both harvesting and aquaculture country. About 7 tonnes were farmed and 35 tonnes harvested in 2018 in France. We have registered four operating farms as illustrated in Figure 12 below. the French companies France Haliotis and Groix Haliotis, both producing the species *H. tuberculata*, also known as ormer. In Ireland there are two farms producing less than 2-3 tonnes, according to an informant. Spain recently started farming, and production was 2.68 tonnes in 2018 from the company Galician Marine Aquaculture. This firm seems to have ceased abalone production. According to the industry informant, there is one small trial farm in Galicia. In Spain there is no wild harvest registered. Previously, firms in the Channel Islands have been production but seem to have ceased operations around 2013.

Figure 12 Farming of abalone in EU (map from Google Maps)

The EU is currently both importing and exporting abalone. According to EUMOFA (www.eumofa.eu) data, EU imported abalone worth 0.8 mEUR and exported very little, about 0.02 mEUR. Imports were primarily from Australia, Chile and New Zealand and were primarily frozen products. Hence, the import prices are not very useful for comparisons with the EU production. Frozen abalone from Australia received average prices of about 40 USD/kg, while imports from Chile and New Zealand obtained from 20 to 25 USD/kg. The small export from EU primarily went to Hong Kong, USA, Iceland and Singapore. Abalones are also traded between EU countries. Here, the main receivers are Italy, France and the Netherlands. Based on the EUMOFA data the apparent consumption in EU is about 70 tonnes in 2018. Hence the size of the market is very small compared to the Asian markets.

Imports: 0.8 mEUR
- Australia 6.3 t
- Chile 13.3 t
- New Zealand 6.6 t

Production:
- France 7 t
- Spain 2,7 t

Export: 0.02 mEUR
- France 0.6 t
- Spain 0.2 t
- Belgium 0.1 t

Figure 13 EU trade and production of abalone 2019 (Source: EUMOFA for trade data, FAO for production)

Wild harvests from France are sold through auctions (about 45%) and other channels. Prices at these auctions have increased by about 20%, from 22,8 to 27,2 EUR/kg from 2009 to 2018 (EUMOFA 2019). Some of the harvests from the Channel Islands are also sold through the French auctions. Prices for farmed abalone are higher, partly due to higher meat content, at about 40% of total weight compared to wild abalones having about 35%. Farms also target high-end restaurants; these also place a premium on secure supply over the year. Wild abalone are bigger, at about 9 cm against 4-7 cm for farmed animals.

Aquaculture farms primarily target niche markets in the restaurant segment, where stable supply and high quality is valued. Meat yield from aquaculture is higher than wild stocks, typically about 40% vs. 35% respectively.

Like in the EU, South African supply of abalone is both from harvesting local stocks and from farming. In 2018, reported catches were zero due to this being banned to replenish stocks. There is, however, a considerable illegal fishery taking place. Aquaculture production is about 1,500 tonnes.

In 2015, there were 18 abalone on-growing farms of very different scale. 16 of these were land-based and two operated sea cages. The majority of these were vertically integrated upstream to the hatchery stage, with 12 operating hatcheries as well, and only four being grow-out operations only (DAFF 2016). In addition to these were three sea-ranching operations. The largest farm produced 400 tonnes annually. Based on information from informants and internet and map search, the number of farms currently operating land-based farms at commercial scale is about 11 and illustrated in the map below. They are distributed primarily along the western coast, as the species prefers temperate to cool conditions. This renders a large share of the coastline unsuitable for aquaculture.

Generally, the sea conditions are considered of too high energy for cage culture, and we have not been able to identify current operators of sea-based cage culture.

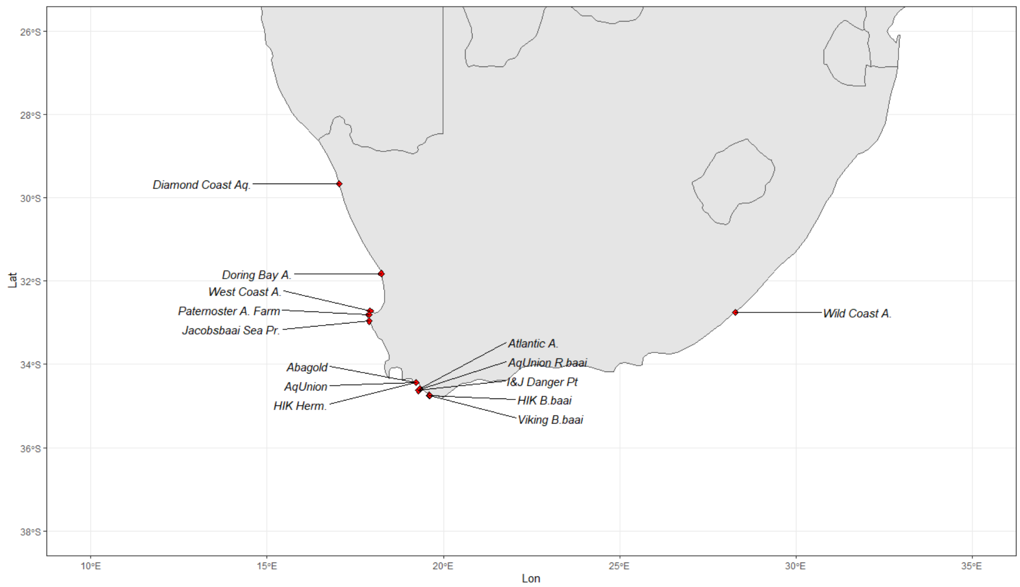


Figure 14 Abalone on-growing farms in South Africa

Four companies account for a large share of production with production of 400-600 tonnes (Abagold, I&J, Aqunion and HIK Abalone). As seen from the map some of these are horizontally integrated operating two farms. These are all vertically integrated from hatchery to processing plant. One firm also owns a major feed supplier. Most of the smaller producers are also integrated with hatcheries and primary processing. Some rely on purchases of seedstock. The four major producers own and operate secondary processing facilities. The smaller producers generally send their production to these processing plants for drying and canning, but there are also smaller external processing plants that are used. These primarily cater for the wild harvesting.

The farmed abalone are primarily processed into three main product forms: fresh, canned and dried. Production is to a very large extent exported, and imports are close to zero. In 2019, South Africa exported 1,025 tonnes of abalone products distributed as shown in Figure 15. The product mix has changed considerably from 2015 to 2019. The share of prepared abalone, reflecting primarily canning, has been relatively stable, while the share of live/fresh has increased at the expense of smoked/dried/salted. This may in part be due to the officially registered wild fisheries being reduced from 142 to 0 tonnes from 2015 to 2018, as a large share of these harvests was dried. A small share of frozen abalone export is registered from 2018.

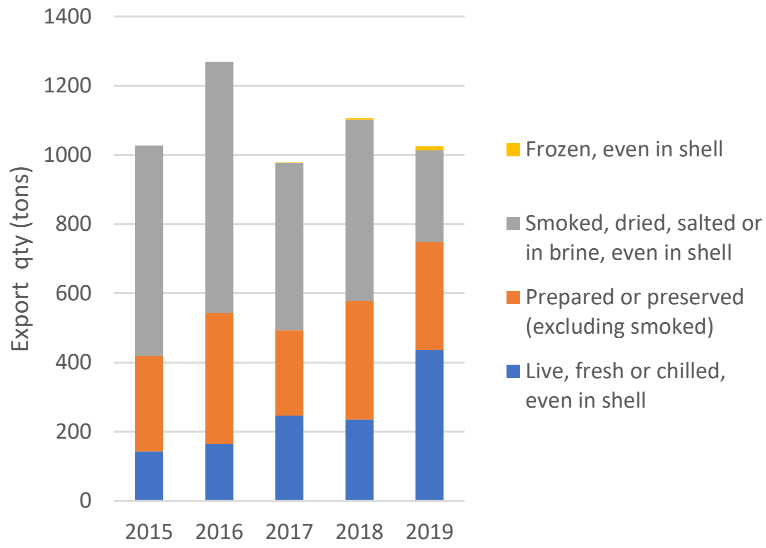


Figure 15 Export quantity by product form from South Africa (Source: trademap.org, based on data from South African Revenue Services)

In South Africa, farmed abalones are typically harvested at about 100 grams, known as cocktail abalone. Products are primarily exported as canned, prepared and preserved in the HS system, but some also as fresh and some frozen. The main markets are Hong Kong, Taiwan, Singapore and China, as illustrated in Figure 16. These four countries accounted for about 96% of export value in 2019. Of these, Hong Kong is the most important with an import share of 79%. Japan used to be an important destination, but exports have been small since 2015.

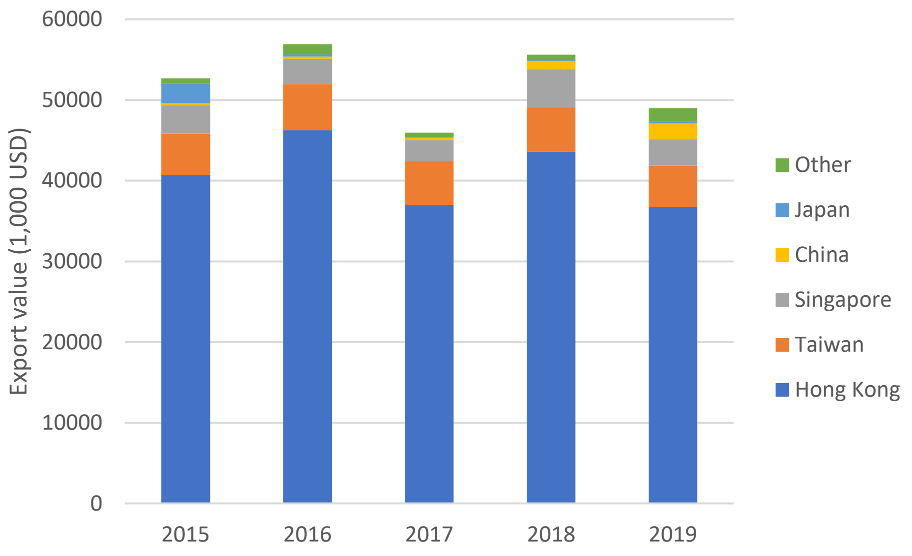


Figure 16 Export value by importing country for South Africa (Source: trademap.org, based on data from South African Revenue Services)

Farm gate prices in South Africa vary with size. We have not found official statistics being published. Based on interviews in 2018, Urban-Econ (*op cit*) reported that 40-gram abalone sold for about 25 USD/kg, while 100 and 200 gram specimens could fetch an equivalent price of 45. Frozen prices are generally less, prices for corresponding sizes are 20 and 35 USD/kg.

Export prices are available by product form and country. In Figure 17 we have illustrated the price development in Hong Kong, being the most important market and giving a good illustration of prices. As also export markets place a premium on larger sized animals, changes in size composition may influence the average price observed. Prices for live products have been stable at about 32 USD/kg since 2017, after having declined sharply from about 50 USD/kg. Dried products have had the opposite development, with prices increasing strongly in 2019 from about 50 to over 70 USD/kg. Prepared (canned) products have fluctuated between 50 and 60 USD/kg.

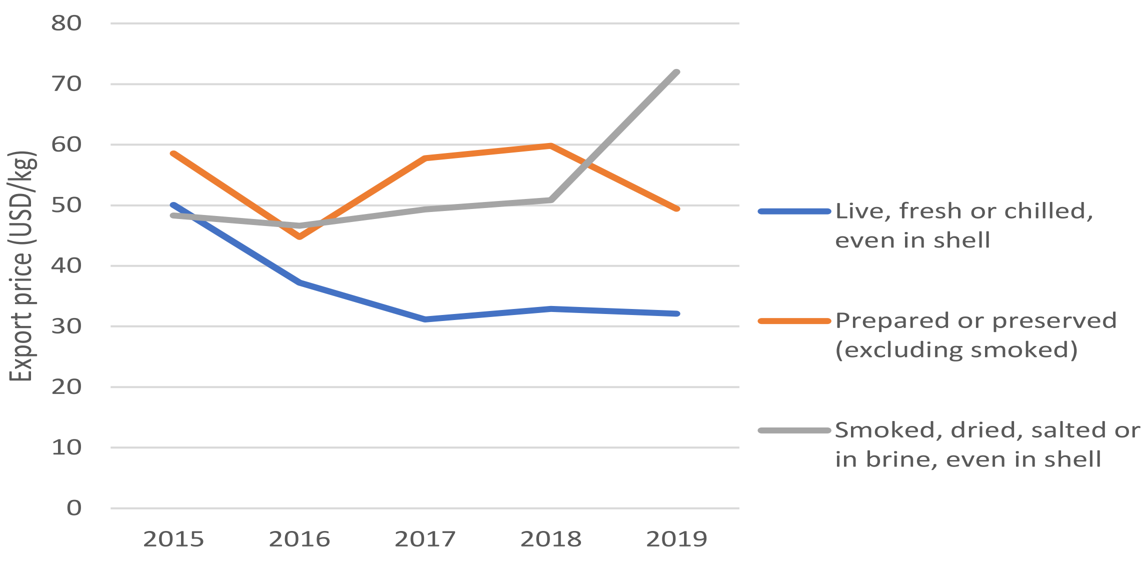


Figure 17 Prices by product form for exports from South Africa to Hong Kong (Source: trademap.org, based on data from South African Revenue Services)

3.4 Case-study value chain

In this section, we focus in more detail on the case study, describing the value chain of the industry partners involved in AquaVitae. In addition to the sea-based culture of abalone in France, we also include land-based production performed in South Africa as AquaVitae has industry partners here and for comparison of the closely related production processes.

3.4.1 Input-output structure

The general abalone production process follows rather typical stages. Broodstock is held, providing supply of fertilized eggs. These develop and hatch, go through a larval stage feeding on their yolk sac, metamorphose and settle on the bottom, then start first-feeding. Next, they are weaned to a different diet and are referred to as spat. When ready, they are transferred to a grow-out system, where they feed and grow until ready to harvest. Then they are processed into different product forms and shipped to markets through various logistical channels. The value chain is generally illustrated in Figure 18 below. There are of course subtasks being performed at each of these main stages.

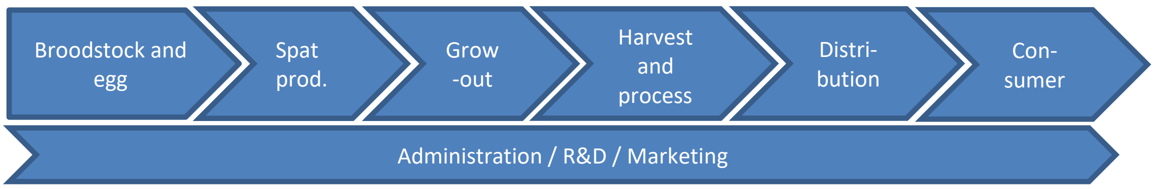


Figure 18 General value chain of abalone aquaculture

A general timeline of stages and activities in the aquaculture production process of abalone is shown in Figure 19. In South Africa the total production time from spawning to harvest of about 100 gram individuals is generally 45-48 months, illustrating that abalones grow relatively slowly. European abalone grow more slowly, with the water temperature being lower, but are generally harvested after 36-48 months after spawning at about 40 grams (20-90 grams) and up to 9 cm length.

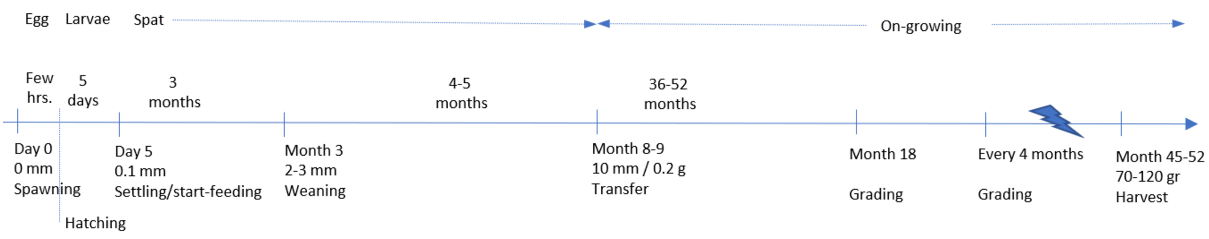


Figure 19 Generalized timeline of stages and activities in South African abalone production

The varying tasks and stages are generally performed in specialized facilities. Figure 20 illustrates a common layout of a hatchery, where the stages up until grow-out take place. This is a fully land-based facility with sections for holding broodstock, free swimming larvae, larvae during settlement and for weaning spat to feed used during grow-out. After this, spat are transferred to grow-out systems that can be sea-based cages, land-based tanks or sea-ranching areas.

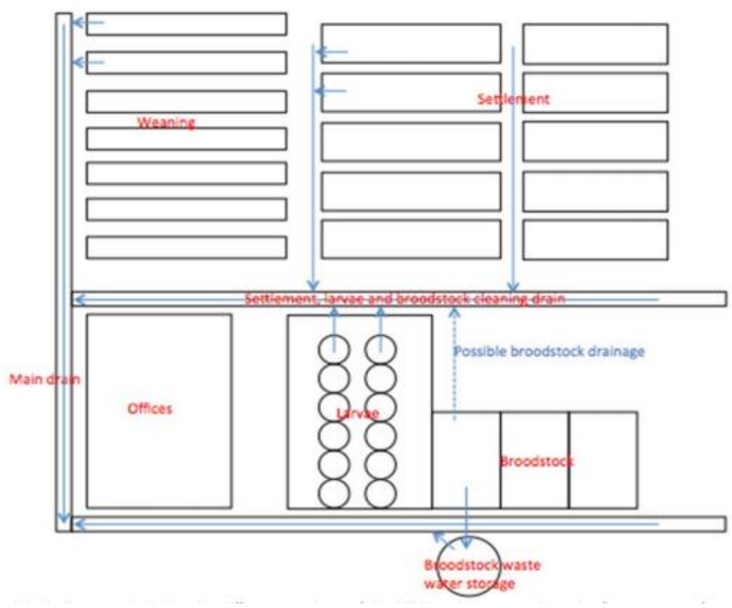


Figure 20 General layout of a land-based hatchery in South Africa (From Fourie (2014)*)*

Each of the stages in the value chain will here be described in relative detail, focusing on the development of the animal, the tasks performed, input use and timeline.

Broodstock and egg production

Even if the chicken and egg problem is clearly relevant when describing closed-cycle aquaculture, we start the discussion with broodstock. Originally caught from the wild, broodstock are kept providing eggs as the basis for the further value chain. Adult abalone reach maturity at an age between 4-7 years. Both in South Africa and in France, breeding programs are in operation to improve the genetic basis for the seedstock. The breeding program in South Africa is a collaboration with the five biggest producers and is monitored and advised by a genetic consultancy firm. Broodstock are kept in tanks in land-based facilities.

Figure 21 Broodstock room, left South Africa (Photo: M Naylor), right France Haliotis (Photo: A. Devouard)

In South Africa it is common to monitor and control water quality parameters, especially temperature. In France, ambient temperature is used, as the production is relatively small and requires one spawning season per year. Tanks are aerated and supplied filtered seawater. Males and females are kept in separate tanks, with 1-5 animals per tank. In France these are fed macroalgae, whereas in South Africa this can be combined with formulated feed. Wastewater drains directly to the sea.

Abalones spawn by releasing eggs and sperm through the breathing holes. Spawning time in farmed abalone can be artificially manipulated using sodium hydroxide and hydrogen peroxide (Fourie 2014). This is done about every fortnight, allowing for relatively constant supply of seed. Eggs and sperm are mostly filtered from the drainage of the tanks and then mixed at appropriate ratio for fertilization.

The major tasks that are performed for holding broodstock and egg production are thus monitoring of the animals and water parameters, feeding and cleaning of tanks, inducing spawning and collecting fertilized eggs. Inputs utilized are primarily connected to the water supply, feed and labour.

As the fecundity of abalone is high, a small stock can sustain high production. For the South African farm producing, a broodstock of about 3 animals per tonne of production is maintained. This is considerably higher than is required for the target monthly spat requirement of 900 spat/tonne at 10 mm for transfer to grow-out. This allows the farm to select only eggs from the best performing broodstock animals, depending on spawning success as well as generally culling the poorest performing spat when grading at about 18 months. Spat that are deformed are also culled. Sometimes the farm ends up using only eggs from 5 animals in one cycle.

Hence the resource use in this stage is small, also in terms of labour use. The South African example farm has about 7.5 employees/100 tonnes of production in the hatchery. This is the main resource used. Water use and electricity to pump and heat/cool the water is the other major resource. The hatchery in total uses about 1 m^3 per tonne of production per hour yielding an annual energy cost of about 200 USD/tonne. In addition, there is some use of various chemicals, especially for anaesthetizing, and laboratory equipment.

At France Haliotis, although production is low, one employee is needed for the operating the hatchery. The broodstock and egg area only occupies about 50-100 m^2 and the area used for the hatchery in total is about 2,000 m^2. This, however, has capacity to produce about 10 million, considerably more than the currently needed about 300,000. Energy consumption per month to run pumps and other equipment is about 8,000 kWh.

Larvae production

In South Africa, eggs are put into a relatively big volume larvae tank. After a few hours, depending on temperature, the larvae hatch. Fertilized eggs and larvae are positively buoyant, while unfertilized and dead eggs and larvae sink and are collected in a tray at the bottom. Larvae feed on their yolk-sac and metamorphose into a sedentary snail, this taking approximately five days. This stage is supplied filtered and aerated seawater at about 18°C, sometimes UV-treated.

When the yolk-sac is emptied, the larvae begin swimming in search of food, indicating that they are ready to settle. They are now transferred using buckets to the start-feeding tanks.

The tasks performed during this stage are to a large extent monitoring of the developing eggs and larvae, collection and transfer to the next stage. Input use is very little apart from labour and water supply.

Figure 22 Larvae at 5 days (Photo: Stephanie Bordenave, French Natural History Museum)

Nursery – settlement/start-feeding

Larvae are transferred to settlements tanks. These are rectangular and relatively shallow trays that have vertically placed polycarbonate sheets covered in diatom microalgae for nutrition. These are grown by farm personnel starting about 2 weeks before. Stocking density is 100-150 per sheet. Temperature is about 18°C. The larvae settle on the plastic sheets and start feeding on the microalgae. After settling, water flow is turned on. The abalone is now called spat. In France the size at settling is about 0.2 mm, whereas in South Africa the size is about 0.3 mm.

Figure 23 Settlement and start-feeding plates, left South Africa (Photo: M Naylor), right France Haliotis (Photo: A. Devouard)

In South Africa, spat stay in this system and feeds on the algae for about 3 months, growing to between 2-3 mm. The density of spat and algae need to be within a range, otherwise the food will run out or the algae will outgrow the spat. This is tricky to manage, primarily through light conditions.

In France, small diatom algae are required in the beginning for survival, switching to larger ones to ensure growth. Abalones are transferred to new sheets with diatoms as they consume algae. New algae are grown in separate tanks. Survival from settlement and end of this stage is usually 70%.

Tasks in this stage are again related to monitoring of the animals and water quality. Particularly important is to monitor and adjust the algal growth on the start-feeding plates and growing these. Little inputs apart from the water supply and nutrition is used.

<u>Hatchery – weaning/on-growing</u>

In South Africa, after settling and start-feeding, spat are anaesthetized and individually wiped off the settlement plates in a labour-intensive process. Then they are transferred to weaning tanks containing little hides, as they are generally becoming photophobic during this stage. Here artificial diet is introduced.

Mortality is relatively high during the initial stages of this phase. The handling process is rough and the change in feed and associated changes in their gut and behaviour is large. Survival can be about 50% during the stage. Once they are weaned, survival is very high, about 98% for the whole rest of the production. The South African firm has experimented with keeping the spat longer on the settlement plates, to about 4-5 mm length. The animals seem to be better able to cope with the stresses of weaning and survival can be about 80%. This strategy would require more settlement tanks and prolong the tricky algae/spat density management. Density management is performed by moving cones to new tanks, when stocking density is becoming too high.

Tanks in this system are rectangular shallow tubs equipped with cones. Spat are grown in these systems until they are ready for transfer to a grow-out system. The size of transfer varies, but is generally between 1-2 cm. This stage takes about 4-5 months.

Figure 24 Weaning system (left) and cone with abalones underneath (right) (Photos: M Naylor)

France Haliotis does not transfer spat to another system between start-feeding and weaning. Diatoms are used for the first 3-4 weeks and up to about 2 mm length, then feeding is changed to a combination of diatoms and different macroalgae. This is done by supplying the spat with plates where diatoms and macroalgae are co-cultured. The spat can thereby switch diet by itself. During this stage, the larvae are fragile, and difficult to satisfy. High mortality can occur. Usually mortality during nursery/weaning stage can be about 30%. During this stage culling is done to ensure that only good quality spat are carried further in production.

Maintaining good stocking density is important during this stage. France Haliotis adjusts density three times during the nursery/weaning stage. As the animals are attached to a surface, this is a relatively labour-intensive task. Another main task is supplying and growing macroalgae for feed. The spat are transferred to the sea grow-out cages at about 15 mm and 0.2 grams.

Grow-out

Spat are transferred to grow-out systems. In South Africa, most producers employ suspended baskets in specially designed tanks flow-through systems on land. Recirculation systems are also used, as well as sea ranching. The grow-out time varies, especially depending on temperature, but generally 36-52 months in South Africa. To reach 100 grams takes about 45-48 months, but animals can also be grown to 2-300 grams requiring longer time for grow-out. In France Haliotis a sea-based cage system is used for grow-out and this stage lasts 36 months. Harvest size varies considerably, from 20 to 90 grams, but is on average 40-50 grams. The long time spent in this stage makes this by far the most resource intensive.

In sea-cage culture, abalones are held in mesh enclosures. These are generally rectangular PVC frames covered in plastic mesh and suspended from longlines or floating barges. In the cage there are plates for the abalone to attach to. Cages in the sea are susceptible to fouling from algae and other organisms. This requires the cages to be regularly cleaned. As cages both hinder flow of water and reduce water quality, the density of cages is important to optimize.

France Haliotis uses cages that are placed on the sea bottom in sandy areas, hence not needing buoyancy elements, just a buoy for the hauling line. Using the seafloor is not permitted in many countries, creating a legislative barrier for others to employ this technology. The cages are 4 m^2 and with a volume of 2 m^3 but have a total farming surface area of 80 m^2 for the abalone. The company operates about 180 cages. Survival during grow-out is about 70%.

Figure 25 Hauling of cage at France Haliotis (Photo: France Haliotis)

Feeding is the main task during this stage. France Haliotis harvests wild macroalgae that is supplied to the cages by lifting them up to a work-vessel and adding it to the cages. The macroalgae is live, and hence feeding can be done only once per month. This reduces workload considerably. Other tasks that are performed are cleaning the cages, although a lot of organisms can grow on and in the cage. Predominantly cancer crabs and conger are removed from cages.

No grading is performed, but stocking density is adjusted as the abalones grow. Starting density is about 12,000 animals and being reduced to about 2,500 per cage. Growth is negatively affected by stocking density as they compete for space and food (Del Pino Viera Toledo 2014). Thus, choosing the right density is vital. For ormers, initial stocking densities of 83 versus 386 per sqm may result in 52% reduction in growth. About 4 employees are required to run both the harvesting of macroalgae and cage management. Each feeding and cleaning operation takes about 10-15 minutes per cage.

In land-based systems, abalones are kept in rectangular baskets suspended in relatively shallow "raceways". The example South African farm uses "raceways" that are 4 by 2 m long and 0.8 m deep. These may be concrete, fibreglass or canvas on wooden frames. The latter are cheaper at about 4-5,000 R/tank (300-380 USD), compared to about 50,000 R for concrete tanks. Within each tank, there are 12 baskets with racks within them. They have a plate on the top that gives shade. Most farms in South Africa are flow-through, where water is pumped from the sea, via a header tanks and a drum filter, and to the tanks. Some farms recirculate water. Here, treatment of water is required in addition to pumping. Sufficient water exchange to maintain water quality parameters is of course also mandatory. High water flow has been shown to stimulate feeding activity, increase growth and improve FCR, as well as counteracting negative stocking density effects (Del Pino Viera Toledo 2014).

Figure 26 Baskets in tanks (Photo: M Naylor)

A South African farm can use about 14 m^3 of water per hour and tonne at an annual electricity cost of 2,600 USD/tonne. In addition, there are costs for aeration, filtration, maintenance and other supplies.

A prime task during the grow-out stage is feeding. Abalones can consume up to 35% of its own weight in macroalgae per day. Abalone can be fed a mix of macroalgae that are grown on farms or harvested nearby or artificial diets (Cook 2014). Most farms in South Africa use a formulated feed. The price of this feed is about 2 USD/kg and a feed conversion ratio (FCR) of 1.5-1.6 can be expected. The feed is also said to increase yield, reduce the number of feeding times and grow-out time. Using kelp, FCRs of about 12 can be expected. The price of kelp varies but can be 0.1-0.25 USD/kg kelp depending on the location of the farm. Feed is generally provided daily in the afternoon on the top of the basket using small pellets. Quantity depends on uneaten pellets. Larger pellets are provided in the bottom of the basket.

Survival in land-based farms is very high at about 98% during this stage. However, at about 5-8 grams and month 18, the first grading is performed, and the slowest-growing and deformed individuals are culled. This usually accounts to about 20%, and hence bringing total survival during grow-out to typically ranging from 80-85%. Bacterial diseases are common, but no viral diseases are documented. Fungal infection with tubercule mycosis has been problematic especially for RAS farms.

Grading is another major task that is performed regularly. This takes place about every four months, thus happening 7-9 times during the production process. During grading, the density in the baskets is adjusted as well as ensuring that animals of roughly the size occupy the same basket. This is beneficial for growth. The baskets weighing about 10 kg are manually carried to dedicated grading stations, keeping them out of water only for a short while. At start, about 2,500 individuals are stocked per basket. At the end, each basket has 50-80 animals at the max size of 2-300 grams. Stocking density is managed by the area covered, of which a density of about 18% is targeted. During grading, empty shells are counted and mortalities registered.

The final major regularly performed task is cleaning. All the tanks are cleaned at weekly intervals. For the example farm this is probably the most labour-intensive tasks. The abalone is relatively sensitive to poor water quality, uneaten feed at the bottom of the tanks cause such problems. Baskets are lifted to a fresh tank and the current tank is drained and cleaned. Self-cleaning using sloped bottoms has proven difficult to achieve. Baskets are cleaned when the abalone are graded.

The total labour use during this stage is by the example farm estimated to about 23 employees per 100 tonnes of production. In addition, there is technical and maintenance staff overseeing the whole farm. These are estimated to about 4.5 per 100 tonnes of production.

As abalone grow slowly, this stage is prolonged, making utilizing infrastructure efficiently very important for profitability. This is particularly important in land-based systems, as both the investment and operating costs are higher. Common farming tank area of about 60 m^2 per tonne of production. This translates to investment of about 2,700 – 27,000 USD/tonne of production, depending on the system used.

In the prime producing countries, China and Korea, the grow-out stage takes place in cages in the sea. Production has rather recently evolved from using simple suspended baskets in land-based farms to offshore cages held from floating platforms. In 2004, about 60% of Chinese were land-based, while in 2010 more than 95% were sea-based. In China, many farms are in southern provinces Fujian and Guangdong. The industry has experienced temperature exceeding abalones preferred range both in the north and south. Some use ships with tanks to move farm site between seasons. Production in Korea mostly takes place in the South Jeolla province. During grow-out, farms may experience mortalities due to disease, especially mortalities from *Vibrio harveyii* can be over 50%.

Harvesting

Abalones in South Africa are typically harvested at about 70-120 grams. This is a good plate size for a serving at a restaurant. There is, however, a wide range of harvested size with common sizes being from 35 grams and up to 250 grams. Although growth rates slow, the South African abalone, *H. midae*, can obtain such sizes, whereas the Chinese species generally do not grow to more than 140 grams according to informants. There is a demand for larger specimens, thus providing an advantage here for South African producers. When harvesting, the baskets are size graded and the needed size groups are taken to the packing and processing area.

France Haliotis uses the workboat for harvesting. Cages are lifted and transported to shore to a processing facility. The animals can be transported dry for shorter periods, so no tank is required for the boat.

Figure 27 Harvest ready abalone, left South Africa (Photo: M Naylor) and right France Haliotis

Processing
In South Africa, animals destined for live sales are processed at the farms. Animals are packed in Styrofoam boxes with ice and shipped to the airport. Animals that are to be processed further, for canning or drying are transported to a separate processing plant where these processes take place. These are anaesthetised by bubbling CO_2 and then placed in mesh bags in aerated tanks to purge. In the processing plant they are shucked, viscera is removed, then washing and salting before being they are cooked or dried and packed in cans or bags. Viscera can be discarded or processed into low-value foodstuffs.

A general product split is 40% live, 50% canned and 10% dried. Dried abalone can be rehydrated and eaten or also be included in broths as seasoning. There is bigger competition within the canned market, with more producers and species.

Labour use depends on the product type. In South Africa, both packing of live abalone and canning/drying is estimated to use about 0.2 employees/tonne. Additional inputs such as boxes and ice are used for live products, and cans and fuel are used when canning.

Figure 28 Drying of abalone (left, source: Abagold Integrated Report 2020), canning (right, photo M Naylor)

In the France Haliotis processing facilities, the animals are sorted according to size and placed in holding tanks awaiting orders and dispatching. No cleaning is required. In some cases, and for some customers, the animals are de-shelled at the facility. On rare occasions, some have been sent to freezing plants. The processing is done by the same staff taking care of marketing, sales and administration. Currently there are 2.5 employees overseeing all these activities.

<u>Distribution</u>

Abalone from South Africa are to a large extent exported to southeast Asia. The main market is Hong Kong and China. The farmers generally have an externally owned agent each in the receiving country. This agent communicates with the next stages in the value chain, generally being restaurants and distributors.

Live abalone requires specialized transportation capacities (“tank to tank”) and quick transport, taking less than 48 hours. Despite this, there is risk of high mortality rates. Common transportation is boxed to local airport, then by plane to Johannesburg and by plane to Asia. Usually, abalones would go as cargo on regular passenger flights, but with COVID-associated reductions in flights, chartered cargo flights have become more regular. This has increased transport costs considerably.

Canned and dried products have considerably lighter logistics demands and is not considered a big expense. Transport from South Africa to Hong Kong port can typically cost 0.6-0.8% of the invoice price for a sea freight container. The capacity of one container is about 2,000 cans of abalone.

Although most of the production process is done in-house, France Haliotis has outsourced delivery to external express delivery firms. These collect live abalone in boxes with ice and ship them directly to their customers by truck. The maximum transport time anywhere in France is 48 hours. The most important buyer segment are restaurants, buying boxes with 2-3 kg. Private customers are also served, buying boxes with less than one kg. Freight cost is paid by the customer, and generally amounts to 10 Eur/kg. France Haliotis has considerable interaction with many of their customers, as securing most of the value added along the chain and maintaining strong relationships with the customers is considered important for profitability.

3.4.2 Cost structure and profitability

The major cost components of abalone farming are infrastructure fixed costs, labour and energy. For a separate on-growing farm, spat costs would also be a major cost item. For this presentation, we will assume the latter to highlight the cost associated with spat production. The results are based on a simplified bioeconomic model with parameters taken from Urban-Econ Development Economists (2018) and interviews with farmers within AquaVitae. The publication illustrates costs associated with a sea-based cage farm of abalone although there presently does not seem to be any such farms operating in South Africa. As these are aspects that will be covered in more detail in later stages of AquaVitae, these are used to provide an illustration of production economics.

We assume a sea cage farm producing about 40 tonnes per year to illustrate the production economics. The bioeconomic model has the parameters shown in Table 6.

Table 6 Parameters for the bioeconomic cost model

	Parameter
Selling price / size	31.7 USD/kg at 100 gr
Feed FCR and price	1.4 / 2.04 USD/kg
Spat price and size	0.21 USD/pc / 10 gr/pc
Mortality rate	14%
Freight mortality	5%
Drip loss	7%
Production time	45 months
Labour at steady state / labour cost	28 persons (1,400 USD/month)

Variable costs are spat, feed and transport. Fixed costs are labour, insurance, general expenses, licensing, veterinary services, water test, other (2% of variable costs). Assumed investments per category for a farm of this size is shown in Table 7. The major costs in a sea-based system are related to the cage system itself.

Table 7 Investments in cage-based abalone farm producing about 40 tonnes (1,000 USD, source (Urban-Econ Development Economists 2018)*)*

	Investment	Assumed lifespan
Land	21	50
Buildings	874	20
Cage system	2,435	10
Equipment	28	5

The modelled production costs and revenues are shown in Table 8. Labour is by far the major cost item, at 37% of costs as production is highly labour intensive. Depreciation and capital costs are also major cost items estimated respectively at 23 and 18% of total costs. Feed and spat are respectively about 10 and 9%. The model yields an estimated profit of 0.9 USD/kg. Hence profitability is highly sensitive to especially changes in prices, but also production and costs.

Table 8 Modelled production costs (1,000 USD), absolute and per kg

	Revenue/cost	USD/ kg	% of costs
Revenue	1,313	31.7	
Spat	109	2.6	9
Feed	133	3.2	10
Consumables	0	0.0	
Transport	37	0.9	3
Labour	469	11.3	37
Insurance			
Other	74	0.1	
Depreciation	293	7.1	23
Capital cost	226	5,5	18
Sum costs	1,274	30.8	
Operating profit	38	0.9	

The reduction in operating farms in the EU indicates that farming has not been economically viable for the firms stopping production. The case firm, however, reports that farming is currently profitable and has been for some years. They also expect profitability to improve when scaling up production. Several factors can contribute to firms experiencing differing economic results. The production process is long and knowledge intensive, and firms may have different skills and resources available. Many unforeseen and stochastic events can occur during the process, and to achieve profitability in a relatively high-cost environment such as the EU is likely highly dependent on being able to reach and satisfy buyers that have very high willingness to pay.

South African production also is reported as having yielded good economic returns over time. The present COVID problems and Hong Kong situation strongly affects demand, and thereby also profits.

3.4.3 Profitability and pricing along the value chain

The price development through the chain for production of live abalone sold to Asia from South Africa is generally as shown in Figure 29. The major value adding is occurring within the grow-out stage. Spat price has been converted to per kg final product.

Production costs for spat are generally about 0.06 USD per piece. These are 10 mm long and about 0.2 grams. These generally sell for 0.12-0.14 per piece to on-growers without hatchery. During on-growing there is a relatively long time where the abalone are too small to be marketed. The smallest size generally processed and sold is 35 grams. Prices are strongly size-dependent. The smallest now generally have an export price of about 20 USD/kg. This includes processing and transport costs. Prices for the most common size 70-90 and 90-110 grams are about 25-26 USD/kg. The larger animals at 130-150 and 180-200 have prices at about 33.5 and 35.5 USD/kg. Prices have recently been reduced by about 30% down due to the Hong Kong and pandemic problems. In 2017, prices were generally 12-17 USD higher per kg.

Agents sell to restaurants and other further distributors. Prices to consumers do not seem to have changed substantially, according to interview information. Hence the middlemen have increased their share of value adding, although selling considerably less.

Freight costs are considerable. From the farm to Cape Town and by flight to Johannesburg and further to Asian markets used to cost about 2.5-3 USD/kg. With the current situation, more of transport is by chartered flights, that has about doubled the freight costs.

Processing costs depend on type of product. The packing cost of live products are about 2.11 USD/kg. Processing of canned and dried products are slightly higher at about 2.23 USD/kg. If sourced externally, processing is 3.45 USD/kg.

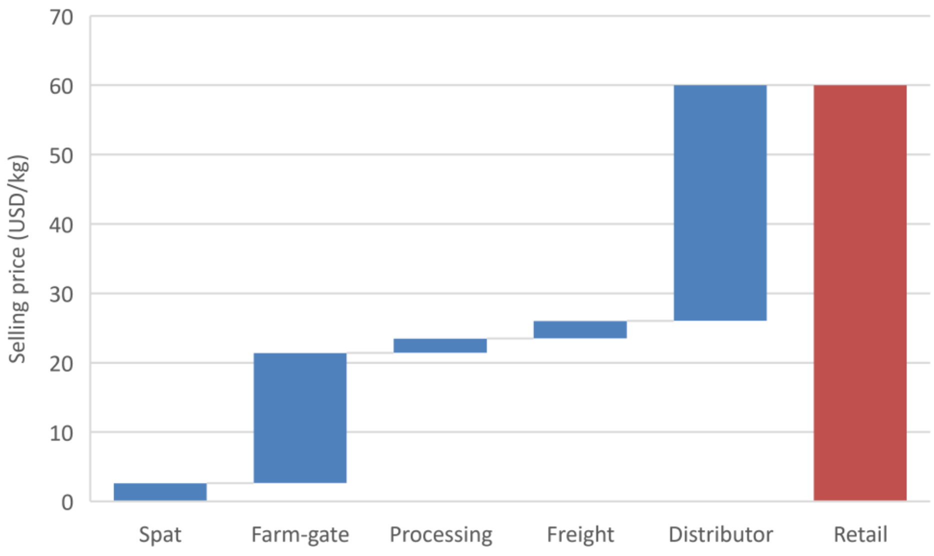


Figure 29 Price development through the value chain, fresh abalone from South Africa. Price at retail is just an example and will be further explored in coming deliverables

The value chain in France is shorter, as France Haliotis primarily sells directly to consumer or retailer. The distribution is carried out by an external service provider, so the farmer receives the sales price, about 60 Eur/kg. Transport costs vary, but are about 10 Eur/kg, hence the farmer captures a relatively large share of the value adding. France Haliotis of course needs to maintain the marketing and customers relations in-house, thus requiring additional staff and resources for this than would otherwise be carried by distributors.

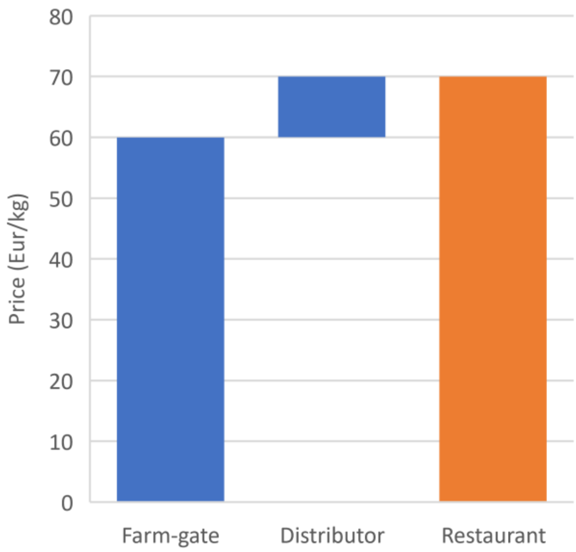


Figure 30 Price development through the value chain for fresh farmed abalone in France

3.4.4 Organization and governance

South-Africa

Farms are generally integrated vertically with their own hatcheries. Only the four larger mentioned farms have their own secondary processing facilities. Smaller farms (50-100 tonnes), pack and sell live products themselves, but production destined for canning and drying is sent to external processors. There are also some independent processors that primarily processes wild harvested abalone. As these catches have dwindled, such supplies are interesting for these plants.

One of the farming companies is further integrated upstream, owning feed production facilities, producing the formulated feed and supplying other farms that use this type of feed as well. One semi-independent feed producer is co-owned by two farming companies. There are two major feed suppliers, MariFeed and Specialized Aquatic Feed. One of the bigger farms utilizes a large share of wild-harvested kelp to feed their abalone. Other producers to a very large extent rely on formulated feed. Using kelp for feeding requires logistical adaptations as the quantity of feed is large. Macroalgae is also grown in the wastewater of the abalone tanks and then fed to the abalone. Farmers are advocating inclusion of more macroalgae in the artificial feeds.

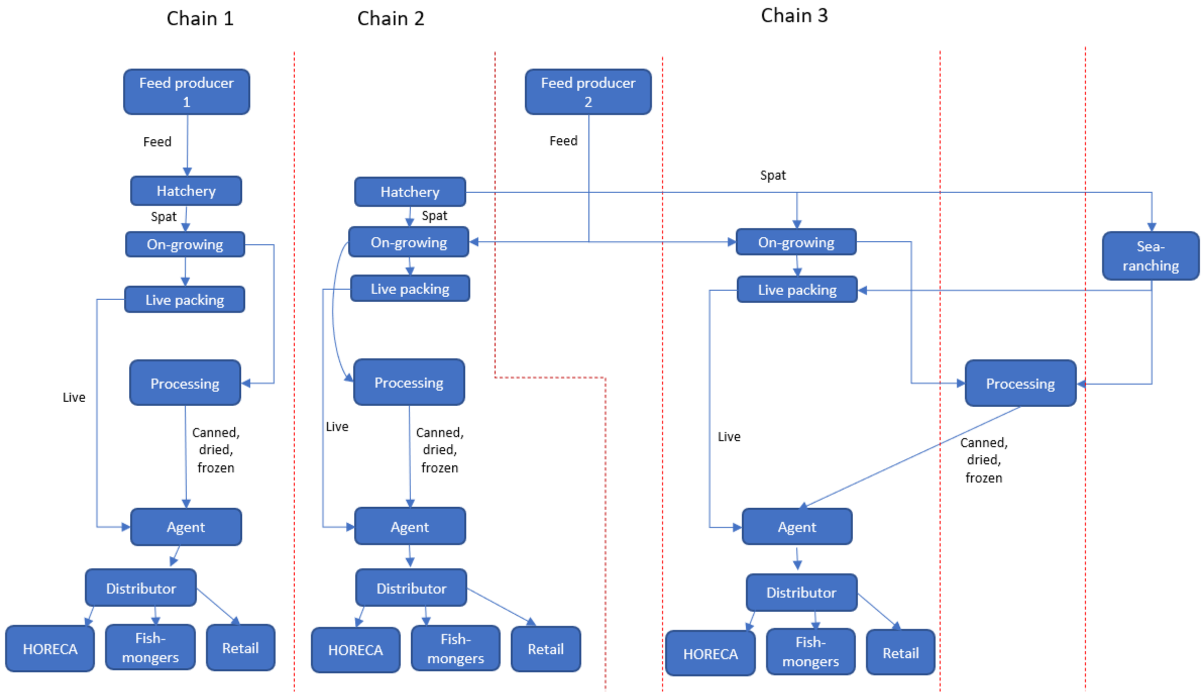


Figure 31 Illustration of organization differences in the value chain for abalone in South Africa. Chain 1 represents the organization vertically integrated from feed production through processing. Chain 2 is buying feed from the external feed producer, and chain 3 buys both feed and spat externally, as well as externally sourcing secondary processing services.

There have been attempts at collaboration between the farmers to improve competitiveness and bargaining power against the importing agents. These have not been very successful, especially with the crisis in Hong Kong and the COVID pandemic seeing demand dropping and logistical challenges.

In addition to the farming production and small wild harvests, there is considerable poaching from the wild. These are dried in makeshift facilities and enter the market through smuggling and in lower-quality segments of the market. Reductions in the wild and poaching fisheries due to COVID lockdown has contributed to reduced supply and increased prices for large abalone dried products.

The abalone producers sell to a large extent through "agents" in the relevant markets in Asia. They have relatively stable relationships with these, and each agent serves primarily one of the major South African farmers. Small quantities can be sold through other agents, depending on the demand from the agent's customers. These agents handle the communication further downstream, although the farmers also attempt to monitor the end-market developments. These agents have a strong bargaining position. Although we have not been able to obtain detailed information about how the distribution network from this stage is organized and how value is distributed between actors, it seems reasonable to assume that these actors are capturing a considerable share of the final selling price and value added in the chain.

EU

We have only registered a few current producers of farmed abalone in the EU, all with comparatively small output per farm and in total. The French case study farmer is a small-scale producer, focusing on organic production and use harvested macroalgae as feed. The firm is vertically integrated with hatchery and primary processing, as well as harvesting their own feed. They have also a strong marketing activity and do most of the sales activities in-house. There is a strong focus on maintaining close contact with especially restaurant buyers. If necessary, secondary processing is done by external firms. Transport of live abalone from packing plant to the end-user is done by two externally hired transport companies. France Haliotis primarily targets upper segment markets such as restaurants and sells to about 100 restaurants and several hundred private buyers in several cities. Restaurants order directly from the company generally once per week, although demand can vary strongly with season. The firm has the impression that the restaurants are happy with this form of distribution and would not prefer sourcing from a wholesaler.

3.4.5 Value chain improvement areas

Abalone production in Europe seems to have faced considerable difficulties. Despite several investments having been made in farms, production is very limited and several of the initiatives have stopped production. Being both labour and capital intensive, primarily due to the long production process, current production costs have only allowed firms to serve upper segments of the market with high willingness to pay. These markets also have a strong affinity for local species and production. France Haliotis has already established a value chain where very little of the value adding is outsourced to other organizations. There are few stages in the value chain, especially marketing and sales to end-customers are done internally and with small resources. Thus, there is little potential for improving the value chain by streamlining distribution and restructuring sales activities. At the current technology and production costs, sales growth may be achieved by the high-end market expanding and the firms being able to reach and serve these customers. With products knowledge spreading and with the improvements in e-marketing and commerce, this is a viable option, but growth is likely to be slow.

The main improvement areas in the production of abalone must thus be achieved from production growth and cost savings from technology development, scale or other innovations. Reducing production costs could allow reaching markets with less buying power, but in these segments, competition from imported products with lower production costs is likely to be higher.

Current farming technology is relatively space demanding, as each cage is occupying 8 m^2 and requiring special bottom conditions. Increasing scale would also require more farming area. Seabed with reasonable conditions may be scarce. Technology developments that increase production per area could represent an interesting option for improving the value chain.

Considering the integrated culture of abalone and other species, this could be a source of improvement. The primary mechanism would be to improve the utilization of the invested capital in infrastructure, such as cages, mooring, farming vessel, but also the husbandry activities. Being farmed within the cage, scallops and oysters could contribute to this as they are likely to occupy different niches of the cage systems and not impact negatively on the abalone production. These products will also be marketed to the current restaurant customers and will likely increase the product portfolio that the firm is able to supply, strengthening the relationship with these.

For co-culture of scallops and oysters, as planned and trialled by France Haliotis, survival during transfer is a major critical challenge. Currently this is too low and needs to improve considerably for this to become viable. The activities in AquaVitae will contribute to this as a specific task is related to developing protocols for such co-culture.

Culture of macroalgae could also contribute positively, but through other mechanisms. Culture could rationalise the harvesting of food for abalone, and perhaps provide options for optimizing feed and improving feed quality through the production process. Excess macroalgae could also be sold externally, as markets seem to expand and prices to consumers rising. Thus, farmed macroalgae could be more economical to sell directly, rather than feeding abalone, but still represent an improvement in revenues. At present, harvesting is more cost efficient, so the productivity in farming needs to be improved. Again, the development of protocols for this type of culture is a task that is investigated in AquaVitae.

In South Africa, cage-based culture seems not to have been viable with current technology. The developments required to change this situation are unclear. This section focuses on value chain improvements for abalone production in general. South Africa is exporting primarily to Asia. Thus, the current COVID crisis is causing major problems, both reducing demand and creating logistical challenges and increasing transport costs. There has also been a vast increase in production from farming in particularly China and Korea. The development in these areas will be of major importance for the industry going forward. French production, being especially aimed at the restaurant segment is facing similar demand challenges, but as production is primarily locally consumed and French favouring the local species, increasing production or changes in demand in Asia will likely be of less importance.

Other marketing related issues also provide opportunities. Sales currently rely on agents in each country market. It is likely that these are capturing a considerable share of value adding, as indicated by prices observed along the value chain. Thus, being less reliant on these or reducing their bargaining power represents a clear opportunity for improving the value chain for South African farmers. This is also likely to make the value chain more efficient. As Asian markets are complex to understand and relationships between the chain actors being of major importance, this is not an easy task. Developments in e-commerce in Asia could contribute positively to improving the competitive position of farmers. Improving marketing activities and differentiation from local species in the main markets is likely also a source of improvement.

Red tides have become a challenge in recent years. For about 20 years, red tides were not impacting farms. The first major event was experienced in 2017, causing about a 40% loss of the stock for three of the major abalone farmers. Mortality is likely related to toxins disrupting gills and external epithelia (Mouton 2017) This first event happened unexpectedly. When another red tide event developed, farmers were more prepared. A monitoring system had been developed and farmers responded by e.g. stopping the water supply in times when monitoring showed that the concentration of dinoflagellates was above thresholds. Improving monitoring and knowledge about the impact of red tides represent opportunities for improvement. Developing management responses as well. Technical solutions such as deeper water intakes could also be explored.

For South African farmers, they are facing challenges related to competition for space. Good farmland may be of interest other users, such as real estate developers or tourism industry. Some areas are also experiencing red tides more frequently than others. Technology developments that improve productivity per unit of space could thus also bring improvements.

Electrical supply is considered especially problematic by farmers. The supply of electricity is scarce in South Africa, especially as abalone farms have high power consumption. Some farms have installed solar power to supply parts of the energy consumption. Energy saving technology developments are thus attractive. Considering the space shortages, this makes sea-cage systems attractive. Of prime importance is the currency development. Products are sold in USD and costs are incurred in local currency. Thus, strengthening of local currency will be problematic. Legislation is often considered problematic by industry representatives, with bureaucracy being too strict. At the same time, it is not certain that changes will be for the better - legislation is necessary and relatively well-functioning.

4 CS6 Sea-urchin roe enhancement

4.1 General introduction

Sea urchins are in many countries a highly valued, sought after seafood product. Good quality sea urchin roe is considered to have a delicious, tasty and unique flavour. Subsequently, there is a substantial world market for sea urchin roe with the largest market (approximately 80% of worldwide consumption) in Japan. The worldwide supply of sea urchins has diminished over the last decades, from 100 thousand tonnes in the 1990s´ (with a peak of 120 thousand tonnes in 1995), to around 75 thousand tonnes in following years (Stefánsson et al. 2017; FAO 2020b).

Around 60 thousand tonnes of sea urchins are traded between countries. Traditional harvesters have experienced reduced catches, while no major harvesting countries have emerged to cover the potential demand. The sea urchin market is not considered saturated, especially in the off-season, with demand estimated to be higher than supply (Stefánsson et al. 2017). In contrast there are areas where there is an abundance of sea urchins. This is due to the lack of a traditional fishery in these countries (North Atlantic countries such as Norway) and the low quality of the sea urchins that are found there in very high densities. The result of these high-density sea urchin populations is overgrazing and destruction of macroalgae forest. This has converted large seabed areas into sea urchin "barrens" (areas where only sea urchins live and all macroalgae species have been destructively grazed). These barrens provide low nutrition availability for sea urchins, resulting in smaller urchins with small gonads (Gundersen *et al.*, 2010). But the combination of this ecological problem and the non-saturated market for sea urchins also represents a business opportunity. Sea urchins with low gonad yield can be turned into a valuable product through roe enhancement. This is where wild sea urchins with low gonad yield are harvested, held in a holding system and fed to increase the size and quality of the gonad, before being transported live to market or value-added processing. This is made possible both through the development of specific sea urchin roe enhancement feeds and improving roe enhancement technology and practices. This is the aim of Case Study 6.

Currently, all the world supply of sea urchins comes from wild harvest fisheries as aquaculture and roe enhancement activities are not yet developed to a commercial level. Case Study 6 focus on the opportunity for achieving commercially viable roe enhancement for sea urchins, as illustrated in Figure 32.

Figure 32 Sea urchin roe enhancement: from 4% to 20% roe content (From James et al., 2016).

The quality of wild sea urchins varies significantly with species and season, with the roe content as the main indicator. The gonad index (GI) is the ratio of the weight of the gonad to the wet weight of the whole sea urchin, where a high index means bigger gonads. In Norway, the GI is at its lowest immediately after spawning (March/April) and will increase during summer and fall, depending on species and reproductive cycle. The GI of urchins in the wild can vary hugely and can be less than 1% or as high as 20%, whilst for cultured and enhanced sea urchins GI values can be as high as 35% (James et al. 2018).

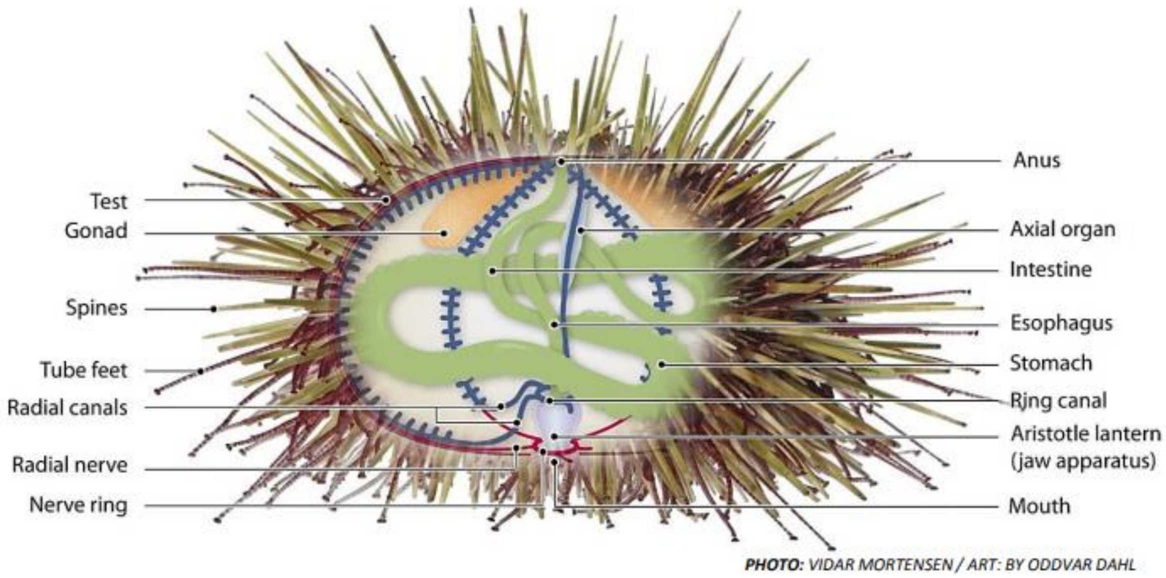


Figure 33 Longitudinal cross section of the sea urchin (From James, Siikavuopio and Johansson, 2018*).*

Factors that affect GI are feed availability, environmental conditions (e.g. daylight period, water temperature/quality and presence/absence of water currents) and the reproductive cycle of the urchin (James et al. 2018). With roe enhancement, the GI might be brought to commercially desirable levels in six to twelve weeks. Enhancement can also increase the length of the seasons of good-quality sea urchins.

4.1.1 Methodological remarks

The value chain analysis primarily covers the first aspects of the Global Value Chain framework - input-output structure for the project partner and their sea urchin roe enhancement project. Firm-level input-output structure is extensively described based on information from interviews with project partner representatives and informants from the more established value chain for farmed sea urchins. As there is a well-established market for wild-caught sea urchins, and also production information based on full life-cycle aquaculture, we have covered also aspects of these value chains. Information on these chains were obtained from both published literature and interviews with the project partner and other industry informants. Another GVC aspect, organization and governance of the value chain is to a small extent described based on interviews with project partner and other industry representatives.

Supply and markets for the general sea urchin industry are described utilizing public data from FAO, in addition to published grey and peer-reviewed literature. Price development along the value chain is mainly based on estimates derived from interviews and some published market trials, with Norwegian export prices for sea urchins gathered from Statistics Norway (SSB). The identification of improvement areas is based on interviews with industry informants. An interview guide was developed, and semi-structured interviews were conducted based on this guide. As sea urchin roe enhancement is still on a pilot scale, describing the governance and competition within an industry, were found of little relevance and are not discussed. Both chain governance and the Porter five forces perspective are likely relevant in later AV tasks, where we will study cost determinants and business models.

4.2 Introduction to the wild sea urchins harvest industry

This section will cover production and trade of sea urchins, as well as outlining major markets and products. Chile is the largest producer of sea urchins. Sea urchins are also captured in North America (Mexico, USA and Canada), Peru, Japan, Russia and Iceland. China is also a large producer (possibly the second largest, but irregular data access makes it hard to estimate an accurate size of the fishery).

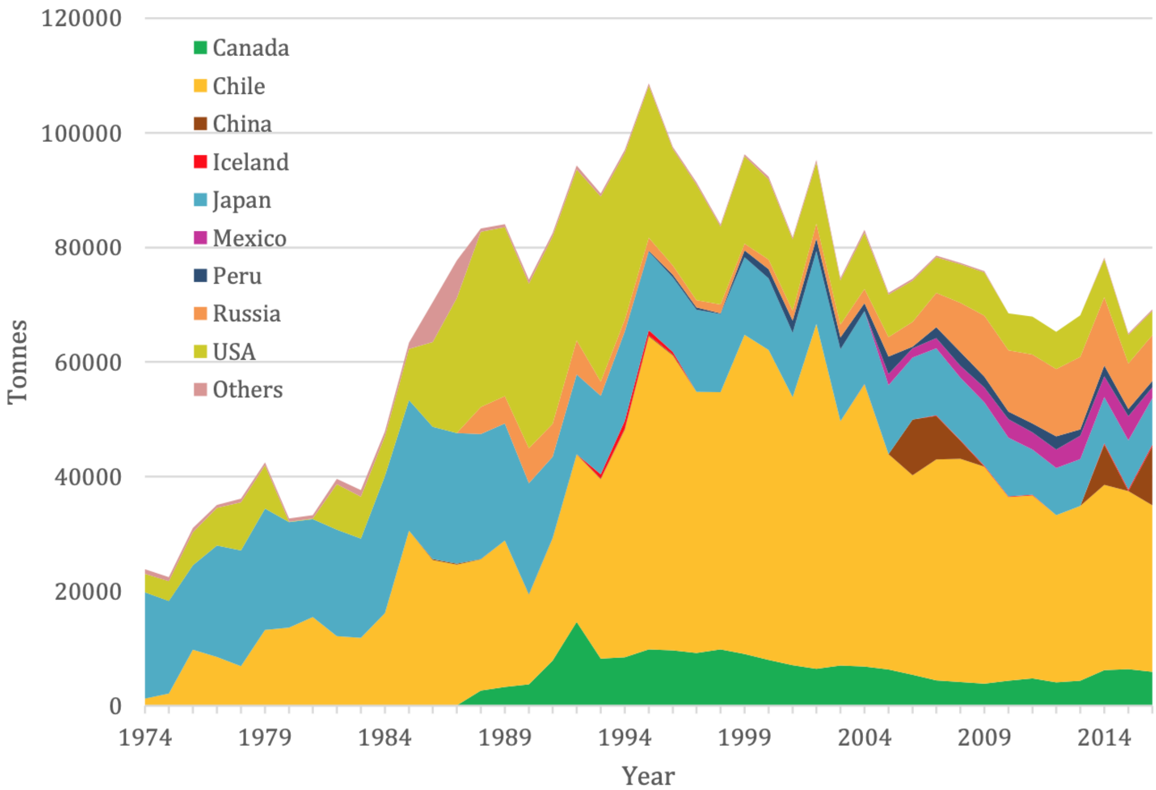


Figure 34 Global landings of sea urchins, 1974-2016. Source: FAO.

Japan is by far the largest market for sea urchins, accounting for 80-90% of worldwide demand (Sun and Chiang 2015; Stefánsson et al. 2017). Japan was also the world's largest harvester of sea urchins until the mid-eighties. Since 1987, Japanese harvests have declined steadily due mainly to declining stock abundance from fishery pressure (Sonu 2017). Since then, Chile has grown to be the largest supplier globally (FAO 2020a).

The Japanese market is estimated to be around 50 thousand tonnes, with 8-10 thousand tonnes landed domestically. Sea urchins are imported to Japan both as live, fresh, frozen, salted and processed. In the late 1980s, the United states, Canada, China, North Korea and South Korea were all major players in this market, but since 1999, the live urchin market in Japan has been dominated by Russia (Sun & Chiang, 2015). Of the 8 thousand tonnes imported live to Japan in 2016, 96 % came from Russia, with small quantities of imports also from Iceland, Canada and the USA.

Although Japan is the largest market for sea urchin, it is not the only market in Asia where sea urchins are eaten. Countries such as Korea and China also consume significant quantities. These markets are mainly for raw sea urchin roe, to be eaten as sashimi or in sushi (also raw, but with rice) or preserved in bottles mixed with brine or alcohol and salt (Andrew et al. 2002). There is a large variety of sea urchin species eaten in Japan and elsewhere in Asia (including *S. droebachiensis* from the North Atlantic). Japan is not only the largest market, but also an important influencer for demand elsewhere. The sushi trend is still spreading internationally, and products finding it´s place within international sushi menus might experience a growth along with this trend, as has been the case with salmon. As Japanese domestic harvest is not likely to increase in the short term, increased export of sea urchins and sea urchin roe has significant potential (Sonu 2017).

In Europe there is also a strong and established traditional market for sea urchins in countries such as Italy, France, Portugal and Spain. It is either eaten raw, with pasta or preserved in jars or cans. In Europe, the most common species eaten is *Paracentrotus lividus* although there is also some import of *S. droebachiensis,* mainly from Iceland (approximately 200 tonnes per year) (Stefánsson et al. 2017).

Due to decreasing wild catches worldwide and increasing demand there is tremendous scope for sea urchin roe enhancement to add value and utilise the substantial sea urchin populations that generally have poor roe quality in areas such as the North Atlantic. There is also capacity to add value to existing fisheries by maximising the value of the product (e.g. selling out of season) in areas where there are limited sea urchins but a very strong traditional market (e.g. Spain and Portugal).

4.3 The wild sea urchin fishing value chain

The value chain for wild caught sea urchins is relatively straight forward, with few stages of production and organisations involved. They are harvested (mainly using divers) and sold whole and alive directly into wholesale markets. Alternatively, they can be harvested and then processed to remove the roe which is then sold separately into wholesale markets. In Asia the quantities tend to be large and almost all products go through the wholesale markets such as the Japanese Tsukuji market. The European market is much more varied and can involve selling live whole sea urchins to wholesale markets at Boulogne-Sur-Mer and Rungis in Paris or to small high-end restaurant customers. Alternatively, the roe can be removed and sold separately which is more common in Southern Europe in traditional markets for *P. lividus.*

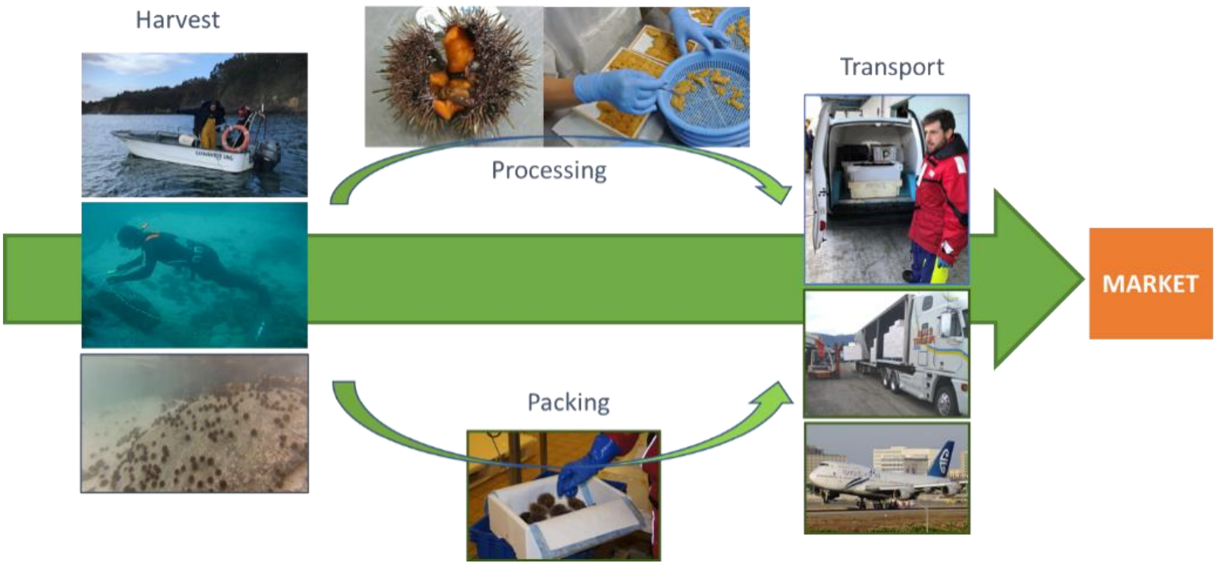


Figure 35 The relatively simple value chain for wild harvested sea urchins

In Europe there are several sea urchins harvested and sold (*Psammechinus miliaris, Echinus esculentus* and *S. droebachiensis*). However, the most sought-after species is *P. lividus*, which has driven the French market and the expansion of the fishery across Europe.

In the late 1950s' stocks of *P. lividus* were starting to decline in Brittany and the fishery expanded into the south and west coasts of Ireland in the 1970s'. This fishery lasted more than 25 years until the collapse of the Irish fishery, where the maximum exports of 400-500 tonnes per year were reported. Ireland was seen as the main supplier of *P. lividus* to the Paris markets due to the high-quality roe and large size of the sea urchins for this 25 year period. The methods of transportation were by road or by air where the live sea urchins were packed dry in insulated boxes. With direct flights from Ireland to Paris on daily basis allowed for product to be sold from the Paris Rungis market daily for the season from October to April. The acceptance of Irish sea urchins is very high and the routes to market and the value chain are also well defined (Stefánsson et al. 2017).

Regarding the supply of *P. lividus* to the other European markets from outside of Ireland. It is supplied directly as it is harvested, then consumed or processed domestically in Italy, Spain and Portugal without the need to transport or reliance on the French wholesale market for their country's harvests.

The domestic market and value chain for sea urchins in Spain and Portugal is well defined with local harvesters supplying direct to wholesaler and processors. Unlike the boom bust fishery experienced in Ireland, fisheries management legislation is in place in Spain and Portugal, which has managed to afford protection to the natural stock of sea urchins. Notwithstanding the protection of sea urchin fisheries in Europe, it still does not fully protect the stocks from poaching and illegal harvesting.

Due to the long-standing culture of consuming sea urchins in continental Europe there is a robust domestic market for live sea urchins, and processing is used as a means for utilising sea urchin with low gonad content. The processing of sea urchins both extend the shelf life of the product and extends the range of supply throughout Europe.

4.3.1 Input-output structure of the sea urchin fishing value chain

As illustrated in Figure 35, the value chain for sea urchin fishing has three major stages, collection, processing and transport of sea urchins. These will be described below (while holding systems, feed and enhancement will be covered in the next section).

Sea urchin collection

Harvesting sea urchins has been based on three main methods, the use of divers, dredges or ROVs for automated collection of sea urchins.

Diving is the most common form of sea urchins harvesting, used in all areas with commercial harvests. In Norway, experiences are good, even though the combination of a labour-intensive operation and high Norwegian salaries makes for a costly process. To reach a commercial scale, one company used a two-hull workboat (15meters long). The operations required a team of at least five people, of which at least 3 must be divers. The number of effective diving days is limited by weather and underwater visibility in the sea, which worked out roughly at 160 days per year.

Static demersal traps are were also tested, the traps have a diameter of around half a meter, each trap is baited, (discards from fish processing or macroalgae) and the traps are linked in a in a string, with 20-30 traps in each string. The catch per trap is typically 1-2 kg per day of soaking. An example of how this model would work with a two-person team on a small boat, operating 300 traps on 10 strings and can theoretically catch 300-600 kg per day. The number of fishing days per year under this model would increase as there is no direct need for underwater visibility as this does not affect the fishing method.

Figure 36 Collection by diving (left) and traps (right).

Dredging has been attempted by a type of beam trawl that catches the sea urchins by lifting them off the substrate. This method can only be used on suitable seabed and bottom type. A proportion of sea urchins tend to get damaged in the dredge, but they are graded out of the harvest at processing. Operators using this method supply both a wholesale live market and processed roe market. Animals that are damaged get processed once they are landed. Dredging for sea urchins may not be suitable for roe enhancement as some of the sea urchins will die within a few days due to the handling stress. Dredging is the most common method in Iceland as there is a hard-compacted bottom type and there is legislation in place to allow the fishery and the fishing method. A few different concepts of ROVs (remotely operated vehicles) for harvesting sea urchins have been also developed and tested but are not commercially available or viable. There is now a novel remote operated device that will be commercially trialled in Norway and Canada in 2021.

Processing
The processing of sea urchins is well established in Europe and Asia, the process involves opening the sea urchins test, removal of roe, cleaning, stabilisation, quality grading and packing. Processing of live sea urchins is somewhat simpler, with chilling, sorting and packing (typically in 5 kg insulated boxes for the European restaurant market, and in 15 kg boxes for the Japanese roe processors).

Transport
The shipping of live sea urchin places great demands on transport logistics where direct routes are not well defined. A simulated transport trial has been carried out which indicated that it was possible to send sea urchins (*S. droebachiensis*) for up to 44hr packed in 'isopro' boxes with gel ice, and they will arrive alive and in relatively good condition (James, Evensen, and Samuelsen, 2017).

However, the trial also tested long-term survival when sea urchins were transported and then kept alive for two weeks. The results showed that urchins transported 44hr had a significantly higher mortality than those transported for 34hr (or less). This is an important consideration when transporting live sea urchins to market, and/or transporting urchins to any live holding facility for subsequent roe enhancement.

4.4 Sea urchin roe enhancement Case Study introduction (Norway and Spain)

Norway
There are several species of urchins found in Norway, but only the green sea urchin, *S. droebachiensis,* is found in commercially available quantities. There is an enormous biomass of *S. droebachiensis* in Norwegian waters, estimated to be 80 billion individual animals, or 56,000 tonnes (Gunderson et al., 2010). However, sea urchin fishing in Norway is still sporadic with between 10 - 50 tonnes being landed annually. Only one company (Arctic Caviar AS) has consistently harvested sea urchins for over a decade but in very small quantities to serve high value, low volume markets, primarily Michelin star restaurants in Europe. This company has since ceased harvesting. In addition, there are a small number of other companies harvesting sea urchins as one of a range of species harvested and sold (e.g. Statsnail AS). There are several companies interested in starting harvesting for roe enhancement activities. The development of a substantial sea urchin industry in Norway has been hampered by the fact that there is no traditional fishery and a very limited domestic market for sea urchin roe, the environmental conditions are harsh, particularly in winter and the labour costs in Norway are very high.

Considerable efforts have been made in the past to develop both hatchery production of the green sea urchin in Norway as well as developing commercial scale roe enhancement (James et al., 2017). This case study is focused on **sea urchin roe enhancement**, which has been attempted several times in Norway by various companies with varying levels of advancement and success. The following is a summary of these in approximate chronical order of their activities.

Scan Aqua AS was a dedicated sea urchin enhancement venture that operated in Hammerfest in the North of Norway. When roe production was permanently ceased in December 2009, Scan Aqua AS had produced approximately 3,000 kg of roe of satisfactory quality. Scan Aqua developed a complete value chain from capture via feeding to packing of live sea urchins and production of sushi-quality roe, as well as sales and logistics associated with distribution. Scan Aqua AS had an industrial approach to the production and processing of sea urchins. The sea-based production based on the capture of sea urchins of saleable size, followed by a feeding period of 2-3 months using the Nofima sea urchin feed and SeaNest sea-based holding system to increase the roe content from a natural level of typically 5-10% to 15-20% (Gjøvik 2011).

Troms Kråkebolle (Troms Urchin) operated between 2011 and 2017 and explored both land-based and sea-based closed-cycle farming of sea urchins (from eggs to market). They ran a small scale, land-based hatchery production of sea urchins, with sea-based on-growing facilities. They reached the point of having product for sale when they shut down operations. One of the main reasons there is low uptake for the culture of sea urchins is the very slow growth of this species and the cost of growing sea urchins from eggs to market (at least 3 years). The goal was that it should not take more than two years from the spat until market ready sea urchins. Troms Kråkebolle built facilities to produce 5 million sea urchins a year.

Lyngsskjellan is a small family owned and operated mussel farm that has run some pilot scale trials in collaboration with Nofima (James et al, 2017). The roe enhancement trial was conducted in Lyngen, Northern Norway, utilising wild harvested sea urchins from Tromsø. The commercially available SeaNest holding system and the Nofima sea urchin roe enhancement feed was used in the trial. The sea urchins showed a significant increase in GI over the 10-week enhancement period (from an initial GI of 3.9% to a final enhanced GI of 20.3%). This increase in roe content is typical for this species (*S. droebachiensis*), fed the Nofima roe enhancement diet for 10 weeks based on previous research conducted by Nofima. The overall survival of the sea urchins was relatively low after 10 weeks compared to previous trials. Sea urchins were distributed to four restaurants in Norway and one sea urchin processor in Hokkaido, Japan for quality assessment. Three of the four Norwegian restaurants considered the sea urchins to be of good quality. The company decided to not start commercial production.

Arctic Caviar has used divers to harvest sea urchins for over a decade supplying a high value low volume market in Europe. Arctic Caviar has finished commercial fishing activities in 2018.

Ecofang is a start-up company based in Tromsø in the North of Norway. The company has developed a novel technological solution for harvesting and plan to extend beyond wild harvesting and begin sea-based roe enhancement in the future.

Statsnail AS is a start-up small fishing company utilising SCUBA and free divers to harvest a variety of seafood. They have run small experimental scale sea urchin roe enhancement trials in the middle of Norway. They have also investigated exporting live sea urchins to Europe and have an ongoing interest in sea urchin roe enhancement.

URCHINOMICS Nordic AS is a company that began in 2013 with the original aim of relief effort to provide work opportunities for Japanese fishermen after the devastating tsunamis that impacted the coast of Japan. Since that beginning the concept has developed considerably in Japan and in Canada, USA and is under investigation in Australasia and also in Norway. In addition to the economic benefits of sea urchin roe enhancement URCHINOMICS also focus on the environmental benefits from the removal of sea urchin barrens, allowing the recovery of macroalgae forests in their place. It is unclear exactly what caused the rapid increase in wild populations of sea urchin along the coastline of mid and Northern Norway. Regardless, these have decimated productive macroalgae forests. When the macroalgae forests are gone sea urchin barrens can persist for decades, but the sea urchins in these barrens have very little, or no roe and therefore have no commercial value. One method of creating value from this massive standing stock of sea urchins, while at the same time aiding environmental restoration, is through sea urchin roe enhancement.

Figure 37 An example of a sea urchin with virtually no gonad (roe). Photo: Noriko Hayashi

The company URCHINOMICS intends to produce sea urchins in several locations around the world. They are planning to do land-based roe enhancement in Norway, Canada, US, Canada and Japan. They have an operative site in Newfoundland, a site in Quebec and one in California that are both close to start operations, and a site in Stavanger in the South of Norway that has produced sea urchins at a pilot scale in 2020. In Japan they plan to produce sea urchins in cooperation with a local partner and will be ready to start commercial production in March 2021.

At this point the pilot scale facility in Stavanger is in the process (through collaboration with the AquaVitae project) of establishing proof of concept of sea urchin roe enhancement in Norway. The start-up of the facility has been delayed by COVID as well as the necessity to re-build the facility to avoid spread of nematodes from the north of Norway. The facility will now be run as a recirculating aquaculture system (RAS) (which also necessitated chilling the water in the system), as opposed to a flow-through operation. They hope to have sea urchin enhancement trials underway by the end of 2020 with a limited production (1-2 tonnes). It is likely that if the Stavanger trial is successful then a commercial facility will be built in Northern Norway.

Spain

There is a very well-defined market and value chain for sea urchins in Spain, which primarily focuses on *P. lividus* for both live and processed sales. The total annual harvest from Spain is predominately consumed domestically with only processed sea urchin roe being exported. The end product of the processing of sea urchin roe is in the form of small tins or cans.

The fishery is regulated by the local government and advises a TAC (total allowable catch) for the fishing season every year. The harvests are conducted by small teams of commercial divers working from licensed commercial boats where they have to land the harvest at local ports where they must declare where the harvested sea urchins have come from and how many kilos have been harvested. This is strictly controlled and monitored by authorities.

Porto Muiños is an example of a company harvesting sea urchins in Galicia in Northern Spain with a well-defined value chain. Porto Muiños is an SME in Galicia who harvest and supply a large range of fresh, live and value-added products from the sea, including macroalgae and sea urchins. They employ commercial divers to harvest their quota of sea urchins once the fishery is open each season (September – April). These sea urchins are graded into live whole sales and sea urchins for processing. They process their own sea urchins into value added canned products and preserved sea urchin roe products. Porto Muiños is interested in improving their sea urchin output by establishing a pilot roe enhancement trial through the AquaVitae project and their pilot sea urchin farm Algafres. Algafres is establishing protocols for producing sea urchins from egg to market and roe enhancement of wild sea urchins. Both are well suited to their well-defined market and value chain.

4.5 Sea urchin roe enhancement value chain

The value chain for sea urchin roe enhancement is a relatively simple addition to the value chain for wild harvested sea urchins. Once the sea urchins are harvested, they are transferred or transported by road/sea or air to a holding facility (land or sea-based). There they are held for relatively short periods (8-10 weeks) and fed a specially manufactured feed designed for roe enhancement. During this period, the roe increases in size and quality and becomes a valuable seafood product.

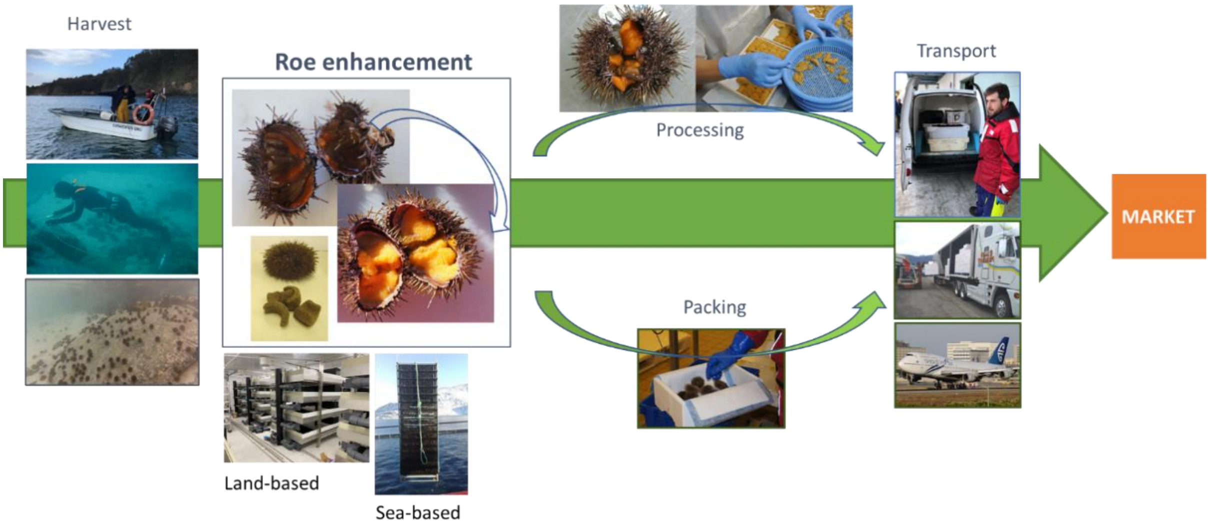


Figure 38 Value chain for sea urchin with roe enhancement.

An example of where roe enhancement can slot straight into an existing value chain is in Spain where they can process and can their own wild and enhanced sea urchins. This would be a sea urchin roe enhancement value chain based on *P. lividus* where there is a domestic market for both live and processed sea urchins. *P. lividus* has not been enhanced on a commercial scale prior to the AquaVitae project, this will be the first large scale commercial trial.

In addition to the steps described in section 4.3.1, for roe enhancement this section will cover holding, enhancing (including feed development) and market issues regarding enhanced sea urchins.

Holding systems, for instance the Seanest sea-based crates, have been developed for transport and holding for roe enhancement. The SeaNest system consists of specially developed plastic boxes for storing sea urchins under high density, and a hydraulic rig for handling the box stacks for launching, feeding and landing for further processing. The boxes can be joined in stacks of 20 - 30 boxes, which are hung from a floating pipe in the sea at a depth of 5 to 10 m. A stack of 30 boxes can hold 450 kg of sea urchins. For the Scan Aqua plant, the total holding capacity was 45 tonnes (3,000 boxes).

Enhancement. Sea urchins are held and fed to enhance the roe content, where the gonads will reach a satisfactory market size in about 10-12 weeks (James *et al.* 2017), or even shorter (4-6 weeks if new feed development goals are reached). Roe enhancement can thus make sea urchins commercially viable in Norway and Spain under the right conditions.

Controlling or improving the consistency of roe is a key area for the development of roe enhancement. Fresh roe is soft and tolerates transport and handling poorly. For the Japanese market the roe must go through a series of salt baths (potassium alum) to obtain satisfactory firmness.

Feed. Numerous studies have shown that the composition and type of feed used for sea urchin roe enhancement have an enormous impact on the efficacy of the enhancement and the resulting quality of the sea urchin roe (Sætra 2019). Nofima (previously Fiskeriforskning) has worked for a number of decades on the development of feed and feeding protocols for sea urchin roe enhancement. The work has led to a manufactured feed that provides good roe growth and colour. In addition, taste has also been part of the development (Dale et al. 2006, James et al. 2017). Dale et al. (2006) ran a feeding experiment with six types of feed with different protein and carbohydrate content/sources. The sensory analysis showed that diet affects both the 'bitter taste' and 'sweet taste' of the resulting roe. There were clear differences between gonads from wild and enhanced sea urchins, as well as within group differences. The biggest differences in consistency were found for the property 'firmness' where half of the enhanced gonads were significantly less firm than gonads from wild sea urchins. There was also a clear relationship between the protein content of the feed and the firmness of the gonad, where firmness seems to decrease with increased protein content. The very early versions of the feed from Nofima were successful in terms of consistency in sea water, and its ability to deliver nutrients over time. However, they did not yield roe of optimal quality in terms of taste and consistency.

In 2018 the Nofima feed was licensed for production to URCHINOMICS who are producing it under license in Japan. They have made further composition changes to refine the resulting roe flavours for the Japanese market. Currently to our knowledge this is the only commercially produced sea urchin feed in the world. Trial amounts of sea urchin feed have in the past been produced by various research institutes and feed companies. There has been a Wenger extruded diet produced in the USA in the past and the Portuguese company Sparos has also produced a variety of experimental feeds. There is a history of feed production for marine benthic invertebrates such as abalone. This species is farmed in significant quantities in countries such as China, Korea, Australia, South Africa and Chile. There is a very limited production of abalone feeds in Europe. Le Gouessant in France is one company that has supplied feed to the European abalone industry. However, this feed may not be directly suitable for sea urchins, but it may be possible to modify the feed components and extrusion techniques. The commercial technology is currently available in Europe but its application to the developing sea urchin industry is unknown.

Market issues for enhanced sea urchins. The global sea urchin market is used to wild caught sea urchins, and the quality that varies with species and season. Sea urchin enhancement can in principle supply a more consistent quality but has so far lacked consistency with regards to the quality aspects that the market demands (Sun & Chiang 2015).

There is relatively little available information available on how enhanced sea urchin roe would be accepted into traditional markets. In Japan there is no history of accepting enhanced roe and so the market placement and value in a very traditional market is unknown. In Europe, where new products may be more easily introduced, enhanced roe may have a greater chance of being sold as a valuable seafood product.

Currently there are not yet enhanced sea urchin products on the market from Europe, despite the high value of sea urchin roe on export markets. Sea urchins harvested in Norway have virtually all been exported to the European market, mostly to small exclusive end users such as high-end restaurants in Scandinavia, Germany and France (Stefánsson et al. 2017).

The routes to European markets are well defined from Norway with good freight connections throughout. Although the market potential seems to be huge in Japan, the relatively low value of the product (as is the case with all imported sea urchin products in Japan) and high transport costs must be considered when investigating the viability of roe enhancement in Norway for the Japanese market.

In both the case of Norway and Spain the European market is considerably easier, less expensive, and achievable to reach than the Japanese and Asian markets. In addition, sea urchin roe that is not sourced from Japan and is subsequently sold in Japan is generally sold for relatively low prices. Only roe from Japanese sea urchin species, harvested in Japan fetch top market prices. These factors indicate that the European market is a much more likely destination for sea urchins enhanced in Norway or Spain. In fact, Spain and Portugal have a relatively strong domestic sea urchin market where it is a lucrative product. Roe enhancement efforts in Spain could develop niche markets for consistent quality and out of season roe.

Experiments have shown that enhanced sea urchins are different from wild captured sea urchins, with the process having multiple effects on the roe. Feeding wild captured sea urchins artificial feed is an effective way to increase gonad indices, but dietary input also seems to affect biochemical composition (Sætra 2019). This means that there is need for more knowledge on how feed may affect various roe quality parameters, particularly taste.

4.5.1 Initial efforts to introduce enhanced sea urchin roe into markets

The only trial the authors are aware of that sent enhanced roe of *S. droebachiensis* from Norway to Japan showed the sea urchins were in good condition post transport and the roe had good colour (specific to this market requirement). According to the Japanese wholesalers who received the product, the texture was rather soft and did not have a strong or sweet sea urchin flavour, which meant it would not be considered best quality in that market. (James et al. 2017).

The roe from these sea urchins was sold in the Tsukiji market for 1,000 to 2,000 ¥/ 100 g of roe, the average price of 1500 equating to 10.5 NOK (1.25€) / individual sea urchin or 30€/kg (James et al. 2017). This was the first attempt to send Norwegian enhanced sea urchins into Japan so the results of the trial in terms of market value should be treated with caution.

Figure 39 Sea urchins on arrival at the processing plant in Hokkaido (A), being opened (B), cleaned and sorted (C), and packed in traditional trays for sale (D).

More qualitative market evaluations were conducted after the arrival of the sea urchin roe in Japan (James et al. 2017). A Japanese processor assessed the quality of the roe after live transportation to Japan:

- The quality of the sea urchins at delivery to the processor was good. As long as the level of freshness is good, dead sea urchins are not problematic. The quality of sea urchins received from Canadian or U.S. east coast origin is much lower as spines flatten and occasionally the sea urchins have an unwanted smell.
- Sea urchin sizes were generally on the small side. The larger size sea urchins in the samples were the normal preferred size of Japanese sea urchins.
- The roe itself is considerably softer than other products, but roe colour was very good (in line with market requirements).
- After immersing in 'alum water' (standard processing procedure for increasing gonad firmness) for 30 minutes, the roe was still softer and waterier than the normal Japanese product.
- The taste is considered weak and does not have enough flavour or sweetness for top grade value.

Since 2017, URCHINOMICS have continued to explore the Japanese market for enhanced sea urchin product. A more recent enhancement trial run in Japan, based on a commercial pilot production and using a local Japanese sea urchin species, has shown good potential in this market. This trial was based on the sale of live sea urchins without the need for treatment with potassium alum, which results in a more fresh and natural taste.

URCHINOMICS have also further developed the feed formulations (based on the inclusion of a macroalgae called kombu, *Lamanaria japonica*). This is what wild sea urchins around Hokkaido feed on, and what contributes most to their umami taste. The new feed composition seems to make the resulting roe even more acceptable to the discerning Japanese market and this is the feed formulation that is now produced commercially in Japan by URCHINOMICS. They further claim that taste will differ slightly for different sea urchins using this feed, but it has been shown to work well on green sea urchins (S. *droebachensis*).

URCHINOMICS are working on strategies to generate market prices at the top of the price range. One starting point is that eating urchin roe straight of the shell is a rare experience in Japan. Even though it is possible to sell in "super-expensive" places, it is also an affordable luxury, that can be brought to a wider range of restaurants, and a luxury that, with enhanced roe urchins, can be available all year round. This example is one that has is being developed by URCHINOMICS and may not suit operators in Europe and elsewhere.

Europe

The European market, primarily the French market (which is the second largest market for sea urchins), is likely to be a more economically viable option for enhanced sea urchin roe produced in either Norway or Spain due to a known higher market value, lower transport costs and the relatively large scale of the market. Distribution to the European market will be considerably easier than to Asia. The European main market of Paris and Marseille rely mainly on whole live sea urchins from suppliers, and enhanced sea urchins have not yet been tested on the French market.

The company Statsnail AS has been exporting live wild sea urchins to Paris and holding in live hubs before selling to local markets. Similarly, wild caught sea urchins have also successfully been exported to high-end restaurants in Scandinavia for almost a decade.

As previously stated, the traditional markets in Europe are well defined and the majority of sea urchin harvests are consumed domestically (Spain & Portugal) and are not reliant on the French wholesale market. Roe enhancement of wild caught sea urchins in Spain may prove a valuable product on the main French market once continuity of guaranteed supply can be established.

4.5.2 Organization and governance

The value chain for sea urchins has in some markets, like for many small-scale products, been long and diverse, with many actors involved. There are well-proven seafood value chains, that may sell all kinds of seafood products, in large or small quantities. The downside is that this flexibility comes with a cost: the process is time consuming and there are many links in the value chain that all require their own extraction of revenue. The result is that the initial producer is left with a low share of the market value.

As some producers try to develop production and markets for enhanced sea urchin roe, the wish for taking control of more of the value chain arises, to capture more of the margins. With more planned and regular production, shorter value chains might be developed.

In some cases, like for sea urchins from Norway, a shorter value chain also arises out of need: there is simply not an existing market for sea urchins, or a lack of knowledge or interest from trading parties for it to be efficient to utilise existing trade channels for seafood. The alternative for some firms has then been to develop the entire value chain themselves, from diving to selling directly to restaurants. In one case the potential producer did not find it worthwhile, or possible, to build the market knowledge and organization required (*Lyngsskjellan*). Another producer (*Scan Aqua*) built an entire value chain, that gave control, but that took an enormous amount of effort and investment before a single sea urchin was enhanced. In the long run this venture was not viable.

A selection of sea urchin value chain versions is illustrated below. At the top is what might be considered a traditional, non-coordinated value chain to Japan. Sea urchins are caught by a diver, sold to a processor, exported from Norway to an importer in Japan, auctioned at Tsukiji to a national distributor, who sells it to a regional distributor before it is sold to a restaurant. Second and third are examples of shorter value chains, where in 2) a producer also exports the products, with a distributor taking responsibility for finding end customers, either through a physical market like Rungis in Paris, or through more closed distribution channels, like for chains of restaurants. The third illustrates the case where the producing company organizes the whole chain, dealing directly with restaurants.

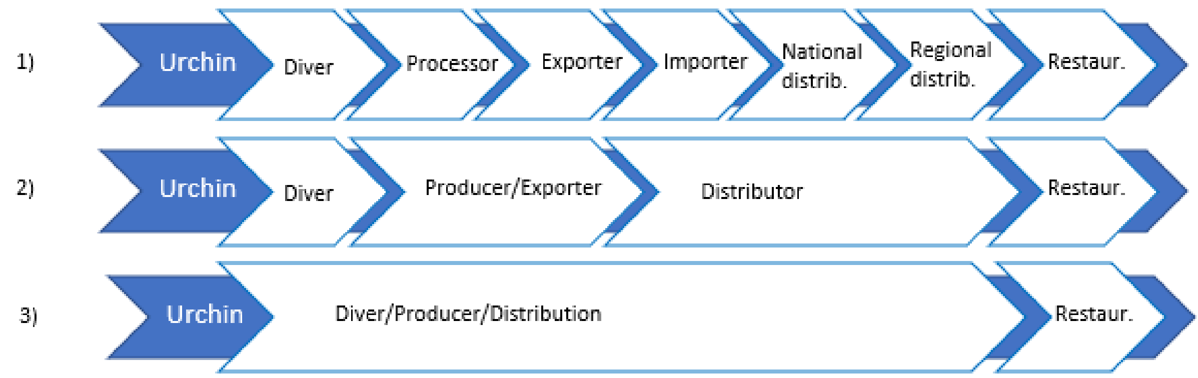


Figure 40 Three stylized value chains for sea urchins.

URCHINOMICS plan to make the value chain shorter, at least to 2), but later maybe into a totally integrated value chain. Today they outsource the sea urchins harvesting, and they have very close cooperation with a distributor in Japan (with open books), gaining the possibility to ensure that top quality reaches the customer, and that feedback from customers might reach all the way back to the producer or diver.

4.5.3 Cost structure and value adding

Prices

While prices for wild fished sea urchins are quite transparent, prices for enhanced sea urchins are harder to find, as production and sales has been only in the form of trials. Prices for sea urchins vary immensely, reflecting, species, season, size quality and product form, and realistic prices for enhanced sea urchins are hard to foresee. This will be discussed at length in future deliverables from this work package. In this section, a few price examples are given to illustrate differences and the price range for sea urchin products.

In the Japanese market most fresh sea urchin roe are sold through auction at the Tsukiji (Tokyo Central Wholesale) Market. The is a huge price range for sea urchin roe, dependent on species and quality. Norwegian export prices have ranged from 370 to 540 NOK/kilo[15]. The examples of extreme high prices experienced when selling sea urchin into small, high-end niche markets may contribute to some of the unrealisable optimism surrounding sea urchin fisheries and enhancement. The following quote is from a sea urchin harvester:

> *"The price of the roe can vary from NOK 500 to NOK 12,000 per kilo in special cases. These are not meals that are measured in kilos. We're talking about small appetizers that are measured in grams," one producer noted[16]. He further points out that "Only the very, very best wild sea urchins may sell for 12,000 NOK per kilo".*

The top price for green sea urchins imported to Japan has been around 2,000 yen per kilo. This equals 1.25 Euro per individual sea urchin, imported whole and processed in Japan (James et al. 2017). This is the wholesale price at the Tsukiji market, imported sea urchin species has traditionally been sold at

[15] Sea urchin roe was mainly exported from Norway from 2004 to 2009, with only minor quantities in later years. Export prices ranged from 370 to 540 NOK in those years. Source: SSB (National Bureau of Statistics).

[16] https://nofima.no/en/nyhet/2013/06/wow-sea-urchin-roe-what-a-taste-of-the-coast/

considerably lower prices than local sea urchins from Japan. In later years, the prices for imported sea urchins appear to have reduced the difference and reached the level of local sea urchins[17].

More recent trials by Urchinomics, with live servings, have proved high potential, with around 10 Euro per individual sea urchin. Sea urchins have in Norway, Sweden and Denmark so far been sold mostly to high-end restaurants and sushi restaurants.

Price is estimated by one of our survey participants to be 150-200 NOK/kilo for wild sea urchins, which corresponds quite well with official export prices (also uncertain due to low quantities). The most likely price in Norwegian restaurants have previously been estimated to roughly €1.6 to €2.2 Euro per single live urchin (James et al. 2017). Norwegian live sea urchins have been sold for about NOK 40 to 50 per piece to high-end restaurants, in very small quantities. These examples point to possibilities, but it is hard to tell how much lower the price would need to be for more widespread distribution.

Prices in Norway has been noted by some to be the same regardless of origin, wild or enhanced, others have experienced huge differences, dependent on quality (colour and taste), size and evenness, with maybe twice the price for farmed sea urchins than for wild. This is very small-scale niche markets, and such observations would need to be verified through more robust statistics or controlled trials.

Sea urchin fisheries in France are one of the oldest in the world. Now they mainly supply the markets in Paris and Marseille (Andrew et al, 2002). The main wholesale markets in France are Rungis and Boulogne-Sur-Mer, where the majority of live whole sea urchin product is sold. The average market price per kg wholesale for sea urchins reported by Stefánsson et al. (2017) €7-€10 per kilo (wholesale price).

This price was dependent on the species, what country it came from and quality. The market price also fluctuated at the time of year dependent on holiday seasons and availability of live sea urchins.

Processed sea urchin (*P. lividus*) roe in a tin (120g) can fetch between €20 - €25 in Spain.

Suppliers can increase the price they can get at the main markets by being able to guarantee the roe content of the sea urchins which makes the implementation of roe enhancement value chain achievable.

<u>Economic performance</u>

Low commercial uptake for roe enhancement production means that little data is available to evaluate the progress of commercialisation of roe enhancement. Cost structure will be looked more closely into in later deliverables. The most important cost drivers will be labour, feed and investment in equipment for harvesting and processing. As labour cost is high, particularly in Norway, the success of on-going technology development for both harvesting and holding might greatly influence cost structure, by replacing costly labour with more efficient processes.

The low commercial uptake also means that production cost potential has probably not been realised, and that production cost might be lower than what has so far been realised. Improved feed, improved knowledge and experience, increased scale, improved logistics and marketing might all contribute to lower cost and a more profitable production. Previous attempts at commercial scale roe enhancement

[17] https://asia.nikkei.com/Business/It-s-sea-urchin-season-in-Japan-if-you-can-afford-it

have been unsuccessful, for various reasons, but with current and future improvements in scale and technology, and by avoiding mistakes from previous attempts, profitable operation might be within reach. Prices and margins indicate that there is potential for obtaining profitability as production reaches commercial scale. These aspects will be covered in more depth in the coming deliverable on business economics.

Value distribution

Distribution of value adding along the chain is hard to determine, as most initiatives have been vertically integrated and small scale. Value adding is also something that we will gain better understanding of in the next task.

4.5.4 Value chain improvement areas

This section will discuss critical areas that need to be developed for sea urchin enhancement to become viable and competitive. Some of these industry barriers have also been previously identified (Stefánsson et al, 2017). The lack of a traditional fishery for sea urchins means that there exists little expertise in fishing benthic invertebrates. Also due to a small and variable local market, fishing is sporadic. Additionally, despite the large biomass of sea urchins in Norway, many of them are found at very high densities, in areas where they low availability of nutrients. These sea urchins have little roe content and subsequently very low commercial value. On the other hand, a lucrative value-added product and improved environmental conditions of the kelp forest is a major motivator for future roe enhancement projects.

SCUBA diving (the traditional method of collecting sea urchins) is (at least in Norway) very expensive and logistically challenging, and suitable technology to increase efficiency in collection (like ROVs) is still under development. Knowledge and experience reside with only a few parties, sea urchin diving as a service is thus not easy to buy, leaving potential producers with few options other than organizing collection themselves. For operations in Spain and Portugal, diving is less of a bottleneck, but roe enhancement has yet to be implemented.

Sales channels for sea urchins are not well developed from Norway, resulting in high barriers for producers wanting to engage in sea urchin roe enhancement, as they need to control or build much of the value chain themselves. To reach the market, cooperation with customers further down the value chain might be an option, for instance in the form of strategic alliances. With current production technology and strategy, profitability seems hard to obtain. Increased scale of operations might be necessary to reduce costs, bringing down costs for collection, holding and feeding. Technology development and improving holding practices might be necessary both for collection, holding and feeding.

Environmental conditions in Norway are challenging (particularly in winter) and the logistics of shipping sea urchins from remote locations is both costly and involves risk of delays. Improvement to logistics needs to be developed. A parasitic nematode, Echinomermella matsi, is found to a varying degree along the Norwegian coast. This nematode affects the growth and survival of sea urchins (at least S. droebachiensis) as well as its economic value (Stien 1999).

5 CS9 Offshore production of blue mussels

5.1 Case study introduction

Case study 9 studies the feasibility of cultivation of blue mussels in exposed areas. Most of the mussel production currently takes place in coastal areas where their natural food sources are highly concentrated, and recruitment of mussel larvae is abundant due to the presence of wild mussel populations. Yet, to increase food production offshore, as envisioned by the European Blue Growth initiative, adequate technologies and cost-efficient methods to be able to operate and expand in exposed and offshore areas must be developed. This section will focus on enterprises operating in the Great Belt in Denmark and the west coast of Sweden where prospects to move offshore are likely and interesting for the producers. The section is developed through a literature review of blue mussel culture and interviews with experts and farm owners to elaborate and detail the specific value chains.

5.1.1 Methodological remarks

The value-chain analysis conducted in this case study is based on data obtained from public sources and information gained through interviews and email correspondence with two novel blue mussel growers, one in Sweden and one in Denmark. Public sources are used to assess world production and main producers, as well as important socio-economic parameters of the European mussel industry.

A fuller description of the value-chain of blue mussel cultivation was obtained through personal interviews with stakeholders which yielded more information on the input-output structure at firm level, governance, markets and the organisation of the value chain. The geographic scope of the case study was also mapped out. Information on costs structure and value-adding was sparse, and that is one of the main weaknesses of the analysis conducted in this case study. However, the case study allowed us to pinpoint some critical issues which could lead to improvements in the value-chain.

5.1.2 General description of the case study specifics

The blue mussel (*Mytilus* spp.) is found throughout the temperate and polar littoral zones in both the northern and southern hemisphere. In the Northern hemisphere four species are found; *M. edulis*, *M. galloprovincialis*, *M. trossulus* and *M. californicus*, the last of which has not been found in the North Atlantic (Leopold et al. 2018). The blue mussel is a hinged, filter-feeding bivalve that constitutes a substantial component of many coastal benthic communities. They are an important economic resource for the aquaculture industry in Europe but are also harvested wild. Culture of blue mussels (*Mytilus edulis,* Figure 41) is the oldest recorded organized shellfish farming in Europe, reportedly taking place in France already in 1235 (European Commission 2020). Today, Spain, France, and the Netherlands are the main European producers of *Mytilus edulis,* but cultivation of this mussel species also takes place in 10 other European countries, including Denmark and Sweden. Denmark is also the world leader in harvesting wild *Mytilus edulis whereas* Spain and Italy are the main aquaculture producers of Mediterranean mussel, *M. galloprovincialis* (European Commission 2020). Both species are grown in their natural setting, in areas rich in microalgae, where the mussels feed by filtering the microalgae from the sea water.

Figure 41 Blue mussel (Mytilus edulis) (European Commission 2020)

Mussels are well suited for farming due to their tolerance for a wide variety of environmental conditions, such as changes in salinity, temperature and oxygen levels, among other factors. As a low trophic species, mussels exploit natural primary production (microalgae), and they show high fecundity and productivity, as they grow naturally in highly dense settlements (Brenner et al. 2009). Mussels are popular among consumers due to their taste and nutritious value. In Europe, their popularity differs from country to country, where per capita consumption varies from less than 200 g to nearly 4 kg.

The need for increasing sustainable food production has led to the exponential growth of aquaculture activities in recent years (FAO 2020b). Producers of mussels are interested in expanding their operation, but with coastal space scarcely available and decreasing social acceptability of industrial structures, there are limited options. Moving the operation offshore could therefore be a viable alternative. Such development will also increase the environmental sustainability of mussel production by decreasing the probability of diseases spreading and decrease damage of the bottom sediment due to higher water circulation (Mizuta et al. 2019). Moving offshore could also mitigate climate change risks to coastal mussel farming (Hare et al. 2016). This highlights the importance of environmental site conditions when considering expansion (Kapetsky et al. 2013). However, offshore facilities are currently not available, likely to be more expensive, may require higher operation costs and weather conditions may also limit days-at-sea.

Four methods are used in mussel cultivation namely, raft culture, long-line culture, bottom culture and *Bouchet* (Avdelas et al. 2020).

I) Raft culture consists of suspending lines up to 30 meters long from a floating platform. The lines may be folded in the form of a matrix. Seed mussels are attached to the line and then covered by a net which progressively decomposes, and the mussels attach themselves more firmly to the line,

II) long-line culture consists of a horizontal line that is suspended by several anchored floats, e.g. buoys or polyethylene tubes. Lines or nets with of mussels are then hung from this line back-bone,

III) bottom culture involves transferring mussel seed (spat) from areas where they have settled in considerable abundance to culture plots where they can be re-laid at lower densities to improve growth and fattening, and to control predation, and

IV) the cultivation method called *Bouchot* culture which takes its name from the fact that the technique uses vertical pilings or poles which are called *bouchot* in French. Lines, on which the mussel grows, are then tied in a spiral on the pilings and covered with a mesh to prevent the mussels from detaching and protect them against predation. Rafts and longline culture are applicable in offshore environment.

5.1.3 World production

World production of all cultivated mussels has doubled in the last three decades, reaching 2.2 million tonnes in 2018 (Fishstat/FAO 2020). Although mussels are also harvested from the wild, cultivated mussels completely dominate the market, accounting for 96% of total production in 2018, with harvests of wild mussels only totalling 84 thousand tonnes.

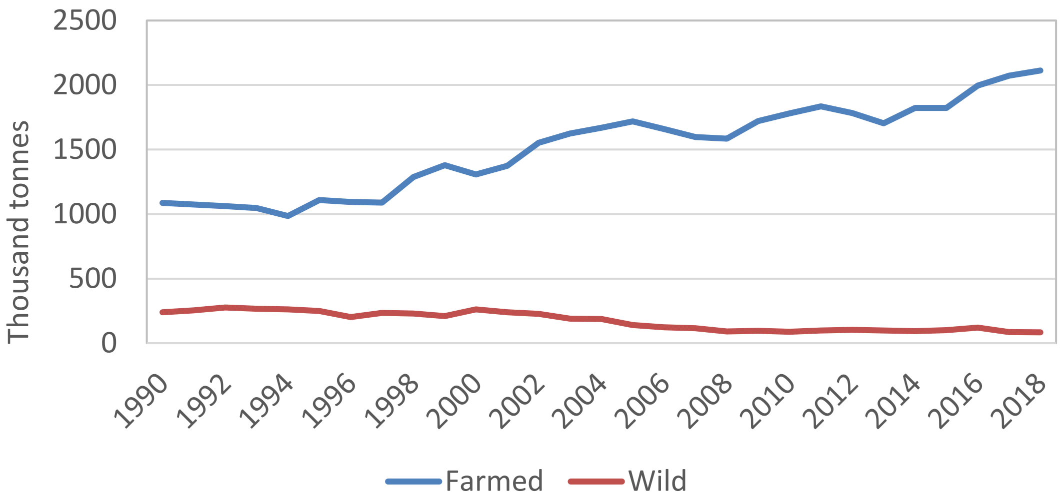


Figure 42 World production of wild and cultivated mussels 1990-2018. Thousand tonnes. Source: Fishstat/FAO (2020b).

China is the largest producer of cultivated mussels, with production in 2018 reaching just over 900,000 tonnes. Chile produced 370,000 tonnes of mussels in that year and Spain 284,000 tonnes. Together, these three countries accounted for 74% of world production in 2018. Apart from Spain, other large producers of farmed mussels in Europe include Italy (62,000 tonnes), France (56,000 tonnes) and the Netherlands (45,500 tonnes). Denmark produced 4,500 tonnes of farmed mussel and Sweden 2,000 tonnes.

Table 9 World production of farmed mussels in 2018. Source: Fishstat/FAO (2020).

COUNTRY	TONNES	% SHARE	MUSSEL SPECIES
Norway	1,649	0.1	Blue mussel
Portugal	1,746	0.1	Sea mussels nei
Sweden	1,986	0.1	Blue mussel
USA	2,165	0.1	Blue mussel
South Africa	2,182	0.1	Mediterranean mussel
Bulgaria	2,531	0.1	Mediterranean mussel
Australia	3,781	0.2	Australian mussel

Cambodia	4,050	0.2	Green mussel
Denmark	4,516	0.2	Blue mussel
India	9,000	0.4	Green mussel
Brazil	12,500	0.6	South American rock mussel
Ireland	13,889	0.7	Blue mussel
United Kingdom	14,800	0.7	Sea mussels nei
Germany	15,864	0.8	Blue mussel
Greece	21,916	1.0	Mediterranean mussel
Canada	26,300	1.2	Blue mussel
Philippines	26,303	1.2	Green mussel
Indonesia	38,120	1.8	Green mussel
Thailand	44,879	2.1	Green mussel
Netherlands	45,500	2.2	Blue mussel
France	55,848	2.6	Blue mussel, Mediterranean mussel
Korea	49,500	2.3	Korean mussel
Italy	62,035	2.9	Mediterranean mussel
New Zealand	86,176	4.1	New Zealand mussel
Spain	283,801	13.4	Sea mussels nei
Chile	368,916	17.5	Chilean mussel, Cholga mussel, Choro mussel
China	903,361	42.8	Sea mussels nei
Other Countries	8,075	0.4	
World Total	**2,111,388**		

In 2018, 1.2 million tonnes of the mussels farmed were classified by FAO as Sea mussels nei (*Mytilus* spp.). Other main species harvested and cultivated included Chilean mussels (*Mytilus chilensis*), Blue mussels (*Mytilus edulis*), Green mussels (*Perna viridis*), Mediterranean mussel (*Mytilus galloprovincialis*), New Zealand greenlipped mussels (*Perna canaliculus*) and Korean mussels (*Mytilus coruscus*).

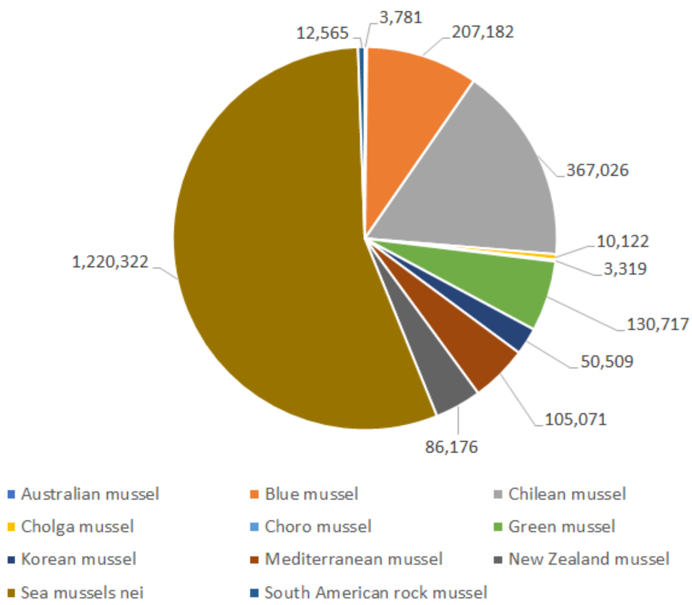


Figure 43 Production of wild and cultivated mussels by species in 2018. Tonnes. Source: Fishstat/FAO (FAO 2020b)

Although production of cultivated mussels has increased world-wide, production in the EU has stalled. European mussel aquaculture peaked at 600,000 tonnes in the late 1990s and has since decreased to around 450,000 tonnes.

5.1.4 Socio-economic parameters of the mussel industry in Europe

In 2016, there were just over 3,200 enterprises in Europe engaged in the cultivation of mussels. Almost two out of three firms were in Spain, with another 385 located in France and 224 in Italy. There were then eight Swedish and five Danish firms farming mussels, according to the data collected by the European Commission's Scientific, Technical and Economic Committee for Fisheries (STECF 2018). According to this data, EU mussel farms employed 12,900 individuals, many on part-time contracts as witnessed by the fact that the total full-time equivalents (FTE) number 6,600. The combined turnover of the industry was € 365 million. Annual wages in the industry varied a great deal between countries. Average wages per FTE were highest in Denmark, € 66.0 thousand and the Netherlands, € 64.7 thousand, but only € 2.9 thousand in Bulgaria. It should be noted that in many countries, enterprises are family owned and family members and friends may periodically contribute to the activity without a formal contract or salary.

Table 10 The European cultivated mussel industry in 2016. Source: (STECF 2018)

Country	Enterprise Number	Volume Tonnes	Turnover Million €	Employment Number	FTE Number	Av. Wage Thousand €
Bulgaria	33	1.6	1.2	94	86	2.9
Croatia	112	0.7	1.3	157	92	12.3
Denmark	5	1.7	1.3	10	7	66
France	385	55.2	141.9	2,215	1,426	26.4
Germany	10	22.2	25.3	127	103	40.6
Greece	201	25.7	10.3	585	575	5.5
Ireland	87	16.2	12.3	369	207	30.7
Italy	224	70.0	45.4	1,023	947	14.3
Netherlands	51	53.2	44.8		158	64.7
Portugal	17	0.9	1.8	109	90	9.8
Slovenia	6	0.6	0.7	11	11	17.2
Spain	1,969	215.4	56.7	7,859	2,641	13.9
Sweden	8	2.3	1.5	40	17	30
UK	103	14.7	20.8	323	247	31.6
Total	**3,211**	**480.4**	**365.3**	**12,922**	**6,607**	**18.6**

Gross value added (GVA) in the farmed mussel industry totalled € 232 million in 2016 and earnings before interest and taxes (EBIT) totalled € 75 million. It is interesting to note that although Spain produced four times as much as France, GVA was much higher in France. Profits, as measured by EBIT, were also higher in the Netherlands than in Spain. The return on investment (ROI) was a remarkable 741.5% in Greece, 39.4% in Sweden and 23.4% in France. Labour productivity was highest in Germany, the Netherlands, Denmark and Sweden, but capital productivity was by far the highest in Greece, or 1080% and 118% in Spain.

Table 11 Profits in the European cultivated mussel industry in 2016. Source: (STECF 2018)

Country	GVA Million €	EBIT Million €	ROI %	Labour Product-ivity 1,000 €	Capital Productivity %
Bulgaria	1.1	0	-0.3	12.9	17.7
Croatia	1.6	0.9	16.8	17.9	29.6
Denmark	0.8	0.2	9.3	113.1	31.6
France	103.7	52.2	23.4	72.7	46.5
Germany	14.4	8.7	19.4	139.7	32.0
Greece	10.1	6.9	741.5	17.5	1,080.9
Ireland	6.1	0.2	0.5	29.4	15.6
Italy	18.1	2.1	3.1	19.2	27.1
Netherlands	21.7	8.9	6.7	137.1	16.2
Portugal	0.5	-7.4	-23.1	5.4	1.5
Solvenia	0.6	-0.3	-5.3	54.5	10.6
Spain	43.0	4.5	12.4	16.3	118.2
Sweden	1.8	1	39.4	109.4	74.5
UK	8.6	-2.9	-10.7	34.8	32.1
Total	**232.1**	**75.0**	**14.3**	**38.1**	**38.7**

Spain, France, and Italy are the main European markets for mussel. In 2016, total consumption in the EU amounted to 577 thousand tonnes, with those three markets together accounting for 432 thousand tonnes.

Table 12 Mussel consumption in the EU in 2016 by main markets. Thousand tonnes. Source: (EUMOFA 2019)

Country	1,000 tonnes
Denmark	2
Ireland	3
Germany	12
Greece	17
Netherlands	26
UK	26
Italy	120
France	147
Spain	165
Other countries	59
EU-28 Total	518

5.2 Case Study specific value chain analysis

5.2.1 The mussel sector in Denmark and Sweden

Blue mussel (*Mytilus edulis)* is the main species cultivated and harvested in Denmark and cultivated in Sweden. In Denmark, the wild mussel fishery takes mostly place in the Limfjorden the north of Julland, in the Isefjord on Zealand, in the southern Kattegat, and in the Belt Sea. The Danish mussel farms are mostly located in the Limfjorden Figure 44, marked 3). In Sweden, the production of blue mussels takes place along the west coast. The mussel industry is a relatively minor economic activity in Sweden, whereas in Denmark it has considerable importance. Accordingly, this section focuses more on the Danish mussel sector.

This case study is based on discussions with the owners of Kerteminde Muslinger (KM) and Bohus Havsbruk (BH) that both operate exposed mussel-growing facilities. The facilities of Kerteminde Muslinger are located 2 km offshore in the Great Belt, the strait between Zealand and Funen, in Denmark (Figure 44, marked 2) and, south of Kerteminde town. Bohus Havsbruk has facilities on seven sites in three different production areas off the west coast of Sweden; two in Stigfjorden between the islands of Orust and Tjörn, and one in Koljöfjorden, north of Orust (Figure 44, marked as site 1).

Figure 44 Denmark and South Sweden map. 1. Location of Bohus Havsbruk. 2. Location of Kerteminde Muslinger. 3. Limfjord Source: Directorate of Intelligence, CIA - https://www.cia.gov/library/publications/the-world-factbook/geos/da.html (Own edits)

National Production and markets

During 2007-2016, total Danish blue mussel production fluctuated between 58,300 tonnes in 2007 to 28,500 tonnes in 2010 but has in the last few years been quite stable at around 45,000 tonnes. Harvests of wild mussels amounted to 41,000-45,000 tonnes in 2014-2016, but aquaculture has been increasing and cultivation reached 2,200 tonnes in 2016.

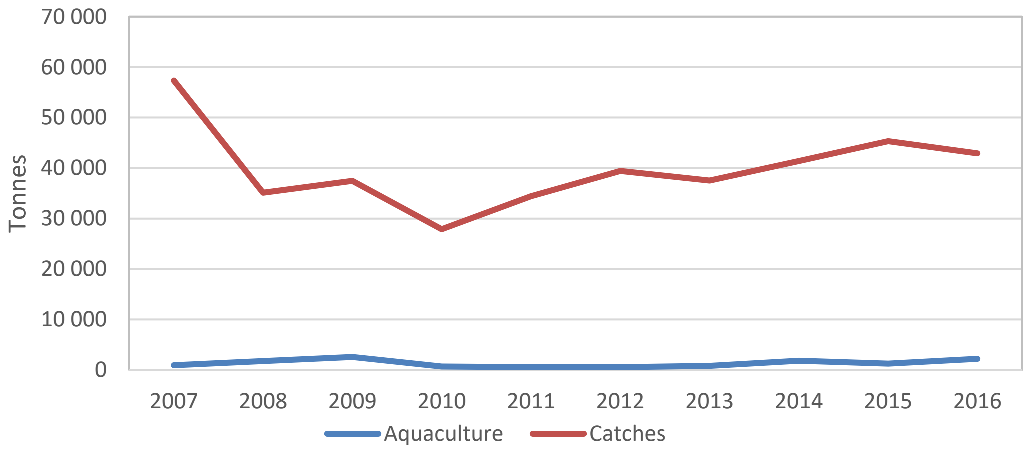


Figure 45 Blue mussel production in Denmark. Thousand tonnes. Source: (EUMOFA 2019)

The fished mussel in Denmark is either sold whole live, or shelled, cooked or frozen, whereas the farmed mussels are mainly sold as whole live. Although some of the mussel is consumed in Denmark, most of the landings are exported as fresh, canned, or frozen products to the rest of Europe, primarily the Netherlands and Germany. In 2017, exports to the Netherlands totalled 22,500 tonnes, or 45% of total mussel exports, with exports to Germany totalling 8,300 tonnes.

Table 13 . Danish exports of blue mussel products in 2017 in Tonnes. Source: (EUMOFA 2019)

Country	Fresh	Frozen	Processed	Total
Netherlands	11.350	57	11.060	22.467
Germany	4.003	110	4.221	8.334
Sweden	596	110	3.413	4.119
France	347	73	2.847	3.267
Ireland	1.538	0	59	1.597
Other	468	432	8.742	9.642
Total	18.302	782	30.342	49.426

In 2017, the apparent blue mussel consumption in Denmark is estimated around 2,300 tonnes. The mussel is sold to supermarkets and large retailers, small retailers, and fishmongers and to the HORECA sector.

Production process of blue mussels

Fishing is the first step in the wild mussel value chain. Fishers bring fresh mussel to processing plants where the first step is to leave the mussels in containers with running seawater for hours to clean the mussels from sand. The catches are then separated into mussels, undersized mussels, and waste, e.g. shells, mud, stones and by-catch of other species, mainly crabs and starfish. Undersized mussels are brought back to the sea by relaying in on bottom cultivating area. Larger individuals are sorted and graded according to size, i.e. determined how many individuals of each size make up a kg. The mussels are now either packaged into trays, plastic netting or bags and sold fresh, or cooked and processed into cans and jars. The meat content of the products is around 16%. The products are sold to fishmongers and retailers, as well as to wholesalers who either sell the products to retailers in Denmark or for exports.

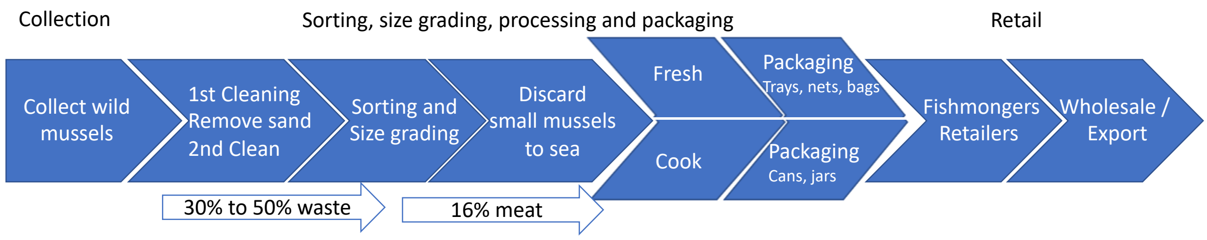


Figure 46 Production steps for wild mussels harvested in Denmark. Own graph. Source: (EUMOFA 2019)

The first step in the cultivation of mussel involves cleaning and preparing the long lines, from which spat collectors are suspended. In due time, mussel larvae coming from the natural mussel population on the bottom will attach to the spat collectors and after a few months the small mussels (spat) are harvested, sorted in size fractions, and then re-seeded with lower density, a process called socking. When the mussels have reached commercial size, they are harvested and brought ashore to the processing companies if they are sold for the domestic market, else they are exported as bulk. The meat content of cultivated mussel is generally about 30% but varies with season, almost double that of the wild mussel, and a lower percentage of the harvests go to waste.

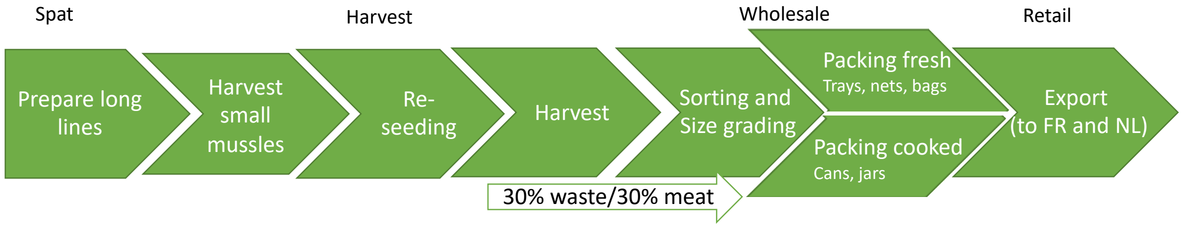


Figure 47 Production steps for cultivated Blue mussels. Own graph. Source: EUMOFA (2019).

5.2.2 Cost and price structure in Denmark

In Denmark in 2018, the raw material cost (harvested, unprocessed mussel) for blue mussels was € 0.68 (EUMOFA, 2019). The ex-factory price was € 2.70, with wages the largest input cost (€ 0.81), followed by energy, water, cleaning and packing, transport, and processors margin, € 0.41 each of the three. Retailer logistics and transport total € 0.81 and the retailer’s margin also € 0.81. The retail price excl. VAT was € 4.32, but price to consumers incl. VAT € 5.40.

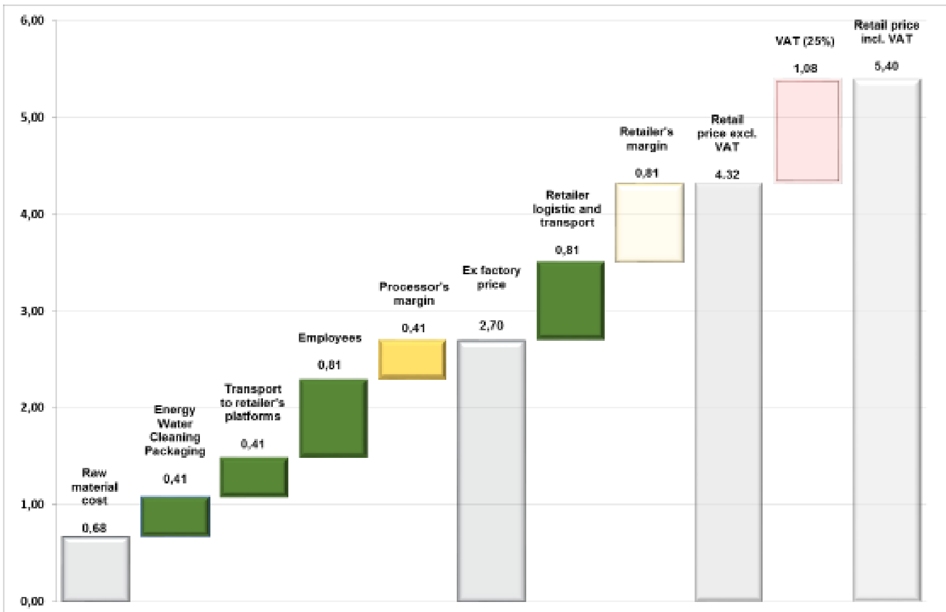


Figure 48 Costs and price structure of fresh mussel in Denmark for supermarkets in 2018. Source: EUMOFA (2019).

In 2016, wages made up 34% of the production costs of shellfish farms in Denmark that mostly cultivate mussels but also some other shellfish. Maintenance accounted for 17% of total costs and depreciation 9%, with administration, sales and distribution only 3%.

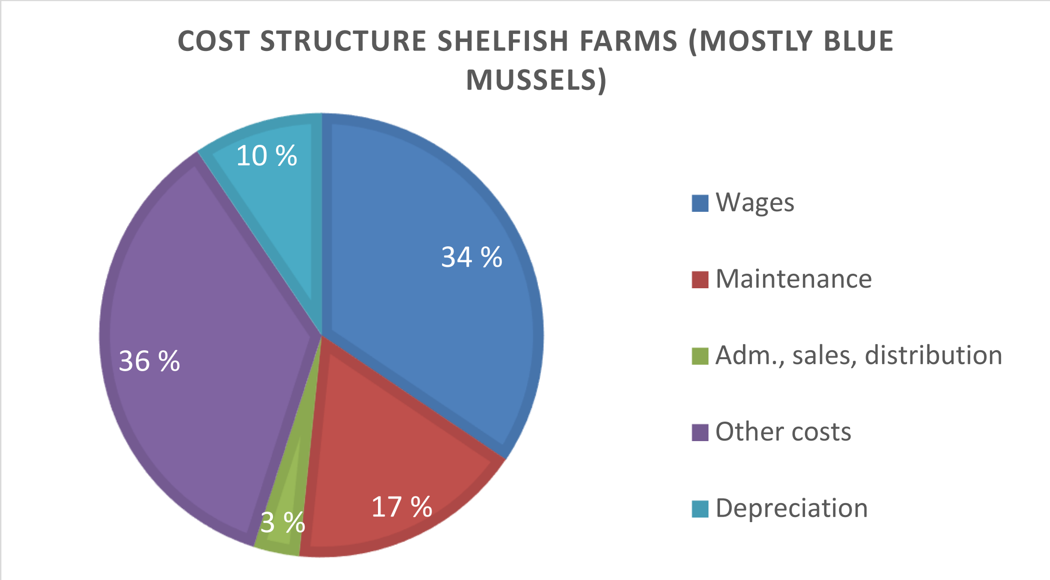


Figure 49 Cost structure Shellfish farms (mostly blue mussels) Source: EUMOFA (2019).

5.2.3 Detailed Input-output structure from Case Study partners

Kerteminde Muslinger (KM) was established in 2018. The facilities cover a 250x750 meter large area, which include 12 lines which is 25% of the full capacity (48 lines). Current annual production is around 100 tonnes. Bohus Havsbruk (BH) was established in 2015 and has now reached a production capacity of 5,000 tonnes. Production has though been less but will be scaled up in the next coming years. The mussel is grown using both nets (BH) and lines (KM and BH). The following sub-sections describe each of the stages of the value chain in detail.

Cleaning and seeding

The larvae come from the natural mussel beds in the areas and will settle on a wide variety of substrates, a process called spatfall. Natural mortality caused by predation on both larvae and spat is often higher at the bottom, but can be reduced by use of collector substrates, like lines or nets, since predation from benthic organisms e.g. crabs and starfish is lower. At KM, the mussels are grown on lines which act as spat collectors and are fastened at one-meter intervals at right angles to the backbone lines. The lines are 200 meters long and are fastened to anchors that are drilled around 1.5 meters into the ocean bottom. BH utilizes both lines and nets. In Kerteminde the lines are cleaned in late winter/early spring with the main larvae settling occurring in April/May, but in Bohus, the lines and nets are cleaned for seeding in May/June, and this work is completed before midsummer (June 21st). Cleaning is done by machines and the lines and nets stay in the ocean all year.

Re-seeding and growth

In Kerteminde, the mussels are removed from the lines in August/September, spat are separated from byssus and each other and sorted to size, and then placed in socks and allowed to attach themselves to the lines again. Optimal density is 500-700 mussels per meter, placing them more densely will result in mussels pushing each other off or slower growth. Kerteminde is considering waiting until July-August with putting the spat collectors into the water, as the larvae settlement is then not so dense as in spring, and this may avoid re-socking which is time consuming and labour-intensive. Some of the mussels may be left on the spat collectors for 2-3 months longer at which point they may have grown to 2-3 cm in size and can be used for canning. The final harvest takes place in August one year later, 15-17 months after the larvae settlement took place.

BHT has found that nets are better for collecting seeds, but lines are better for on-growing as they give better quality mussels. To reduce the labour intensity, BH uses PE tubes for buoyancy of nets and lines which makes re-seeding faster. Controlling the density gives a better quality and reduces size differences, and results in better meat content. BH produces both small (4.5-5 cm) and large (up to 10 cm) mussels. The Swedish market accepts all sizes, whereas other markets have more specific demands. After re-seeding, mussels are harvested in time for Christmas the following year, 18 months after the nets were cleaned. BH aims for faster growth. There is a good window of opportunity for exports to France in December, once the mussels from other countries intended for Christmas have sold out.

Mussels grow more slowly in the Great Belt and off the west coast of Sweden than in Limfjorden in Denmark where the main production of wild and cultivated mussels takes place. While the normal growth cycle for farmed mussel to reach commercial size in Limfjorden is around 12 months, KM and BH have growth time of up to 18 months, and even longer for large mussels.

During grow-out, predation from especially eider ducks can cause considerable losses.

Harvest

Kerteminde operates a working boat, 7x3 m, with a crane, and a water jet, but no propeller so as not to interfere with the lines. The boat has a load of 5-6 tonnes and the capacity to harvest up to 10 tonnes per day. A harvest machine is on board which consists of a conveyor belt that goes 1.5 m down in the sea. There are usually 10-15 kg of mussel per meter of line and the machine rubs the mussels of the line, while the conveyor puts the mussels in 0.5 tonnes bags. To be able to operate the bags on the boat, KM use bags which are smaller than the 1.0 tonne standard bag.

Although BH is a larger firm than KM, the firm does not constantly operate large boats. The strategy is to work with barges that are left on the platforms for re-stocking and harvesting and other work, and then use small boats for trips between units. Using large boats for trips back and forth to the farm is expensive and time consuming. Employees are therefore shuttled between platforms and units in speedboats.

As BH uses both nets and lines, harvesting is more complicated. For the nets, the firm employs a big harvesting machine with a conveyor belt and centrifugal pump. With line it is easier, as the line passes through plates where mussels fall off.

Transport and processing

During harvesting in Bohus, the mussels are loaded into 1.0 tonne bags, and once ashore the harvests are transported by trucks to France and Holland. Each truck can carry 22 tonnes. Upon arrival there, the mussels are cleaned, sorted, and packed, and then sold fresh.

Onshore in Kerteminde, the bags are lifted with a forklift on a refrigerated truck that transports the harvest to cleaning and packing facilities. Then it is shipped to buyers in Denmark or abroad. Currently, KM is experimenting with test production of high-quality organic canned product, in cooperation with a local factory that sells the products under private label.

5.2.4 Markets

Markets

Only line-mussels can be organic certified, and this kind of labelling would be more useful than the Aquaculture Stewardship Council (ASC) labelling in the Danish market. KM would like to be able to get a certification like Label rouge in France, but that is not easy as the whole production needs to be certified. Meat content in KM mussels is about the same as in other mussels from Limfjorden but because growth is slower, the fat content is higher, and the taste is sweeter.

The mussels produced by BH are sold in Holland and France, as well as in the home market and plans to enter the Norwegian are on the horizon. The buyers in mainland Europe clean and package the mussels in nets or plastic trays and sell it under their own brands but BH has no contact with end consumers in these countries. In Sweden, BH sells to distributors that sell the mussel on to supermarkets, restaurants, and fishmongers. The firm is currently engaged in a big communication project that aims to increase sales to Swedish consumers, as they want to be in touch with fishmongers and supermarkets. A lot of information is getting lost in the value-chain from harvester to consumer. Danish firms have a large presence in the Swedish market, with a supply share of around 50%.

Investment, employment and prices

KM is a spin-off venture from the research project MarBioShell which ran in 2008-2012. The establishment of the firm in 2018 was made possible through an EU grant of DKK 400 thousand, but investment in real assets is estimated around 1 million DKK. The owner of the firm is currently the only full-time employee, but during socking and harvesting another employee is needed and sometime a third one during absolute peak periods.

BH has invested around 30 million SEK and received some government support. The firm employs a staff of 6-7, in addition to the two owners and a biological controller. BH has often experienced difficulties in finding and recruiting skilled and dedicated employees. The fact that the firm's operations are not land-based but take primarily place on the ocean has proved to be a major drawback in attracting labour. The firm has consequently frequently hired foreign workers. The firm does not use external service providers. BH is currently experiencing losses, but break-even should be achieved in the near future. BH can follow prices along the value-chain. Prices for a bulk are 0.5-2.5 euro per kg, depending on quality and market demand.

KM is a small firm which is currently not making profits, as the production costs of KM are too high to support the production of organic mussels. KM receives an ex-harbour price of around 1 euro per kg, the price after cleaning and processing in Limfjorden is around 3 euros and this is the price obtained in Denmark. End-prices in Holland are 7-8 euros. Other commercial producers in Denmark have bigger boats and multiple sites to make a living and profit, and they usually produce only fresh mussels.

5.2.5 Organization and governance

Denmark

There are currently 14 active mussel farms in Denmark, most small single ownership, or small companies. KM's main national competitors are in Limfjorden where there currently are four large mussel producers and some smaller ones. There used to be many more Limfjorden producers, up to 30, when long-line farming was initiated in Denmark in the beginning of the 2000s. However, to become profitable, mussel farming needed to be manged professionally and scaled-up by having more farms. Two of those are vertically integrated, as either partly owned by a processing company or have their own onshore processing plants, whereas other farms are either selling directly to e.g. Dutch buyers or collaborating with processing companies like KM.

Most of the cultivated mussels and some of the wild mussels are exported fresh to buyers in the Netherlands. Danish producers are price-takers and cannot affect the market price, since the European market for mussels is dominated by firms in the Netherlands (Nielsen and Hoff 2020).

Sweden

The cultivation of blue mussels is a small-scale activity in Sweden with Scanfjord the main producer with over 90% of the production. The firm was established in 1979. The production of both Scanfjord and BH is primarily directed towards a domestic market, and competition between the two firms is quite fierce. There are also a few smaller mussel farms. Competition with the Danish firms active in the Swedish market is not as strong.

The mussel farmed by BH is sold for domestic consumption or exports. In foreign markets, BH regards itself as a price-taker, as buyers in the Netherlands and France determine the prices. BH believes that the prices in the Dutch market are very standardized and dependent on meat content, size of shell and other qualities and attributes. Some buyers will try to bargain and disagree about quality, and BH has heard stories about Dutch buyers trying to hassle producers, but this has not been a big problem for BH. Buyers in the French market are smaller businesses where relationships are built on trust, and where people may only be fooled once.

In Sweden, the authorities and regulations represent major challenges. There are many laws and ordinances, as well as authorities, which are involved in the management of aquaculture. It can therefore be difficult for farm operators to find their way in the government maze. This complexity is further enhanced by the fact that only a small part of the Swedish coastline is suitable for marine aquaculture. The Baltic Sea salinity does not allow mussel farming for food production as the mussels grow too slow and never reaches market size, so farms are located on the west side of Sweden where there are many islands. Ideal sites for farms are therefore often located close to the mainland or islands in the archipelago. Although mussel farms are not allowed to operate closer than 300 meters from shore without a special permit from from the municipality, this can cause conflict with other uses of the marine environment. BH experiences the authorities as problematic and feel that other stakeholders are given too strong weight in decisions on farm space allocation and license. They also feel that licenses can be revoked prematurely before a proper investigation has taken place.

5.2.6 Value chain improvement areas

Both Kerteminde Muslinger and Bohus Havsbruk are young enterprises that are not yet operating at full capacity. It is therefore imperative for the firms to expand their level of production.

KM intends to develop high-end organic products such as fresh and canned mussels instead of scaling up the bulk production to processors. The big mussels that are more than 18 months will primarily be sold as fresh directly to consumers or processors. The smaller mussels that are not re-seeded is cheaper to produce and would be good for canning. More investment is needed to process some of the mussels locally and develop a strong brand for these products.

Bohus Havsbruk intends to optimize and scale-up the production level to make it profitable but is also looking to exploit new markets at home and in Norway. The firm would also like to offer a wider range of products, e.g. large and small mussels. In foreign markets, BH acts as supplier of mussels for foreign retailers and distributors but does not sell the products under its own name. Contact with final consumers in these markets is therefore limited. Establishing its own brand could be a possibility, but that might require considerable effort. Improving the firm's standing in the domestic market might be a stronger move. The firm is already engaged in efforts to establish better communication with Swedish consumers. Extending the reach of the value-chain would lessen the risk of market signals going astray on the way from final consumers to producers.

The Dutch market usually runs out of mussels in January, and it would be advantageous to be able to harvest early in the year. However, the current in the Great Belt is sometimes high in winter, which makes it difficult for KM to harvest in March. The byssus is also often very strong at that time of the year, thus making harvesting difficult and that causes the shells to break. Although mussels produced by other Danish firms usually have quite low meat content until after the spring bloom, the mussels produced by KM do not suffer from this deficiency and have good meat content in March. Finding ways to deal with this could significantly strengthen KM's position in foreign markets.

Both KM and BH are small players in a large international market which is dominated by buyers in the Netherlands. Because the firms are price-takers in European markets, they need to find economic and technical ways of reducing costs, for instance by increasing the size of their operation and taking advantage of the economies of scale or finding niche markets. This development could take place through further consolidation and vertical or horizontal integration and would strengthen the firms' position viz-a-viz Dutch buyers. Seeking alternative markets for their products, for instance, in the firms' respective home markets, would also reduce their dependency on Dutch buyers. However, that may be expensive and can take time. In line with this, BH is now in the process of establishing their own processing facility and establishing their own brand on the local market.

6 CS10 Emerging freshwater finfish aquaculture

Case study ten is focused on the analysis of the tambaqui production in Brazil, with specific value chain (VC) study in the state of Tocantins. To focus on one specific state is necessary as tambaqui is produced in 25 out of the 27 Brazilian states. The geographic dimensions of Brazil and also the natural and socioeconomic differences among the states poses difficulties to carry out a unique analysis of this VC.

Methodological remarks

This section is based on multiples sources of qualitative and quantitative data, collected principally from the project partner and other industry informants, research projects and literature. The conceptual framework is based on the of Global Value Chain (GVC) approach, with its 4 main dimensions:

- Input–output: concerns the main activities and segments linked to the GVC. Mapping the core activities of a chain is a key element for this dimension. Additionally, understanding the structure and dynamics of the chain by observing each firm and its roles is another key factor.
- Geographic scope: describes the geographic dispersion of agents evolved in the inputs supply, production, processing and distribution. In this sense, this approach enables an analysis of the configuration and position of the firms in the GVC.
- Governance: analysis of how the chain is controlled and governed on the basis of players' power asymmetries. Based on the variables of transaction complexity, the ability to codify these transactions and supplier competence (capacities), this dimension observes the characteristics of the main types of governance in the GVC.
- Institutional context: local, national and international conditions, rules and policies influencing the participation of the agents at each segment of the value chain. Among economic conditions that play a major role for the production, include availability and price of inputs, labour, current infrastructure and financing. Social aspects are skill levels of labour and education. Institutional aspects include tax and labour regulations, culture and innovation policies.

The GVC approach is instrumental to understand how industries are organized by analyzing the value-added sequences, from conception to production and end-use. It concerns aspects as job descriptions, technologies, standards, regulations, products, processes and markets, offering a holistic view of industries. The GVC approach has been increasingly used in aquaculture development studies in several countries as shown in the works of Bush et al. (2018), Belton et al. (2018), Bjorndal et al. (2014), Little et al. (2018) and Hernandez et al. (2018).

Concerning the data collection, the main sources used were:

- Interviews with project partner and tambaqui value chain agents: interviews were the main source of primary data, and it is mostly related to aspects of the governance and institutional context dimensions. Main interviewed actors were fish farmers, input suppliers (e.g., fish feed, fingerlings), processing industries, extension service, and consultants. A grid was used as the basis for the construction of the interview guides. Both construction of interview guides and analysis grids were based on the dimensions of the GVC approach, especially concerning the governance between the value chain agents.

- Data from scientific experiments and research projects of Embrapa: The Embrapa Fisheries and Aquaculture is located in the Tocantins state, and therefore some sources of data relied on experiments and research projects carried out in the tambaqui value chain. Main information from these sources concerns technological aspects and zootechnical indicators used in the input-output dimension.

- Literature: main sources were based on technical reports, scientific articles, and specialized publications. For instance, recent technical reports published by the Tocantins state extension service provided relevant information on the input-output dimension.

- Statistics: FAO, IBGE (Brazilian Institute of Geography and Statistics), Tocantins Extension Service. These information were principally used to contextualize the tambaqui value chain and also to provide data on the geographic scope dimension.

Because the tambaqui value chain is already well consolidated in the state of Tocantins, most of information used in this CS is based on data obtained at company or farmer level. Therefore, the close relationship with project partner (PEIXEBR), chain agents and extension service (Ruraltins) were fundamental to access the information. However, the large size of the state of Tocantins (277.621 km², i.e.; larger than New Zealand) and the presence of tambaqui production in all regions resulted in an important logistical challenge for the data collection. This obstacle was overcome by using different sources of information and online interviews.

6.1 Case study introduction

Tambaqui (*Colossoma macropomum* (Cuvier, 1818)) is a tropical species of the Characidae family, and it originates from South America, particularly from the Amazon and Orinoco basins. It is second-largest scaled fish after pirarucu (*Arapaima gigas*) in the Solimões–Amazon rivers and in nature it can weigh up to 45 kg. The tambaqui is found in water bodies with high primary productivity and average temperatures ranging between 25 to 34 °C. (Woynárovich and Van Anrooy 2019; Chagas e Val, 2003; Almeida *et al*., 2006; Santos *et al*., 2006) (Figure 50). Its natural diet includes zooplankton, fruits, and seeds, being considered an omnivore with a tendency to frugivory (Honda, 1974). In South America, it is also known by other popular names, such as cachama, in Venezuela and Colombia, and gamitana, in Peru (Baldisseroto and Gomes, 2010).

Figure 50 Tambaqui Colossoma macropomum

Tambaqui has an excellent potential for farming because of its good growth, gregarious habit, resistance to low levels of dissolved oxygen (~1 mg. L^{-1}), and excellent use of food (i.e. Low FCR and consumption of zooplankton and phytoplankton), in addition to adapting to confinement and feeding (Melo et al., 2015; Saint-Paul, 1984). Tambaqui presents fast growth and can reach 2 kg in 12 months (Correa et al, 2018). It has high commercial value and great economic and social importance in Latin America, being cultivated not only in Brazil but also in other South American countries. According to Woynárovich and Van Anrooy (2019) the main characteristics behind the popularity of tambaqui farming in water reservoirs and fishponds are:

- The handling is easy along the production cycle and require neither special culture techniques nor special conditions to reach good productivity.
- It is an omnivorous fish and consumes a wide range of natural foods, presenting satisfactory growth on many different types of feeds under culture conditions.
- Tambaqui is suitable for fish ranching (i.e., Culture-Based Fishery-CBF), and fits well into polyculture fish farming.

World production of tambaqui has increased from 90,936 tonnes in 2013 to 105,177 tonnes in 2018, i.e., 15.7% growth in that period (Figure 51).

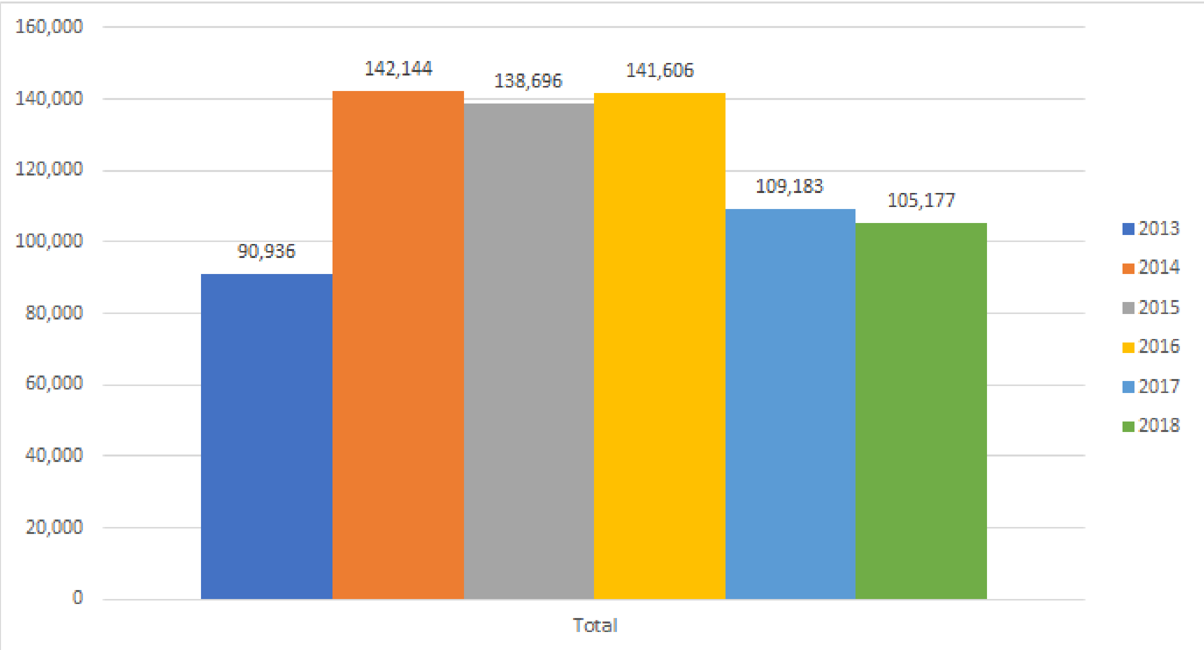


Figure 51 World production of tambaqui, from 2013 to 2018. Source: Fishstat/FAO (2020).

Brazil is far the biggest producer of tambaqui accounting for 97.9% of world production in 2018 (Table 14). The other countries producing relevant quantities of tambaqui are Peru and Bolivia with 1,109 and 850 tonnes respectively in 2018. Guyana, Suriname, Panama and Dominican Republic produce less than 100 tonnes each and the individual contribution to overall production was below one percent.

Table 14 World production of tambaqui by countries in 2018. Source: Fishstat/FAO (2020).

Countries	Tonnes	%
Brazil	103,000	97.93
Peru	1,109	1.05
Bolivia	850	0.81
Guyana	92	0.09
Suriname	75	0.07
Panama	31	0.03
Dominican Republic	20	0.02
Total	**105,177**	**100.00**

The majority of tambaqui farming in Brazil is carried out in extensive production systems in earthen ponds and reservoirs. However, despite presenting a relatively low cost of production and low complexity in terms of technology, the productivity of these systems is very low with a final density of 0.8 to 1 kg/m² (Pedroza et al, 2016). In the last years, more intensive production systems using net cages have started aiming to elevate productivity (~35 kg/m3) but the production cost is higher than earthen pond farming (Figure 52).

Figure 52 Earthen ponds for tambaqui production. Photo: Manoel Pedroza.

Despite presenting a consumer market which remains much regionalized, with prominence in the north and central-west regions, tambaqui has the potential to be consumed on a national scale, because of its low price and good taste (Pedroza et al, 2020). In addition, tambaqui has also stood out in Brazilian aquaculture exports, being the third most exported species in the first half of 2020 (Pedroza Filho e Rocha, 2020). Its potential for insertion in the international market has aroused the interest of companies and institutions such as FAO, which recently launched a technical publication on tambaqui production (Woynárovich and Van Anrooy, 2019).

The popularization of tambaqui consumption in South America and abroad demands important changes in the value chain in terms of quality, productivity, and other competitive aspects. In this context, present research can contribute to the consolidation of the tambaqui value chain in Brazil and other countries.

However, the tambaqui value chain in Brazil presents some challenges to be overcome to assure a sustainable development:

- **Seasonality of fingerlings supply**: tambaqui breeding occurs during six months per year. It varies according to region, and in some cases is from October to March (Pires et al., 2018; Junior et al, 2012). That seasonality affects the harvest regularity, which is particularly important for large retailers such as supermarkets.
- **Absence of genetic improvement**: the tambaqui produced in Brazil is a wild species that had their reproduction domesticated. Thus, there is no lineages genetically improved aiming to increase zootechnical performance (e.g., feed conversion rate, growth rate). Embrapa is carrying out a breeding program for the tambaqui and it is expected to present results in the coming years (Shiotsuki et al, 2019).
- **Lack of specific feed**: the feed utilized for tambaqui is not specific for that species (Rodrigues, 2014) but is formulated for omnivorous fish or for other fishes in the Characidae family and their hybrids.
- **Presence of intramuscular "Y" bones**: tambaqui presents an intramuscular bone with "y" format, which makes the consumption of the whole fish inconvenient – especially for children. Some processors do the manual extraction of this bone, but the process is not simple and normally results in losses of meat. Some farmers in Brazil have found natural populations of tambaqui lacking "Y" bones (Perazza et al., 2017), and therefore researchers have started aiming to develop lineages with absence of this bone.
- **Low productivity in net cages**: the performance of tambaqui in net cages is worse than in earthen ponds (Porto et al., 2018). This hampers the development of a more intensive production system and the utilization of the great potential of Brazilian hydroelectric reservoirs. Embrapa is researching different approaches to improve the performance of tambaqui in cages.

Therefore, to overcome the several bottlenecks of the tambaqui value chain in Brazil it is necessary to carry out significant investments in research in different areas. Embrapa, universities and the private sector have conducted many projects aiming to reach the demands of the sector, but these are many and challenging. However, these innovations are crucial to unlock the great potential tambaqui has.

The Case Study (CS) 10 of the Aquavitae Project is addressing some of these bottlenecks through two specific tasks:

- "**Characterization of the intermuscular bones development of tambaqui (*C. macropomum*)**": this task aims to characterize and evaluate the structural diversity of the intermuscular bones (IBs) along development of tambaqui. This task will contribute towards getting predictive classification models by quantitative methods that can be used to measure, objectively, intensity and geometric patterns (i.e., type, number and length variation) of IBs in tambaqui. This is considered an important first step to enable reducing numbers/types of intermuscular bones in future breeding programs for tambaqui. In addition, the proposed approach opens new possibilities in the field of automated visual inspection to automatically detect IBs in tambaqui fillet.

- "**Large scale production of triploid tambaqui (*C. macropomum*)**": this task aims to identify an optimal protocol for the large-scale production of triploid sterile tambaqui. The development of such a protocol is very interesting for a section of the tambaqui industry where hybrids are produced (crossings females of *C. macropomum* with either *Piaractus brachypomus* or *Piaractus mesopotamicus*). There are reports indicating the resulting hybrids are fertile, what poses risks to the natural stocks in case of escapees. Therefore, a protocol for triploid sterile fish production could aid this industry sector produce sterile tambaqui hybrids, while also protecting the genetic material from developing breeding programs, and also presents a potential zootechnical gain if compared to other triploid fish (i.e., Salmon), although research on triploid production (especially nutrition) will be needed in the future.

6.1.1 Introduction to tambaqui value chain in Tocantins state

The state of Tocantins has been chosen to be the focus of the present case study because this state is one of the main tambaqui producers in Brazil, and also because it has one the best natural conditions for tambaqui farming in terms of fresh water availability, a warm climate and a large production of grains (i.e., soybean and corn). In addition, Embrapa Fisheries and Aquaculture is located in the Tocantins capital, Palmas, and therefore several research activities regarding the tambaqui industry has been performed there over the last years.

Tambaqui is produced in 25 of the 27 states of Brazil. The state of Rondônia is the main producer with 40,141 tonnes produced in 2019. The state of Tocantins is the fifth largest producer in Brazil accounting for 6,081 tonnes (Figure 53).

Tocantins presents a great potential for aquaculture production because of competitive advantages such as: water availability (i.e. several rivers and three large hydroelectric reservoirs), warm climate and expressive grain production (i.e. soybean and corn). Tocantins has two of the most important rivers in Brazil, the Araguaia and Tocantins (that gives the name of the state) (Figure 54).

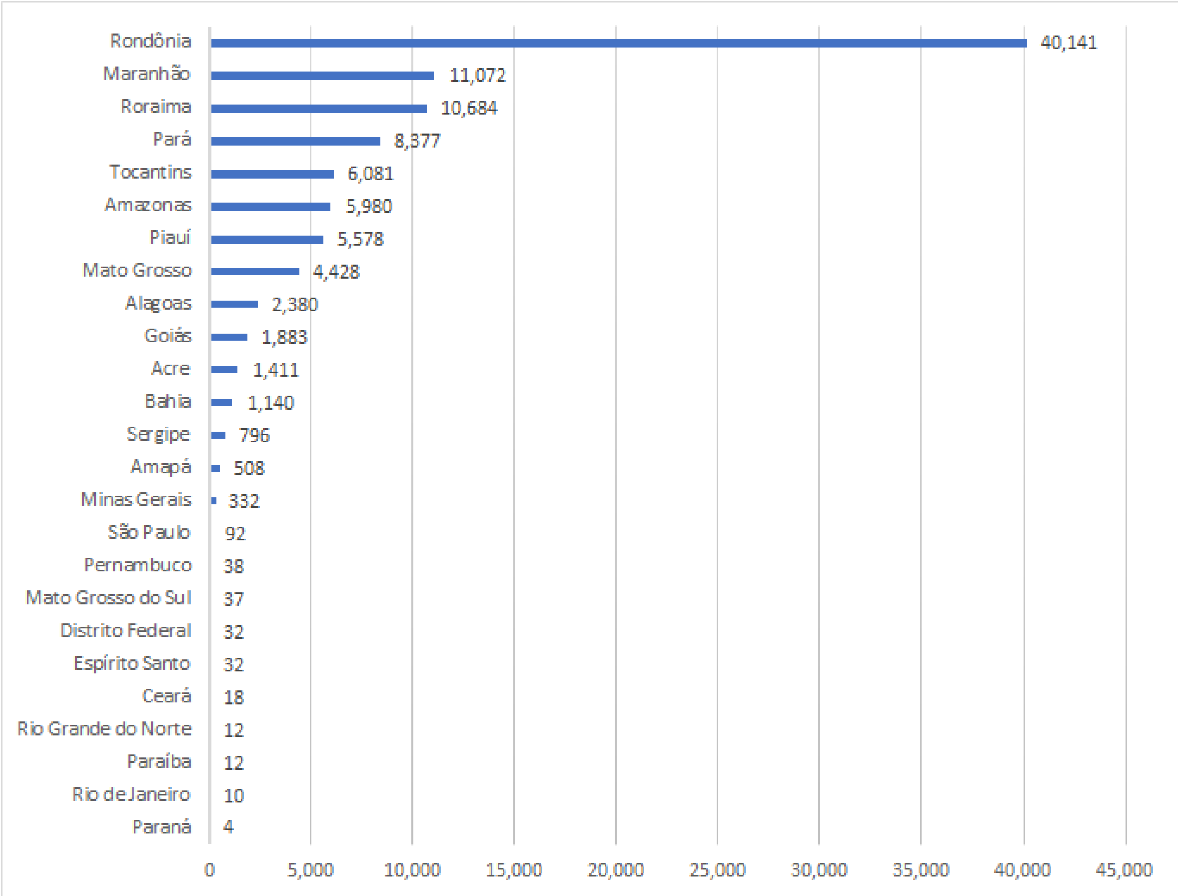


Figure 53 ***Tambaqui production (tonnes) in the Brazilian states in 2019.*** *Source: IBGE/PPM (2020).*

Figure 54 The Araguaia and Tocantins rivers, State of Tocantins.

Tocantins has about 1.000 tambaqui farmers, mostly small-scale ones (Pedroza Filho et al, 2014). They use principally semi-intensive production systems as earthen ponds and water reservoirs. Data from the census carried out by the Extension Service of Tocantins State (Ruraltins) shows that 47% of the tambaqui farmers use semi-intensive systems (Costa et al, 2020).

Table 15 presents some indicators of the typical farmer[18] of tambaqui in Tocantins state, gathered by Embrapa. The size ranges from 24 to 45 tonnes per year, but there are a few large producers with outputs over 1,000 tonnes per year. Final density is less than 1 kg/m2, which is inferior to tilapia in earthen ponds (2 to 5 kg/m2). Despite having no genetically improved lineages, the growth rates represent good performance, reaching up to 2 kg in 300 days.

Table 15 Technical indicators of the typical farmer of tambaqui in Tocantins state. Source: Correa et al (2018); Pedroza et al (2016); Munhoz et al (2014a); Munhoz et al (2014b).

Indicator	Value
Average water surface of ponds	30,000 to 50,000 m2
Annual production per farmer	24 to 45 tonnes
Feed conversion rate	1.76 to 2.14
Productivity (Final density)	0.8 to 0.9 kg/m2
Production cycle duration	300 days
Initial weight	2 to 5 grams
Final weight	1,200 to 2,000 grams
Mortality rate	20%
Levels of crude protein in the feed	40%, 36%, 32% and 28%

In general, tambaqui farmers in Tocantins use a low level of technology. As production systems are semi-intensive, the productivity is low and structure in terms of equipment is quite simple. For instance, basic technologies such as aeration, control of water quality and automatic feeders are scarcely utilized (Figure 55).

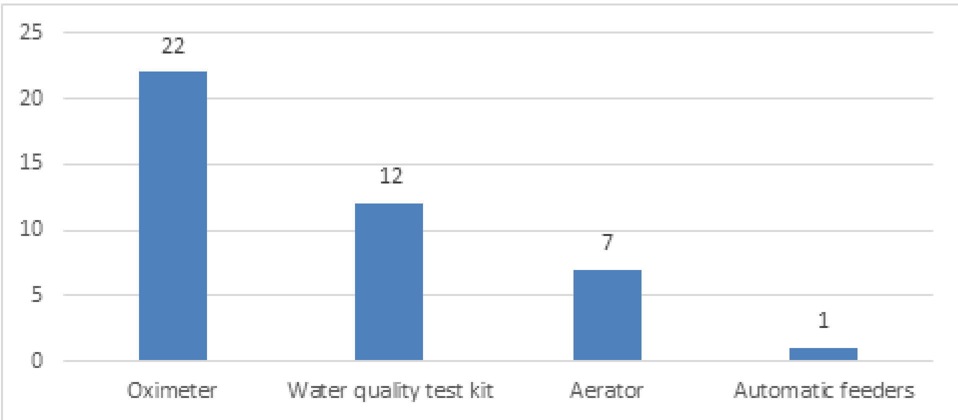


Figure 55 Technologies used in tambaqui value chain in Tocantins (in % of the total farmers). Source: COSTA et al (2020).

[18] The typical farm approach (TFA) is used for analysing economic data at the farm level, and it is defined as a modal farm in a frequency distribution of farms of the same universe. It is representative of what a group of farmers is doing in a very similar way (PEDROZA FILHO et al, 2017).

6.1.2 Industry description

Tambaqui value chain in Brazil

Brazilian aquaculture has shown a growing trend in recent decades. Although there have been declines in production associated with the country's economic crisis in 2016 and 2017, the sector has resumed its growth trend and in 2018 it produced 579 thousand tonnes of farmed fish, which represents a 5.8% increase compared to 2017 (Figure 56).

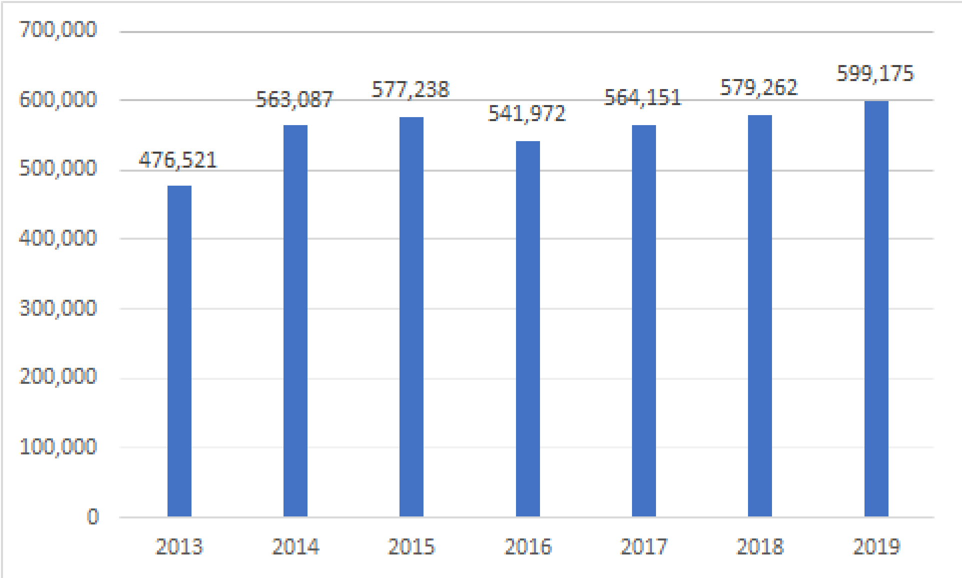


Figure 56 Brazilian aquaculture production (tonnes) from 2013 to 2019. Source: IBGE/PPM (2020).

The great diversity of species is a characteristic of Brazilian aquaculture. About 64 species and their hybrids are commercially produced in Brazil, the vast majority of which are native and farmed in freshwater (FAO, 2020; Calixto et al, 2020; Roubach et al, 2003). Tilapia is the most produced species in Brazil with a production of 323,714 tonnes in 2019, representing 54% of the total production of Brazilian fish farming, followed by tambaqui (*C. macropomum*), with 101,079 tonnes, representing 17% of the total production (Figure 57).

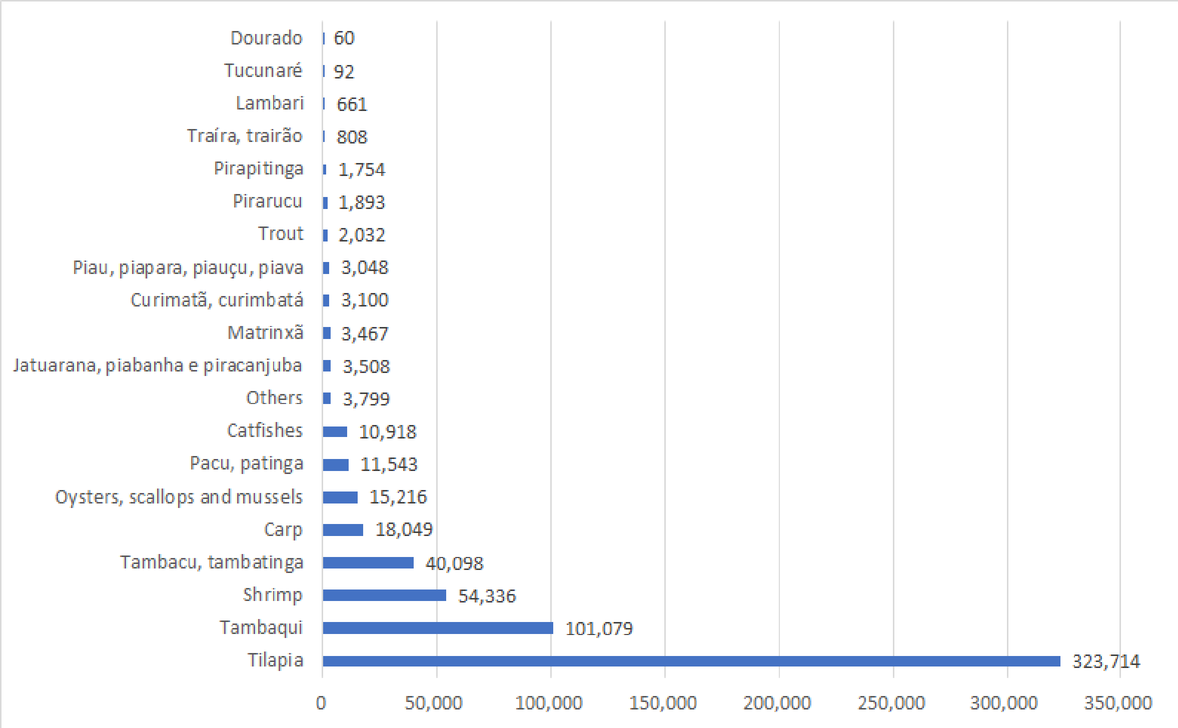


Figure 57 Production of Brazilian aquaculture by species in 2019 (tonnes). Source: IBGE/PPM (2020). Note: IBGE aggregates some species in a single category (e.g. tambacu and tambatinga) and does not specify which species make up the category "others".

From 2013 to 2019 the tambaqui production in Brazil grew by 14%, from 88,719 tonnes to 101,079 tonnes (Figure 58). Despite being reduced from 2014 – in part related to the economic crisis in Brazil, the tambaqui remains the second most important species in the Brazilian aquaculture. Tambaqui has great socioeconomic relevance in terms of rural income and food security, especially in the northern and centre-west regions of Brazil.

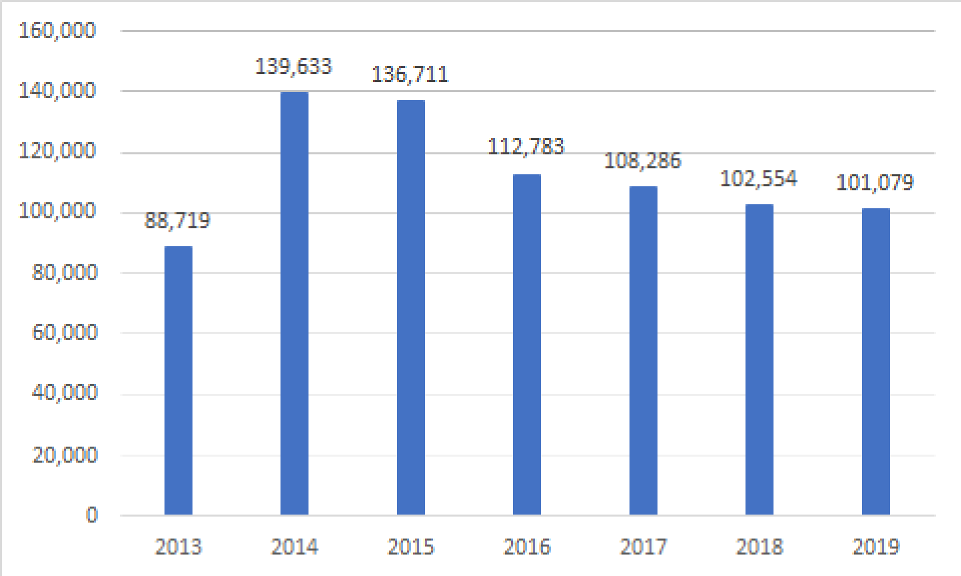


Figure 58 Tambaqui production in Brazil, 2013 to 2019 (tonnes). Source: IBGE/PPM (2020).

6.2 Case study specific value chain description

6.2.1 Input-output structure

Figure 59 shows the segments of the tambaqui value chain in Tocantins. As most of the tambaqui farms are based on semi-intensive production systems, the input structure is relatively simple and the main items are fingerlings, fish feed and health products.

In the production segment there are two main profiles of farmers: (a) the small and medium scale working individually; (b) large scale farmers and processing industry with vertical production. The differences between these two categories and their implications over the entire value chain will be explored in the governance section.

The presence of middlemen is common as this agent acts as an intermediate between the small-scale producers and the traditional retailers (i.e., fish mongers, public markets), bypassing the fish processing plants. The processing segment is an important agent in the tambaqui value chain – despite being linked to large producers. The distribution is composed of a set of channels, where currently the supermarkets are the most dynamic and important in terms of volume.

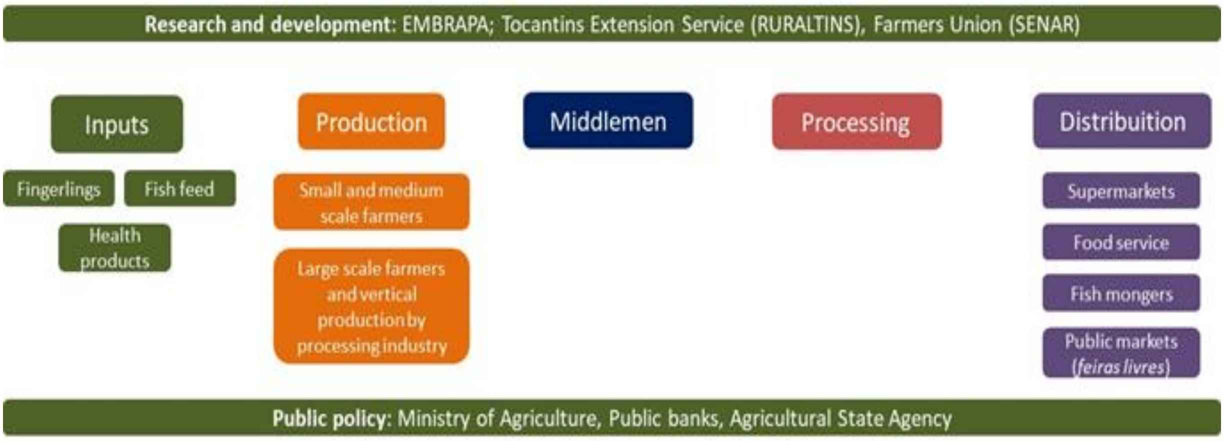


Figure 59 ***General diagram of activities in the tambaqui value chain in Tocantins state.*** *Source: Authors.*

Concerning the research and development activities, the presence of Embrapa has been very important for the consolidation of this value chain, as most of the research is focused on the tambaqui as well as the pirarucu.

Regarding public policy, the main actions are carried out by the Ministry of Agriculture, Livestock and Food Supply (regulation and promotion), the public banks (financing), and the agricultural state agency (promotion).

Table 16 Input-output structure of the tambaqui value chain in Tocantins.

	Description
Inputs	- Extruded fish feed (40%, 36%, 32% and 28% of crude protein) - Fingerlings (3-5 grams) - Health products: antiparasitic, antibiotic - Other inputs: lime, limestone (pond soil management)
	- Feed conversion rate: 1.76 to 2.14
	- Equipment: fishing nets for harvest, water analysis kit - Cost of production = US$ 0.8 to 1.1/kg - Investment per hectare (ponds structure): US$ 8.000 to 10.000/ha
	- Scope of sourcing: All inputs are produced in Brazil. The fingerlings are mostly produced in Tocantins and fish feed is supplied by companies located in Tocantins and neighbour states. Health products and other inputs come from other more distant states.
	- Scarcity of commodities: There is no scarcity of the main commodities. The Tocantins is a large producer of soybean and corn – the main ingredients for tambaqui feed. In addition, Tocantins has important suppliers of fingerlings.
Production	- Main types of products: Tambaqui with average weight of 1.5 kg
	- Production process: Most of farmers use single-phase cultivation, starting with fingerlings from 2 to 5 grams that grow until harvest at about 1.5 kg. Sometimes the fingerlings remain in nurseries or other protective structures in the pond until 50 to 100 grams, aiming to avoid predator attacks (e.g., birds, invasive fishes).
	- Scale:

	Small (up to 5 ha of water surface) and medium (5 to 50 ha of water surface) scale producers: production oriented to traditional retailers in the local market through middlemen, bypassing the processing industry. Large producers (over 50 ha of water surface): production integrated to processing industry and oriented to supermarkets in more distant regions
Intermediation	Middlemen buy production of small and medium scale producers and sell to local retailers
Primary processing	- Processing process: Washing, evisceration, fish scales removal, cooling. - Source: Fishes come from vertical production and from integration with large producers - Labour involved: Large participation of female workers in the processing industries - By-products: Fish gut is the main by-product from processed tambaqui, and the majority is destined to make fish oil and fish flour by fish feed mills.
Distribution and marketing	- Main retailers: Fishmongers, public markets, supermarkets, food service - Main products: Whole fish, frozen or fresh. More recently, some market niches have been developed for specific cuts (i.e., ribs, filets) and ready to eat dishes.
	- Transport mode and times: Most of the processed tambaqui is sold fresh and is transported by refrigerated trucks with ice (which is mandatory according to sanitary regulation). Time of delivery from industry to retailers varies according to the market, for retailers located in Tocantins it is two to six hours and for more distant markets it can be more than 12 hours.
	- Sales channels: Supermarkets (main retail channel), fish mongers, street markets (feiras livres), food service
	- Storage: As most of tambaqui is sold fresh, storage of frozen fish is rarely used
	- Marketing activities: Very few marketing strategies are carried out by the value chain agents. Main marketing actions are performed by supermarkets with promotion campaigns and advertising in the local television networks.

10 tambaqui hatcheries are in different areas of Tocantins state (Figure 60). The hatchery segment is well consolidated and supplies also other states in Brazil.

Figure 60 ***Hatcheries of tambaqui in the Tocantins state.*** *Source: Authors.*

The hatcheries located in Tocantins supply 92% of the fingerling demand of local producers. The rest (8%) is supplied by hatcheries located in neighbour states (Figure 61).

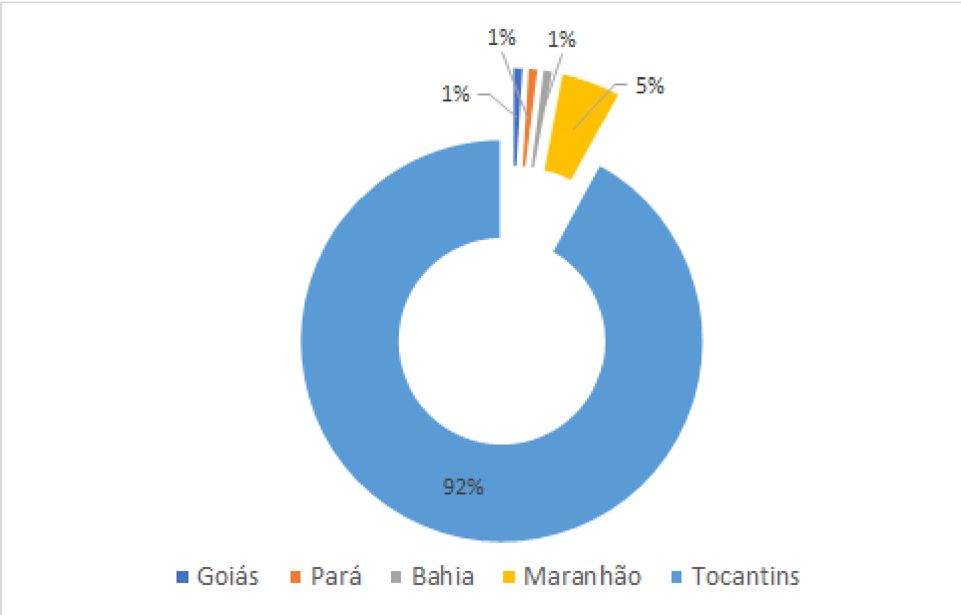


Figure 61 Fingerlings supply by state in the tambaqui value chain in Tocantins. Source: COSTA et al (2020).

Concerning the feed segment, 80% of the tambaqui feed used in the farms is composed of commercial feed. The rest is alternative feed (e.g., corn, soy and cassava) with 11%, natural feed (phytoplankton and zooplankton) with 5%, and homemade feed with 4% (Figure 62). Despite their low performance these alternative feeds are used because of lower price compared to commercial feed.

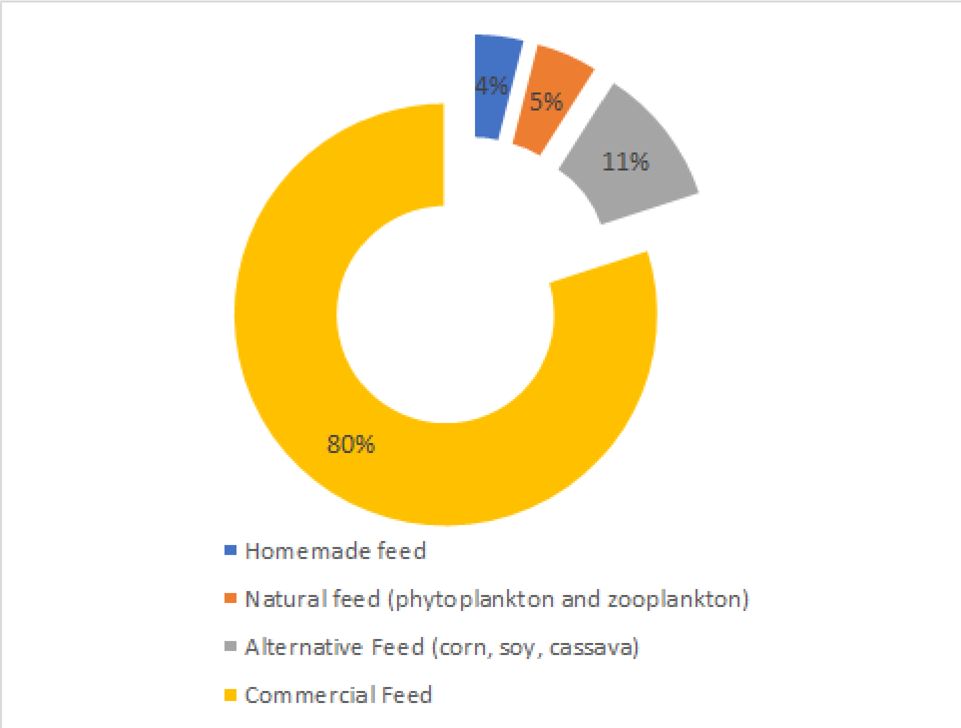


Figure 62 Main types of fish feed for tambaqui used by farmers in the Tocantins state. Source: Costa et al (2020).

Regarding the suppliers of the commercial feed, most of the farmers buy in the local agricultural shops ("casa agropecuária"). The acquisition of tambaqui feed directly in feed mills is the second most important source (Figure 63).

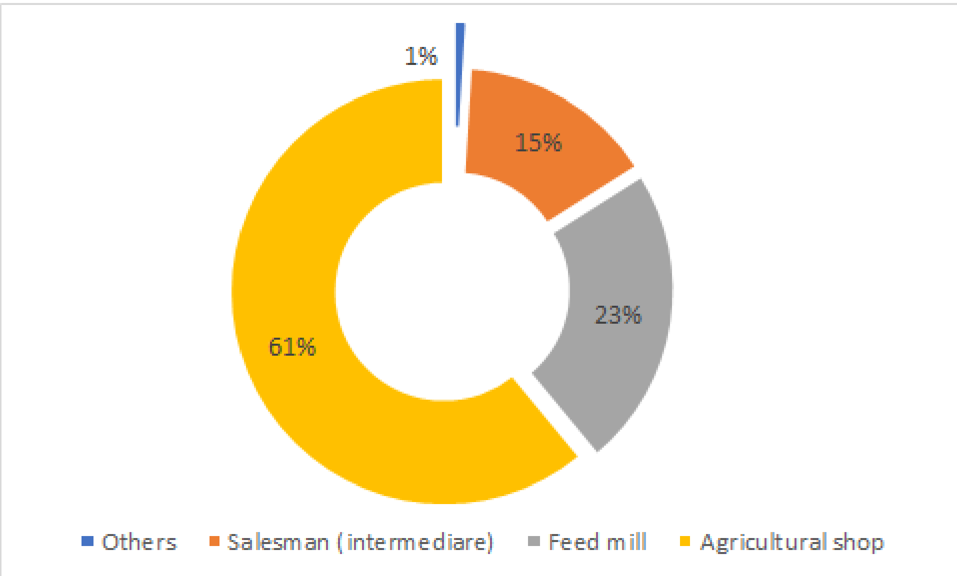


*Figure 63 **Main suppliers of feed for tambaqui in Tocantins state.** Source: Costa et al (2020).*

Most of tambaqui production is carried out in earthen ponds (figure 43). The other main structures used are the small reservoir with multiples uses (e.g., water supply for cattle), large reservoir exclusively for tambaqui farming, and net cages.

Figure 64 Main structures for tambaqui production in Tocantins state. Photos: Manoel Pedroza.

The majority of tambaqui producers (87%) don´t use treatment for water effluent from the earthen ponds. The main treatments made by the farmers are use of decanting tank (5%) and fertigation (4%) (Figure 65).

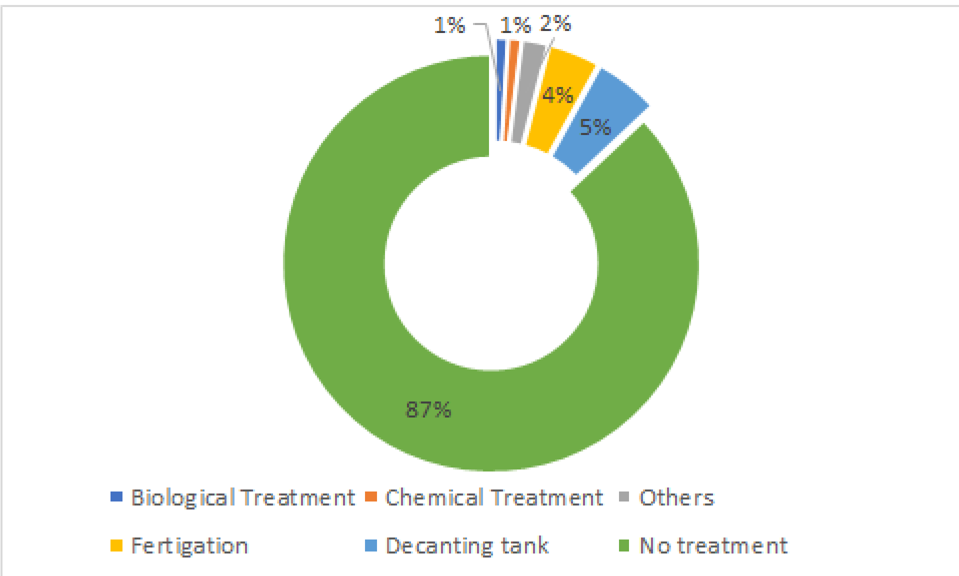


Figure 65 ***Types of treatment for water effluent from earthen ponds.*** *Source: Costa et al (2020).*

The state of Tocantins has 5 fish processing plants working (Figure 66) but most of fish farmers do not access these industries. Many of these plants is supplied by own production, with low volume of fish from third-party suppliers. Three other fish processing plants are out of service.

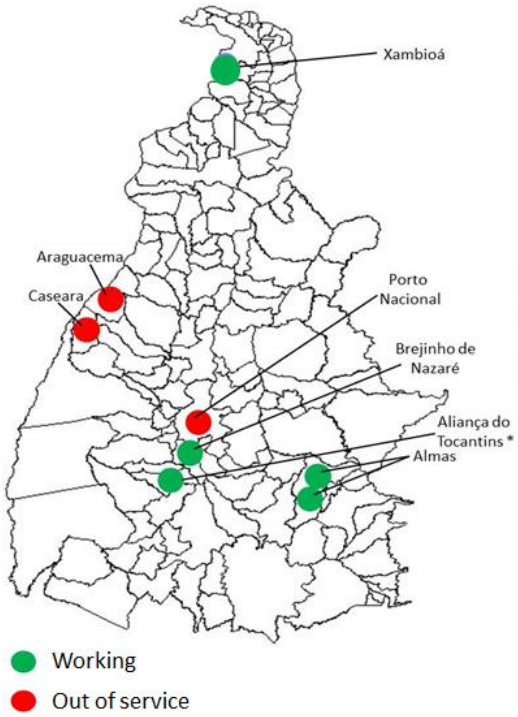


*Figure 66 **Tambaqui processing plants in Tocantins State. Source: Authors.***

The three processing plants that are out of service are public structures and were built by the federal government, but it never was active. Lack of financial resources and management capabilities to operate the plants are the main reasons behind their failure.

Concerning the transportation of tambaqui from the processing plants to the retail market, the products are distributed by trucks with different sizes. These trucks use different refrigeration systems, ranging from sophisticated equipment to simpler structures as cool boxes (Figure 67).

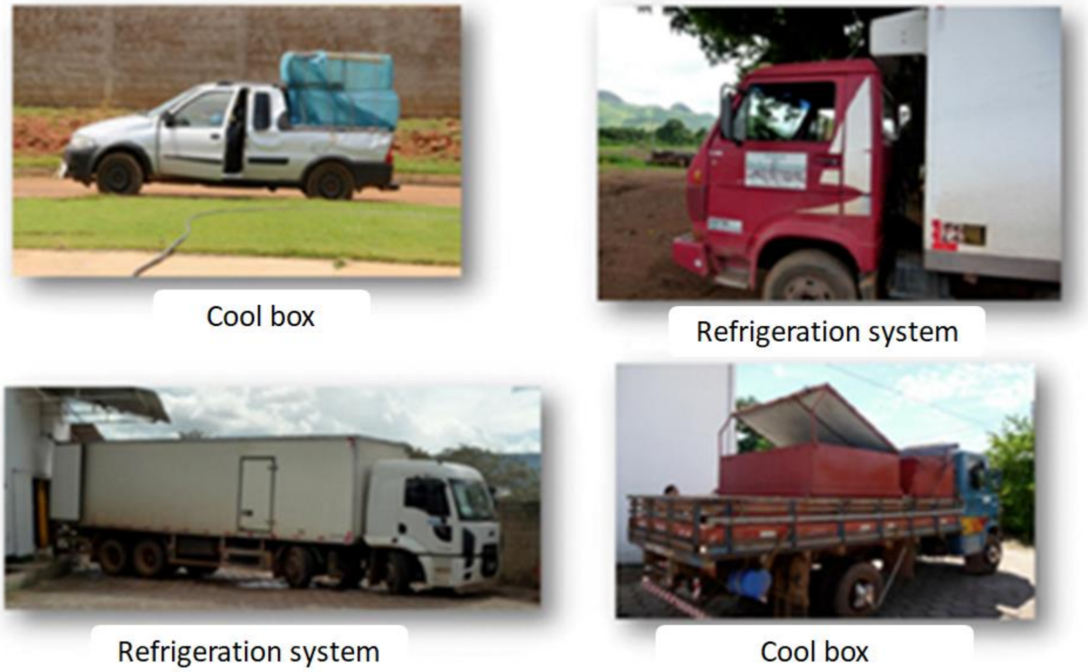


Figure 67 Main forms of transportation for tambaqui in Tocantins state. Photos: Manoel Pedroza.

Regarding transportation from small-scale farmers to the middleman and to retailers, just 18% of the producers use ice (Figure 68). This situation is problematic because according to Brazilian sanitary laws the use of ice is mandatory in all phases of fish transportation after harvest.

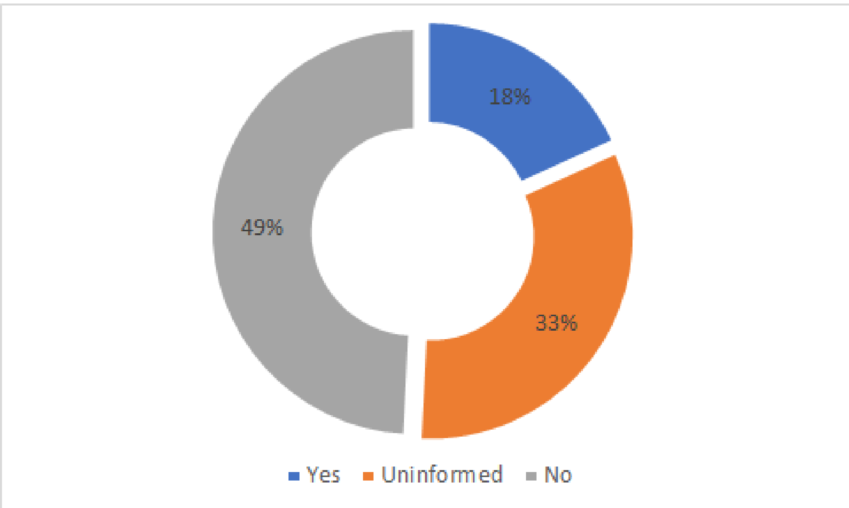


Figure 68 ***Percentage of tambaqui farmers using ice in the harvest.*** *Source: COSTA et al (2020).*

Concerning the main retail channels for tambaqui, the supermarket is most important, and their participation has increased sharply over the last years. Other relevant retailers for tambaqui are fish mongers, street markets, and direct sales to final consumers (principally by small-scale farmers) (Figure 69).

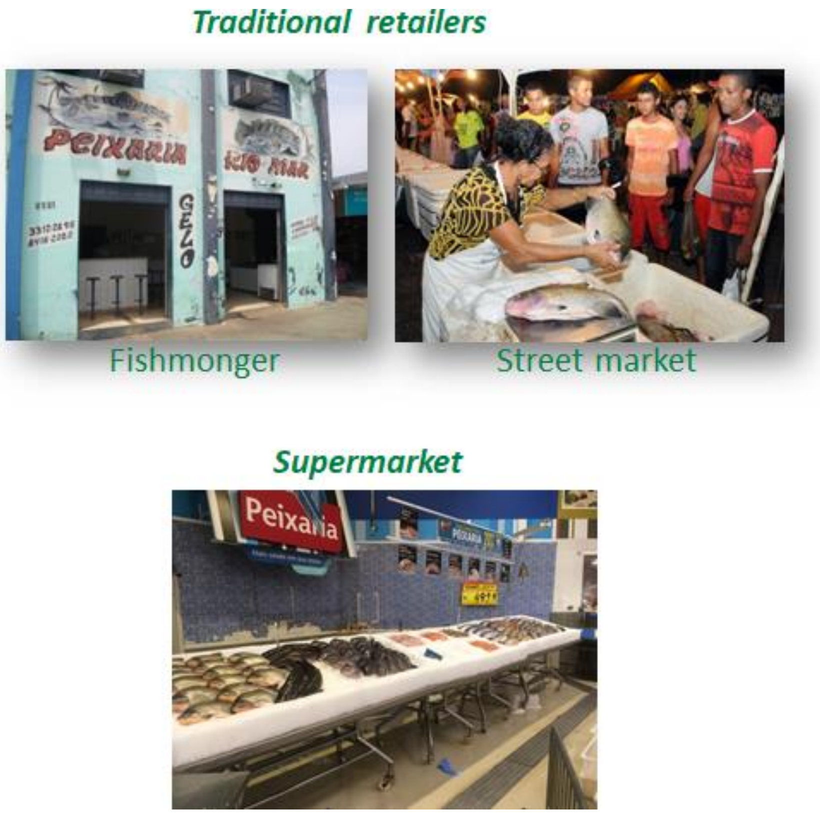


*Figure 69. **Retail channels for tambaqui farmers.** Photos: Manoel Pedroza.*

The whole gutted and fresh is the main product of tambaqui sold in the local and national market (Figure 70). On the last years, a niche market for cuts like ribs and fillets of tambaqui is developing but still in very smaller quantities. However, these products present a great opportunity in terms of adding value strategies.

*Figure 70 **Tambaqui products.** Photos: Manoel Pedroza.*

6.2.2 Organization and governance

In Tocantins a large share of tambaqui farmed by small and medium scale producers is sold directly to local markets through middlemen or traditional retailers as street vendors and fishmongers, bypassing the processing industry. This situation is very common in other tambaqui production regions in Brazil, and it highlights some legal issues because primary fish processing (i.e., fish cleaning and evisceration) in a certified plant is mandatory in Brazil[19]. Besides problems related to sanitary and formality issues, this situation highlights the low added value obtained by fish farmers.

Figure 71. Primary tambaqui processing. Photo: Manoel Pedroza.

There is no official data concerning the quantity of tambaqui marketed directly to consumers bypassing the certified processing industry in Tocantins. However, according to estimation of experts just about 30% was processed (i.e. 2,000 tonnes) of the 6,081 tonnes of tambaqui produced in Tocantins in 2019. The rest of production was sold directly to the market (Figure 72).

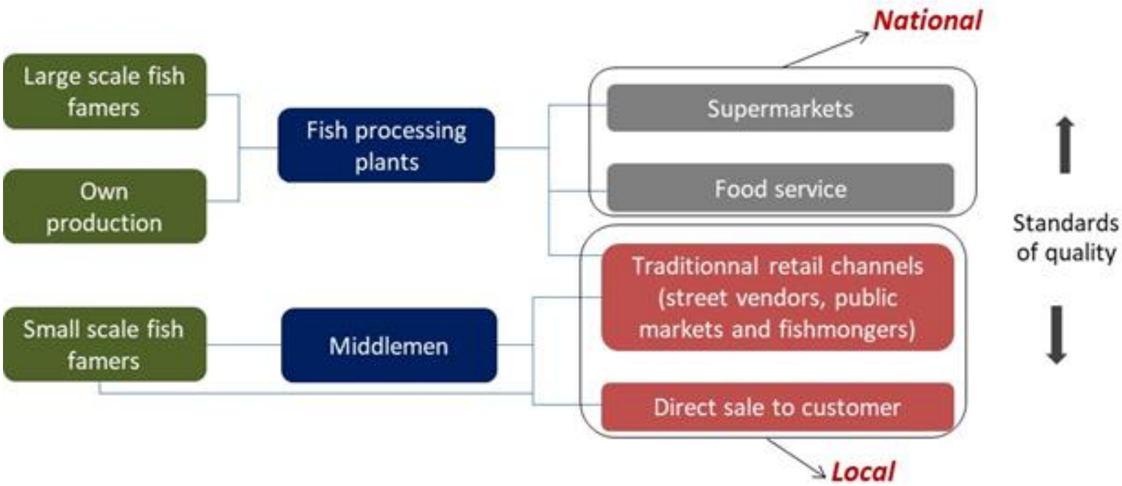


Figure 72 Market channels for tambaqui in Tocantins. Source: Authors.

The situation affects particularly the small and medium scale producers as most do not have processing plants and therefore need to be integrated to a third-party industry. Nevertheless, in Brazilian

[19] For further information about the Brazilian regulation on sanitary certification of animal products see the Decreto Nº 9.013, de 29 de Março de 2017 issued by the Ministry of Agriculture.

aquaculture these partnerships are not common and the integration between small scale producers and processing industry is restricted to a few cooperatives, principally in southern region of Brazil[20].

This lack of integration between tambaqui farmers and processing industry results in several problems such as: (a) low quality of fish due to absence of sanitary control; (b) great informality and non-payment of taxes; (c) impossibility to access supermarkets due to lack of sanitary and fiscal requirements; (d) low added value to fish (Castilho and Pedroza Filho, 2020).

This situation is harmful for both fish farmers and processors. The fish processing plants face many difficulties concerning the underutilization of its industrial capacity, due to the lack of fish. Moreover, the industries face losses in terms of competitiveness as theirs costs are higher than those of the tambaqui sold informally by the small-scale fish farmers. On the other hand, the small-scale fish farmers suffer due to the low added value for their tambaqui and because of difficulties in accessing the supermarkets and other markets with higher standards of quality.

The integration of fish farmers and processing plants is crucial to assure the development of the tambaqui sector because the processing segment is a fundamental part of this value chain. It is based on the premise that the orientation towards industrialization is a fundamental aspect in enabling the sustainable commercialization of aquaculture products in large consumer centres, which demands greater volumes and higher standards of quality. In addition to the economic benefits of raising workers' incomes, industrialization enables the qualification of the actors, contributing to the insertion of local products in more demanding or distant markets, which gives dynamism to the activity (Castilho and Pedroza Filho, 2020).

Because the lack of processing and sanitary certification the small scale tambaqui farmers have limited their sales to only the local market and the traditional retailers (i.e., street vendors, public markets and fishmongers). Moreover, transit of fish (and other animal products) between the states requires sanitary certification. Therefore, this situation forces the small-scale fish farmers to distribute their production in the local market.

The processed and certified tambaqui can reach supermarkets and foodservices located either in the local market or in more distant regions as it meets the sanitary requirements of these retailers and sanitary authorities at states borders (Castilho and Pedroza Filho, 2020).

To overcome the lack of processing and sanitary certification in Brazilian aquaculture, the former Ministry of Fisheries and Aquaculture had implemented 27 public fish processing plants in Brazil, including one in Tocantins. These plants should be operated by the small-scale fish farmers under collective organizations as cooperatives, associations, consortiums, etc. However, because of several problems related to management and lack of financing to cover operational costs (i.e., electricity, maintenance) all of plants are currently out of service, including that located in Tocantins (Figure 73).

[20] The states in Southern Brazil, especially Paraná, account for a large number of agricultural cooperatives working principally with grains (i.e. soybean, corn), pork and poultry. According to specialists, the reason behind the success of the cooperatives in this region is related to sociocultural aspects linked to the European heritage of these communities, especially German and Italian, because of the great number of immigrants arriving there in the early century 21.

Figure 73 Public processing plants for tambaqui out of service in Tocantins state. Photos: Manoel Pedroza.

In this context, the integration between small scale fish farmers and private fish processing plants emerges as a viable alternative to assure processing and certification for tambaqui producers. However, some barriers have prevented the partnership between these actors and currently the small-scale fish farmers do not operate with the fish processors in Tocantins (Castilho and Pedroza Filho, 2020).

This situation has reinforced the emergence of new governance structures lead by the processing plants which are increasing their own production and implementing contracts of supply with large producers. It results in more vertical and hierarchical governance structures with a power control in processing industry hands. This type of governance aims to keep the margins that would remain with the fish farmers and middleman in the case of the informal market (Castilho and Pedroza Filho, 2020).

This lack of integration is harmful to the development of the aquaculture value chain in Tocantins state because it results in several problems such as (Castilho and Pedroza Filho, 2020):

- **Decreasing in the demand for the fish from small scale producers**: the local consumers are increasingly more conscious about the sanitary quality of fish. The local fish processors are making several advertisement campaigns aiming to inform the consumers about the importance of sanitary certification for the fish quality and food safety (Figure 74). Therefore, the consumers are increasing their preference to fish with sanitary certification.

Figure 74 Advertisement campaigns made by processors in Tocantins concerning the importance of sanitary certification of fish.

- **Sanitary risks for consumers related to the poor hygienic standards and raising doubts regarding the absence of adequate cold chain for fish bypassing processing plants**: the lack of correct processing and cold chain increases the risk of sanitary problems as contamination and deterioration of the fish. It is particularly serious in the Tocantins as that region presents a very warm temperature along the year.
- **Impossibility for small scale fish farmers to access supermarket and other more developed markets due to lack of sanitary certification**: as a result, there is a saturation of local markets and a stagnation of fish prices due to increase in supply from small-scale producers, which cannot access more distant markets or supermarkets.
- **Underutilization of industrial capacity of the processing plants**: All fish processing plants in Tocantins were planned to be partially supplied by third part production from small scale fish farmers, in addition to their own production and vertical contracts with large fish farmers. Consequently, the processors do not reach the full capacity of the industries due to the lack of fish from small scale fish farmers.

As result, more vertical governance structures have emerged with coordination power in processors hands, which are increasing vertical integration in production and establishing strong partnerships with large producers to overcome the lack of fish. This governance enables the processors to assure quantity and quality, which allows them to reach more demanding markets (e.g., São Paulo, Brasilia, Rio de Janeiro) (Castilho and Pedroza Filho, 2020).

6.2.3 Cost structure and value adding

Fish feed is the main item of the cost structure of tambaqui farming in earthen ponds. Labour and fingerlings are, respectively, the second and third most important components of the costs (Table 17).

Table 17 Cost structure of tambaqui production in earthen ponds in Tocantins.

Fish feed	75.74%
Labor	9.21%
Fingerlings	5.57%
Ponds and infrastructure maintenance	2.89%
Electricity and fuel	2.75%
Taxes and management costs	2.00%
Soil corrective	1.37%
Equipment maintenance	0.30%
Fertilizers	0.14%
Total	**100%**

Source: Authors based on data of Projeto Campo Futuro/Embrapa.

The price of commercial feed for tambaqui with 32% of crude protein ranges from US$ 0.32/kg to US$ 0.41/kg, according to the different municipalities of Tocantins (Figure 75).

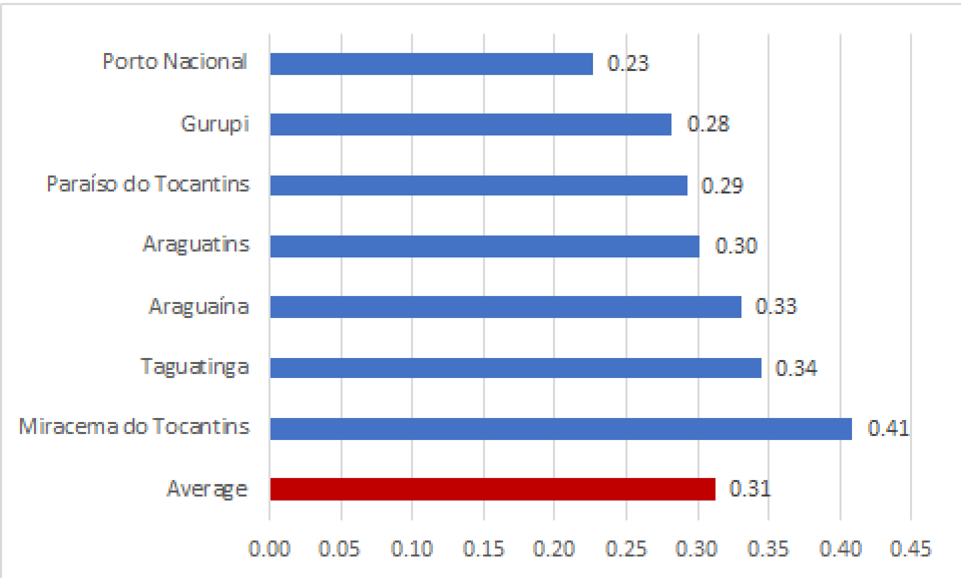


Figure 75 Prices of fish feed for tambaqui in some municipalities of Tocantins state, 2019 (in US$/kg). Source: Costa et al (2020).

The tambaqui value chain in Tocantins is supplied by feed mills located in the state and in neighbour states. The distance from the feed mills and the Tocantins capital, Palmas, ranges from 531 km to 1,548 km (Figure 76). Therefore, transportation is one especially important component of the feed cost.

Figure 76 Location and distance of the main fish feed plants supplying the Tocantins state. Source: Authors.

One of the main strategies carried out by tambaqui farmers to add value is related to the advantages for fish farmers from selling to middlemen. The low price of tambaqui paid by processors (US$ 1.30/kg) compared to middleman or local retailers (US$ 1.68/kg) makes the transaction not attractive as small-scale fish farmers have high costs of production due to small scale and low technological level. Despite being informal, the price paid by middlemen is 29% higher than processor´s price (Castilho and Pedroza Filho, 2020) (Figure 77).

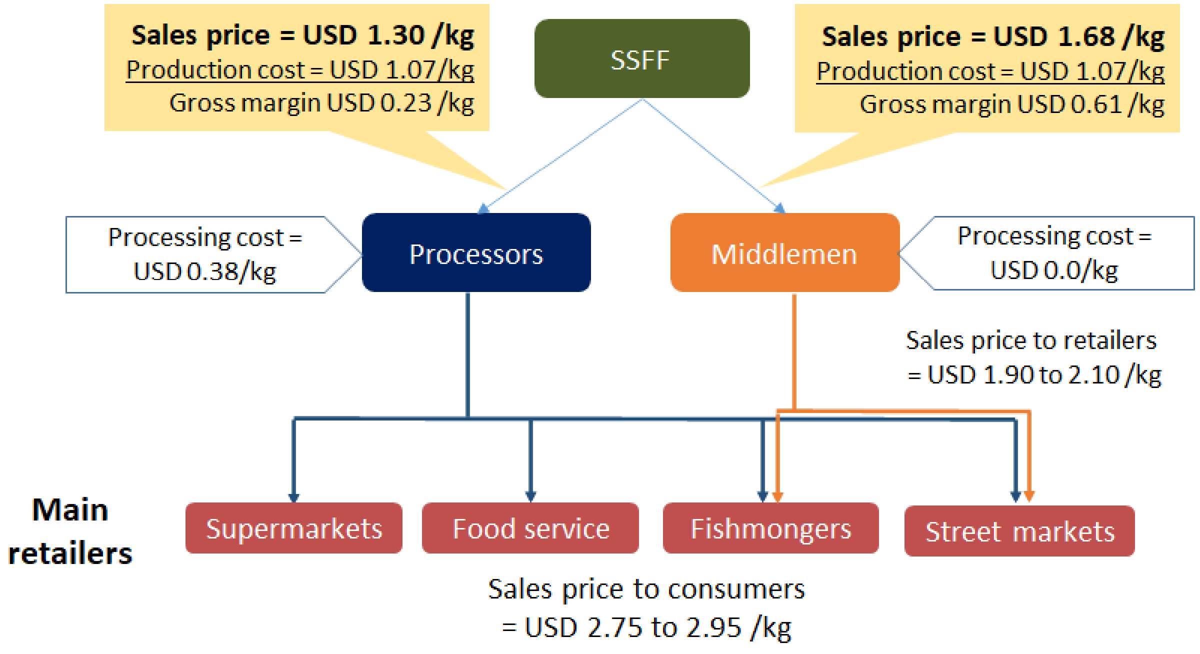


Figure 77 Price and cost structure for fish from small-scale farmers marketed for the industry and middlemen in Tocantins. Source: Adapted from Castilho and Pedroza Filho, 2020. Note: Currency exchange 1 US$ = 5.43 R$ Real.

Another possible added value strategy could be the implementation of cooperatives or producers' organizations aiming to increase volumes and to process the tambaqui. However, the small-scale farmers face huge difficulties to establish cooperatives or other forms of producer organizations. The main difficulties are related to lack of management capabilities necessary to establish and to coordinate the producer organization. This situation is particularly important as the small-scale fish farmers work individually and, consequently, don´t meet supermarket demands in terms of volume, regularity of supply, and quality standard.

6.2.4 Value chain improvement areas

The main specific bottlenecks for the development of tambaqui value chain in Tocantins are:

- Difficulty to achieve vertical integration to the processing industries
- Difficulty to access financial credit for fish farming
- Problems related to environmental compliance
- Lack of technical assistance by public extension service
- High production costs
- Low price paid for the tambaqui

Most of tambaqui farmers, principally small-scale ones, work individually and they are not part of any producer organization or cooperative. The majority of the tambaqui producers are also not vertically integrated to the processing industries operating in Tocantins or neighbour states. The main reasons behind the difficulty in integrating small-scale tambaqui producers and processors in Tocantins state are:

- Low price paid by processors (US$ 1.30/kg) compared to middleman (US$ 1.68/kg) makes the transaction not attractive as small-scale farmers have high costs of production and low technological level
- Small-scale farmers present resistance in establishing cooperatives or producer organizations in order to increase quantities to meet processors demands or to operate an own processing plant
- Despite being mandatory, sanitary control by regulatory agencies is still weak which encourages the practice of non-compliance
- However, there is a tendency to reinforce this type of control in the future, which represents a great risk for small-scale farmers

Tambaqui processing industries are adding value by sanitary certification and consumers are getting more conscious of this certification. In addition, the primary fish processing in certified plants is mandatory in Brazil (i.e., fish cleaning and evisceration) according to federal sanitary law. Because of the non-integration between small-scale tambaqui producers and the processing industry, new arrangements and governance structures have emerged:

- More vertical governance structures have emerged with power in processors hands, which are increasing vertical production and partnerships with large producers
- This governance enables the processors to assure quantity and quality, which allows reaching more demanding markets (e.g., São Paulo, Brasilia, Rio de Janeiro). Without sanitary certification and with fragmented volumes, small-scale farmers orient their production to local markets and prices has decreased due to increasing offers.

Therefore, two tambaqui value chains co-exist in the Tocantins state, where one is industrialized and capitalized, and oriented to more consolidated market (I.e., Supermarkets in larger cities), and another is informal (and illegal), with low capital and technology, oriented to local markets and their traditional retailers. The scenario is complex as the public policies are reinforcing sanitary control but does not offer alternatives to process production from scale-scale farmers.

In this context, the integration between small-scale farmers and processing industry can be instrumental to assure the consolidation of the tambaqui value chain. That integration can assume different kinds of arrangements such as vertical integration, joint ventures, consortiums, or alliances. It can reduce some important bottlenecks in the tambaqui value chain:

- Risks associated to absence of fish processing
    - Sanitary risks for consumers related to the poor hygienic standards and absence of appropriate cold chain
    - Impossibility to access supermarkets and other more demanding markets due to the lack of sanitary certification
    - Sanitary regulation for fish is getting reinforced in Brazil
- Lack of alternatives to process fish
    - Initiatives aiming to implement collective/public fish processing plants for farmers has failed
    - Individual farmers have no output and capital to enable an own fish processing plant

The informality of tambaqui production in Tocantins is representative of many regions of Brazil. That situation is the result of the failure of the public policies aiming to include the small-scale fish farmers into the market.

The small-scale tambaqui farmers assume an institutional and sanitary risk because the tolerance of the traditional retailers concerning the absence of processing and sanitary certification relies on the lack of control from local sanitary agencies. Nevertheless, public policies are reinforcing sanitary regulation for fish but does not present alternatives to process production from small scale producers. Moreover, the absence of processing can result in sanitary risks for the consumers because of poor hygienic standards and absence of appropriated cold chain (Castilho and Pedroza Filho, 2020).

The initiatives carried out by the government aiming to implement collective/public fish processing plants for small scale producers have failed. On the other hand, small scale fish farmers working individually have no output and capital to enable their own fish processing plant. However, the alternatives to overcome these problems are necessarily based on productive organization of the fish farmers, to increase scale and meet processors' demands in terms of quality and volume. Another measure concerns the access by fish farmers to technical assistance to improve capabilities in terms of production efficiency (Castilho and Pedroza Filho, 2020).

The successful model of vertical integration utilized by poultry and swine sectors in Brazil could be adapted to the aquaculture sector. Successful initiatives are being implemented by large agricultural cooperatives with tilapia in southern Brazil (Castilho and Pedroza Filho, 2020).

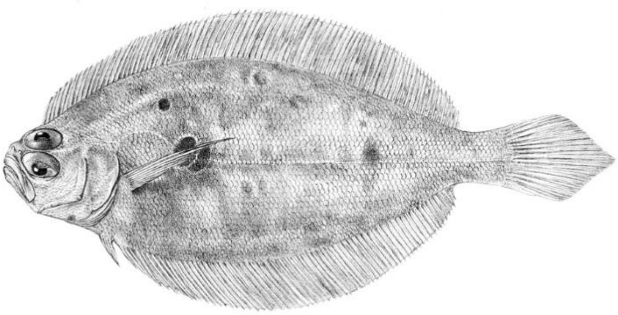
Another strategy to overcome the problems related to the lack of processing is the implementation of cooperatives or producer association between tambaqui farmers. Nevertheless, data from Costa et al (2020) shows that majority of tambaqui farmers in Tocantins are not part of an association or cooperative.

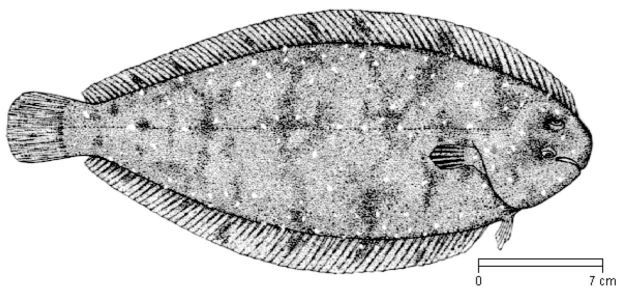
7 CS11 Marine fish farming

7.1 Background

Aquaculture of finfish in tropical temperatures is relatively small on a global scale. The aim for CS11 is to develop the aquaculture of *Paralichtys orbignyanus* in Brazil. This species is distributed in the wild from the southern coast of Brazil to the northern coast of Argentina. It's known in Portuguese and Spanish as linguado/lenguado, and we will use the name linguado as we are not aware of an English name. Currently, broodstock is kept and flounder juveniles produced in research stations in the three mentioned countries, and Uruguay. The Laboratory of Marine Fish Culture at FURG in Federal University of Rio Grande, Brazil, is among the hatcheries working with linguado. Grow-out is also done in indoor tanks at the FURG research station. Aquaculture production is, however, restricted to research scale, and there are key areas that need improvement to facilitate expansion to commercial scale production.

Portugal was identified during the project application phase as having a limited, but commercial scale production of another species of flatfish (the generic name for Pleuronectiformes). The species produced in Portugal shares the same name of the Brazilian species *linguado*, but it refers to Senegalese sole (*Solea senegalensis*). Although both being flatfish, there are considerable differences that may limit the usefulness of the Portuguese experience and knowledge. There is also a larger scale production of other marine species. Information from these production systems and value chains may also be utilized to further develop the Brazilian case study.





Linguado (Image: GM. Woodward, Wikimedia Commons)   Senegalese sole (image from FAO)

Figure 78 Drawings of linguado flounder (left) and Senegalese sole (right).

7.1.1 Methodological remarks

Linguado is currently only farmed on experimental scale, but at research institutes in different countries. This has major implications for the value chain analysis. The input-output structure is only described for a hypothetical production process, based on publicly available documents describing primarily the biologically related aspects of production and interviews with the case study leader, being strongly involved in research on this species. Information about the supply of linguado from capture fisheries and other related flatfish aquaculture is obtained from FAO data. Distribution of products to markets is illustrated using information from reports about the turbot markets in the EU. The cost-structure of potential production is illustrated using a bio-economic model with variables based on information available literature about the actual species, interviews with case study leader and supplemented by information from literature on turbot and sole farming in the EU and public information on actual costs from Spanish turbot and sole farms. Some information about the organization of the value chain and suppliers of key inputs such as juveniles and feed is obtained from the case study leader. Until commercial-scale production is established, it is difficult to employ methods that better can describe the value chain aspects.

7.2 Industry-level value chain

7.2.1 Input-output structure

Figure 79 introduces the general value adding stages in a finfish food aquaculture value chain. Broodstock is kept and managed to obtain gametes that are fertilized. This stage could also include breeding activities to maintain and improve the genetic traits of the offspring. Fertilized eggs develop to juveniles ready for stocking in what is here known as the juvenile stage. Stocked juveniles are grown to market size in the grow-out phase. Market size fish are harvested and, in some cases, transported to processing plants where varying degrees of processing takes place. This can include transport to a secondary processing facility. However, this is uncommon in these value chains where only minimal processing such as gutting and packing generally takes place. Fresh fish are then distributed to sales outlets or end consumers through a variety of channels. The various stages can be organized within a vertically integrated firm or distributed between more firms. Activities can also be horizontally distributed across stages. This can also be within or between firms. It is especially common to have multiple grow-out operations and distribution channels, while broodstock, juveniles and processing tend to be more centralized. Within each organization there is supporting activities such as administration, research and development and marketing.

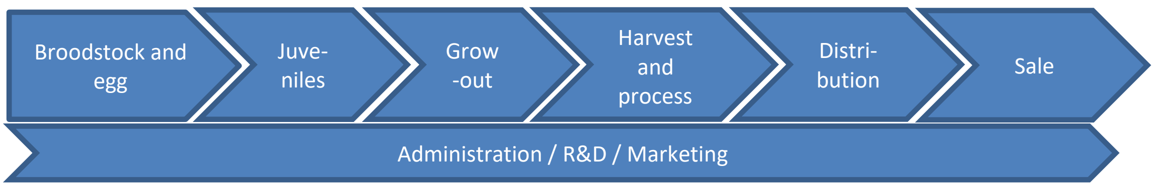


Figure 79 General value chain of finfish production

7.2.2 Supply

P. *orbignyanus*, (linguado in Brazil), has a natural distribution in marine and estuarine waters from Rio de Janeiro to San Matias Gulf off Argentina in relatively shallow waters (Boccanfuso et al. 2019). Both in the local Brazilian and Argentine markets as well as internationally, the fish is in high demand for its quality meat and relatively large size. It is typically consumed fresh, but very often processed in fillets. Together with *P. patagonicus*, linguado is the most common flatfish landed in these areas, although also other flatfish are caught. Landings in both Argentina, Uruguay and Brazil, shown in Figure 80, have been reduced – total flatfish landings in Argentina was reduced from 7,335 in 2009 to 3761 tonnes in 2017. Uruguay caught less than 100 tonnes in 2016, down from a peak of 500 tonnes in the second half of the 1990ies. Brazil landed about 2,550 tonnes in 2016 and landings have been relatively stable over time. Even before these reductions in quantity, the fish was considered “fine fishing” by fishermen, as the sales price was high (Fabré and JMD De Astarloa 2001).

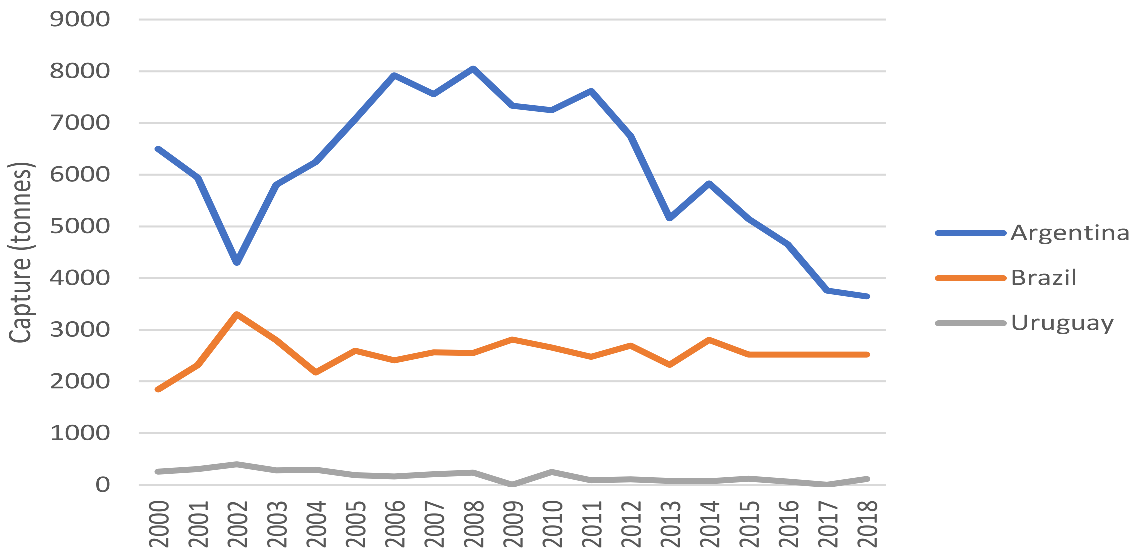


Figure 80 Capture production of bastard halibuts in Argentina, Brazil and Uruguay 2000-2018 (Source: FAO Fishstat)

The high prices and quality spurred research into closed-cycle aquaculture of this species. Tolerance against changes in salinity, and other environmental factors such as temperature, pH and nitrogen as well as high stocking densities has further strengthened the view of a promising candidate for farming (Sampaio and Bianchini 2002). Induced spawning and larvae production from wild-captured broodstock was achieved as early as 1993 (Cerqueira et al. 1997).

No production of linguado flounder is registered in FAO Fishstat. There are records of undefined flatfish, but in recent years these have been from China, Korea and Peru, thus not the same species, but congeneric. Other flatfish species may be relevant for production of linguado, hence we will introduce estimates and developments in world production of flatfishes before focusing more on European production.

World production is illustrated in Figure 81 and Figure 82. China is dominating production, having a production share of about 2/3 in 2017, followed by Korea at about ¼. Production has grown rapidly since the turn of the century. In 2003, production was merely 83,000 tonnes and more than doubled to about 200,000 tonnes in 2015 before declining somewhat. This growth has in all essence been coming from China, with Korea and the rest of the world being relatively stable. Among the rest of the world, Spain is the major producer at about 10,000 tonnes, and having grown rapidly from 2003 to 2008, before being relatively stable until 2017. This is likely linked to the economic situation following the financial crisis in 2008.

Japanese production has declined steadily, while Portuguese increased rapidly from 2008 to 2012, before levelling out with significant fluctuations. Norway has been rather stable at about 1,500 tonnes and the rest of the world has only very minor production.

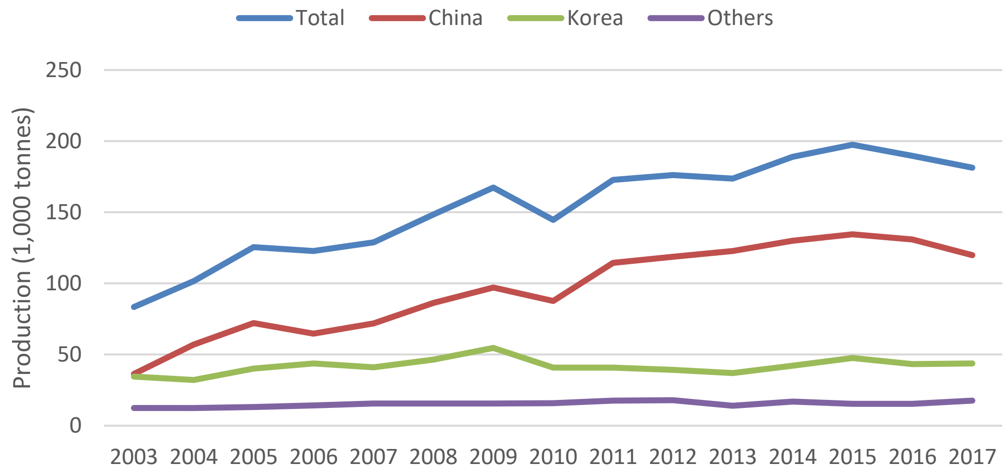


Figure 81 World production of flatfishes 2003-2017 (Source: FAO Fishstat)

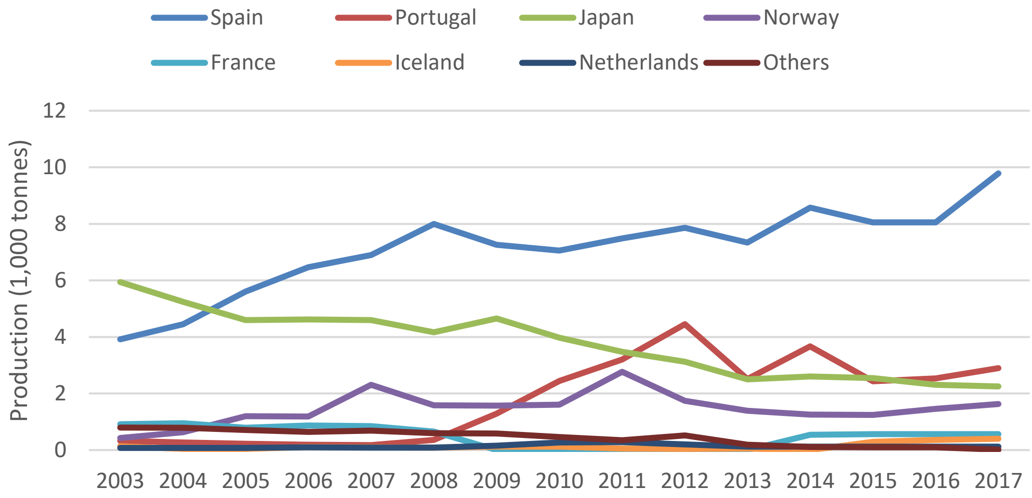


Figure 82 Selected countries' production of flatfish (Source: FAO Fishstat)

Looking at the species produced, turbot, lefteye flounders, bastard halibut and righteye flounder together make up 98% of production, with respective production shares of 33, 33, 22 and 10%. The rest of production consists of Atlantic halibut and soles (Senegalese, common and spp.) as shown in Figure 83.

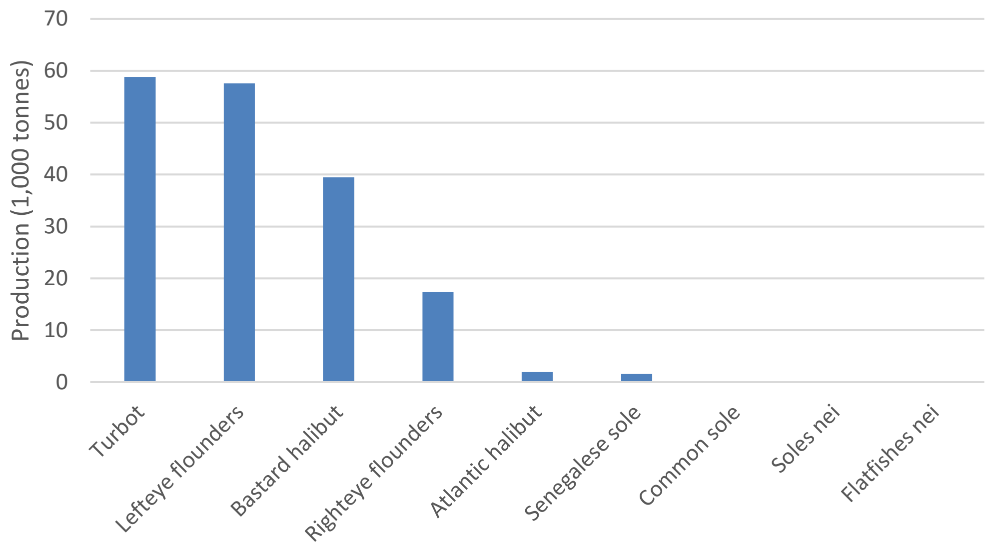


Figure 83 Production of flatfishes by species in 2018 (Source: FAO Fishstat)

Going into detail on the Portuguese production, we supplement the FAO data for 2018 with data from INE (2019) for turbot production in 2018. Turbot also dominates in Portugal, but there is only a small production of about 150 tonnes of sole annually. Turbot expanded greatly from 2008 to 2012, before decreasing somewhat and seemingly stabilizing at about 2,500 tonnes. Prices were reduced from 2007 to 2012 but stabilized and have increased the later years to about 9.8 USD/kg in 2018.

Sole production is considerably less and grew from 2011 to 2015. Since then it has been relatively stable at 150 tonnes. Prices seem to have been reduced with the increase in production but grew again in 2018 to about 15 USD/kg. Prices for sole have been considerably higher than for turbot during the whole period.

Land-based farming of sole was researched and experimented with for many years in EU countries. Scaling up was faced with difficulties, both biologically and economically. Fish growth is relatively slow hence production time is long. Cost were also high and competition from wild-caught sole meant that prices were relatively low. Nonetheless, production has risen and reached 1,700 tonnes in 2018, all from European countries. All being EU countries, except Iceland producing about 400 tonnes.

In South America, several flatfish species related to linguado have been the subject of research and have been trialled for aquaculture. Chilean sole (*P. adspersus*) and turbot in Chile, but production of commercial quantities ended in 2013 according to FAO data. Peru has a small production of flatfish, likely turbot, but reported in FAO data as flatfishes nei.

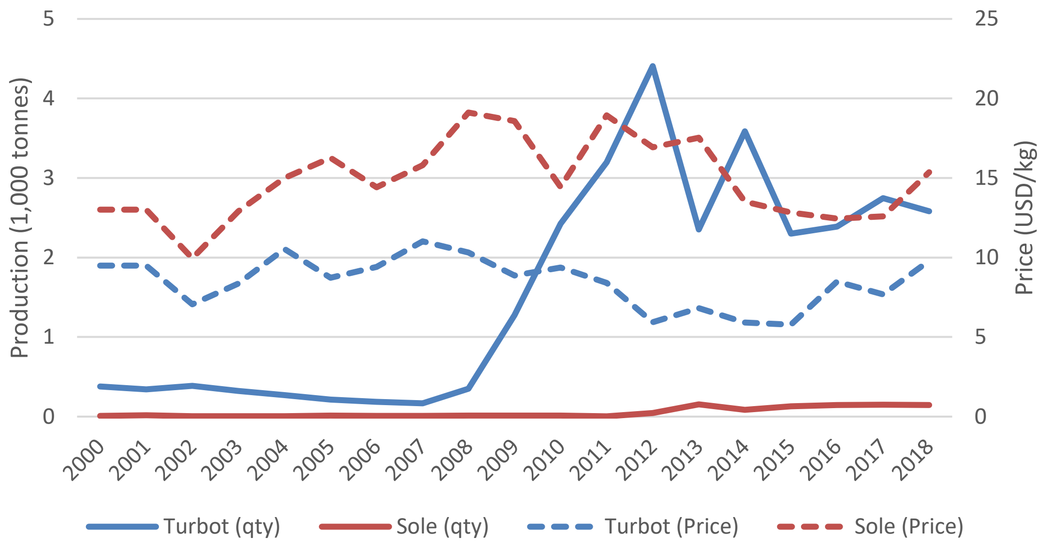


Figure 84 Production and prices of flatfish in Portugal (Source: FAO Fishstat and INE (2019))

7.2.3 EU market for turbot and sole

In the EU market, sole is appreciated for its nice taste, and fine and boneless meat. Hence, processing is limited, and the fish are sold to consumers as fresh or frozen whole fish. Sole is predominantly steamed, fried, boiled or baked (EUMOFA 2018). Sole is to a large extent consumed in Portugal, but about 23% was exported in 2018.

Turning to the turbot market, which is considerably bigger both in terms of Portuguese and EU production. In contrast to sole, the Portuguese turbot is almost exclusively exported - 99% of sales were international in 2018 (INE 2019). The prime receiver and the by far biggest market being Spain. Estimated sales in the main EU markets is estimated in EUMOFA (2018) using different data sources for aquaculture, landings and external trade. The results are illustrated in Figure 85. Spanish consumption of turbot is to a large degree based on own farming and imports from Portugal, although imports are more than offset by exports. The total market is estimated to about 6,300 tonnes. Italy and France are estimated to utilize about 2,500 tonnes, with supply in Italy to a very large extent being based on imports. France has significant own landings and some aquaculture supplementing large imports.

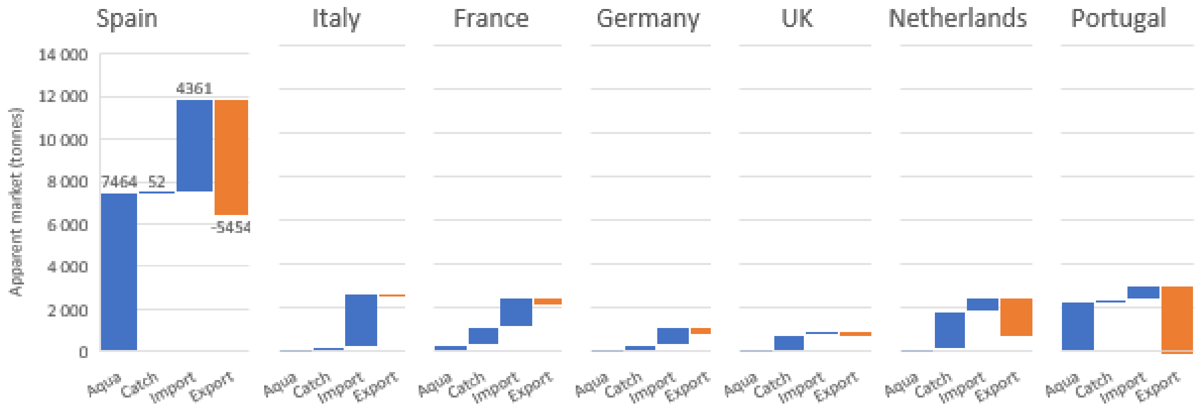


Figure 85 Apparent consumption of turbot in main EU markets (Based on EUMOFA 2018b)

As there are very few producers of sole, we here focus on the turbot market in the EU and in slightly more detail on the major producer and consumer, Spain. There were in 2016 17 licenses for farms producing turbot. A very large share of this production was controlled by two companies. This illustrates that the supply side is highly consolidated.

As illustrated in Figure 86, production from national aquaculture is supplemented by imports of both wild and farmed products and a very small wild catch and reduced from exports. There is a net trading loss of about 1,200 tonnes rendering a Spanish market of about 6,400 tonnes. This is distributed into three main outlets, but through different distribution chains. A large share is sold directly from farmers to supermarkets and fishmongers. This is often distributed via so-called "platforms", where large shipments are collected and split into smaller quantities for transport to the individual outlets. The total quantity going to these segments was estimated to about 4,900 tonnes (EUMOFA 2018). Another large share is distributed via the large wholesale markets in Madrid, Barcelona and Bilbao. About 2-2,500 tonnes is estimated to be sold through these channels. These products are supplied to both the Horeca segment (about 1,000 tonnes) and to fishmongers.

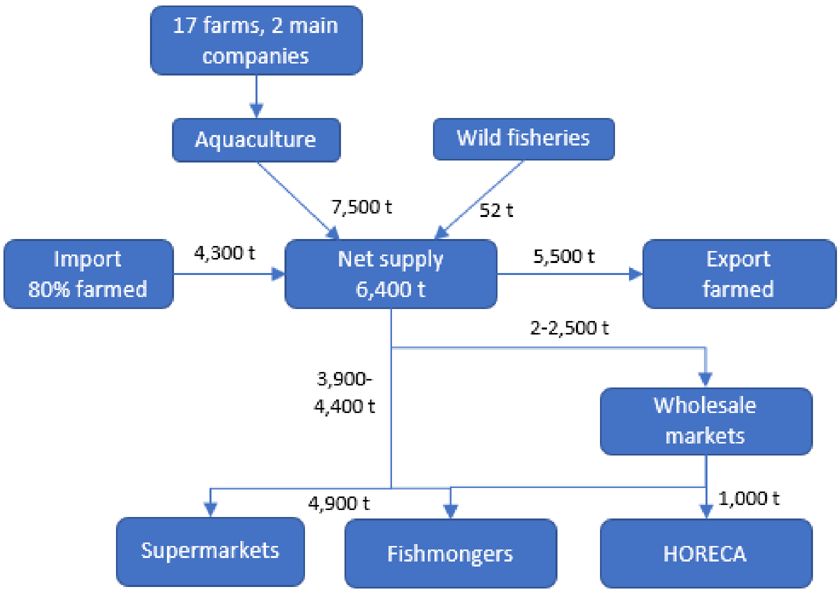


Figure 86. Illustration of the Spanish market for turbot (Based on EUMOFA (op cit)

7.2.4 Cost and price structure

Based on studies from the Spanish aquaculture authorities on cost structure in bass and bream farming and interviews with industry representatives, EUMOFA (2018) estimated a cost and price structure in the turbot farming value chain. This chain assumed that the fish was sold directly to a supermarket fish counter. The results are shown in Figure 87. Included in the farmgate price is harvesting and packing in boxes. The data do not distribute the costs between juveniles, grow-out and harvesting. Based on experience from other species, it is clear that the majority of costs are incurred during the grow-out stage. Distribution costs are relatively minor, whereas the operating costs of the fish counter, including gutting loss, are considerable. The margin for supermarkets is very small, likely reflecting that fish counters are an important customer attracting feature, but not very profitable.

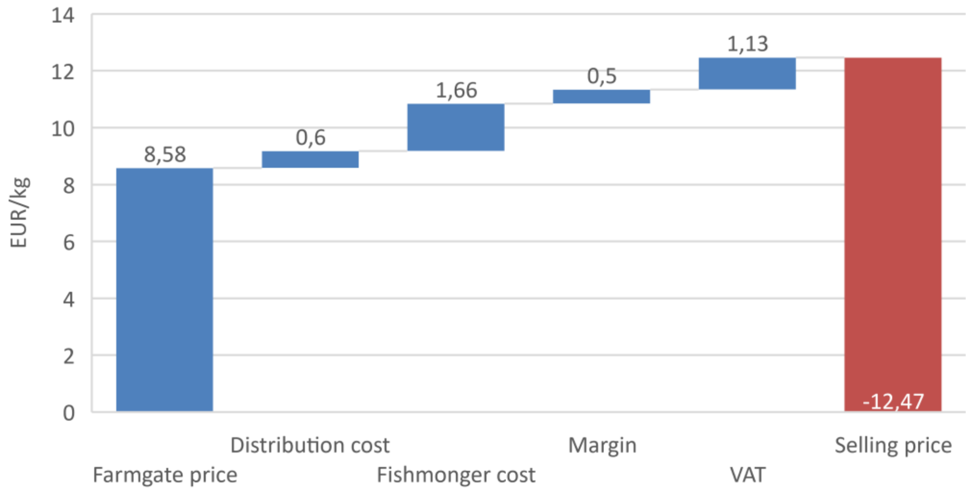


Figure 87. Price/cost structure along the value chain for farmed turbot (Based on EUMOFA (2018))

7.3 Case study specific value chain

This section describes the value chain directly related to the production of linguado (*P. orbignyanus*). As there currently is no commercial production, only the production related aspects will be discussed, including critical issues. Experience from production of other flatfish species will be employed to shed light on the cost structure and value adding potential using a bioeconomic model of production.

7.3.1 Input-output structure

The production process of linguado can generally be divided in the following stages: broodstock and egg, larvae, first-feeding, juvenile and grow-out. The value-adding process of a potential farm production would follow the general description from the industry value chain in chapter 7.2.1.

Broodstock and egg

Broodstock are kept in tanks where lighting and temperature is controlled. This allows for thermal-photoperiod manipulation of spawning time. Research indicates that salinity also influences spawning, as the fertilized eggs will only float in seawater. Males and females are kept in the same tank the whole year. Spawning can be both natural and induced using hormone analogues that is injected in usually only the females. In the latter case, cryopreserved semen from males can be used to fertilize eggs. Eggs and semen are stripped from anaesthetized fish by gentle pressure on the ovaries/testes towards the genital opening. Quality of eggs is generally better using natural spawning.

Broodstock tanks in FURG research facilities are circular tanks with 3 m diameter and 0.8 m depth. Sea water is supplied from a RAS system at about 25% exchange per hour, depending on stocking density.

Tasks that are performed during regular management are feeding and cleaning the tanks to remove uneaten food, faeces and possible mortalities. Feed varies from wild fish and squid and semi-moist prepared mince of fish, squid, fish meal, fish oil and other nutrients and additives. Generally, fish are fed every day.

During spawning, eggs are collected from a net mesh at the tank outlet if natural spawning is used. If spawning is induced, fish are injected and stripped and eggs and semen are mixed. Eggs are washed and placed in a cylinder to separate floating and sinking eggs. The size of broodstock fish varies; males are usually 1 kg or less, while females can be larger, from 1-3 Kg. Fecundity is very variable - ranging from 60,000 to 95,000 eggs/kg.

Larvae

Fertilized eggs are transferred to smaller conical tanks (500 l) or flat-bottom cylindrical tanks with gentle aeration at a density of about 100-120 eggs/l. Hatching time decreases with increasing temperature. At 17°C, hatching occurs after 50h, while at 26°C it takes less than 30h for hatching. On the other side, length at hatching is not influenced by temperature, standard length averages 1.8 mm.

During incubation there is no management of eggs, however as dead eggs sink to the bottom of the tanks, they can be purged from the tank in order to keep good water quality.

Figure 88 A linguado larvae after start-feeding (Photo: FURG)

First-feeding

Linguado, as other marine fish, depend on live feeds during the larval phase. This includes production of microalgae (*Nannochloropsis sp)*, rotifers (*Brachionus plicatilis)*, artemia nauplii and metanaupliii (*Artemia sp*). Larvae rely on their yolk sac nutrients before first feeding. Small rotifer is the preferred food item for first feeding, which is temperature dependent. At 23°C the larvae start preying on rotifers four days after hatching, while at 17 °C this takes eight days. Independent of the temperature, larviculture is performed in green water, this is because water is populated with microalgae. As larvae grow, they start preying on artemia nauplii. Again, this is temperature dependent, at 23°C larvae are able to capture and ingest artemia nauplii 15 days after hatching, but at 20°C it takes 19 days. After a week, it is possible to switch the diet to the larger and fatty acid enriched artemia metanauplii.

Weaning onto a dry diet is a major problem for flounder larvae. It can take 1-2 months after hatching for successful weaning. Weaning is only achieved after larvae has metamorphosed into a juvenile. Externally it is observed the formation of fins and scales, coupled to the migration of the left eye. Metamorphosis is also temperature dependent. At 23°C, larvae will begin to settle to the bottom of the tanks 16 days after hatching and fully metamorphosed individuals can be found after 4 days. However, at 20°C, the whole process takes 35 days to be completed. As they metamorphose into a juvenile, linguado is 8-9 mm long.

Tasks performed during this stage are first and foremost production of algae, rotifers and artemia that are fed to the larvae at least four times a day. Control of water quality and prey density in the larval tanks are also performed. Larvae are inspected daily under microscope to make sure they are feeding and that there are no external signs of disease.

Juvenile

As mentioned above, juvenile linguado is weaned from live feeds into dry diets between 45 and 60 days after hatching. The change from live food should be gradual, until all individuals are able to capture the new diet.

When weaning is complete, juveniles have already settled to the bottom. Transference for nursery tanks will depend on each hatchery, but once linguado become demersal, rearing tanks should have flat bottom. Opposite to the larval phase, where 24h of light is provided, juveniles should be kept under 18h light/6h dark per day. Salinity preference also changes for juveniles. Larvae are reared in full strength sea water, but juveniles can be reared in brackish water (salinity 10).

Fingerlings will remain in nursery tanks in flow-through system or RAS until they are large enough to be transferred to grow-out tanks. At this moment their weight can vary from 2-3 g to larger individuals 10-30g.

Figure 89 Juveniles ready for grow-out (Photo: FURG)

Figure 90 shows the weight development over time for a juvenile linguado based on experiments from the research station in Cabo Polonio (Uruguay). About 150 days after hatching, the juvenile is 5 grams and after about 6 months (180 days) 10 grams.

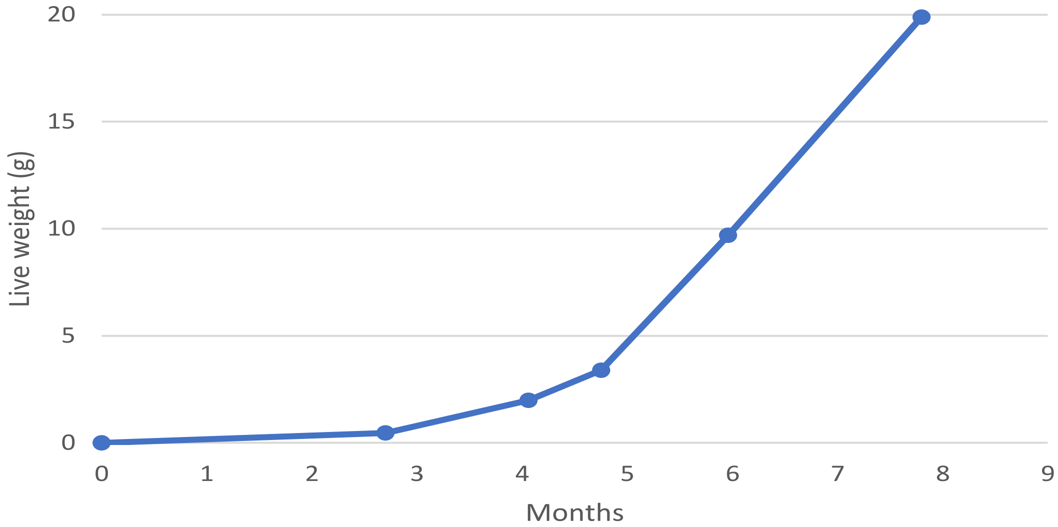


Figure 90 Weight development of linguado during the hatchery stage (From: Bessonart and Salhi 2018*)*

Grow-out

After the fish are sufficiently large and robust, they can be transferred to the grow-out system. This generally has larger tanks or raceways and simplified water treatment. The size of the fish at transfer varies. For turbot and sole, it is common to transfer fish at 5 grams.

There is a variety of production systems employed. For turbot and sole, shallow square and round tanks and shallow raceways that can be stacked are commonly used. Water supply can be flow-through or RAS systems. The common denominator has been shallow tanks with flat bottoms. These can be rectangular, octagonal or round, made of concrete or fiberglass. Recirculation systems have been developed and are now more affordable, so they have been increasingly popular for flatfish farming. In an Argentinian research facility, described in Sedem (2010) a farming room of 124 square meters was used, containing two tanks that were 6 m in diameter and 0.8 m deep. In both the Argentine and Uruguay research facilities, juvenile and grow-out have been carried out in recirculation systems. These are especially good for maintaining conditions under control for research purposes. Water temperature was kept between 20 and 22 °C.

Water exchange in Uruguay was kept at about 2 times per hour and the fish were fed six times a day. The feed was based on local fish meal made of by-products from local fish processing, with less protein content. This was primarily due to prices being considerably less, at 575 USD/tonne, compared to about 1600 USD/tonne for more standard dried pellets. The feed had about 45% protein and 10% fat. Feed conversion rates varied between 1.2 and 1.7 up to 500 grams

The results from a growth experiment is illustrated in in Figure 91 . The fish are here divided in cohorts according to growth, with the 10% representing the 10% fastest growing fish. Growth rates were about 1.6% daily up to 40 grams and 1.2 % to 100 grams, 0.9 to 200 grams and 0.63 to 500 grams. This results in weight development as illustrated. Taking the 50% cohort as example, it takes about 16 months to grow from 10 grams to about 0.5 kg, being referred to as harvest size. Adding in the 6 months from hatching to 10 grams, total production time is 22 months. There is rather large variation in growth, with 10% of the population reaching 0.5 kg in 12 months and the whole population in about 22 months.

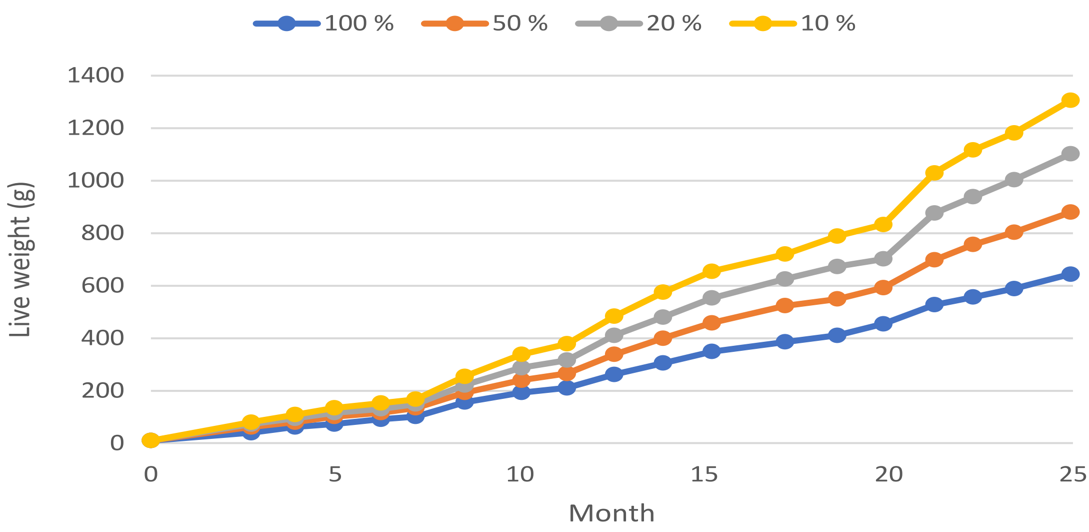


Figure 91 Linguado growth from 10 gram fish in Uruguay Cabo Polonio research station (From Bessonart & Salhi (2018)*)*

Harvesting, processing and distribution

Currently, there is only research facilities producing fish, hence there are no commercial procedures for harvesting, processing or networks for distribution of finished products.

Figure 92. An adult linguado (Photo: FURG)

7.3.2 Organization and governance

The intention of this section is to describe how the value chain is organized, especially in terms of the degree of vertical and horizontal integration, how communication flows, the bargaining power of chain actors and how decisions regarding production are being made. In Brazil, commercial-scale aquaculture of marine species is in its infancy, with just 20 tonnes of “marine fishes” being registered by FAO in 2018. This despite the country having a large coastal sea area and a number of suitable candidate species for culture. There has been considerable research on linguado culture, but this has not translated into commercial ventures. Smaller scale farming of cobia is taking place in near-shore cages, and presently groupers are being trialled.

Expansion of finfish farming is facing several bottlenecks according to Myhre *et al.* (2017). Current fish feed formulations are inadequate and/or expensive, farm management is problematic increasing disease occurrence, fingerling supply is problematic and expensive, lack of breeding programs and poor communication between research and producers. In addition, as far as we can see, there is not a well-developed supplier industry. This implies that there is a need for importing goods and infrastructure, often at higher prices. Not having such an industry close by is also likely to hamper innovations in both production and farming systems. According to Redemar Alevinos there are also difficulties in getting licenses for farming, this can take 18-25 months, and legal uncertainties. The high investments associated with farming has also been discouraging investors.

In addition to research facilities at universities, there are three fingerling producers in Brazil that produce marine finfish (Mariculture Operators of Ilha Grande, AMBIG, Maricultura Itapema and Redemar Alevinos (Rombenso et al. 2016)). There are two main producers of feed for grow-out, Guabi and ADM. The composition was initially based on a recipe from Vietnam. As mentioned, this feed has been criticised for being suboptimal quality and being costly.

It is likely that products from farming of finfish will be processed further rather than only primary processing taking place near the farm.

There are many distribution channels and sales outlets for marine fish. The main markets are in the larger cities such as Sao Paolo and Rio de Janeiro. Here, major quantities are sold through wholesales markets. The CEAGESP wholesale market in Sao Paolo is the largest in Brazil, containing 841 wholesale stores for fish. These stores gather fish from farmers, middlemen and others. There are also other wholesale markets and large private distributors. Supermarket chains are often supplied through distribution hubs that gather supplies from several sources such as industrial fisheries, middlemen and others. Restaurants are commonly served by distributors.

An anonymous grouper farm experienced that the primary producer of groupers received about 40% of the supermarket selling price.

In summary, the value chain of marine finfish farming in Brazil is small and primarily consisting of firms that are neither horizontally nor vertically integrated. Each stage in the value chain is generally individual operators of hatchery, on-growing, feed supplier and distribution.

7.3.3 Cost structure

There is very little data available concerning cost structure and sales prices, being prime components of value adding. Experience from production of other closely related species and models can, however, provide some insight into the potential economics of farming linguado. Based on the input-output description, the following important cost components can be identified for an imaginary grow-out operation:

- Capital
- Juveniles
- Feed
- Labour
- Electricity
- Maintenance
- Administration
- Harvesting/processing
- Distribution
- Depreciation

Some of these will generally be independent of production quantity (fixed costs), such as depreciation, capital costs associated with infrastructure and labour associated with administration. Others, such as juveniles, feed, labour associated with production, electricity and distribution will vary closely with produced quantity (variable costs). As there is no statistical data to use for cost estimation, we will here employ the engineering approach, describing cost drivers, conversion factors and prices to arrive at rough estimates of production costs and value adding. Here, experiences from other flatfish culture will be extensively used.

To shed light on the potential cost structure of farming, we here develop a simplified bio-economic model of an imaginary farm. The model is deterministic and in discrete time with steps of one month. The model uses weight dependent growth and mortality, a fixed feed conversion rate to describe the biological development and harvest quantity. Utilization rates of labour, water and electricity as well as fixed prices drive these cost items. The assumptions for required parameters in the model are described below.

Number of fish and individual weight

Planned harvest quantity, size, stocking weight and mortality determine the number of juveniles to stock. The investment cost of a farm is highly uncertain, as no commercial farms of this type has been built in the region. As a starting point, we employ figures from a study on the economics of sole farming (Bjørndal et al. 2016). Here, the investment for a planned production of 350 tonnes is estimated. Key assumptions here are a starting weight of 5 grams and harvest size of 350 grams that is attained after 18 months.

The average growth of linguado from Bessonart and Salhi (2018) is very similar, as the average for the population is about 350 grams after 18 months, correcting for about a month difference from starting with 10 gram juveniles. We use this weight in the model. How a domesticated fish population can perform under good farming conditions and practices is uncertain. The growth results for parts of the population seem to indicate that there is potential for faster growth. Optimal harvest size for linguado is not known and not studied in literature. Sedem (2010) uses a harvest weight of 1.0 kg but assumes the fish to grow considerably faster than Bessonart & Salhi (2018). Experience from the FURG research indicates that fish can grow to 0.7 kgs in 18 months.

Sedem (2010) assumes a mortality of 10% over the whole on-growing cycle. In line with this, we assume a mortality rate of 2.3% the first month, and 0.5% the following months until harvesting. This corresponds to a mortality of 10% after 18 months. This is slightly higher than the assumption in Bjørndal et al. (2016) for sole, at 9.1%.

Harvesting 350 tonnes at steady state of production with these assumptions requires stocking 1.1 million juveniles. These are assumed to be stocked at 5 grams to parallel the sole study.

There is currently no market price for juveniles, as there is no commercial production of linguado juveniles. Observed prices for other species can serve as indicators. According to Redemar Alevinos, grouper juveniles are available for 8 reals per piece (2.3 USD at Jan 2020 exchange rate). In Bjørndal et al. (2016) a price of 1.59 USD/juvenile is used for sole. Sedem (2010) assumes that linguado will be available at 0.89 USD/pcs at 16 grams. Given that linguado farming is a new venture, and the scale of production is likely to be considerably smaller than the hatcheries producing sole farming juveniles in Europe, we take the average of the grouper and sole prices as our estimate for seedstock price.

Feed

Feed use is calculated monthly as the change in individual weight multiplied with the initial number of fish and an assumed FCR. The FCR varies from 1.2 for small sizes to 1.7 for larger fish according to Bessonart and Salhi (2018). This is attained using locally produced feed. In Brazilian research production of linguado a dried and pelleted feed developed for cobia production is used. With this feed, average FCR of 1.2-1.3 has been attained and the feed costs about 7-8 real per kg (1.8-2.0 USD/kg) (Sampaio, pers. comm). In an analysis of cobia culture profitability, de Bezerra *et al.* (2016) assumed a feed price of 1.64 USD/kg based on 2012 information. We here assume a biological FCR of 1.2 and a feed price of 2 USD/kg.

For comparison, in their study of sole culture, Bjørndal, Guillen and Imsland (2016) assume a fixed FCR of 1.1, and a feed price of 1,860 USD/tonne. This reflecting the use of commercially available formulated feeds with very low moisture content.

Energy and other costs

Energy costs are difficult to estimate but are likely to be important in a land-based facility. Bjørndal et al. (2016) assumes a cost for electricity, gas, water and other costs at 530,000 USD annually. Although the conditions may vary considerably between Brazil and Europe, especially in terms of energy prices, we use this as a starting point.

Direct labour

Bjørndal et al. (2016) assumes that a labour force of 8 workers and one administrative staff is required for a 350 tonne sole farm. Hence, we here use the estimate from the sole farm model but add 20% due to less experience with farming and a further two persons for handling feed logistics and production. We use the implied annual labour cost from de Bezerra *et al.* (2016) of about 8,500 USD per employee.

Insurance

Insurance of the fish stock is calculated as 0.17% of the inventory value of the standing stock on a monthly basis.

Maintenance

Annual maintenance is assumed to be 2% of the initially invested value.

Depreciation

Depreciation reflects the annual reduction in value of the fixed assets that are employed. For simplicity, the required investment is based on the sole study, even though both land, machinery and tank costs are likely to differ between the regions. The required land and tank area, pump and recirculation capacities are uncertain, but the assumptions of similar production, harvest size and production time makes similar infrastructure requirements likely. Total, investments are assumed to be 6 million USD. With an average lifespan of 20 years for the building and tanks, and 5 years for pumps and other equipment, constituting 20% of equipment, annual depreciation is 444,000 USD.

Capital costs

Especially for production cycles that span over long periods, capital costs can be important. Fish farmers bind capital in both infrastructure and inventory especially through juvenile and feed costs. The payments for administrative costs and other expenses also need financing and are relevant. For simplicity, we here calculate only the monthly inventory based on variable costs and the fixed assets. Capital costs are calculated using a monthly interest rate of 0.6%, corresponding to an annual interest rate of 7.5%.

Administrative costs

Sedem (2010) employs an estimate from FAO (1998) for administrative costs that amounts to 7.5% of direct production costs. In the sole study, management costs are estimated at 100,000 USD including labour cost for one manager. Assuming a wage cost of 35,000, management costs are then 65,000. For simplicity, we employ this estimate here, although there is considerable uncertainty.

Marketing costs

Marketing costs are taken from FAO (1998), estimating these to be 2.9% of variable costs.

Summary production costs

The associated production costs are summed up in Table 18. Total unit production costs are estimated at 14.7 USD/kg. The main cost factor is juveniles, accounting to 42% of total costs. Capital and depreciation are also major primarily fixed costs. These cost items could likely be strongly influenced by changing harvest size. Adding tanks for holding large fish at high densities is likely not to proportionally increase investments and capital costs. The juvenile unit costs will be reduced about proportionally to harvest size change. Of course, this will increase feed costs, but as these currently are about 2.5 USD/kg, this seems a profitable opportunity.

For comparison we have included production costs from Bjørndal et al. (2016) and costs for Spanish turbot and sole farming. The latter are own calculations based on annual production and economic survey from the Spanish ministry (www.mapa.gob.es). The modelled costs are relatively close to the sole farming model, but about 50% higher than for turbot and sole farming. Especially the juvenile cost is higher, likely due to higher harvest size, and likely problems in isolating these costs in the Spanish economic survey. Labour is considerably higher in the Spanish estimates, as well as maintenance. Depreciation is less in the Spanish estimates, likely due to higher productivity and scale effects in turbot farming.

If the farmgate prices for sole in Portugal are indicative of sales prices in Brazil, farming seems an attractive option from an economic perspective with the current assumptions. When comparing against prices from the Sao Paolo market for wild linguado, obtaining higher prices is necessary.

Targeting the larger size fish seems especially important, as there was a considerable price premium. Achieving higher harvest size than 350 gram would also be beneficial for reducing the very high juvenile cost share.

Table 18 Modelled production costs for hypothetical linguado farm

	Qty	Price (USD)	Cost (USD)	Unit cost (USD/kg)		Bjørndal sole	Spain turbot
Juveniles	1 101	1.90	2,086	5.96		5.01	0.15
Feed	444	2.00	888	2.54		2.02	2.75
Direct labour							
- **Technical**	10	8,500	85	0.24		0.61	2.15
- **Admin**	1	10,000	10	0.03			
Electricity, other			530	1.51		1.51	1.84
Water	8	0.38	3	0.01			
Insurance		0.17 %	86	0.25		0.27	
Maintenance		2 %	119	0.34		0.32	1.95
Depreciation			444	1.27		~1.20	0.70
Capital costs			610	1.74		~1.55	0.42
Administrative costs			65	0.19		0.28	
Marketing costs			207	0.59			
Total cost			5,132	14.7		12.78	10.0

7.3.4 Sales prices

Sales prices are often the single most important determinant of profitability and value added. As we saw for cultured turbot and sole in Portugal, 2018 prices were respectively 10 and 15 USD/kg. Statistics on prices for linguado is relatively scarce. We have obtained average prices from sales of wild-caught linguado from a market observatory study sampling data from the wholesale market in Sao Paolo (www.ceagesesp.gov.br) shown in Figure 93. These reflect sales prices from firm at the market to customers that can be restaurants, processors, consumers, middlemen etc. The monthly data are averages for three size groups and have for the last three years generally fluctuated between 12 and 14 real per kg. Due to depreciation of the real during this period, prices in USD have been reduced from about 4 to 2.5. As a considerable share of the farming costs are likely to be incurred in local currency, this highlights the need for caution when comparing costs and sales prices across countries with different currency developments.

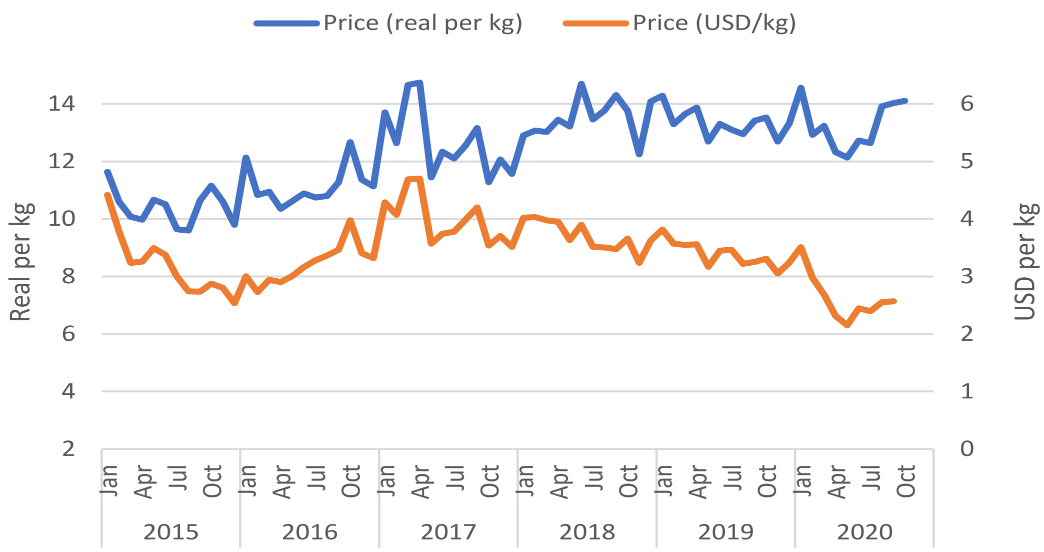


Figure 93 Average linguado prices from the Sao Paolo wholesale market (Source: http://www.ceagesp.gov.br/)

Unfortunately, data by size group is only available for the last two weeks, and quantities are not sampled. Prices from the 21st to 28th October are shown below, as we have recorded prices in this period. Fish are sold in three size categories, large, medium and small. The actual sizes of the categories are not stated. There is a considerable price premium for large fish. It will thus likely be important to grow the fish so that it reaches this category.

Table 19 Average sales prices (USD/kg) by size group for linguado at the Sao Paolo wholesale market (Source: http://www.ceagesp.gov.br/)

	21.10.2020	23.10.2020	26.10.2020	28.10.2020
Grande	4.1	4.1	4.1	3.2
Medio	1.9	1.9	1.9	1.5
Pequeno		1.0	1.0	0.8

Linguado is currently sold to end-consumers primarily as fillets (Sampaio, pers. comm. Thus, fillet yield is an important parameter. The fish has a quite high yield, wild caught fish about 50% of round weight, and aquaculture fish even higher at about 60% (Robaldo et al. 2012).

These prices reflect the willingness to pay and bargaining power of the current value chain that is distributing wild-caught linguado. This is not necessarily representative of prices that can be attained in a value chain from farmed products. Although anecdotal, we have obtained example prices ranging from 38-65 real/kg (about 10 to 16 USD/kg) for whole linguado at wholesalers and retailers in Rio de Janeiro and Sao Paolo. A fish-farm is currently selling cobia for 45 real/kg (about 11 USD/kg) and grouper at 70 real/kg (17.5 USD). These indicate a clear potential for farmers to achieve higher prices than at the CEAGESP market. This is, however, an area that needs further research.

Advantages from aspects such as fillet yield, larger scale, logistics and reliability and others are likely to add value for the end-customers and distributors. Coupled with a likely increase in the bargaining power of the farmer compared to a fisherman, the price to farmer is likely to be higher.

7.3.5 Value chain improvement areas

As production of this species has only occurred on a research scale, there is no current value chain and hence areas for improvement in all aspects of production. The biological process is relatively well understood. Of particular importance for planning of commercial fish farming is good knowledge about characteristics such as growth rates, FCR, farming densities and mortality. For linguado, there is still considerable uncertainty around some of these characteristics. Especially growth and densities under commercial conditions seem important to enhance to enable better decision making for commercial ventures considering this species. With high price premium for large fish, profitability will strongly depend on attaining such size classes. However, due to growth rates being generally reduced, mortality, and increased farming space there is an economic optimal harvest size that needs to be estimated. The research in AquaVitae will contribute toward these areas by investigating growth performance in raceway RAS systems.

Improvements in other concrete production aspects of the value chain would also be beneficial. Minced fish and cobia feed have been used for grow-out and this is clearly not optimal for linguado. A specialized weaning feed has also not been available. To develop feeds that are better suited for linguado at the various stages of development can bring considerable cost savings, as feed is a major cost component. AquaVitae research can have a positive impact on these aspects through the task investigating nutrient composition in juvenile feed.

Another critical issue raised by project researchers is the reliability and efficiency in seedstock production. Key to achieving profitable finfish production, especially in capital intensive land-based production systems, is reliable and frequent stocking of high-quality juveniles. The value potential from improvements in the juvenile production is also highlighted by high juvenile prices and budgeted juvenile unit cost. The AquaVitae contributions from improving weaning feed as well as planned workshops with the commercial-scale sole farming sector in Europe can lead to improvement in this particularly important stage in the value chain.

Brazil has little experience with land-based farming, and a poorly developed supplier sector. Thus, the technology available, both in terms of tank infrastructure and equipment is likely to be suboptimal and at elevated prices. The workshops are also very likely to improve knowledge on infrastructure requirements and farm construction, farm management and several production aspects.

In addition to missing a supporting sector, a developing industry faces scale related challenges. Here feed is particularly important. Stopping current production to make small batches of feed for linguado will be costly for the few established fish-feed companies. Prices will be higher and R&D resources limited. Distribution cost are also elevated when catering for small volumes. Thus, expanding production will bring value chain improvements.

Expanding production will also bring benefits to the distribution and marketing of finished products. Not only will it make logistics easier and unit cost less. This may also open new market channels. For an investigation related to grouper culture, Redemar Alevinos interviewed 40 representatives from the distribution segment in the fish value chain. The general feedback they got was that there is a demand for different species, especially where regular supply, high quality and traceability could be guaranteed. Sustainability was also important for some distributors. There was also a supply shortage as wild harvests had declined. These aspects are also likely to apply for linguado culture. Having a regular and predictable supply will strengthen the competitive position of the producer and allow for them to capture a higher share of the final selling price. This can stem from bargaining with current wholesalers or middlemen or being able to supply other customers, such as supermarkets directly, avoiding middlemen. The supplier of groupers receives about 40% of the selling price. This is far less than for the turbot value chain in Europe. Hence, this seems a clear area for improvement in the value chain.

8 Conclusion

The overarching aim of AquaVitae is to improve selected aquaculture production processes - in particular, processes involving low-trophic species. These species have the highest potential for contributing to sustainable increase in food production from the ocean. Better understanding of the economic aspects of production may be important both for making well-informed investments in production and identifying areas of improvement in current production. For production where there are considerable positive socioeconomic externalities, this may also contribute to better public management. This first analytical contribution from this WP describes the value chains of preselected case studies. In this we improve the understanding of the production process, distribution, markets for both finished products and inputs and input-output conversion factors. This provides a basis for the coming studies on profitability and socioeconomics.

The “value chains” of the respective case studies differ considerably. Some are well developed with many producers, suppliers and buyers, while others have not reached commercial production. The end-product from the chains also varies. Some chains’ products are ready for consumption, while others are used as inputs in other value chains. These differences have necessitated a case-by-case approach, where the actual issues being considered vary.

For all the case studies, the production processes are described in detail by stages in the value chain. Resource use and important conversion factors are described. There is high diversity among the case studies with regards to production stages and duration. Some production processes take 4-5 years from start to the final finished product, while others take far less time as it the case with sea urchin roe enhancement, which can take 2 – 3 months. How value develops along the value chain is described where reasonable data have been available. Where there is an actual value chain and industry, brief description of industrial organization is given. Here again there is diversity, both within case studies and between them. The offshore macroalgae controls from broodstock to primary processing. EU abalone is even more highly vertically integrated, controlling also feed supply and sales to end-users. Most firms within the South African abalone industry have a high degree of vertical integration, while others primarily control one or few stages of the chain. Blue mussel culture also has a diverse degree of vertical and horizontal integration. In most of the industries there seems to be little horizontal integration, with one firm structure primarily operating one farm, although with exceptions.

Due to the differences across the case studies, it is challenging to make comparisons or general conclusions. Profitability across the case studies varies. Some value chains, for instance abalone and tambaqui, have been giving acceptable returns, although the co-culture trial with abalone is currently problematic. Several of the others are currently making losses and rely on technological development, improvements to breeding and farming practices and importantly scaling up production. Linguado aquaculture is still trying to attract investors to move from research to more commercial-scale production. Compared to farming of flatfish in Portugal and Spain, this may especially suffer from a lack of suppliers of many important inputs, as there is limited related aquaculture activity in Brasil. Aspects relating to economic viability of these productions will be further analysed in the upcoming deliverable D7.3 on profitability in new and emerging LTS aquaculture.

Since several of the LTS aquaculture productions are relatively novel, there are also some regulatory and governance challenges related to the value chains. One good example is macroalgae cultivation.

To increase production, it is necessary to identify and obtain licenses in suitable sites, alongside other pre-existing uses of the marine space. Related to this, is the need for an acknowledgement of the beneficial ecosystem services the cultivation provides through nutrient uptake and carbon sequestration. AquaVitae will develop methods for ecosystem valuation and specifically valuate the ecosystem services provided by the productions in selected case studies. In doing so, AquaVitae aims to facilitate the increase use of ecosystem valuation within the policy context. In forthcoming deliverables, AquaVitae will also analyse how existing policy frameworks affect low-trophic level aquaculture and will provide recommendations to promote the development of macro-algae cultivation and other LTS aquaculture.

The value chain improvements that have been in focus here are primarily related to process and yield improvements and scaling up production. This reflects the early phases of industry development for many of the case studies. Over the coming years, as the production improves and grows, it is likely that the focus will move more towards value chain aspects such as marketing, distribution channels, sales channels and industrial organization issues such as vertical and horizontal integration, governance of the value chain and distribution. These aspects will also be considered further in the development of business plans for the LTS aquaculture production. The business plans will be specifically tailored to each commercial partner in the case studies, highlighting options and actions towards further commercialisation based on amongst other things improvements across the value chain, supported by the AquaVitae project.

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