GROW-OUT PROCESSES FOR *HALIOTIS SP.* PRODUCTION

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INDEX

Tables

Figures:

Abstract

Aquaculture activities provides reliable marine food sources required by human population and a potential solution to the depletion of natural oceanic resources. Data indicate a steady increase of aquaculture production throughout the years, in comparison to the one originating from fisheries. World aquaculture production differs significantly between different regions. China being the world main aquaculture producer, while Europe, and other locations present significantly lower aquaculture production mainly due to environmental policies and sustainability concerns. Europe specifically, has developed advanced technologies to produce high quality marine products. Within Europe, Spain is located the sixth position in terms of fish production while it is the sixth biggest producer worldwide in terms of mussel production. A situation which confers to this country high level of aquaculture production diversification opportunities

One species of interest that could confer another interest for aquaculture diversification is the European abalone *Haliotis tuberculata sp.* Abalone are mollusc species of high commercial value that also present interest due to the low environmental impact of their production.

In abalone aquaculture, different techniques are currently employed in the context of grow-out processes being divided between land-based grow-out processes and sea-based grow-out processes. The first ones being more expensive but more reliables for research studies while sea-based grow-out systems are often used for commercial production due to their economic and less energetic cost, although are more exposed to the environment.

In both of these production systems abalone aquaculture specimens are fed by macroalgaes or compound feed, both strategies having advantages and disadvantages. Macroalgaes are abalone natural feed in the wild, they are an economic and a healthy strategy to feed abalones, but they don't always cover all the nutritional requirements needed by abalone, while compound feeds can provide better and more tailored rnutritional values than algaes. However, compound feeds present to the eyes of the public opinion less healthy option in comparison with seaweeds.

Innovate strategies such as IMTA systems have demonstrated their potential to increase macroalgaes nutritional values, enabling higher proteins content (the most value abalone component)in the algae, and consequently enabling quicker and better abalone develop while recirculate closed systems are presenting interesting opportunities for the future grow-out facilities. Both systems still require further development in order to become potential grow-out systems for aquaculture of interest for abalone aquaculture.

Keywords: Abalone, Haliotis sp., growth, feed, grow-out production, IMTA, aquaculture.

1. Introduction

1.1 World Aquaculture: its history and actual development

As defined by the United Nations Food and Agriculture Organization (FAO), aquaculture is the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. The world community views aquaculture as a recent practice and potential solution to the resources depletion of the seas and oceans, even though it is a practice that has been performed since long ago. In fact, this practice has been dated back thousands of years but with unknown origins. It most likely grew out of necessity when foraging and hunting were not sufficient to provide a stable source of food to local communities. (*White et al., 2004*).The lack of knowledge of the marine life systems have made aquaculture development slower than terrestrial farming during human history. However, investments in aquaculture have grown steadily in the last decades as it is considered as a future system to provide marine resources instead of fishing.Nowadays, aquaculture is among the most widely traded commodities and one of the sectors with the fastest growth in the last years (*Freitas et al., 2020*) mainly attributed to a high degree of technological innovation going from relatively extensive to more intensive production systems. An evidence of this, was in 2014 when the 50% of the fish for human consumption (excluding non-food uses such as fishmeal or fish oil) was from aquaculture production according to (*FAO, 2020*). It is expected that world aquaculture production will be higher than the one of capture fisheries in the years to come.

Table 1 it shows the quantitative data of the last years of production of fisheries, aquaculture and their utilization. As we can see in the fig.1, global fisheries production increased until 1995, then started to remain around the same levels of production, while global aquaculture production presented constant increase since the introduction of new technologies and is nowadays still raising.

The graph shows quantitative data of aquaculture production being above the quantitative fisheries data in the total production of marine resources worldwide.

Table 1. Quantitative world fisheries and aquaculture data between 2011-2016. Source: *FEAP, European Aquaculture Production Report 2008-2016.*

Category	2011	2012	2013	2014	2015	2016
Production						
Capture						
Inland	10.7	11.2	11.2	11.3	11.4	11.6
Marine	81.5	78.4	79.4	79.9	81.2	79.3
Total capture	**92.2**	**89.5**	**90.6**	**91.2**	**92.7**	**90.9**
Aquaculture						
Inland	38.6	42.0	44.8	46.9	48.6	51.4
Marine	23.2	24.4	25.4	26.8	27.5	28.7
Total aquaculture	**61.8**	**66.4**	**70.2**	**73.7**	**76.1**	**80.0**
Total world fisheries and aquaculture	**154.0**	**156.0**	**160.7**	**164.9**	**168.7**	**170.9**
Utilization[b]						
Human consumption	130.0	136.4	140.1	144.8	148.4	151.2
Non-food uses	24.0	19.6	20.6	20.0	20.3	19.7
Population (*billions*)[c]	7.0	7.1	7.2	7.3	7.3	7.4
Per capita apparent consumption (*kg*)	18.5	19.2	19.5	19.9	20.2	20.3

[a] Excludes aquatic mammals, crocodiles, alligators and caimans, seaweeds and other aquatic plants.

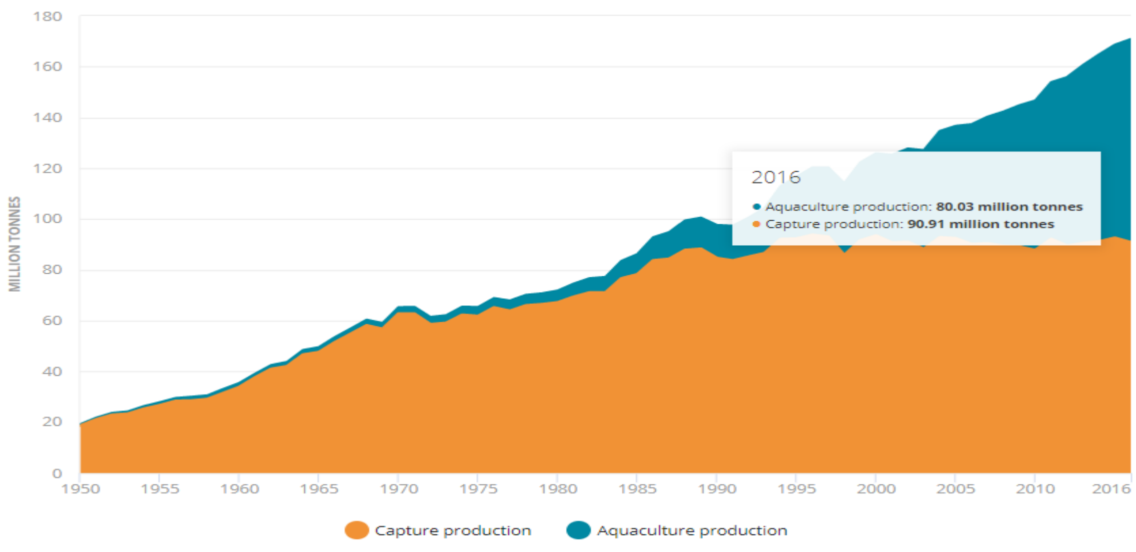

Fig. 1 World capture fishes (orange) and world aquaculture production (blue). Source: *FEAP, European Aquaculture Production Report 2008-2016*

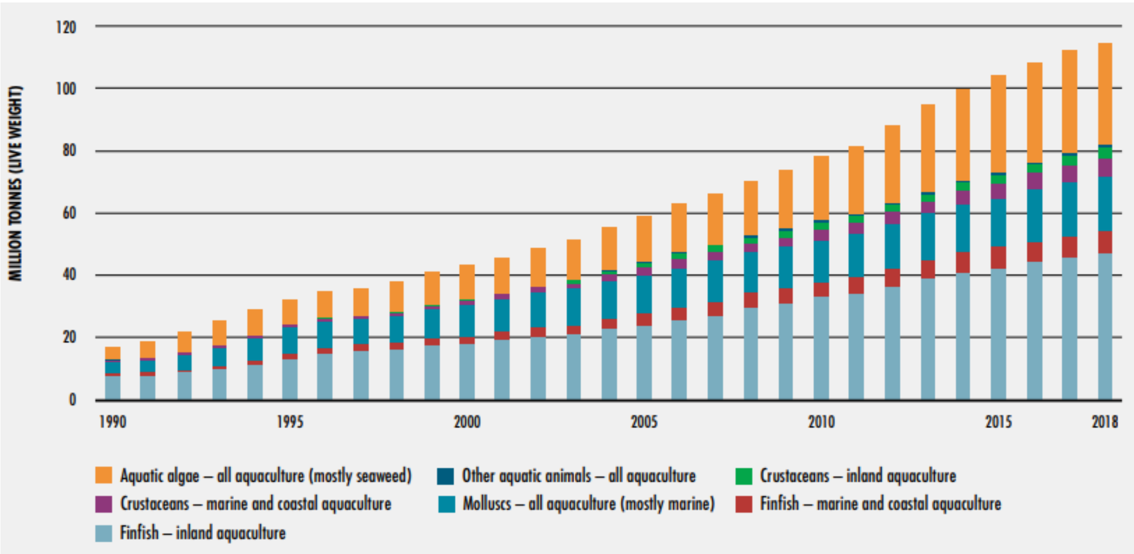

Fig. 2 World aquaculture production of aquatic animals and algae 1990-2018. Source: *FAO*

World aquaculture production of farmed aquatic animals grew on average at 5.3 percent per year in the period 2001–2018 (Fig 2.), although the growth was only 4 percent in 2017 and 3.2 percent in 2018. The recent low growth rate was caused by the slowdown in China, the largest producer, where aquaculture production growth of only 2.2 percent in 2017 and 1.6 percent in 2018 were witnessed, while the combined production from the rest of the world still presented moderate growth of 6.7 percent and 5.5 percent, respectively, in the same two years (*FAO, 2020*).

1.2 European Aquaculture

The increase in global world aquaculture production is not evenly distributed. Asian countries produced 92% of the total volume in aquaculture resources in 2014 and 77% in real value. While European Union's aquaculture sector represented only around 1.7% of the world production and 3.1% in value. Europe possesses around 55.000 km of coastline and good oceanography, physical and environmental traits for optimal conditions to provide good aquaculture development. Also, European Union has other advantages. They are on the top of technology and research. They have human resources well-formed and the proper conditions to produce most of the main species demanded for consumers. The strict regulatory standards of the European Union designed to ensure the production of secure and healthy products. Despite these positive traits, European aquaculture hasn't been able to balance the sharp reduction of the European fisheries production since 1999.One reason behind the lack of growth in EU is mainly linked the strict environmental regulations and the widespread use of control instruments to manage negative environmental externalities that have contributed to slow down it development (*Guillen et al., 2019*). Consequently, UE wants to compensate the decreasing on fisheries investing in aquaculture, focusing on finfish and mollusc which are the main sold products in Europe(*APROMAR, 2019*) (APROMAR, 2018). Moreover, the Scientific Advice Mechanism (SAM) recommends becoming aquaculture an explicit priority of the UE.

Table. 2 Fish Farming Production in Europe. Source: *FEAP, European Aquaculture Production. Report 2008-2016*

PRODUCTION (tons)	YEAR								
COUNTRY	2008	2009	2010	2011	2012	2013	2014	2015	2016
NORWAY	904.623	967.235	1.018.201	1.093.300	1.325.550	1.270.150	1.370.090	1.382.750	1.307.182
TURKEY	149.589	155.802	164.197	187.136	210.824	231.672	232.152	234.000	247.754
UTD. KINGDOM	144.015	154.933	158.252	161.033	175.292	174.897	194.092	187.292	178.887
GREECE	148.509	138.513	122.590	111.217	116.073	125.580	115.200	112.159	108.959
FAROE ISLANDS	45.506	57.900	47.190	62.400	76.800	76.480	86.449	66.090	77.000
SPAIN	65.835	69.866	63.200	61.992	59.920	56.804	59.356	64.186	64.754
ITALY	64.054	65.120	64.365	64.781	58.100	57.590	57.990	55.480	53.790
FRANCE	47.110	45.954	44.342	45.980	44.540	40.205	41.641	44.521	45.471
DENMARK	39.886	38.322	38.009	38.653	33.552	39.281	38.934	38.829	35.272
POLAND	34.370	35.048	29.250	28.745	32.524	33.535	37.070	38.613	37.811
CZECH REPUBLIC	19.814	19.516	19.994	20.448	19.462	18.201	19.092	19.113	19.861
GERMANY	34.967	33.359	33.456	16.467	15.155	16.150	16.449	15.216	15.216
HUNGARY	15.892	14.016	13.562	15.343	14.477	14.251	14.378	16.124	15.470
FINLAND	12.000	12.700	10.400	9.220	9.000	9.954	12.448	12.550	13.187
IRELAND	12.020	14.500	13.934	13.434	13.434	12.450	11.400	12.000	17.300
SWEDEN	6.703	7.023	9.171	11.963	12.441	11.657	11.144	11.144	11.108
CROATIA	7.642	9.952	9.829	10.687	8.822	8.512	10.201	12.093	13.881
ICELAND	5.014	5.116	5.018	5.260	7.368	6.886	8.289	8.249	16.700
NETHERLANDS	8.440	7.110	6.570	6.150	5.620	6.305	6.305	6.355	6.355
PORTUGAL	4.024	4.097	4.674	5.130	7.000	3.635	5.760	5.919	5.023
CYPRUS	2.452	3.343	4.118	4.665	4.313	6.171	4.810	5.409	6.590
Total	**1.772.465**	**1.859.425**	**1.880.322**	**1.974.004**	**2.250.267**	**2.220.366**	**2.353.250**	**2.348.092**	**2.297.571**

According to the Federation of European Aquaculture Producers report (FEAP), the total European production of fish was more than two million tonnes in 2016. Within the European territory, Norway is the main producer providing 58% of the total supply, with 1.3 million tonnes of mainly salmon and trout. Spain was in 6th position producing close to 65000 tonnes of fish, Sea bass being the main fish species produced. (Table 2). On the contrary, Spain apperars as the first European producer when mollusk production is being considered and the sixth major producer worldwide. Effectively, the production of mollusk in Spain was of 273.600 tonnes in 2018, principally lead by mussels, which were produced mainly in NW Spain (Galicia). The mussel produced is *Mytilus galloprovincialis* with a production between 210.000 to 225.000 tonnes in 2018. Several species of clam are also produced in this Spanish region such as *Ruditapes phillipinarum, R. decussatus and Venerupis pullastra*.

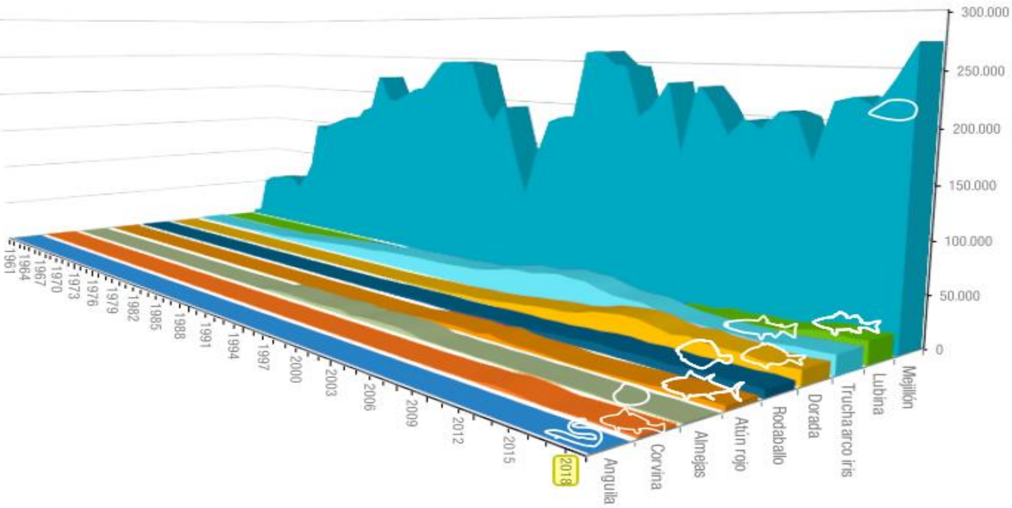

Fig. 3 Evolution of the aquaculture crop in Spain (tonnes by species) in the period of 1980-2018. Source: *APROMAR*

The data obtained at the national level in terms of mollusc production are significantly higher compared with other farmed species like sea bass with 22.460 tonnes (the second most produced species in Spain) and the gilt-head sea bream with 14.930 tonnes. Adding the rest of the species, the total aquaculture produced in Spain in 2018 were 348.395 tonnes (Fig. 3)(*Apromar, 2019; Robert et al., 2013*).

1.3 World and European Mollusc aquaculture

In 2018, world aquaculture production reached 82.1 million tonnes. Within this value, molluscs (mainly bivalves) represented 17.7 million tonnes. Shelled molluscs, with an average of 17,3 million tonnes represented 56,3 % of the production of total marine and coastal aquaculture which is a major contribution to the aquaculture species being produced worldwide. Finfish and crustateans represented 42,5 % and the rest 1.2 % consisted of other aquatic animals (not counting on inland finfish produced) (Fig. 2) (*FAO, 2020*)

China is the biggest producer of molluscs with a significant margin (14,2 million tonnes) in comparison with the rest of the world (2.5 million tonnes in total) in 2020. Spain is classified as the 6th country worldwide in terms of most molluscs production. In Europe it is the first producing country followed by France with the main production of the Japanese oyster (*Magallana gigas)* and then Italy with Japanese littleneck clam *(Venerupis philippinarum)*.

Table. 3 Major mollusc species produced in world aquaculture. Source: *FAO, 2020*

	2010	2012	2014	2016	2018	2018 share
	(thousand tonnes)					(percentage)
Molluscs						
Cupped oysters nei, *Crassostrea* spp.	3 570.7	3 807.4	4 181.6	4 690.8	5 171.1	29.5
Japanese carpet shell, *Ruditapes philippinarum*	3 500.2	3 618.7	3 838.6	4 175.8	4 139.2	23.6
Scallops nei, Pectinidae	1 366.6	1 360.9	1 576.5	1 849.9	1 918.0	11.0
Sea mussels nei, Mytilidae	871.4	937.1	992.9	1 085.4	1 205.1	6.9
Marine molluscs nei, Mollusca	556.3	993.9	1 035.4	1 118.1	1 056.4	6.0
Constricted tagelus, *Sinonovacula constricta*	693.3	690.4	752.0	799.3	852.9	4.9
Pacific cupped oyster, *Crassostrea gigas*	640.7	609.1	623.6	573.8	643.5	3.7
Blood cockle, *Anadara granosa*	456.7	378.2	434.2	430.4	433.4	2.5
Chilean mussel, *Mytilus chilensis*	221.5	244.1	238.1	300.6	365.6	2.1
Other molluscs	1 850.8	1 706.7	2 035.0	1 816.0	1 725.8	9.9
Molluscs total	**13 728.3**	**14 346.7**	**15 707.8**	**16 840.1**	**17 510.9**	**100**

Mussels, clams, scallops and oysters are the main traded bivalve mollusk species worlwide (Table. 3). The bivalve mollusc production industry has grown since 1950 with a production growing from around 1 million tonnes, to 16 million tonnes in 2015.(*FAO, 2018*).

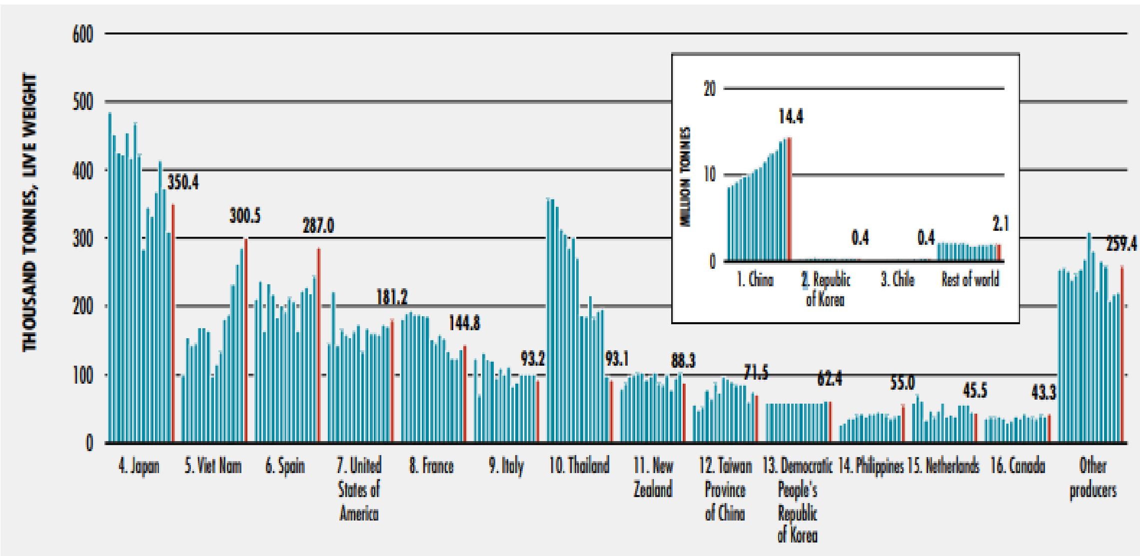

Fig. 4 World Marine and Coastal Aquaculture of Mollusc by major producers. Source: (*FAO, 2020*)

In terms of mollusk production, Europe presents the highest volumes within countries like Spain, France and Italy (Fig. 5). As the wild catches in Europe decreased, aquaculture has to grow up and replace them in terms of production to avoid the main mollusc species to become endangered species.

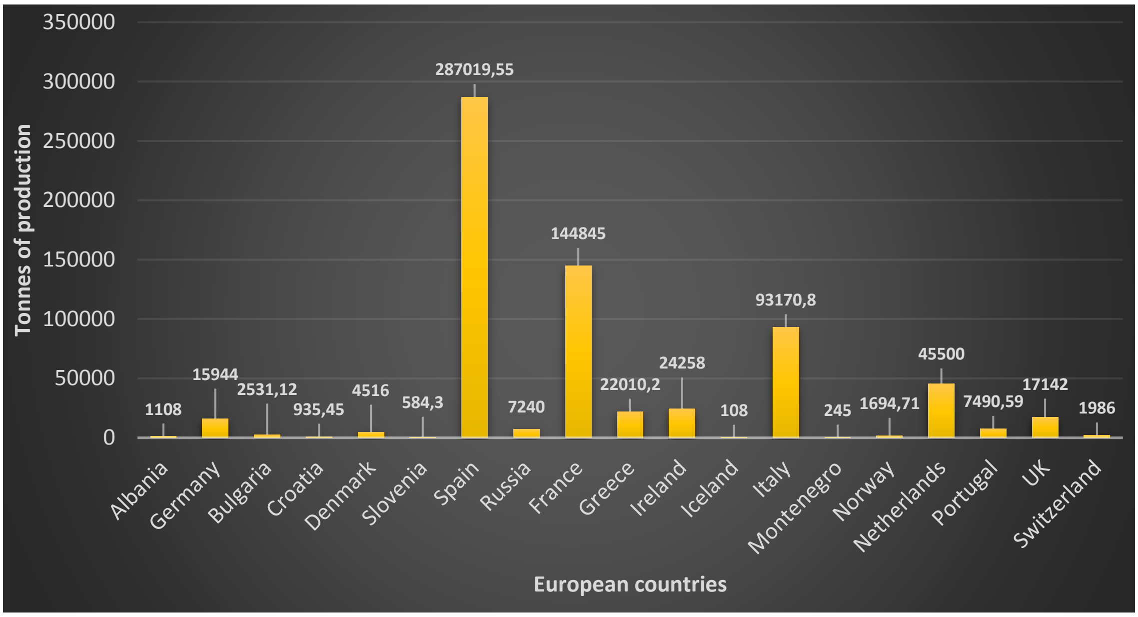

Fig. 5 European mollusc production. Source: *FishstatJ*

1.4 Integrated production systems

As aquaculture production is a sector that is actually evolving due to the development of technologies it also has to adapt to environmental requirements. European consumers are concerned about issues such as food safety, quality, health, animal welfare and the environment (*Aarset et al., 2004*). Moving from monoculture to integrated multi-trophic aquaculture (IMTA), has been proposed as a possible alternative to answer some of the public concerns related to the previously described issues. EU has supported initiatives for the development of IMTA aquaculture production in countries such as Denmark, Norway and Spain (*Kleitou et al., 2018*). IMTA aquaculture production is a production system which aims to create a circular economy that minimises energy flows, losses and environmental deterioration (*Fang et al., 2009*). The principles of, IMTA are based on the fact that cultivates fed species, such as carnivorous finfish, are being produced together with extractive species such as bivalves and/or algae that feed on particulate organic matter (fish faeces and uneaten pellets) and dissolved waste (mainly in the form of ammonia) from the fed species (Fig.6).

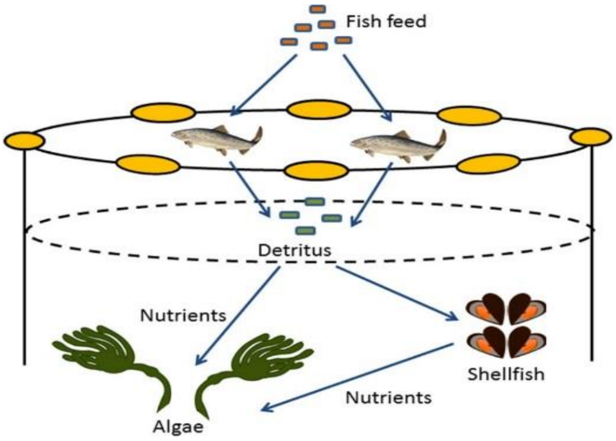

Fig. 6 Diagram represent of an IMTA system (*Alexander et al., 2016*).

2. Characteristics, production and importance of Haliotis aquaculture production

2.1 Haliotis sp.

The single genus Haliotis integrates 56 species that are within the phylum Mollusca and within the family of Haliotidae. All are also known as abalone (*Courtois, 2011*). Abalones are marine, nocturnal herbivorous gastropods that have an extended single shelled with a foot, two cephalic tentacles and two eyes below them. They have sensory tentacles around the feet that helps them to explore space surrounding them (Fig. 7). Males and females can be identified by the colour of their gonads, the male ones being of a white colour because of their sperm content, while the female present colors ranging from greenish tones to grey-violet ones (Fig. 8)

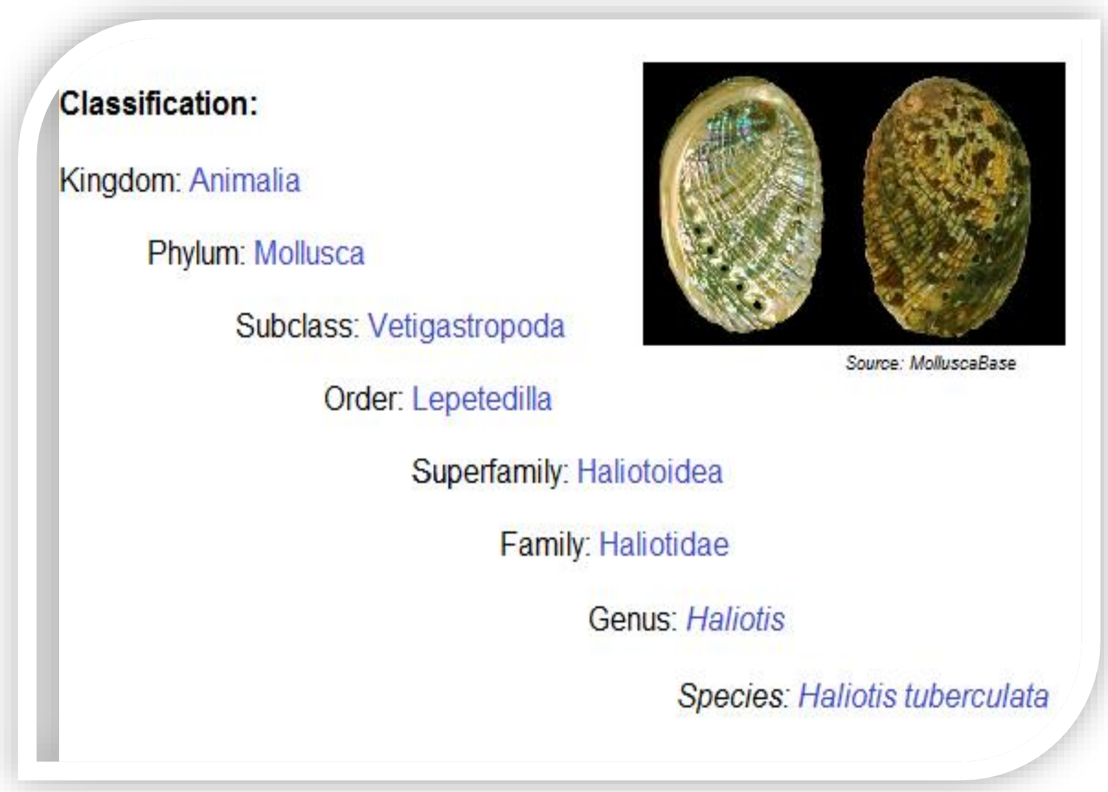

Fig. 7 Classification of *Haliotis tuberculata*. Source*: MolluscaBase*

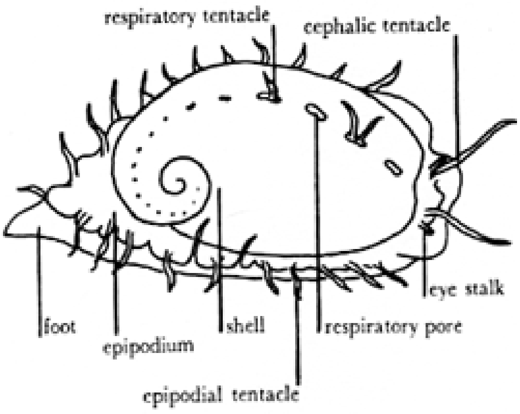

Fig. 8 Morphology of the Abalone. Source: http://www.asnailsodyssey.com/

Fig. 9 *Haliotis diversicolor* gonads. Source*:* (*Courtois , 2011)*

Their life history can be described into five stages: embryo, larvae, post-larvae, juvenile and adult (Fig.10). Each stage requires specific production methods adapted at each of the life stages.

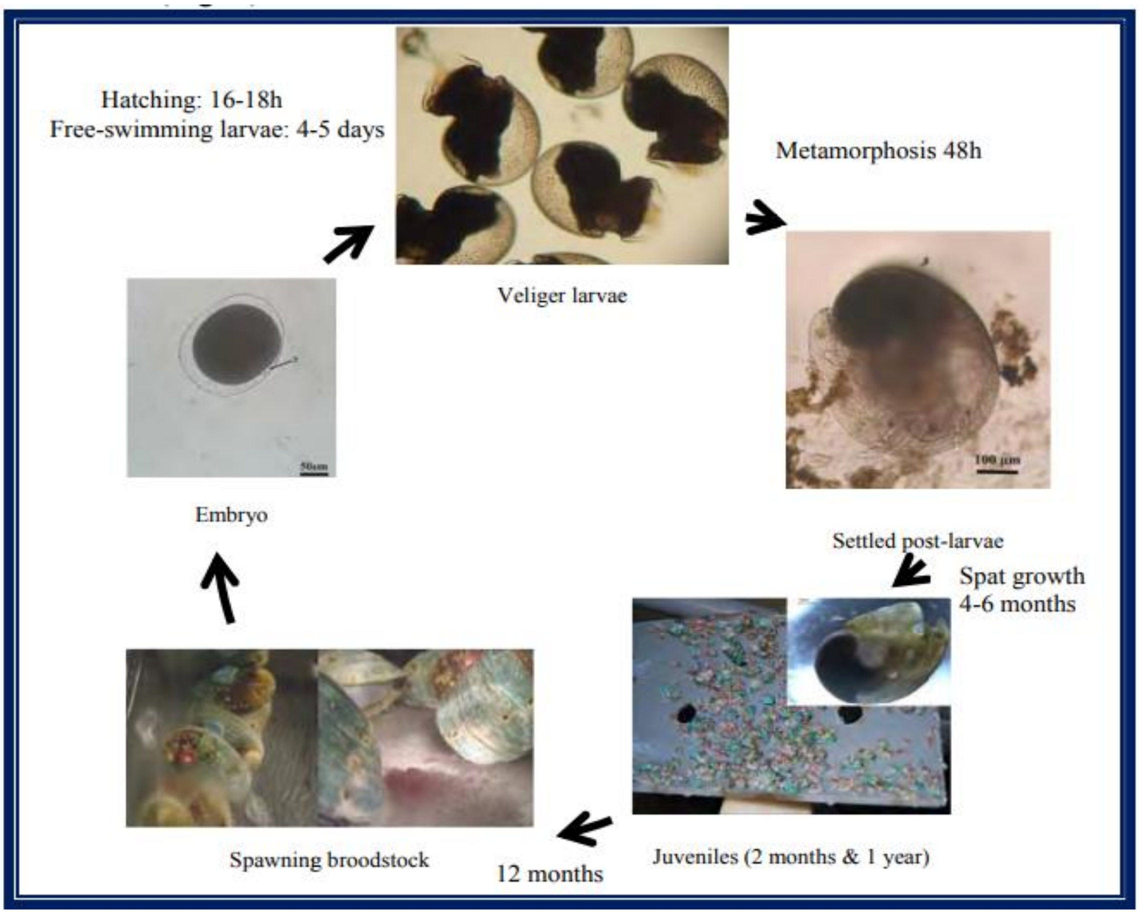

Fig. 10 Life history of Abalone. Source*:* (*Courtoise., 2011*)

2.2 World and European abalone production

Abalone species are highly appreciated in the Asian market as high-quality sea food for their delicate taste and considering large enough size to be commercialized (*Courtois, 2011; Viera et al., 2011*)

Their shells are also appreciated worldwide for jewelry due to the nacre composite present in their shells. *Haliotis sp.* production developed exponentially over the last decades and is becoming important for aquaculture diversification due to their high market price and the over-exploitation of wild stocks. It is estimated that 70% of the wild population will decline and will become endangered species in the years to come. Consequently the aquaculture sector appears as a solution capable to supply the growing market demand (*Courtois, 201,1*).

Worldwide, total abalone production (fisheries and aquaculture) showed low variations between 1950 to 2002 and then, since 2002 a sharp increase in production was observed mainly due to an exponential development of the aquaculture being china the biggest producer (Fig.11 and 12). On the contrary, fisheries suffered a decreasing due to the exploitation of the wild stocks. The aquaculture markets are mainly from Chine, Japan, Hon Kong, South East Asia, USA, Mexico, Korea and Europe (*Oakes and Ponte, 1996*).

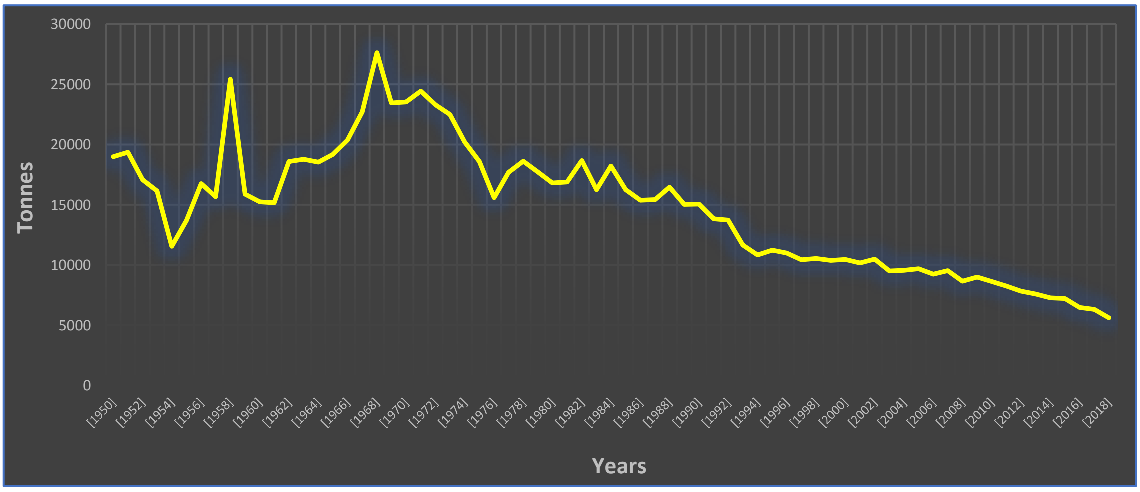

Fig. 11 world Abalone fisheries between 1950 to 2018. Source FishstatJ

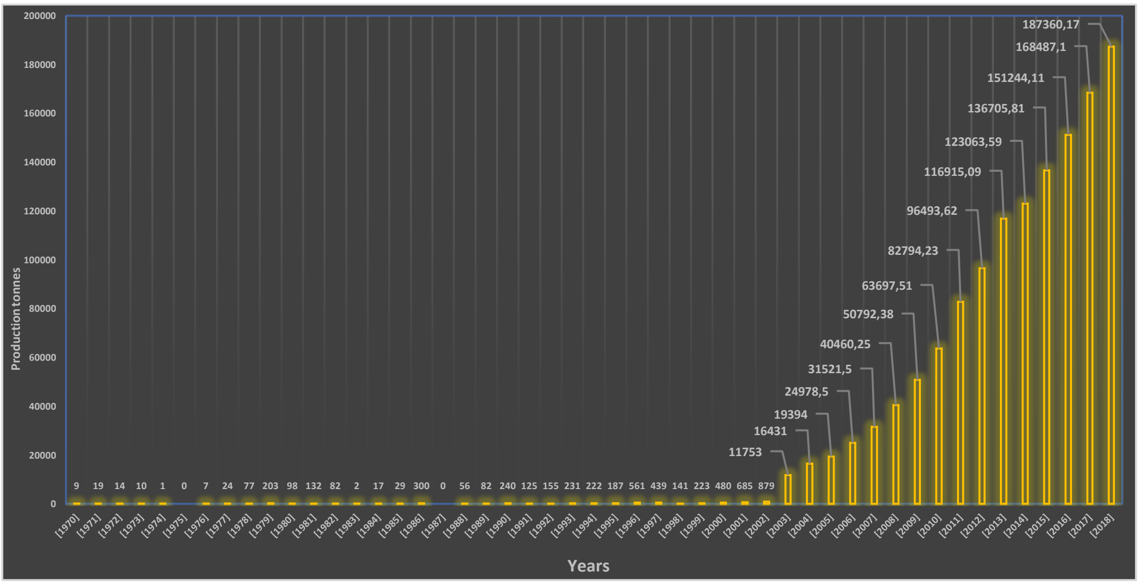

Fig. 12 Worldwide total abalone production between 1970-2018. Source: FishstatJ

Abalone farming in Europe is a very small in comparison with Asia, but it is a growing industry. Farms are located in the UK, the Channel Islands, Ireland, France and Spain (*Cook., 2010*).

In Ireland the farms are producing mostly *H. discus hannai*, with a production below 3 mt, whilst in the Channel Islands two farming companies, are reported to produce less than one metric tonne of *Haliotis tuberculata*. French farms are located in Brittany and Vendee, and these have the advantage of being located in regions where small, natural populations of abalone occur and have been fished for some years. Farm production from the French farms is expected to increase over the next few years. While in Spain the abalone farms developing are planning to increase their production up to 30 mt per year in the coming years(*Cook, 2010*).

3. Techniques and grow-out systems for *Haliotis* sp. production

3.1 Technical grow-out characteristics of *Haliotis* sp.

Abalone species need appropriate conditions for every part of their life cycle. When they reach the post-larvae stage, they need to encounter a settlement substrate. In aquaculture production these are facilitated by preparing tanks with plastic plates, separated from each other, in baskets, and colonized with algal substrates in order to provide the highest possible surface for the settlement (Fig 13).Once settled the abalone post-larvae, are weekly fed with different species of diatoms during a period ranging between 4 to 6 months.

Fig 13 Post-larvae tanks at the IU-ECOAQUA facilities in the ULPGC Marine Parke, Las Palmas de Gran Canaria,

After the inland nursery culture, when they reach a certain length depending on the species of abalone, juvenile phase can be continued in inland grow-out systems or sea-based grow-out systems.

3.1.1 Grow-out at sea

Grow-out at sea can be performed using wider variety of systems in comparison to land-based grow-out systems (*Wu et al., 2016*). Each abalone farming region have their own kinds of sea-based grpw-out techniques, although they present various similarities. In the traditional method, abalones are transferred to large, punctured, black plastic plates placed inside netting bag structures and are then suspended in the marine environment (*Nie et al., 1996*).

Barrel culture is another way to store abalone offshore. These barrels are attached to long lines with flotation buoys to ensure their floatability around 1m below the surface. Such structures can be observed in some locations of Mexico like Baja California and Saint Martin island (*Aviles et al., 1996; McCormick et al., 1989*), Northern Ireland (*La Touche and Moylan, 1986*), Wellington (New Zealand) (*Hollings, 1988*), Northern China (*Nie, 1992*), different locations around

California (USA) (*Ebert, 1989*) and Parsons Bay (Tasmania) (*Cropp,, 1989*). The structure is of low cost, high strength and ease construction.

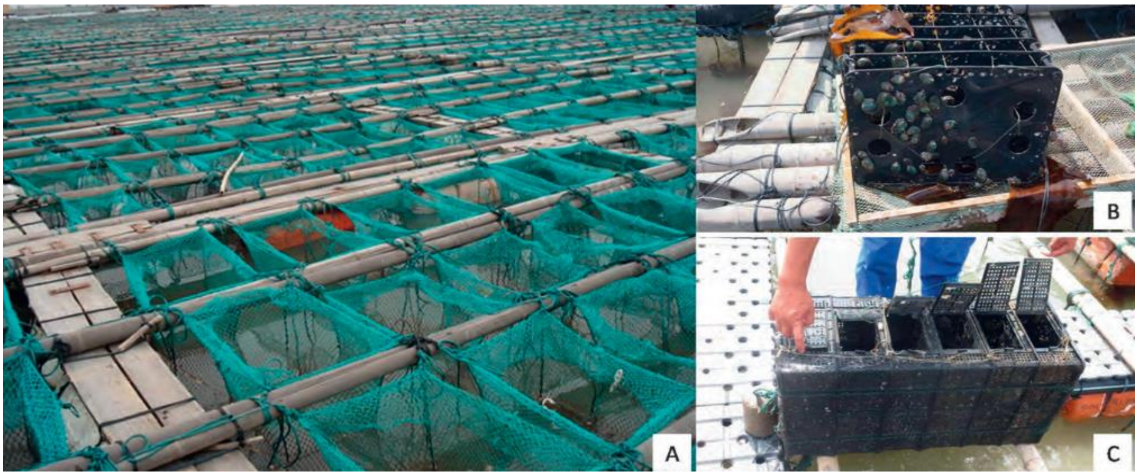

Fig. 14 Traditional and innovative sea-based culture systems in southern China. (A) Whole frames of the innovative culture systems, (B) a typically used shelf-like device for abalone sheltering, and (C) a six-tiered basket traditionally used for abalone farming. See more in Wu and Zhang (2013; 2016)

Modern techniques, used for example in northern regions of china (Fig. 13, A) (*Nie et al., 1996*) introduce abalones from the settlement plates to the bottom of the nursery tank, which is covered by curved blocks (plastic or clay) as shelters (Fig. 14). These curved blocks are then, introduced in grow-out structures. Similar systems like the ones from the Philippines (*Capinpin et al., 1999*), consist in net cages constructed using pipes fitted together and covered with netting material that are suspended about 1-2m below the water surface from floating rafts.

3.1.2 Inland grow-out

Once the specimens have reached juvenile stage (1,5 cm) and they are transferred in grow out tanks, separated by groups depending on their length and sometimes gender. The tank for juveniles, are composed of punctured cages (or maybe square nets) including plastic plates to facilitate shelter and attachment, placed within a tank with circulating sea water. Air flux is also provided. Thanks to the structure, the organic wastes of the juveniles passes through the cage opening and land at the bottom of the grow out tank (Fig. 15). In this part of their life stage, abalone are daily or weekly fed different species of macroalgae or compound feed.

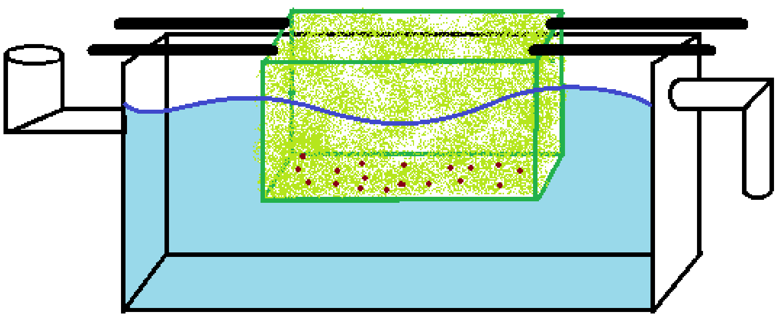

Fig. 15 Inland grow-out tank for juvenile Abalone.

Land-based systems provide the possibility to control the main environmental factors such as air flow, temperature, pH, water flow and irradiation in order to set the suitable conditions for the species development, besides minimizing their variation as much as possible to get the best value out of the grow-out (*Stone et al., 2014*). It has been reported that inland grow-out systems produces abalone with higher protein content than sea-based grow-out systems *(Latuihamallo et al., 2015*). However, it needs a regular cleaning to avoid diseases, dirt accumulation, contamination or population death.

Examples of inland grow-out systems come from South Africa (*Naidoo et al., 2007*), China (*Xiaolong et al., 2018*) and Canary Islands (Spain) (*Courtois, 2011*).

3.1.3 Flow through and recirculated systems

The aquaculture industry is developing fast as well as problems such as water pollution, the occurrence of natural disasters and spatial limitations (*Park et al., 2008; Wu et al., 2016*) thus, it requires changing aquaculture production methods for the intensive and ecological aquaculture practices (*Xiaolong et al., 2018*). Recirculated systems offer the way for high-density production of healthy seedlings and reduces the energy cost.

The concept of recirculated systems is focused on the reutilization of the wastewater generated from animal aquatic tanks after a process of water depuration. It offers potential to culture specimens in land-based grow out systems where compound feed is the main diet *(Fitzgerald., 2007)*. In comparison with conventional running water aquaculture systems, recirculate systems reuse the utilization of water resources, reduces water pollution, reduces the possibility of disease, precise automated control, which enhance production efficiency and reduce work intensity.

In some countries, the use of these systems to culture abalones are in early stage. But some studies have already reported success about abalone development in recirculated aquaculture systems (*Xiaolong et al., 2018*).

4. Nutrition during grow-out

Despite the ability of abalone to utilize a wide variety of energy sources, being mollusc, the metabolic rate of abalone is low and consequently energy requirements are low (*Viera et al., 2009*).

Rate of weight gain is very important in the context of abalone and aquaculture in general, but specifically in this species as they are relatively slow growing. Optimal dietary levels need to be defined to provide suitable growth rate while reducing the cost of ingredients used in the diet.

Among the different nutrients, abalone need specific concentrations of proteins for adequate soft tissue growth being a mollusk. Around 70% of their flesh is composed of proteins, 3-4% by lipids and 5-6% of crude fiber. Abalone also requires high level of carbohydrates and low level lipids for an adequate development (*Fleming et al., 1996*). Abalone species are composed of similar variety of saturated fatty acids and unsaturated fatty acids, being the main saturated fatty acids the palmitenoic acid, the steraenoic acid while the main unsaturated fatty acids are the oleat acid, linolenic acid, arachidonoic acid, and eicosapentanoic acid. Some studies indicate that, both saturated and unsaturated fatty acids of animals grown in sea based systems present higher percentages compared to the ones of animals grown inland systems (*Latuihamallo et al., 2015*).

4.1 Grow-out using compound feed

The use of fishmeal in artificial Abalone diets limit their possibility of utilization in ecologically sustainable aquaculture and affects abalone quality and acceptance by the public (*Freitas et al., 2020; Viera et al., 2015*). However, due to their high protein demand, some studies have shown that abalone fed formulated diets based on animal protein sources as well as a combination of plant and animal protein ones, provide better growth rates than those fed diets without animal protein within de diet (*Boarder et al., 2001; Britz et al., 1997;Viana et al., 1996*) because seaweed proteins are less readily absorbed than animal based protein (*Dlaza et al., 2008; Viera et al., 2015*). These proteins come from marine animals, mainly fish and shrimp and have become an essential, but expensive component of compound diets (*Bautista-Teruel et al., 1999*). The common protein concentration for diets differs from 20% to 30%, but a higher portion is required in order to achieve the maximum growth rate(*Brett., 1979*).

Diets with 3-6% of lipid concentrations, are recommended for a good growth rate of abalone as they seem to present low efficiency in assimilating lipids from their diets (*Bautista-Teruel et al., 1999; Fleming et al., 1996; Johnston et al., 2005*). Indeed, high levels of dietary lipid affect abalone growth negatively (*Thongrod et al., 2003*). Lipids are necessary in this species for an appropriate gonad maturation and growth, although, they are not a primary source of energy. (*Nelson et al., 2002; Viera et al., 2015*). Sources such as wheat flour, rice bran, are complemented in the diets to provide carbohydrates in compound feed. Depending on the diet, carbohydrates may differ regarding its quantity, from 30% to 50% (*Bautista-Teruel et al., 1999*). Carbohydrates enhance the growth of these molluscs (*Thongrod et al., 2003*) which has various enzymes that hydrolyzes complex carbohydrates and posses a good capacity to synthesize non-essential lipids from them (*Fleming et al., 1996*).

Several studies have reported that Abalone species fed with compound feed get better results than those fed natural food in terms of weight gain, shell length and specific growth rate, with a success of a shorter grow-out period to reach the commercial size. Hence, it is commercially present some advantages in comparison to seaweed-based diets (*Nie et al., 1986; Viana et al., 1993; 1996*).

4.2 Grow-out based on macroalgae

A diet based on seaweeds for abalone is more accepted by the consumers that identify it as healthy and natural being the natural food that the specimens depend on in the wild.

As Westen-Europe have abundance of macro-algae, European farms take advantage of this biomass to feed abalone with local different species of fresh seaweeds, varying according to the geographical location(*Fitzgerald A., 2007; Viera et al., 2015*) .

Some studies reported that the low protein content and less balanced amino acid profile of the macroalgae may not be enough to the rapid growth of abalone (*Hahn, 1989; Johnston et al., 2005;Robertson-Andersson, 2003*). However, some articles defend that feeding fresh algae enabled a suitable growth of abalone, specially when considering the high dietary value of the macroalgae reared in the IMTA. In fact, the growth rates attained for large abalones fed enriched seaweeds in some studies seems to be explained by the high protein content of the macroalgae produced under the high nitrogen culture conditions provided by fish tanks outflows (*Boarder et al., 2001; Naidoo et al., 2006; Robertson-Andersson et al., 2011; Viera et al., 2011, 2005)*. As an example, enriched fresh algae produced a significantly higher growth for *H. tuberculata coccinea* (169% weight gain) in comparison to artificial diets tested (49–84%WG)" (*Viera et al., 2015*).

Besides, the kind of species of macroalgae consumed can significantly affect abalone growth by offering different proportions of their nutrients requirement (*Viera et al., 2015*).Farmers reported that abalone fed with a diet mixing red algae with green algae grew better. This is linked to the fact that micronutrients requirements are more fulfilled than with a single algal diet.(*Fitzgerald, 2007; Naidoo et al., 2006; Robertson-Andersson et al., 2011; Viera et al., 2015*).

According to the results of some studies, best performance was observed for *Haliotis tuberculata* fed a diet that included red macroalgae *P. palmata*, while the lowest with *L. digitata* or *L. sacharina* (*Mai et al., 1995, 1996; Mercer et al., 1993*). This low growth performance offered by laminaria species can be explained by their low protein digestibility that could be partly responsible for the low growth obtained in some *Haliotis* grow out studies. *Gracilaria, Ulva, Hynea* macroalgae species are also used to feed the abalone (*Latuihamallo et al., 2015; Viera et al., 2005*). According to *Viera et al., 2005*, species of *Gracilaria* and *Hynea* were tested to find out which one is better for abalone development. *Hynea spinella* showed the best nutritional values of dietary for *Haliotis tuberculata coccinea*. *Gracilaria* species also have been reported to provide high development for *H. asinina* (*Bautista-Teruel et al., 1999*).

One drawback of feeding abalone with fresh macroalgae is that the animals eat significantly more than animals fed practical compound diets due to the significantly lower PE ratio of the fresh algae with artificial feeds (*Viana et al., 2007*), and the high moisture content of macroalgae that reduces nutrient density, which may make it difficult for abalone to consume a sufficient amount to achieve a comparative nutrient intake. Improvement of feeding strategies is still to be further developed and some advances have been performed. As an example, *H. tuberculata coccinea* fed different formulated diets showed that the inclusion of the algae *Palmaria palmata* improved growth, condition index and dietary protein utilization (*Viera et al., 2015*).

4.3 Interest of IMTA systems for *Haliotis* sp. grow-out

In IMTA systems (Fig. 6), the species have to complement each other, in order to grow together, but without competitive interaction. The aim of this interaction is to develop a better quality of the product, in higher quantity while lower energetic and economic cost than traditional systems(*Kleitou et al., 2018*). Seaweeds are considered a key to the functioning of IMTA systems, taking up dissolved inorganic nutrients (nitrogen and phosphorus) and producing algal biomass that can be used as a renewable protein-enriched feed for other cultivated species, as well as a product on its own (*Nobre et al., 2010*). In an aquaculture integrated system, nitrogenous enriched wastewater of intensively cultured aquatic animals could be transformed into an algal biomass of a high protein content to be used as feed for other species or as a seaweed production produced to generate an added income. In abalone production, protein enriched seaweeds like *Ulva* proved tu be suitable to feed abalone species demonstrated for *Haliotis*, *H. discus hannai* and *H. roei* (*Viera et al., 2005*), hence it ensure a high protein level in abalone species fed with algal source. Other benefit about the production of macroalgae on IMTA systems is the reduction of nutrient discharge into the environment (*Robertson-Andersson, 2006*).

Abalone farming can particularly benefit from the IMTA systems as seaweeds, are the abalone natural food (*Nobre et al., 2010*). Also, it has been reported that abalone present higher growth rate when fed diets of enriched and mixed algal diets (*Naidoo et al., 2006*). IMTA systems integrating abalone can also integrate other trophic levels with candidates such as sea cucumber species (*Fang et al., 2009*). Being detrivores, sea cucumbers can be placed in the bottom of the tank (the one represented in Fig. 14) fed on the particulate organic matter from the abalones wastes released from the suspended structures in which the abalone are located. In such scenario the macroalgae produced in the IMTA system would take up the dissolved organic matter and the carbon dioxide produced by the sea cucumbers to convert them in biomass and in oxygen closing the cycle and allowing to ready to be recirculated again through the animal tank.

5. Conclusion

The present study has been written to provide general information about grow-out processes for abalone species, main nutritional requirements as well as the different land-based and sea-based grow-out systems.

Grow-out systems for abalone are divided in land-based and sea-based systems. Nowadays Land-based systems are often used for research studies rather than commercial production, due to the ease to provide high control about the different factors which affects organism's development, when it is difficult to obtain available land spaces and needs high investment develop land installations at a commercial scale. Within the land-based technologies, systems generally include tanks with water and air flux circulation, in which abalones are located on the bottom of the tank or inside punctured cages or square net cages suspended in the tanks. In the case of, sea-based systems, they have been more often selected for commercial production due to their economic and energetic reduced costs, although presenting the disadvantages to be more exposed to external factors such as seasonal variation, water quality, diseases, etc. Around the world, the sea-based grow-out systems most commonly found include, suspended nets, and the long-line barrels.

In terms of product nutritional composition, this later is directly linked to production systems and their associated feeding methodologies. Abalones naturally present protein contents, which can be increased when fed appropriate diets such as enriched seaweeds or high protein-based compound feed as it has been demonstrated in several studies (*Viera et al., 2005*). Although, some studies suggest that protein levels higher than 30% could be detrimental for a high quality product (*Bautista-Teruel et al., 2003*) suggesting levels ranging between 20-30% to be the best diet protein composition for the best abalone's quality. Moreover, it is suggested that the diet protein contents should be kept in portions with lipids and carbohydrates contents. Lipid content is recommended to be between 3-6% while the carbohydrate is recommended to remain between 30% to 50%.

However, there is a wide range of opinions regarding abalones feeding strategies. Actually, compound feed seems to be the best option to increase their abalone protein composition, being the most appreciated components of these mollusc species. However, citizens perceive compound feed as less attractive and healthy in comparison to abalone natural diet.

Macroalgae are abalone natural feed in the wild, but aquaculture farmers find themselves limited by the specific species of macroalgae they can harvest as a feed source, depending on their location and by the fact that abalone might not reach the protein demand by just being feeding on seaweeds due to their seasonal nutritional variations. It has been demonstrated that single macroalgae diet result in the lowest development results in abalone aquaculture. However, recent studies have suggested that enriched seaweed, produced through innovate systems such as recirculated systems or IMTA systems, represent adequate feed source for abalone and could cover their protein requirements.

World aquaculture is currently increasing due to the high demand of aquatic animal production and the culture change amongst the population, becoming increasingly concerned by the depletion of oceans natural resources and contamination. Systems as recirculated and IMTA may reduce the impact of aquaculture production on the aquatic environment while providing high quality commercial aquatic products. However, further knowledge regarding these innovative methodologies is still required to develop their full production potential and having increased impact on the society. Such technological development still requires higher participation and contribution from government and stakeholders to deepen knowledge about aquatic species sustainable production techniques in a quest to alleviate dependence on fisheries as a source of marine products.

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FICHA FINAL

Actividades desarrolladas:

Hay que tener en cuenta que, debido al estado de alarma, no he podido recibir una formación práctica. Sin embargo, el año pasado realicé las prácticas externas con mi misma tutora de este trabajo, Gercende Courtois, donde pude llevar a cabo ciertas prácticas que considero unas experiencias valiosas tales como:

- Respecto al cultivo de *Haliotis tuberculata coccinea*, ayudé en su alimentación, limpieza, preparación de tanques y contaje en las fases:
    - Desove
    - Desarrollo larvario
    - Desarrollo post-larvario
    - Engorde
- Cultivo de especies de diatomeas (*Navicula, y cylindrotheca)*, para la alimentación de las post-larvas de *Haliotis.*

Integración e implicación dentro del departamento:

Mi integración con el personal fue muy buena. Encontré un personal bastante cooperativo en ayudar a otras secciones del centro en caso necesario y no tuve problemas con nadie. Me sentí muy a gusto y cómodo trabajando, ayudando y aprendiendo en aquel ambiente.

Aspectos positivos y negativos del desarrollo del TFG

Desarrollar este TFG ha sido complicado, ya que he tenido que adaptarme a la situación actual y cambiar drásticamente de estrategia. Lo que sería un trabajo experimental acabó siendo un trabajo puramente bibliográfico. De todas maneras, he podido aprender cómo buscar una gran cantidad de información revisando gran cantidad de estudios e informes y de ellos sacar mis propias conclusiones.

Valoración personal del aprendizaje conseguido:

Considero que pese a las muchas dificultades y la desorientación que he tenido en varias ocasiones realizando este trabajo, al final me he adaptado más o menos bien a la situación, consiguiendo un resultado que considero decente y por el que estoy orgulloso. Espero seguir por esta rama de la ciencia, la acuicultura, ya que me interesa mucho y pienso que será un elemento clave para el futuro.