New species for EU aquaculture

Deliverable Report

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WP Title:	Socio-economics – Institutional and organizational context			
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Lead Scientist preparing the Deliverable: Stokkers, R.
Other Scientists participating: Tacken, G., Mylonas, C.C., Fontaine, P., Norberg, B., Papandroulakis, N., Robles, R., Esteves, A.

Objective: In the feasibility study, an analysis on basis of the technical assessment (WP28), market information (WP29, resource and cost analysis (Task 30.1) and the result of the tested strategies (Task 30.2) will be delivered. This study covers a financial analysis, an assessment of return on investment and a definition of efforts needed, a risk assessment, technological assessment (WP 28), political analysis of potential risks of implementation, environmental impact assessment (with information from GWP5 grow out husbandry), a social and market impact assessment and a stakeholder identification to introduce the products in the market. The feasibility study will be reviewed by the participating SMEs.

Description: In the feasibility study, assessments is presented on several themes: financial, return on investment, efforts needed, risks, technological, political (of potential risks of implementation), environmental impact and stakeholder identification. These assessments will be based on the results of WP 27, WP28, WP29 and previous tasks of WP30.

Deviations: There are deviations in the content of the deliverable, since there were no validated economic data available for meagre and grey mullet at the end of the project. Sociological impact, as defined in the DOW has been interpreted as social impact. The deliverable was delayed two months until the end of the project.

Feasibility study

R. Stokkers
G. Tacken

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1 Introduction

Finfish aquaculture production in the EU is dominated both in volume and value by a handful of species that in turn limit the number of aquaculture products available in the market. Combined with low price imports of aquaculture products, innovations in the EU aquaculture has slowed or even decreased. To improve the position of aquaculture in the EU market and the development of new market segments, DIVERSIFY developed potentially interesting new species and products of these species. The project financed and supported by the European Maritime Fisheries Fund in FP7, supports the European blue growth strategy.

In five years of research, a lot of insights are gathered about consumer perception of fish, aquaculture in relation to wild catch in the selected countries (Germany, France, UK, Italy and Spain). Next to that a lot of technical improvements have been made on the selected species (Atlantic halibut, greater amberjack, grey mullet, meagre, pikeperch and wreckfish). This project was started at the end of the financial crises of 2008 – 2012, where unemployment figures in the south of Europe were very high. So in the selection of species warm water species that can be grown in the Mediterranean seas are overrepresented. Only pikeperch can be grown in fresh water, and therefore everywhere in Europe, while Atlantic halibut is a cold-water aquaculture sea fish.

An efficient, sustainable and market-oriented expansion of the EU aquaculture sector based on new species and products will reduce the dependence of the EU consumer on imports (from countries of questionable, often, production, health, environmental and social standards), reduce the pressure on over-exploited fisheries in the EU and explore new segments and tailor-made products for the EU-market. The main goal of DIVERSIFY was to support the diversification in species and products of the aquaculture industry and helping in market-oriented expansion of production to improve competitiveness of the European aquaculture products. Next to that the technical part of the project gave insights in new rearing methods, that can be interesting for the European supply industry, for development of production systems, production management and equipment for aquaculture.

Although environmental analysis is not planned to be done in DIVERSIFY, for cage production it is essential that the water quality remains at high standards. In Greece, France and Italy, around 25 to 40% of the surface water had a good or better ecological status in 2009, before the start of the project. Since EU member states are committed to implement measures under the EU Water Framework Directive (WFD), the water quality was expected to improve towards 2015 in France and Italy. Therefore, the environmental analysis in this report is based on literature.

At the start of the project none of the species was ready to be launched broadly in the European market. Most of the species has several issues in reproduction, larval husbandry, grow out husbandry, health or nutrition. During this project a lot of these problems have been solved, but since all GWPs have worked parallel, the availability of aquaculture fish was sometimes a problem during the project. Therefore, the socio economic work packages have not always been performed for all species.

Wreckfish was at the end of the project still in an experimental phase, so this species is not considered in the feasibility.

In this feasibility study we explore whether the selected species and new products of the European aquaculture industry might help in the market expansion and/or increase of local production.

2 Methodology

This study is based primarily on secondary research of deliverables and reports written by other project team members of DIVERSIFY, that are relevant for the feasibility of the species. Next to that primary research on basis of secondary information is done regarding the financial feasibility.

Financial feasibility

In order to assess the financial feasibility of farming of the selected fish species in DIVERSIFY a bio-economic model has been used that was originally developed for assessing the business opportunities for aquaculture in Ethiopia in 2012 (Rothuis et el., 2012) and afterwards has been improved in several aquaculture projects (Rurangwa et al., 2013; Kamstra et al., 2014; Prins et al., 2015).

The bio-economic model is built in Excel and consists of a number of linked work sheets:

- *System design*. This sheet contains the technical and biological parameters defining the production system and determines the dimensions of the required inputs and resulting outputs. Several production systems and/or production volumes can be compared.
- *Data inputs-outputs*. This sheet contains the prices of all inputs, divided in investment costs (e.g. land/water, buildings, machinery and equipment), operational costs (e.g. juveniles, fish feed, energy, labour and general costs) and financial costs (interest and inflation rates) as well as all outputs (main and side produce and services). In case of investments in durable production means (DPM) also figures on depreciation, maintenance and insurance as percentage of the initial investments are supplied.
- *Investments*. This sheet contains the calculations of the total initial investments and periodic investments every 5 years, 10 and 20 years, as well as the yearly depreciation, maintenance and insurance costs.
- *Cost price ex farm gate*. This sheet contains the calculations of the yearly costs and costs per kg of whole fish for a fully operational farm, so without regarding start-up costs. In the accompanying figure the cost price is split up in the categories juveniles, feed, energy and other variable inputs, durable production means (DPM), labour and general costs. The costs of transportation, slaughtering, processing and marketing and sales are excluded!
- *Cash flow*. This sheet contains the calculations of the cumulative cash flow over a period of 20 years for starting up completely new farms, as well as the rates of return on investment and break-even points. The cash flow is illustrated in the accompanying figure.
- *Scenarios*. This sheet offers the possibility of a sensitivity analysis of for example feed price per kg, fish price per kg and subsidy on initial investments on cost price and return on investments, but was out of scope in this particular study.

For each of the selected fish species in Diversify the bio-economic model has been adapted by using the following approach:

1. Based on the information collected in the previous work packages of Diversify and the fact sheets of the FAO from the Cultured Aquatic Species Information Programme for each species one relevant and viable production system in the grow-out phase was designed and the available species-specific technical and biological parameters and prices on inputs and outputs were collected.
2. Missing data were firstly supplemented from the database on fish farms in the European Union of the Scientific, Technical and Economic Committee for Fisheries (STECF) for comparable fish species and production systems and the database on salmon farms in Norway of the Fiskedirektoratet

Norge. Secondly, additional data from Eurostat on energy and water costs, labour costs and financial costs and from FAO FishStat on producer prices of the specific fish species were used.

3. The preliminary results for each species were presented for validation to the concerning species leader and private fish company or other expert in the Diversify project. If possible and available, the model data and preliminary results were compared with the company data and results and the model input was adjusted and fine-tuned where necessary.
4. Consecutive model runs were performed for a range of farm sizes in an iterative process with the private fish companies until the results were according to the available farm data and judgement of the private parties.

As of mid-November 2018, the financial results are only validated for Atlantic halibut, greater amberjack and pikeperch and will be presented in this report. The preliminary results for grey mullet and meagre are still waiting to be validated by the private fish companies or other experts and are therefore excluded from this report.

Technical risks, environmental impact, social impact and market impact

All these risks and impacts have been done on literature research or analysis on basis of outcome of Deliverables. The literature study has been undertaken as a systematic review of the deliverables brought up in DIVERSIFY. Through the use of a transparent, reproducible, and iterative review process (see Figure 2.1), systematic literature reviews aim to overcome the issue of researcher bias, by using a comprehensive search and analysis framework that combines cross-referencing between researchers, extensive searches of research databases and the application of agreed exclusion criteria (Roehrich, Lewis, & George, 2014; Tranfield et al., 2003). This resulted in technical leaflets with outcomes of DIVERSIFY per species (Norberg et al, 2018; Papandroulakis et al, 2018; Koven et al., 2018; Estevez et al., 2018; Fontaine et al., 2018)

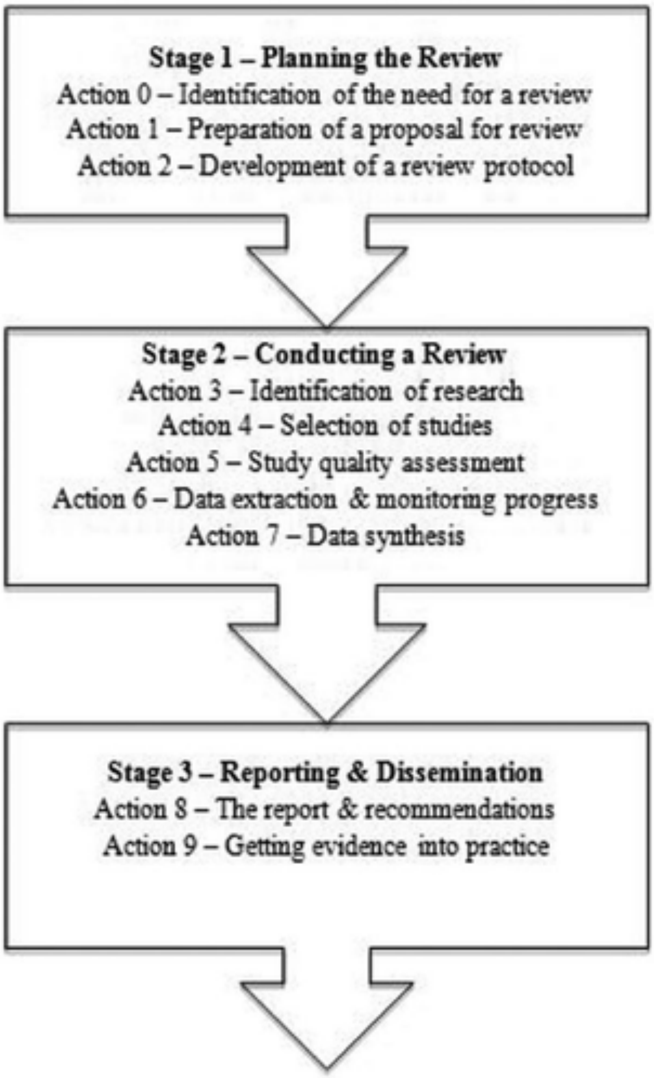

Figure 2.1 Stages of the systematic review (adapted from Tranfield, Denyer, & Smart, 2003)

On basis of th8is systematic review of deliverables, this Deliverable is made. Only for environmental impact secondary information from other sources is used. Per species a summary is made with the intention to bundle information of several Deliverables within the Socioeconomics area added with some information of other WPs.

Social impact and market impact are written on the basis of the Porter analysis in D27.3. In this Deliverable the direct and generic competitors of the new species are defined. This competitive force field determines where social and market impact can be expected.

This deliverable is mainly a dissemination of research elsewhere in the project, so for details the specific deliverables of the WPs can be consulted.

3 Atlantic Halibut (*Hippoglossus hippoglossus*)

Atlantic Halibut is a flatfish that is decreasing as wild fish, resulting in its fisheries being subject to strict regulations (Norberg et al., 2018) and, therefore, market demands cannot be reached. Cultured Atlantic halibut has an excellent reputation and there are lots of possibilities for diversification, because the fish is suitable for making large fish steaks, cutlets, smoked fish, marinated fish in Scandinavian style. Production takes place both on land and in sea cage.

3.1 Financial feasibility

System design

The most promising production system for the grow-out of Atlantic halibut is growing them in cages at sea as is common practice at most Atlantic halibut farms in Norway. With assistance of private company and market leader Sterling White Halibut (SWH) the technical and biological parameters were defined (Table 3.1, indicated in red). Next the dimensions of the required inputs and resulting outputs were determined at four farm sizes ranging from an annual production volume of 500 to 1500 tons whole fish (Table 3.1, indicated in black).

Data inputs-outputs

The prices of the major inputs and outputs are listed in Table 3.2. Most of these prices were provided by Sterling White Halibut (SWH) unless mentioned otherwise. As can be seen in the table no scale effect is expected on the inputs except for fingerlings.

Furthermore, the producer price ex farm gate is set at 7 euro per kg whole fish, whereas the actual sales price according to Sterling White Halibut and the FAO Statistics is around 11 euro per kg. The difference between the producer price ex farm gate and the actual sales price should cover the costs of transportation, slaughtering, processing and marketing and sales.

Investments

The number of units per type of investment as well as the calculated total initial investments and annual depreciation, maintenance and insurance costs are shown in Table 3.3. As can be seen in the table some investments are independent of the scale (e.g. production building and boats), whereas investments in the actual rearing facilities vary with scale (e.g. cages, shelves, nets and camera control and feeding units). The total initial investments range from 2.65 to 6.05 million euro depending on farm size, whereas the total annual depreciation, maintenance and insurance ranges from 320 to 700 thousand euro.

Cost price

The composition of the cost price ex farm gate for each of the four farm sizes is illustrated in Figure 3.1. The total cost price decreases from 7.25 euro per kg whole fish at an annual production volume of 500 tons to 5.67 euro per kg whole fish at an annual production volume of 1500 tons. Around an annual volume of 650 tons the total cost price equals the estimated producer price ex farm gate of 7.00 euro per kg whole fish. The major cost components are juveniles (2.18-2.91 euro per kg) and feed (2.38 euro per kg), with the previously mentioned scale effect at buying fingerlings. With increasing farm size, also the costs of durable production means (DPM) and labour per kg are decreasing.

Cash flow

In the decision-making process of investing in completely new farms the cumulative cash flow over a period of 20 years is of interest. Figure 3.2 illustrates this cash flow for the four identified farm sizes. It shows that during the first four years an investment capital is needed ranging from 10 million euro at an annual production volume of 500 tons to 22 million euro at an annual production volume of 1500 tons. Besides the previously mentioned initial investments in durable production means (DPM) also the costs of building up the fish stock during the first 3.5 years are enormous. After that the revenues from fish sales contribute to an increase of the cumulative cash flow, only interrupted by small dips after 5, 10 and 15 years because of supposed re-investments.

Table 3.1 System design of the out-grow production in cages of Atlantic halibut in Norway at 4 farm sizes.

	Unit	Farm 500 ton	Farm 750 ton	Farm 1000 ton	Farm 1500 ton	Remarks and sources
Production	ton/y	500	750	1000	1500	SWH: minimum 700 ton to break-even and target 1500 ton
Start weight	g	500	500	500	500	SWH
Final weight	g	5500	5500	5500	5500	SWH
Growth period	months	42	42	42	42	SWH
Cycles	#/y	0.29	0.29	0.29	0.29	SWH
Stocking density	#/m2	18	18	18	18	SWH
Survival	%	75%	75%	75%	75%	SWH
Harvest density	kg/m2	74.3	74.3	74.3	74.3	maximum density 50-80 kg/m2 (SWH)
Productivity	kg/m2/y	21.2	21.2	21.2	21.2	
Rearing area	m2	23,569	35,354	47,138	70,707	
Space utilisation	m2/m2	2.50	2.50	2.50	2.50	m2 of shelves per m2 of water space (SWH)
Water space	m2	9,428	14,141	18,855	28,283	
Feed conversion ratio	kg/kg	1.70	1.70	1.70	1.70	decreased from 1.9 to 1.6 (SWH)
Total feed use	ton/y	850.00	1275.00	1700.00	2550.00	
Electricity	kWh/kg	0.25	0.25	0.25	0.25	kWh per kg of production (SWH)
Total electricity use	MWh/y	125.00	187.50	250.00	375.00	
Labour productivity	FTE/100 ton	1.70	1.13	0.85	0.57	SHW and STECF United Kingdom 2012-2014 (salmon)
Total labour use (minimum)	FTE/y	8.50	8.50	8.50	8.50	
Actual labour input:						
- high (e.g. entrepreneur)	FTE	1.00	1.00	1.00	1.00	formula or minimum value in formula can be overwritten
- middle (e.g. assistant manager)	FTE	1.00	1.00	1.00	1.00	formula or minimum value in formula can be overwritten
- low (e.g. production personnel)	FTE	6.50	6.50	6.50	6.50	minimum 0,5 FTE

Table 3.2 Prices of inputs and outputs for the out-grow production in cages of Atlantic halibut in Norway at 4 farm sizes.

S/N	Costs (in euro)	Farm 500 ton	Farm 750 ton	Farm 1000 ton	Farm 1500 ton	Remarks and sources
1.	Investment costs					
	1.1. Water rent (ha)	5,000	5,000	5,000	5,000	
	1.2. Permits (per farm)	50,000	50,000	50,000	50,000	includes all start-up costs
	1.3. Buildings & storage					
	· production building (m2)	1,167	1,167	1,167	1,167	second hand barracks
	1.4. Machinery & equipment					
	· cages (m2)	106	106	106	106	cage with 4 m2 shelves per m2 cage
	· shelves (m2)	12.73	12.73	12.73	12.73	
	· nets (per unit)	25,000	25,000	25,000	25,000	
	· camera control and feeding system (per unit)	25,000	25,000	25,000	25,000	
	· big boat (piece)	65,000	65,000	65,000	65,000	
	· small boat (piece	50,000	50,000	50,000	50,000	
	· other small equipment (per farm)	150,000	150,000	150,000	150,000	
2.	Operational costs					
	2.1. Juveniles (piece)					
	· fingerlings	12.00	10.50	9.00	9.00	nursery produced fingerlings of 500 g
	2.2. Fish feed and other ingredients					
	· high quality pelleted feed (ton)	1400.00	1400.00	1400.00	1400.00	
	2.3. Energy costs					
	· electricity (MWh)	80.20	80.20	80.20	80.20	Eurostat 2012-2017 (non-households excluding taxes and recoverable levies) for Norway
	2.4. Labour (per year per FTE)					
	· high (e.g. entrepreneur)	79,800	79,800	79,800	79,800	
	· middle (e.g. assistant manager)	53,200	53,200	53,200	53,200	SWH and Eurostat 2012-2017 Norway
	· low (e.g. production personnel)	39,900	39,900	39,900	39,900	

Table 3.2 (continued) Prices of inputs and outputs for the out-grow production in cages of Atlantic halibut in Norway at 4 farm sizes.

S/N	Costs (in euro)	Farm 500 ton	Farm 750 ton	Farm 1000 ton	Farm 1500 ton	Remarks and sources
	2.5. General costs					
	· fixed (per farm)	50,000	50,000	50,000	50,000	
	· variable (per kg production)	0.04	0.04	0.04	0.04	
5.	Financial costs (%)					
	· interest rate	2.6%	2.6%	2.6%	2.6%	STECF United Kindom 2012-2014 (salmon)
	· inflation rate	2.0%	2.0%	2.0%	2.0%	Eurostat 2012-2017 for Norway
6.	Outputs					
	· whole fish (kg)	7.00	7.00	7.00	7.00	Sales price SWH 11.50 euro/kg; FAO average 2010-2014 10.47 euro/kg

Table 3.3 Number of units per type of investment, total initial investments and annual depreciation, maintenance and insurance costs for the out-grow production in cages of Atlantic halibut in Norway at 4 farm sizes.

	Unit	Farm 500 ton	Farm 750 ton	Farm 1000 ton	Farm 1500 ton
1.1. Water rent (ha)	ha	0.9	1.4	1.9	2.8
1.2. Permits (per farm)	#	1.0	1.0	1.0	1.0
1.3. Buildings & storage					
· production building (m2)	m2	600.0	600.0	600.0	600.0
1.4. Machinery & equipment					
· cages (m2)	m2	5892.3	8838.4	11784.5	17676.8
· shelves (m2)	m2	23569.0	35353.5	47138.0	70707.1
· nets (per unit)	units	15.0	23.0	30.0	45.0
· camera control and feeding system (per unit)	units	15.0	23.0	30.0	45.0
· big boat (piece)	#	1.0	1.0	1.0	1.0
· small boat (piece	#	1.0	1.0	1.0	1.0
· other small equipment (per farm)	#	1.0	1.0	1.0	1.0
Total initial investment	euro	2,640,000	3,559,571	4,374,428	6,054,141
Depreciation	euro	270,250	353,375	429,000	587,750
Maintenance	euro	43,550	56,175	67,800	92,050
Insurance	euro	7,920	10,508	12,945	17,970

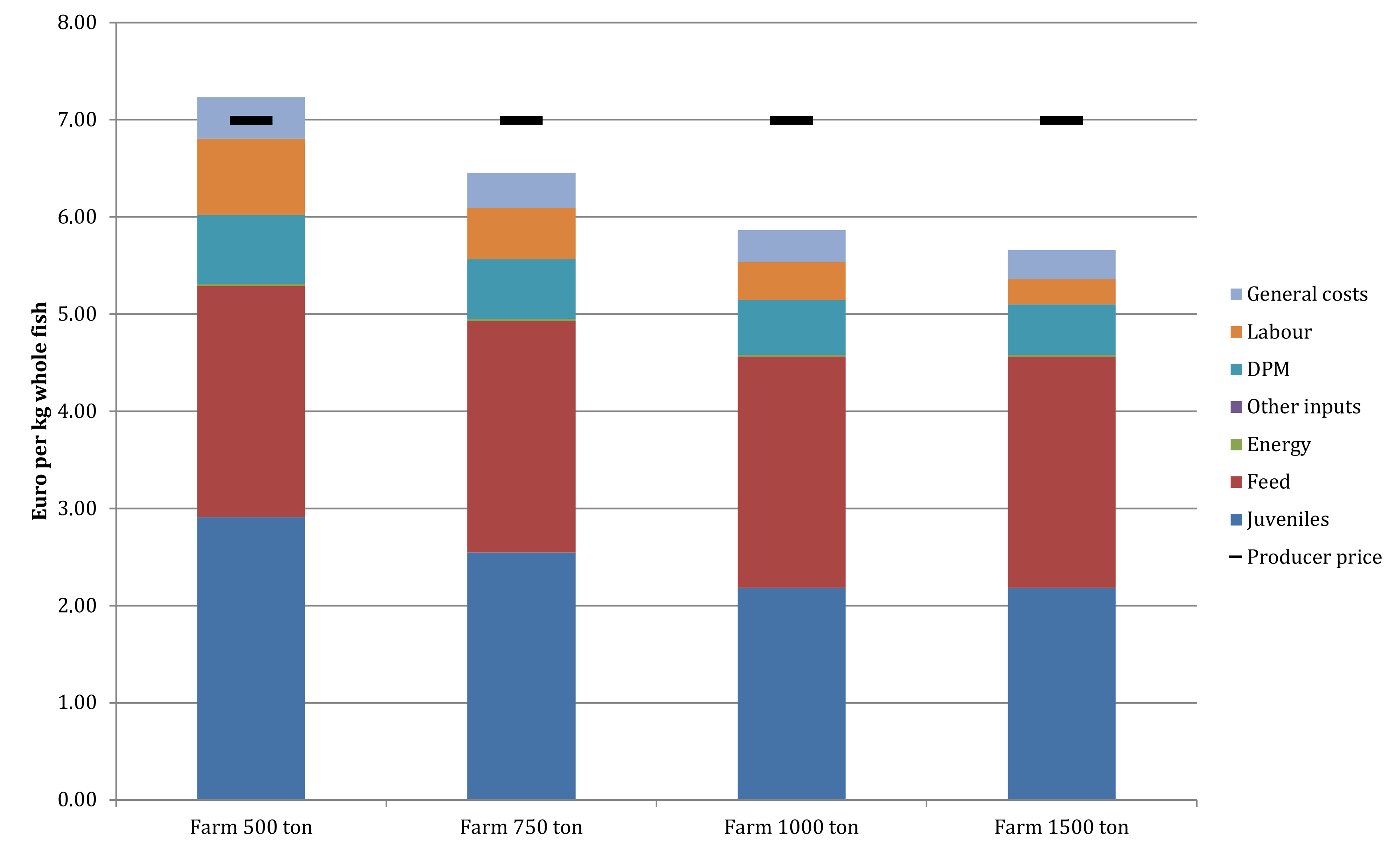

Figure 3.1 Composition of the cost price ex farm gate for the out-grow production in cages of Atlantic halibut in Norway at 4 farm sizes.

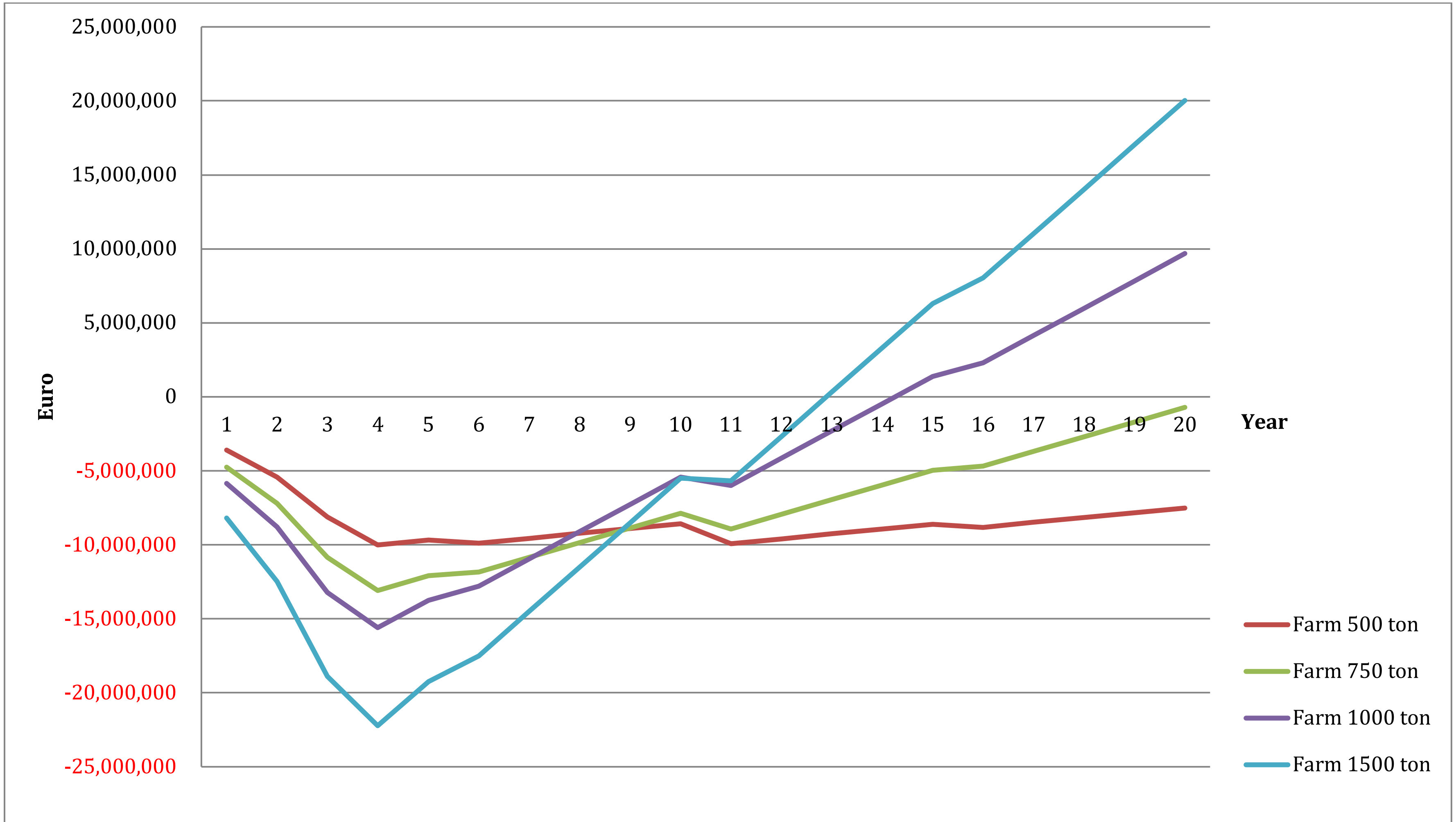

Figure 3.2 Cumulative cash flow for the out-grow production in cages of Atlantic halibut in Norway at 4 farms size over a period of 20 years.

Figure 3.2 shows that only the two farms with an annual production of 1000 and 1500 tons are able to generate a positive cumulative cash flow and offer a viable business proposition. The farm of 1500 tons has an internal rate of return (IRR) of 7% and reaches break-even point after 13 years. The farm of 1000 tons has an IRR of 5% and reaches break-even point after 15 years. The realized producer price is of overriding importance in these calculations and a 10% better price also makes the farm of 750 tons profitable.

3.2 Technological risks

Before the project several technical issues had to be solved for Atlantic halibut (Norberg et al., 2018):

- *Spawning.* Differences were observed between eggs and larvae from farmed and wild fish. Eggs from farmed females were smaller and tended to be heavier, while eggs from wild-caught females remained buoyant near the surface. It's still not clear what causes this.
- *Spawning.* Use of GnRHa implants advanced and synchronized spawning, resulting in improved egg production in F1 females, though egg quality remains highly variable.
- *On grown Artemia.* Tests did not show any positive effects of on-grown Artemia on growth and development in halibut larvae, possibly due to improvement of production methods, such as tank design and dynamics. Good larval performance can be obtained using Artemia nauplii and on-grown Artemia have limited benefits compared to the costs of facilities and labor needed to produce them.
- *Larval husbandry.* First feeding of larvae in RAS systems resulted in improved growth and development compared to flow through systems. Metagenomic analyses of the microbial communities in the water and larvae of the two systems revealed interesting differences, which will be useful in industrial applications.
- *Nutrition.* Larvae fed well and had good survival when dry feed was introduced 28 days post first feeding in small systems. Full-scale systems are needed to evaluate and improve these results in an industrial context.
- *Health.* A range of systems for expression of a capsid protein from nodavirus were tested for use in the development of a vaccine against VNN.

The remaining bottlenecks for increased and stable production (Norberg et al., 2018) are:

- In nutrition the ability of the larvae to digest and grow has to be further tested as well as early weaning.
- Reduction of production time from juvenile to slaughter
- RAS for larval husbandry systems
- Vaccine development
- Gamete quality
- Improve stability and performance in out-of season breeders
- Use newly sequenced, assembled and annotated halibut genome to find good genetic markers for desirable traits
- Detection/screening of pathogens
- Maternally transmitted viral diseases
- Parasite treatments
- Branding, marketing & sales

The main technological risk in early life stages of this species is dependence of stable systems with very narrow limits for temperature and water quality during the earliest stages, development of appropriate diets for first feeding and viral infections during larval stages where vaccines cannot be applied. During ongrowing, the main risks are connected with production systems - in sea cages main risks are escapes and infections.

3.3 Environmental impact

In DIVERSIFY there is no specific environmental study done for Atlantic halibut. So the environmental impact of producing Atlantic halibut can only be based on literature on aquaculture systems for production.

The larval rearing for Atlantic halibut is done in tanks and/or RAS systems. The environmental impact of these systems has been improved in the last couple of years due to water cleaning systems. In general, this type of system has the following environmental impact (Martins et al., 2010):

- A closed production system like RAS or a tank has the main advantage that the feed conversion efficiency is high. There is relatively low wastage of feed and the fish learn very quickly when and where feed is dispersed.
- For a RAS more energy is needed since water circulation is needed. Use of energy has environmental impact as such.
- In RAS and tank systems for on growing, manure of the fish has to be expelled from the tanks and be used somewhere else. It has no direct environmental impact, as long as there is a market for it.
- However, a RAS is a closed system in which everything can be controlled and in which pollution is controlled and no interference with the environment is needed.
- RAS systems and tanks are however controlled in ways that resemble a lot with industrial production of meat and eggs. Animal welfare organisations claim that fish in tanks or RAS system have lower animal welfare than fish in cages, since they are nearly in their own habitat. However, larvae perform better in RAS, which gives the impression that RAS is a good system for larval rearing. More research is needed to confirm that.

The grow out of Atlantic halibut can be done in a RAS system and in cages in the sea. For grow out in RAS the same environmental issues are relevant as in the larval rearing described above. Grow out in cage system has very strict regulations, but it has other environmental issues that have to be taken into consideration (Braaten, 2007; Martinez-Porchas et al, 2012):

- Aquaculture can lead to eutrophication and nitrification of effluent receiving ecosystems, if the carrying capacity of the side is exceeded.
- Beneath the cages, sediments can be found of faecal wastes and uneaten feed, if the above is true, and the depth of water is not great enough. This may attract some wild species.
- Negative effect on fisheries. A lot of fish in a cage can have effect on the oxygen conditions in and just around the cages, what makes that wild life moves away from their natural habitat to other areas.
- Fish in cages might escape (due to damage by storms, collisions with boats, predator attacks and vandalism) so that cultured and wild fish mix with potential spawning in the wild. This might lead to genetic pollution.
- Ecological impacts in natural ecosystems. Due to the feed losses, congregation of wild fish near and around the cages is possible, and interaction between fishes might lead to transfer of microbial pathogens and/or parasites (both ways).
- Large sites of fish farming might lead to water pollution for human consumption, if water is taken from the same area. However, this is less relevant for sea cage systems as used by Atlantic halibut.
- Cage farming might have impact on landscape and hydrological patterns. It could lead to degradation of ecosystems.
- Most cultured species are carnivores, which means that they are fed with fish meal and fish oil. So wild fish have to be caught to make the feed. This makes that increase of such aquaculture species leads to more feed needs and higher pressure on the wild fish population. However, the last years,

the use of marine oil and protein is decreasing and plant-based feed sources are increasing. In addition, new sources such as insect meal and marine oils from microalgae are being developed as plant oil and protein are not sustainable in the long term and also change the fatty acid profile of the fish.

- Other accusations are that toxins and/or heavy metals come in the water as well as infestation of non-desirable phytoplankton and/or zooplankton species.

3.4 Social impact

For social impact analysis we use the definition of Vanclay (2012) "Social Impact Assessment includes the processes of analyzing, monitoring and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programs, plans, projects) and any social change processes invoked by those interventions [...]."
According to this definition, introduction of Atlantic halibut in Northern European countries, since it is a cold-water sea fish, might have the following social consequences:

- Flatfishes are a type of fish that is scarce in the wild, so it has quota. If Atlantic halibut becomes widely available, buyers of wild catch of other flatfish species might replace these species with cultured Atlantic halibut. That has especially economic impact on the fishermen and processors in these countries that are main supplier of flatfish types like sole in the EU, e.g. the Netherlands. Employment in the fish sector in these countries might decrease if they don't adapt to the introduction of cultured Atlantic Halibut in the market. However due to the quota for flatfish, stakeholders in this sector have been warned that wild flatfish is not attractive as business proposition for the future.
- In Norway the aquaculture sector is economically and in employment largely dependent on the production, processing and sales of Atlantic salmon and, to a lesser extent, rainbow trout. So, the image and sales of salmonids determines employability. This dependency might diversify by introducing Atlantic halibut as a third species.
- For the aquaculture producers in Norway and other countries, introduction of a potential successful species like Atlantic halibut might give new perspectives for a good income. The margins in Atlantic salmon are decreasing, so only with cost leadership a good income can be reached. Not all farms have the ability to increase scale. Especially farms that are limited in growth, can find a new future with producing a new species. The margins for Atlantic halibut at farms are large, as shown in the financial feasibility above, so this species might be an alternative for small scale Atlantic salmon farmers.
- Atlantic halibut can grow out both in RAS and in cage. So, both aquaculture farmers in cold water sea areas as producers on land might contribute of the good perspectives of this species.
- Atlantic halibut is a good white fish alternative for *Pangasius*, grown outside the EU and difficult to control on food quality. Introduction of a good European alternative with controlled production and trustworthy certification, might lead to a health increase for fish consumption.
- If Atlantic Halibut turns out to be a good competitor for *Pangasius*, and if consumers prefer European species, introduction of new whitefish species in the EU might result in decreasing employment in Asia in the aquaculture sector due to decreasing demand in the EU. However, the increasing demand for protein in Asia, might give them alternative market opportunities.

So, in general no essential negative social impact of Atlantic halibut aquaculture is expected.

3.5 Market impact

Market impact is defined as the impact of introduction on potential and current markets and impacts on market demand for fish (products) that are to be expected for Atlantic halibut (based on Kotler, 2003).
Atlantic halibut has in potential a high market impact for the fish and aquaculture market:

- Flatfish is very wanted in the European market, and demand exceeds the catch and production of flatfish. Therefore, there is no doubt that this species has a good market future, if:
    - Technological hick-ups are solved
    - Production grows slowly according growth of demand
- Atlantic halibut has in potential the same chances as Atlantic salmon, since Atlantic halibut is easy to process and a lot of potential products can be made with the species. So, it has the potential to become one of the 10 largest species in the EU. Since the European protein market only has a slight growth, and in some countries it even decreases, this has as large substitution effect, on other protein sources. Especially red meat demand is expected to decrease most if the demand for fish increases, since the negative effects of consumption of these types of meat are emphasized a lot by dietitians.
- For aquaculture farmers this species is interesting, since the margins are attractive. As stated above especially small Atlantic salmon farmers might be interested in growing Atlantic halibut.
- Buyers in the retail are interested in new species, since they have the impression that the (cultured) fish assortment is too small. Fresh local produce from the EU is for their margins much more attractive than frozen meat from another continent.
- Supplier of other flatfish species might feel more competition due to introduction of cultured Atlantic halibut.

4 Greater amberjack (*Seriola dumerili*)

Greater amberjack is an interesting new species because it shows higher growth rates than other species reared in the Mediterranean, it has excellent flesh quality, worldwide distribution and market and, due to the large sizes attained, it can be used for developing alternative products (Papandroulakis et al., 2018). Next to that greater amberjack is also used for processed products like sushi. Greater amberjack is grown in cages in the Mediterranean or in warm water RAS systems.

4.1 Financial feasibility

System design

The most promising production system for the grow-out of greater amberjack is the net pen sea cages after adapting the technology already available for sea bass and sea bream. At present there is but perhaps one in Malta no private company that exclusively produces greater amberjack and therefore actual production data are scarce. With assistance of the Hellenic Centre for Marine Research (HCMR) the technical and biological parameters were defined (Table 4.1, indicated in red). As a reference, the most recent farm data from the STECF-database on sea bass & sea bream production in cages in Greece and Spain were used. Next the dimensions of the required inputs and resulting outputs were determined for two farm sizes in Greece and Spain with an annual production volume of 500 and 1000 tons whole fish (Table 4.2, indicated in black).

Data inputs-outputs

The prices of the major inputs and outputs are listed in Table 4.2. The prices of cages and fingerlings were supplied by the Hellenic Centre for Marine Research (HCMR), but most other prices were derived from the databases of STECF, Eurostat and the FAO. As can be seen in the table no scale effect is expected on the inputs except a small one for the cages including installation costs.
The producer price ex farm gate is set at 14.36 euro per kg whole fish according to the FAO Statistics. This price probably also covers the costs of transportation, processing and marketing and sales.

Investments

The number of units per type of investment as well as the calculated total initial investments and annual depreciation, maintenance and insurance costs are shown in Table 4.3. As can be seen in the table some investments are independent of the scale (e.g. office and production buildings), whereas investments in the actual rearing facilities vary with scale (e.g. cages and solar panels).
The total initial investments range from around 4.0 million euro at an annual production volume of 500 ton to around 7.25 million euro at an annual production volume of 1000 with only small differences between Greece and Spain. The total annual depreciation, maintenance and insurance ranges from around 265 to 475 thousand euro.

Cost price

The composition of the cost price ex farm gate for both farm sizes in Greece and Spain is illustrated in Figure 4.1. The total calculated cost price amounts to around 7.05 euro per kg whole fish in Greece and 7.45 euro per kg whole fish in Spain with only a slight difference between both farm sizes. All these calculated cost prices are about half the producer price according to the FAO Statistics! According to the Hellenic Centre for Marine Research (HCMR) the ex-farm gate price in 2018 was also between 12 to 14 euro per kg and the margins for the producers were spectacular. It is doubtful that the price level remains that high when the total production is tenfold.

The major cost components are juveniles (0.71-1.32 euro per kg) and feed (4.16-4.59 euro per kg). The differences between two countries can largely be explained by the start weight of the larvae, feed type and corresponding feed conversion efficiency. With increasing farm size also the costs of durable production means (DPM) and labour per kg are decreasing, in total around 0.10 euro per kg.

Cash flow

In the decision-making process of investing in completely new farms the cumulative cash flow over a period of 20 years is of interest. Figure 4.2 illustrates this cash flow for both farm sizes in Greece and Spain. It shows that during the first two years an investment capital is needed ranging from 8 million euro at an annual production volume of 500 tons to 16 million euro at an annual production volume of 1000 tons.

Table 4.1 System design of the out-grow production in cages of greater amberjack in Greece and Spain at 2 farm sizes.

	Unit	Greece 500 ton	Greece 1000 ton	Spain 500 ton	Spain 1000 ton	Remarks and sources
Production	ton/y	500	1000	500	1000	STECF Greece 2014 (all) & Spain 2011-2014 (sea bass & sea bream in cages)
Start weight	g	15	15	50	50	Diversify: hatchery produced larvae of 15 g/# for Greece and 50-100 g/# for Spain
Final weight	g	3000	3000	3000	3000	Diversify: 3 - 5 kg or 6 - 7.5 kg
Growth period	months	24	24	24	24	Diversify: 2 - 3 years or 2.5 - 3 years
Cycles	#/y	0.50	0.50	0.50	0.50	Diversify
Stocking density	#/m3	8	8	8	8	stocking density can be higher, but for now OK (HCMR)
Survival	%	70%	70%	70%	70%	at the moment survival in cages is not that high, but it is expected to ameliorate (HCMR)
Harvest density	kg/m3	16.8	16.8	16.8	16.8	
Productivity	kg/m3/y	8.4	8.4	8.4	8.4	
Rearing area	m3	59,524	119,048	59,524	119,048	
Space utilisation	m3/m2	10.00	10.00	10.00	10.00	m3 of cage per m2 of water space; this is for a cage depth of 10 m, but it can also be 15 m (HCMR)
Water space	m2	5,952	11,905	5,952	11,905	
Feed conversion ratio	kg/kg	2.31	2.31	2.55	2.55	kg feed per kg of production STECF Greece 2014 (all) & Spain 2011-2014 (sea bass & sea bream in cages)
Total feed use	ton/y	1155.00	2310.00	1275.00	2550.00	
Electricity	kWh/kg	0.53	0.53	0.67	0.67	kWh per kg of production; STECF Greece 2014 (all) & Spain 2011-2014 (sea bass & sea bream in cages)
Total electricity use	MWh/y	608.36	1,216.72	850.74	1,701.47	
Labour productivity	FTE/100 ton	3.93	3.93	2.14	2.14	STECF Greece 2014 (all) & Spain 2011-2014 (sea bass & sea bream in cages); probably too optimistic for Spain
Total labour use (minimum)	FTE/y	19.65	39.30	10.70	21.40	calculated as labour productivity * production volume
Actual labour input:						
- high (e.g. entrepreneur)	FTE	1.00	1.00	1.00	1.00	formula or minimum value in formula can be overwritten
- middle (e.g. assistant manager)	FTE	1.00	1.00	1.00	1.00	formula or minimum value in formula can be overwritten
- low (e.g. production personnel)	FTE	17.65	37.30	8.70	19.40	minimum 0,5 FTE

Table 4.2 Prices of inputs and outputs for the out-grow production in cages of greater amberjack in Greece and Spain at 2 farm sizes.

S/N	Costs (in euro)	Greece 500 ton	Greece 1000 ton	Spain 500 ton	Spain 1000 ton	Remarks and sources
1.	Investment costs					
	1.1. Water rent (ha)	0	0	0	0	
	1.2. Permits (per farm)	10,000	10,000	10,000	10,000	includes all start-up costs
	1.3. Buildings & storage					
	· office building (m2)	650	650	650	650	
	· production building (m2)	225	225	225	225	
	1.4. Machinery & equipment					
	· cages (m3)	50.00	45.00	50.00	45.00	all inclusive; cage of 2000 m3 (radius of 8 m and depth of 10 m) (HCMR)
	· solar energy panels (MWh)	1,148	1,148	1,148	1,148	1,55 euro per Wattpeek including installation; one Wattpeek produces about 1.35 kWh per year in Greece and Spain
	· other small equipment (per farm)	25,000	25,000	25,000	25,000	
2.	Operational costs					
	2.1. Juveniles (piece)					
	· fingerlings	1.50	1.50	2.75	2.75	hatchery produced larvae of 5 g for Greece cost 1.5 euro/# (HCMR) and of 50-100 g cost 3.3 USD/# (Diversify)
	2.2. Fish feed and other ingredients					
	· high protein grow-out feed (ton)	1800.00	1800.00	1800.00	1800.00	similar in both countries (HCMR)
	2.3. Energy costs					
	· electricity (MWh)	121.50	121.50	115.40	115.40	Eurostat 2012-2017 (non-households excluding taxes and recoverable levies); not relevant because of solar energy panels
	2.4. Labour (per FTE per year)					
	· high (e.g. entrepreneur)	55,275	55,275	49,050	49,050	
	· middle (e.g. assistant manager)	36,850	36,850	32,700	32,700	STECF Greece 2014 (all) & Spain 2011-2014 (sea bass & sea bream in cages)
	· low (e.g. production personnel)	27,638	27,638	24,525	24,525	

Table 4.2 (continued) Prices of inputs and outputs for the out-grow production in cages of greater amberjack in Greece and Spain at 2 farm sizes.

S/N	Costs (in euro)	Greece 500 ton	Greece 1000 ton	Spain 500 ton	Spain 1000 ton	Remarks and sources
	2.5. General costs					
	· fixed (per farm)	25,000	25,000	25,000	25,000	
	· variable (per kg production)	0.08	0.08	0.08	0.08	
5.	Financial costs (%)					
	· interest rate	4.4%	4.4%	3.0%	3.0%	STECF Greece 2014 (all) & Spain 2011-2014 (sea bass & sea bream in cages)
	· inflation rate	1.7%	1.7%	1.8%	1.8%	Eurostat 2012-2017
6.	Outputs					
	· whole fish (kg)	14.36	14.36	14.36	14.36	FAO; average 2010-2014

Table 4.3 Number of units per type of investment, total initial investments and annual depreciation, maintenance and insurance costs for the out-grow production in cages of greater amberjack in Greece and Spain at 2 farm sizes.

	Unit	Greece 500 ton	Greece 1000 ton	Spain 500 ton	Spain 1000 ton
1.3. Buildings & storage					
· office building (m2)	m2	150.0	150.0	150.0	150.0
· production building (m2)	m2	350.0	350.0	350.0	350.0
1.4. Machinery & equipment					
· cages (m3)	m3	59523.8	119047.6	59523.8	119047.6
· solar energy panels (MWh)	MWh	608.4	1216.7	850.7	1701.5
· other small equipment (per farm)	#	1.0	1.0	1.0	1.0
Total initial investment	euro	3,875,926	6,955,365	4,154,212	7,511,936
Depreciation	euro	197,546	351,518	211,461	379,347
Maintenance	euro	45,994	83,773	51,560	94,905
Insurance	euro	11,628	20,866	12,463	22,536

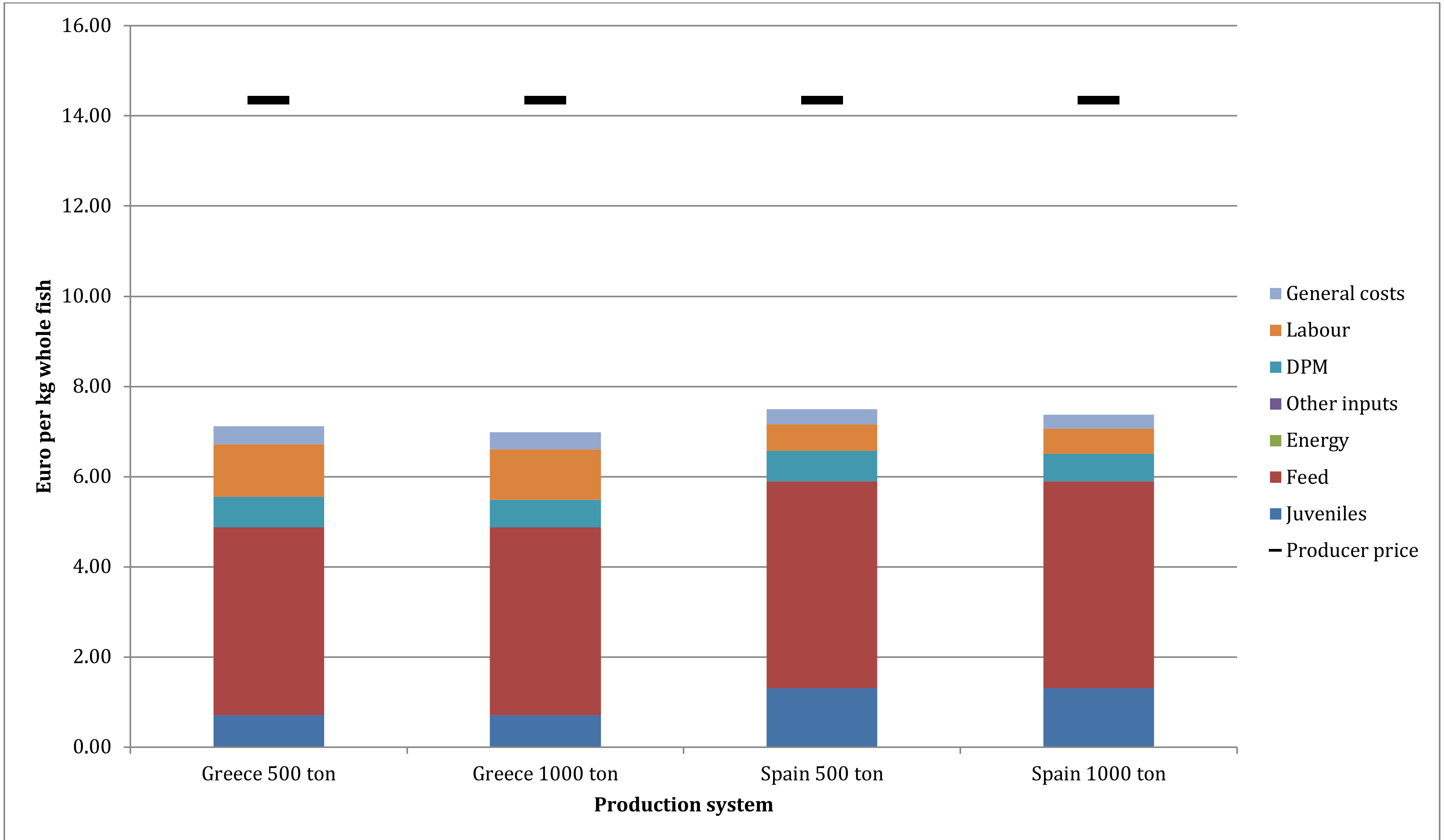

Figure 4.1 Composition of the cost price ex farm gate for the out-grow production in cages of greater amberjack in Greece and Spain at 2 farm sizes.

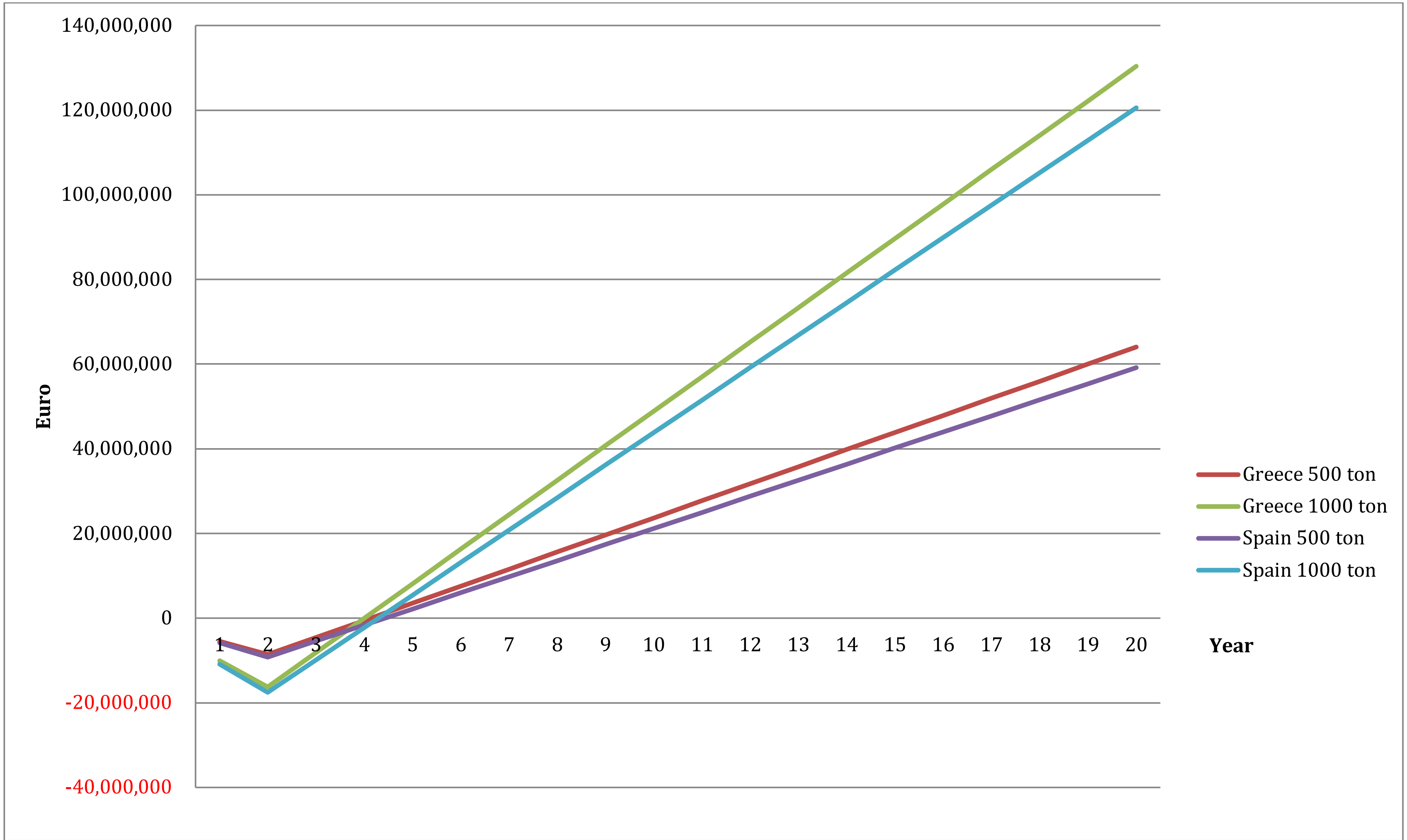

Figure 4.2 Cumulative cash flow for the out-grow production in cages of greater amberjack in Greece and Spain at 2 farm sizes.

Besides the previously mentioned initial investments in durable production means (DPM) also the costs of building up the fish stock during the first 2 years are enormous. After that the revenues from fish sales contribute to a rapid increase of the cumulative cash flow.
Figure 4.2 shows that all farms are able to generate a highly positive cumulative cash flow and offer viable business propositions at the current producer prices. The break-even point is reached after 4 to 5 years and the internal rate of return (IRR) is even 34% to 40%! The realized producer price is of overriding importance in these calculations, but even at a 40% lower price all these farms will be quite profitable.

4.2 Technological risks

Before the project several technical issues had to be solved for greater amberjack (Papandroulakis et al., 2018):

- *Reliable reproduction.* In the Mediterranean no reliable spontaneous reproduction of cultured greater amberjack had been reported before the project. Spontaneous reproduction in captivity is still problematic, but hormonal induction methods have been developed to induce spawning in fish maintained in tanks and sea cages, producing large numbers of eggs of good quality for commercial larval rearing purposes. Hatchery-produced (F1) individuals were shown to undergo reproductive maturation in captivity. Using either GnRHa implants or GnRHa injections production of fertilized eggs has been successful.
- *Larval husbandry; production of adequate numbers of juveniles in captivity.* More information was needed on larval rearing parameters. After studying the ontogeny of the species (digestion and vision systems, somatotropic axis, etc) important information on the biology of the greater amberjack was gathered. Additional studies on the feeding regime and some critical husbandry parameters (tank type and shape duration of the photo phase, tank background and colour, light conditions and stocking density) were also necessary and implemented during the project. This resulted in significant breakthroughs in larval rearing. A larval rearing system based on a large tank and low initial stocking of eggs-larvae (up to25 eggs l^{-1}) improves the growth performance. Light conditions and water quality specific optimum levels are also defined. Feeding protocols have to be coordinated with the rearing conditions and the larval development, while appropriate enriching diets for rotifers and Artemia nauplii have been proposed. Specific husbandry practises have been identified and proposed (sorting in size as early as from 20 days post hatching) although additional work is also needed.
- *Grow out husbandry.* On growing trials until commercialization resulted in important information on feeding patterns and stocking densities, while the species' temperature tolerance has been determined. A major issue during on growing is the infection of species-specific parasites that can cause significant mortalities. However, treatment protocols are defined that can minimise the problem.
- *Health.* Some cases of bacterial infections and parasitic diseases were reported for this species. DIVERSIFY studied the potential pathologies that occurred to develop early diagnosis tools, veterinary solutions and preventive veterinary protocols for sustainable rearing. This included probes for the early detection of epitheliocystis, and methods to control infestations of parasites (*Zeuxapta seriolae* and *Neobenedenia gireliae*).

Further work is needed on two directions. First to overcome the biological barriers and second to develop appropriate marketing strategies for the species:
Regarding the biological barriers,

(a) optimal nutrition in all stages of growth needs further research

(b) reproduction and in particular off-season egg production, reproduction in land-based facilities, natural spawning,
(c) understanding the size variability during larval rearing and develop husbandry practices,
(d) similar for on growing, size variability and husbandry practices and
(e) for pathology, prevention schemes and oral antiparasitic treatment.

Regarding, marketing the focus ought to be on a trademark/ product development considering that G. amberjack should not be "one-more-fish" but rather the base for more fish-products.

4.3 Environmental impact

In DIVERSIFY there is no specific environmental study done for Greater amberjack. So the environmental impact of producing Greater amberjack could only be based on literature on aquaculture production systems.

The larval rearing for Greater amberjack is done in tanks and/or RAS systems. The environmental impact of these systems has been improved in the last couple of years due to water cleaning systems. In general, this type of system has the following environmental impact (Martins et al., 2010):

- A closed production system like RAS or a tank has the main advantage that the feed conversion efficiency is high. There is relatively low wastage of feed and the fish learn very quickly when and where feed is dispersed.
- For a RAS more energy is needed since water circulation is needed. Use of energy has environmental impact as such.
- In RAS and tank systems for on growing, manure of the fish has to be expelled from the tanks and be used somewhere else. It has no direct environmental impact, as long as there is a market for it.
- However, a RAS is a closed system in which everything can be controlled and in which pollution is controlled and no interference with the environment is needed.
- RAS systems and tanks are however controlled in ways that resemble a lot with industrial production of meat and eggs. Animal welfare organisations claim that fish in tanks or RAS system have lower animal welfare than fish in cages, since they are nearly in their own habitat. However, larvae perform better in RAS, which gives the impression that RAS is a good system for larval rearing. More research is needed to confirm that.

The grow out of Greater amberjack can be done in a RAS system and in cages in the sea. For grow out in RAS the same environmental issues are relevant as in the larval rearing described above. Grow out in cage system has very strict regulations, but it has other environmental issues that have to be taken into consideration (Braaten, 2007; Martinez-Porchas et al, 2012):

- Aquaculture can lead to eutrophication and nitrification of effluent receiving ecosystems, if the carrying capacity of the side is exceeded.
- Beneath the cages sediments can be found of faecal wastes and uneaten feed, if the above is true, and the depth of water is not great enough. This may attract some wild species.
- Negative effect on fisheries. A lot of fish in a cage can have effect on the oxygen conditions in and just around the cages, what makes that wild life moves away from their natural habitat to other areas.
- Fish in cages might escape (due to damage by storms, collisions with boats, predator attacks and vandalism) so that cultured and wild fish mix with potential spawning in the wild. This might lead to genetic pollution.
- Ecological impacts in natural ecosystems. Due to the feed losses, congregation of wild fish near and around the cages is possible, and interaction between fishes might lead to transfer of microbial pathogens and/or parasites (both ways).

- Large sites of fish farming might lead to water pollution for human consumption, if water is taken from the same area. However, this is less relevant for sea cage systems as used by Greater amberjack.
- Cage farming might have impact on landscape and hydrological patterns. It could lead to degradation of ecosystems.
- Most cultured species are carnivores, which means that they are fed with fish meal and fish oil. So wild fish have to be caught to make the feed. This makes that increase of such aquaculture species leads to more feed needs and higher pressure on the wild fish population. However, the last years, the use of marine oil and protein is decreasing and plant-based feed sources are increasing. In addition, new sources such as insect meal and marine oils from microalgae are being developed as plant oil and protein are not sustainable in the long term and also change the fatty acid profile of the fish.
- Other accusations are that toxins and/or heavy metals come in the water as well as infestation of non-desirable phytoplankton and/or zooplankton species.

4.4 Social impact

For social impact analysis we use the definition of Vanclay (2012) “Social Impact Assessment includes the processes of analysing, monitoring and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programs, plans, projects) and any social change processes invoked by those interventions [...].”

According to this definition, introduction of areater Amberjack in cages in Southern Europe, might have the following social consequences:

- Greater amberjack may be an alternative for tuna, both for fillet and processed products like sushi. Since tuna was mainly caught and processed in the Mediterranean, and it has low quota a new alternative has to be found to fill this gap in supply of a Mediterranean fish species.
- Greater amberjack is perfectly suitable for production in the Mediterranean, for processing companies a transition from wild catch tuna to processed greater amberjack might not be a big step. Production of greater amberjack could rescue employment in processing companies in the Mediterranean for people who might lose their job due to decreasing quota for tuna.
- For the aquaculture producers in the Mediterranean, introduction of a potential successful species like greater amberjack might give new perspectives for a good income. The margins from farms are large, as shown in the financial feasibility above, in contrary to other aquaculture species. Especially farms that are limited in growth, can find a new future with producing a new species.

In general, no essential large negative social impact of the introduction of Atlantic halibut is expected.

4.5 Market impact

Market impact is defined as the impact of introduction on potential and current markets and impacts on market demand for fish (products) that are to be expected for Atlantic halibut (based on Kotler, 2003).

Greater amberjack has in potential a high market impact for the fish and aquaculture market:

- It has in potential the same chances as tuna or Atlantic salmon, since it can be filleted nicely and it is perfectly applicable in products like sushi.
- Fresh tuna and processed tuna for sushi are both wanted in the European and Asian markets, and demand exceeds the current catch of tuna. Therefore, there is no doubt that this species has a good market future, if:
    - Technological hick-ups are solved

    - Production grows slowly according growth of demand
- For aquaculture farmers this species is interesting, since the margins are attractive.
- Buyers in the retail are interested in new species, since they have the impression that the (cultured) fish assortment is too small. Fresh local produce from the EU is for their margins much more attractive than frozen meat from another continent.
- Suppliers of tuna might feel more competition due to introduction of cultured greater amberjack.

5 Grey mullet (*Mugil cephalus*)

Grey mullet is a species that is cultured for centuries. As it is omnivorous/detritivorous in the wild, it has been stocked in fish ponds to improve sediment quality and to avoid oxygen depletion. Cultured grey mullet is generally grown in polyculture ponds with different types of carp, tilapia, milkfish and European sea bass. Therefore, it is an enhancement of aquaculture in earthen ponds, coastal lagoons and deserted Salinas that exist throughout the EU Mediterranean (Koven et al., 2018). Monoculture of grey mullet is in its infancy. Grey mullet is originally fed with fish meal, and replacement with more sustainable alternatives was needed at the project.

Grey mullet provides an affordable whole fish and fillets and fish roe (bottarga), and is a well-known species around the Mediterranean especially in middle East countries and North African communities.

5.1 Financial feasibility

No validation of financial feasibility was available at the end of the project.

5.2 Technological risks

Before the project several technical issues had to be solved for greater amberjack (Koven et al., 2018):

- *Spawning.* At the beginning of the project the grey mullet culture was capture-based farming, relying almost exclusively on capture of wild fry. Spontaneous reproduction in captivity remains a problem, but spawning was achieved using GnRHa and metoclopramide therapies, producing millions of fertilized eggs. Optimization of the hormone-based reproduction control protocol is still necessary.
- *Reproduction.* The reproductive cycle was not controlled and egg quality was low. However, hormonal treatments have proven their efficacy to produce a healthy and numerous offspring's.
- *Larval rearing.* A rearing protocol has been developed to reduce early mortalities, size dispersion as well as increasing metamorphic synchrony. Algal addition during larval rearing provides beneficial effects in terms of rotifer consumption, and larval survival and growth. Larval stages have a high taurine requirement during rotifer feeding, and the benefit of this nutrient during early feeding was still apparent during juvenile growth. Taurine is essential not only for promoting growth in larvae, but also for other physiological pathways such as muscle function.
- *Grow out.* A production protocol has to be developed that performs well under different environmental conditions of temperature, pond type, and water quality. After metamorphosis, commercial feeds for juveniles should be designed for the omnivorous feeding of this species and include higher levels of starch or other low cost amylolytic energetic compounds.
- *Nutrition.* Fishmeal-free production is needed, to make the production sustainable. Diets with low fishmeal content can be used successfully for on-growing without any detrimental effect on growth performance.

The remaining bottlenecks for increased and stable production (Koven et al., 2018) are:

reduce larvalFurther challenges and studies for grey mullet:

- Reducing mortality during the first ten10 days of larval rearing
  - Improve brood stock diet
  - Investigate specific algal nutrients that stimulate gut maturation
  - Ciliate pre-rotifer feeding to improve the survival past PNR
- Poor growth and size variability during the
  - Major obstacle for the future of grey mullet monoculture
  - Exacerbated with increased stocking density of ponds
  - Small fish separated from large fish grow significantly faster than larger fish; growth compensation

- Possible stress interaction between individuals. Modulate the stress response through the diet
- May lead to female skewed populations, which grow faster
- Improve grow-out diet-fish also feeding on natural productivity as well as feed

The main technological risk of this species is that reproduction in captivity still relays on hormonal treatments. Most of the production still remains captive-based.

5.3 Environmental impact

In DIVERSIFY there is no specific environmental study done for grey mullet. So, the environmental impact of producing grey mullet can only be based on literature on aquaculture production systems.

The larval rearing for Grey mullet is done in tanks and/or RAS systems. The environmental impact of these systems has been improved in the last couple of years due to water cleaning systems. In general, this type of system has the following environmental impact (Martins et al., 2010):

- A closed production system like RAS or a tank has the main advantage that the feed conversion efficiency is high. There is relatively low wastage of feed and the fish learn very quickly when and where feed is dispersed.
- For a RAS more energy is needed since water circulation is needed. Use of energy has environmental impact as such.
- In RAS and tank systems for on growing, fish waste is eliminated from the tanks and can be used somewhere else or processed by an authorized environmental company. It has no direct environmental impact, as long as there is a market for it. Only in case of large expansion of the aquaculture sector, in combination with a low market for application of fish waste in other fields (floriculture…) this can become an environmental problem.
- However, a RAS is a closed system in which culture parameters can be controlled and in which pollution is controlled and no interference with the environment is needed.
- RAS systems and tanks are however, are controlled informs of aquaculture, that might resemble an industrial production of meat and eggs. Animal welfare organisations claim that fish in tanks or RAS system have lower animal welfare than fish in cages, since in cages the fish are nearly in their own habitat although at much higher densities. However, larvae perform better in RAS, which gives the impression that RAS is a good system for larval rearing. More research is needed to confirm that

The grow out of grey mullet can be done in RAS, ponds and in cages in the sea. For grow out in RAS the same environmental issues are relevant as in the larval rearing described above. Grow out in cage system has very strict regulations, but it has other environmental issues that have to be taken into consideration (Braaten, 2007; Martinez-Porchas et al, 2012):

- Aquaculture can lead to eutrophication and nitrification of effluent receiving ecosystems, if the carrying capacity of the side is exceeded.
- Beneath the cages, sediments are integrated by faecal wastes and uneaten feed, if the above is true, and the depth of water is not great enough. This may attract some wild species.
- Negative effect on fisheries. A lot of fish in a cage can have effect on the oxygen conditions in and just around the cages, what makes that wild life moves away from their natural habitat to other areas.
- Fish in cages might escape (due to damage by storms, collisions with boats, predator attacks and vandalism) so that cultured and wild fish mix with potential spawning in the wild. This might lead to genetic pollution.

- Ecological impacts in natural ecosystems. Due to the feed losses, congregation of wild fish near and around the cages is possible, and interaction between fishes might lead to transfer of microbial pathogens and/or parasites (both ways).
- Large sites of fish farming might lead to water pollution for human consumption, if water is taken from the same area. However, this is less relevant for sea cage systems as used by grey mullet.
- Cage farming might have impact on landscape and hydrological patterns. It could lead to degradation of ecosystems.
- Cages could also trap and kill eggs, larvae, juveniles and adults of other species
- Some cultured species are carnivores, which means that they are fed with fish meal and fish oil. So wild fish have to be caught to make the feed. This makes that increase of such aquaculture species leads to more feed needs and higher pressure on the wild fish population. However, the last years, the use of marine oil and protein is decreasing and plant-based feed sources are increasing. In addition, new sources such as insect meal and marine oils from microalgae are being developed as plant oil and protein are not sustainable in the long term and also change the fatty acid profile of the fish.
- Other accusations are that toxins and/or heavy metals come in the water as well as infestation of non-desirable phytoplankton and/or zooplankton species.

Grey mullet is commonly produced for grow out in polyculture earthen ponds with European seabass or other species. We summarise here the most important environmental risks of pond aquaculture:

- Although a pond is an ecosystem per se, a good feed management can minimize the environmental impact of the feed on the quality of the bottom soil.
- In ponds, fish waste accumulates on the bottom. Once the production cycle is finished, the pond is emptied and dried just under the sun or sometimes lime is used to have a deeper disinfection.
- May be in the ponds, the culture conditions are determined by the climatological conditions of the geographic area and the seasonality (hours of light, hours of sun, water temperature etc…). Daily water exchanges using the tides combined with pumping systems can help to modify water temperature and available oxygen, although liquid oxygen is used in some farms.
- Pond culture is based in the application of lower culture density than cages due to the limitations of the possible control of environmental variables in such a system.

5.4 Social impact

For social impact analysis we use the definition of Vanclay (2012) “Social Impact Assessment includes the processes of analysing, monitoring and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programs, plans, projects) and any social change processes invoked by those interventions [...].”

According to this definition, introduction of grey mullet in the market, might have the following social consequences:

- Cultured grey mullet is generally grown in polyculture ponds with different types of carp, tilapia, milkfish and European sea bass. Therefore, it is an enhancement of aquaculture in earthen ponds, coastal lagoons and deserted Salinas that exist throughout the EU Mediterranean. Since it is more a Mediterranean fish species and it is very well known in the middle East market it could be a species that gives new employment in the Mediterranean market.
- Production of this species will not decrease employment in other species since it is an additional species with a specific market.

- Due to a large increase of production, margins in sea bass and sea bream production have decreased. If grey mullet is added to the cages or is able to provide additional margins this could improve the profitability of current farms in the Mediterranean.
- EU grey mullet is an interesting species that can be an alternative for grey mullet grown in Egypt, but also a species that can replace other species grown outside the EU that are difficult to control on food quality aspects. Introduction of the species in the EU might result in decreasing employment in Egypt in the aquaculture sector due to decreasing demand in the EU. However, the increasing demand for protein in Africa and Asia, might give them alternative market opportunities.

In general no essential large negative social impact of the introduction of grey mullet is expected.

5.5 Market impact

Market impact is defined as the impact of introduction on potential and current markets and impacts on market demand for fish (products) that are to be expected for Atlantic halibut (based on Kotler, 2003).
Grey mullet has in potential a low to medium market impact for the fish and aquaculture market:

- It is potentially an easy to process species and a few high-margin products can be made with the species.
- There is already market demand for Bottarga and grey mullet in the Middle-eastern society. So, market penetration can be done relatively easily, by just emphasizing that grey mullet is now available all over Europe.
- Most retailers are trying to find the way to immigrants in their country. Originally, they prefer to buy groceries at guaranteed halal supermarkets and specialty stores that are run by Muslim owners. Buyers from supermarkets are always interested in new species, that can increase their market share in halal buying segments.
- Grey mullet can be attractive as fresh and as frozen product. Fresh local produce from the EU is for their retail margins much more attractive than frozen meat from another continent. But margins are less important for grey mullet as it turns out to be a traffic maker, what means that it attracts new clients to a supermarket.
- Suppliers of grey mullet from outside the EU might feel more competition due to introduction of EU cultured fish.

6 Meagre (*Argyrosomus regius*)

The main advantage of meagre is its rapid growth, large size, good processing yield and low-fat content, excellent taste and firm texture. The main positive characteristics for aquaculture are fast growth, high feed conversion efficiency similar to Atlantic salmon, relatively easy rearing and established induced spawning protocols for production of viable eggs.

6.1 Financial feasibility

No validation of financial feasibility was available at the end of the project.

6.2 Technological risks

Before the project several technical issues had to be solved for meagre (Estevez et al., 2018):

- *Genetic variation.* There was fear for limited genetic variation of broodstocks, since fish from only limited areas in the Mediterranean was sourced. In DIVERSIFY three different populations and sufficient genetic variation was confirmed in a number of broodstocks around Europe; if managed properly there is sufficient genetic variation for breeding programs.
- *Grow out.* Variable growth rates, whose exact cause was not known, that reduce greatly the yield. A multidisciplinary approach of genetics, nutrition, feeding behaviour and grow out expertise is necessary to solve this.
- *Fertilization*. Protocols for meagre paired spawning and for the acquisition of gametes for in vitro fertilization have been developed, as methods to implement breeding programs.
- *Feed efficiency*. A protocol for early weaning was developed and the role of essential fatty acids and vitamins C, E and K in weaning diets was identified.
- *Feeding moment.* Feeding in sea cages can be carried out during day or night using programmed feeders with good results. Optical and mechanical stimuli can be used to improve feeding behaviour in meagre
- *Health.* Emerging diseases, parasites and wide occurrence of Systemic Granulomas are prevalent and possibly caused by the diet, but this was not sure at the beginning of the project. Immune markers have been established for the innate, adaptive and inflammatory responses of the immune system of meagre in order to develop vaccines in the future. Methods to prevent Chronic Ulcerative Dermatopathy, to ameliorate the extend of Systematic Granulomatosis and to address parasitic and bacterial infections have been developed.
- *Socioeconomic bottlenecks.* There is ample market developed for this species beyond whole fresh fish. New product ideas and market information is necessary to develop the market further. During the project several product ideas for meagre have been found, worked out, technically assessed and tested in the market. Meagre turns out to be a very interesting species.

As presented above most of the issues are solved, however for meagre the following research topics are open:

- Cannibalism during weaning and first periods of on growing
- Continue working on sea cage on growing and us of feeding stimuli
- Causes of granulomatosis

The main technical risks for meagre are the relatively small base of broodstock and the prevalence of parasites and bacterial infections that have to be treated in cages in the sea.

6.3 Environmental impact

In DIVERSIFY there is no specific environmental study done for meagre. So the environmental impact of producing meagre can only be based on literature on aquaculture production systems.

The larval rearing for meagre is done in tanks and/or RAS systems. The environmental impact of these systems has been improved in the last couple of years due to water cleaning systems. In general, this type of system has the following environmental impact (Martins et al., 2010):

- A closed production system like RAS or a tank has the main advantage that the feed conversion efficiency is high. There is relatively low wastage of feed and the fish learn very quickly when and where feed is dispersed.
- For a RAS more energy is needed since water circulation is needed. Use of energy has environmental impact as such.
- In RAS and tank systems for on growing, manure of the fish has to be expelled from the tanks and be used somewhere else. It has no direct environmental impact, as long as there is a market for it.
- However, a RAS is a closed system in which everything can be controlled and in which pollution is controlled and no interference with the environment is needed.
- RAS systems and tanks are however controlled in ways that resemble a lot with industrial production of meat and eggs. Animal welfare organisations claim that fish in tanks or RAS system have lower animal welfare than fish in cages, since they are nearly in their own habitat. However, larvae perform better in RAS, which gives the impression that RAS is a good system for larval rearing. More research is needed to confirm that.

The grow out of meagre can be done in a RAS system and in cages in the sea. For grow out in RAS the same environmental issues are relevant as in the larval rearing described above. Grow out in cage system has very strict regulations, but it has other environmental issues that have to be taken into consideration (Braaten, 2007; Martinez-Porchas et al, 2012):

- Aquaculture can lead to eutrophication and nitrification of effluent receiving ecosystems, if the carrying capacity of the side is exceeded.
- Beneath the cages sediments can be found of faecal wastes and uneaten feed, if the above is true, and the depth of water is not great enough. This may attract some wild species.
- Negative effect on fisheries. A lot of fish in a cage can have effect on the oxygen conditions in and just around the cages, what makes that wild life moves away from their natural habitat to other areas.
- Fish in cages might escape (due to damage by storms, collisions with boats, predator attacks and vandalism) so that cultured and wild fish mix with potential spawning in the wild. This might lead to genetic pollution.
- Ecological impacts in natural ecosystems. Due to the feed losses, congregation of wild fish near and around the cages is possible, and interaction between fishes might lead to transfer of microbial pathogens and/or parasites (both ways).
- Large sites of fish farming might lead to water pollution for human consumption, if water is taken from the same area. However, this is less relevant for sea cage systems as used by meagre.
- Cage farming might have impact on landscape and hydrological patterns. It could lead to degradation of ecosystems.
- Most cultured species are carnivores, which means that they are fed with fish meal and fish oil. So wild fish have to be caught to make the feed. This makes that increase of such aquaculture species leads to more feed needs and higher pressure on the wild fish population. However, the last years, the use of marine oil and protein is decreasing and plant-based feed sources are increasing. In addition, new sources such as insect meal and marine oils from microalgae are being developed as

plant oil and protein are not sustainable in the long term and also change the fatty acid profile of the fish.

- Other accusations are that toxins and/or heavy metals come in the water as well as infestation of non-desirable phytoplankton and/or zooplankton species.

6.4 Social impact

For social impact analysis we use the definition of Vanclay (2012) "Social Impact Assessment includes the processes of analysing, monitoring and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programs, plans, projects) and any social change processes invoked by those interventions [...]."
According to this definition, introduction of meagre in the European countries, might have the following social consequences:

- Meagre is a fast-growing species that is very interesting in the European market, but only not well-known yet. Therefore, the social impact is difficult to predict, since it is not known yet what marketing budget will be available to make this species a success.
- Meagre is especially interesting for producers in the Mediterranean, so the main social impact is to be expected in that region. Fish farmers are interested, but market acceptation by mongers and retailers ultimately determines the potential of the species.

6.5 Market impact

Market impact is defined as the impact of introduction on potential and current markets and impacts on market demand for fish (products) that are to be expected for Atlantic halibut (based on Kotler, 2003).
Atlantic halibut has in potential a high market impact for the fish and aquaculture market:

- The market future of meagre is unsure, since:
  - Technological hick-ups are solved
  - Market acceptation is still unclear
  - Production and demand have to be increased in line
- For aquaculture farmers this species is interesting. They love the species since it is a fast-growing species with good feed conversion efficiency.
- Buyers in the retail are interested in new species, since they have the impression that the (cultured) fish assortment is too small. Fresh local produce from the EU is for their margins much more attractive than frozen meat from another continent.
- Producers of other species might feel more competition due to introduction of cultured meagre. But although it is in the market in Spain and Portugal, this project didn't learn what other product it replaces.

7 Pikeperch (*Sander lucioperca*)

According to Fontaine et al. (2018) pikeperch is considered as the most potential fresh water fish for inland aquaculture diversification (Wang et al., 2008, Kestemont et al., 2015). The market growth for pikeperch aquaculture is a result of the strong decrease of wild catch, since wild catch is declined with two-third from 1950 to 2014 (FAO, 2015). Pikeperch is produced in RAS systems in Belgium, Czech Republic, Denmark, France, Germany, Hungary, the Netherlands and Switzerland.
Pikeperch can be characterised as a tender white fish with a neutral taste, which is applicable in lots of recipes, with nice fillets that are easily deboned (unlike competing species) (Fontaine, 2018).

7.1 Financial feasibility

System design
The most promising production system for the grow-out of pikeperch is growing them in Recirculating Aquaculture Systems on land as is common practice on most pikeperch farms in Europe. With assistance of private company Fish 2 Be, a supplier of fingerlings to grow-out farmers throughout Europe and also involved in grow-out farming themselves, the technical and biological parameters were defined (Table 7.1, indicated in red). Next the dimensions of the required inputs and resulting outputs were determined at four farm sizes ranging from an annual production volume of 50 to 200 tons whole fish (Table 7.1, indicated in black).

Data inputs-outputs
The prices of the major inputs and outputs are listed in Table 7.2. Most of these prices were provided by Fish 2 Be unless mentioned otherwise. As can be seen in the table no scale effect is expected on the inputs except for the RAS tanks including installation costs.
Furthermore, the producer prices ex farm gate is set at 8.50 euro per kg whole fish. According to the FAO Statistics the actual producer price is around 15 euro per kg. However, this price is related to the production in ponds (polyculture) for the market of live fish for river restocking and recreational fishing and does not concern production in RAS tanks. The difference between the producer price ex farm gate and the actual sales price should cover the costs of transportation, slaughtering, processing and marketing and sales.

Investments
The number of units per type of investment as well as the calculated total initial investments and annual depreciation, maintenance and insurance costs are shown in Table 7.3. As can be seen in the table some investments are independent of the scale (e.g. office building and heating installation), whereas investments in the actual rearing facilities vary with scale (e.g. production building and RAS tanks).
The total initial investments range from 2.0 to 3.9 million euro depending on farm size, whereas the total annual depreciation, maintenance and insurance ranges from 185 to 305 thousand euro.

Cost price
The composition of the cost price ex farm gate for each of the four farm sizes is illustrated in Figure 7.1. The total cost price decreases from 11.20 euro per kg whole fish at an annual production volume of 50 tons to 7.57 euro per kg whole fish at an annual production volume of 200 tons. Around an annual volume of 125 tons the total cost price equals the estimated producer price ex farm gate of 8.50 euro per kg whole fish. The large cost components juveniles (1.44 euro per kg) and feed (2.18 euro per kg) are supposed to be independent of farm size. The major cost component durable production means (DPM) however rapidly decreases with increasing farm size from of 4.56 to 1.92 euro per kg, as well as the minor cost component labour from 1.30 to 0.70 euro per kg. are decreasing. These are clear examples of the economy of scale!

Cash flow

In the decision-making process of investing in completely new farms the cumulative cash flow over a period of 20 years is of interest. Figure 7.2 illustrates this cash flow for the four identified farm sizes. It shows that during the first two years an investment capital is needed ranging from 2.3 million euro at an annual production volume of 50 tons to 4.8 million euro at an annual production volume of 200 tons. Besides the previously mentioned initial investments in durable production means (DPM) also the costs of building up the fish stock during the first year are considerable.

Table 7.1 System design of the out-grow production in Recirculating Aquaculture Systems of pikeperch in France at 4 farm sizes.

	Unit	Farm 50 ton	Farm 100 ton	Farm 150 ton	Farm 200 ton	Remarks and sources
Production	ton/y	50.0	100.0	150.0	200.0	
Start weight	G	15.0	15.0	15.0	15.0	
Final weight	G	900.0	900.0	900.0	900.0	
Growth period	months	12.0	12.0	12.0	12.0	
Cycles	#/y	4.0	4.0	4.0	4.0	
Stocking density	#/m3	1,000	1,000	1,000	1,000	
Survival	%	85%	85%	85%	85%	
Minimum density	kg/m3	15.0	15.0	15.0	15.0	
Maximum density	kg/m3	40.0	40.0	40.0	40.0	
Average stocking density	kg/m3	27.5	27.5	27.5	27.5	sorting 2-3 times per cycle
Productivity	kg/m3/y	110.0	110.0	110.0	110.0	
Rearing area	m3	455	909	1,364	1,818	
Space utilisation	m3/m2	0.60	0.60	0.60	0.60	m3 of tank per m2 of production space
Production space	m2	758	1,515	2,273	3,030	
Feed conversion ratio	kg/kg	1.20	1.20	1.20	1.20	
Total feed use	ton/y	60.00	120.00	180.00	240.00	
Oxygen	kg/kg	1.00	1.00	1.00	1.00	kg oxygen per kg feed
Total oxygen use	ton/y	60.00	120.00	180.00	240.00	
Soda	kg/kg	0.40	0.40	0.40	0.40	kg soda per kg feed (to reduce pH)
Total soda use	ton/y	24.00	48.00	72.00	96.00	
Manure produced	kg/kg	0.25	0.25	0.25	0.25	kg manure produced per kg feed
Total manure produced	ton/y	15.00	30.00	45.00	60.00	
Water	m3/kg	0.30	0.30	0.30	0.30	m3 water per kg feed
Total water use	m3/y	18,000.00	36,000.00	54,000.00	72,000.00	

Table 7.1 (continued) System design of the out-grow production in Recirculating Aquaculture Systems of pikeperch in France at 4 farm sizes.

	Unit	Farm 50 ton	Farm 100 ton	Farm 150 ton	Farm 200 ton	Remarks and sources
Electricity	kWh/kg	0.66	0.66	0.66	0.60	kWh per kg feed
Total electricity use	MWh/y	39.60	79.20	118.80	145.00	
Heating	MJ/kg	13.00	13.00	13.00	13.00	MJ per kg feed
Total heat use	GJ/y	780.00	1,560.00	2,340.00	3,120.00	
Labour productivity	FTE/100 ton	1.50	1.50	1.50	1.50	STECF France 2010-2014 (rainbow trout)
Total labour use (minimum)	FTE/y	0.75	1.50	2.25	3.00	
Actual labour input:						
- high (e.g. entrepreneur)	FTE	0.75	1.00	1.00	1.00	formula or minimum value in formula can be overwritten
- middle (e.g. assistant manager)	FTE	0.00	0.50	1.00	1.00	formula or minimum value in formula can be overwritten
- low (e.g. production personnel)	FTE	0.50	0.50	0.50	1.00	minimum 0,5 FTE

Table 7.2 Prices of inputs and outputs for the out-grow production in Recirculating Aquaculture Systems of pikeperch in France at 4 farm sizes.

S/N	Costs (in euro)	Farm 50 ton	Farm 100 ton	Farm 150 ton	Farm 200 ton	Remarks and sources
1.	Investment costs					
	1.1. Land rent (ha)	700	700	700	700	
	1.2. Permits (per farm)	10,000	10,000	10,000	10,000	includes all start-up costs
	1.3. Buildings & storage					
·	office building (m2)	650	650	650	650	
·	production building (m2)	225	225	225	225	
	1.4. Machinery & equipment					
·	RAS tanks (m3)	1,800	1,500	1,350	1,200	all inclusive; economies of scale
·	biomass filtration and re-utilization system (piece)	850,000	850,000	850,000	850,000	
·	heating installation (piece)	75,000	75,000	75,000	75,000	gas boiler
·	other small equipment (per farm)	25,000	25,000	25,000	25,000	
2.	Operational costs					
	2.1. Juveniles (piece)					
·	fingerlings	1.10	1.10	1.10	1.10	
	2.2. Fish feed and other ingredients					
·	high protein low fat grow out feed (ton)	1820.00	1820.00	1820.00	1820.00	STECF France 2010-2014 (rainbow trout)
·	oxygen (ton)	140.00	140.00	140.00	140.00	
·	soda (ton)	440.00	440.00	440.00	440.00	caustic or normal
·	manure processing (ton)	75.00	75.000	75.00	75.000	
·	water (m3)	0.25	0.25	0.25	0.25	
	2.3. Energy costs					
·	electricity (MWh)	110.00	110.00	110.00	110.00	Eurostat 2012-2017 (non-households excluding taxes and recoverable levies)
·	heat (GJ)	32.30	32.30	32.30	32.30	Eurostat 2012-2017 (non-households excluding taxes and recoverable levies)
	2.4. Labour (per year per FTE)					
·	high (e.g. entrepreneur)	65,000	65,000	65,000	65,000	
·	middle (e.g. assistant manager)	42,000	42,000	42,000	42,000	STECF France 2010-2014 (rainbow trout)
·	low (e.g. production personnel)	32,000	32,000	32,000	32,000	
	2.5. General costs					
·	fixed (per farm)	25,000	25,000	25,000	25,000	STECF France 2010-2014 (rainbow trout)
·	variable (per kg production)	0.08	0.08	0.08	0.08	

Table 7.2 (continued) Prices of inputs and outputs for the out-grow production in Recirculating Aquaculture Systems of pikeperch in France at 4 farm sizes.

S/N	Costs (in euro)	Farm 50 ton	Farm 100 ton	Farm 150 ton	Farm 200 ton	Remarks and sources
5.	Financial costs (%)					
	· interest rate buildings and land	2.0%	2.0%	2.0%	2.0%	
	· interest rate equipment and fish stock	4.5%	4.5%	4.5%	4.5%	
	· inflation rate	1.3%	1.3%	1.3%	1.3%	Eurostat 2012-2017
6.	Outputs					
	· whole fish (kg)	8.50	8.50	8.50	8.50	

Table 7.3 Number of units per type of investment, total initial investments and annual depreciation, maintenance and insurance costs for the out-grow production in Recirculating Aquaculture Systems of pikeperch in France at 4 farm sizes.

	Unit	Farm 50 ton	Farm 100 ton	Farm 150 ton	Farm 200 ton
1.3. Buildings & storage					
· office building (m2)	m2	100.0	100.0	150.0	150.0
· production building (m2)	m2	757.6	1515.2	2272.7	3030.3
1.4. Machinery & equipment					
· RAS tanks (m3)	m3	454.5	909.1	1363.6	1818.2
· biomass filtration and re-utilization system (piece)	#	1.0	1.0	1.0	1.0
· heating installation (piece)	#	1.0	1.0	1.0	1.0
· other small equipment (per farm)	#	1.0	1.0	1.0	1.0
Total initial investment	euro	2,003,636	2,719,545	3,399,773	3,911,136
Depreciation	euro	150,182	185,977	219,989	245,557
Maintenance	euro	29,536	36,695	43,498	48,611
Insurance	euro	6,011	8,159	10,199	11,733

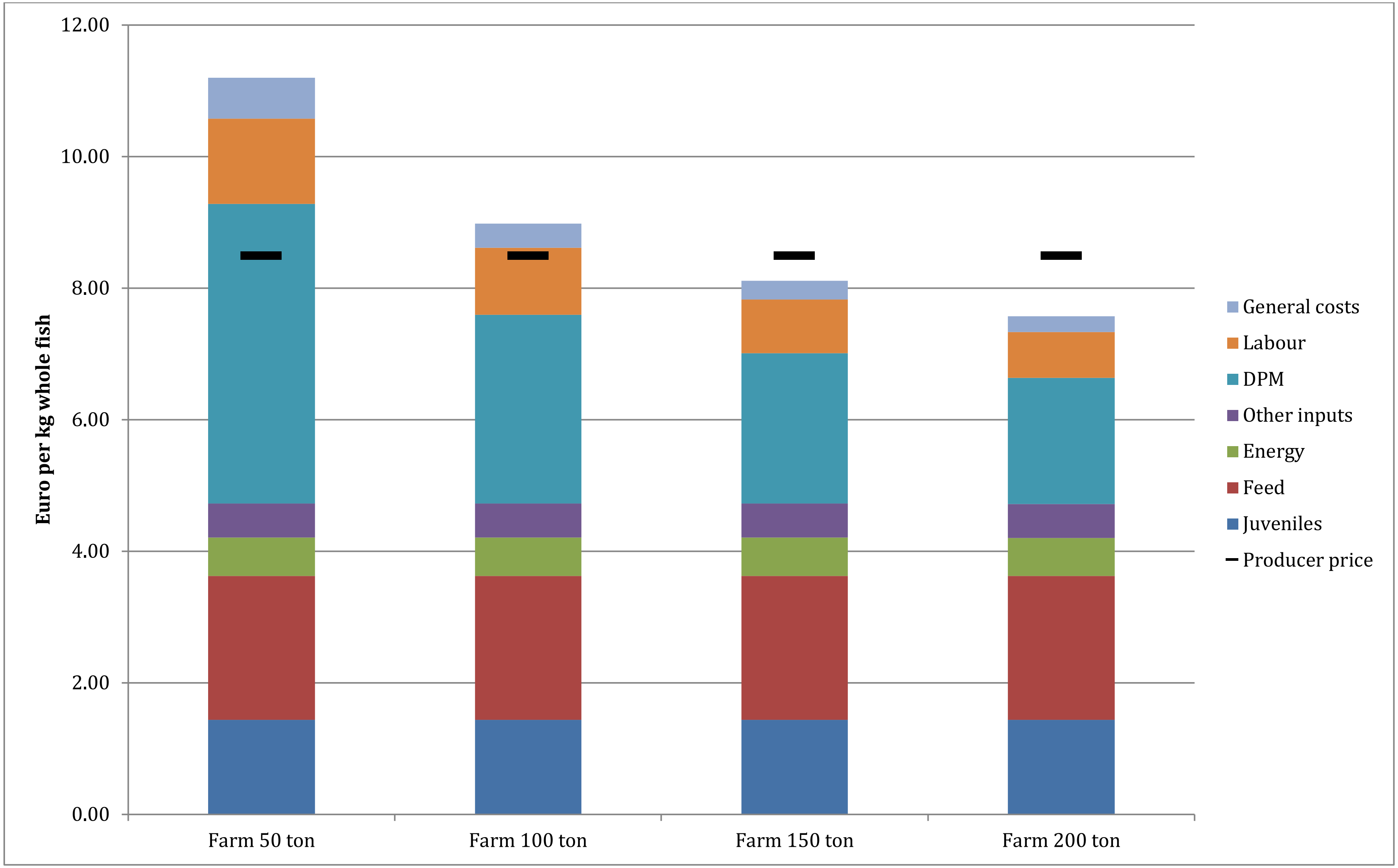

Figure 7.1 Composition of the cost price ex farm gate for the out-grow production in Recirculating Aquaculture Systems of pikeperch in France at 4 farm sizes.

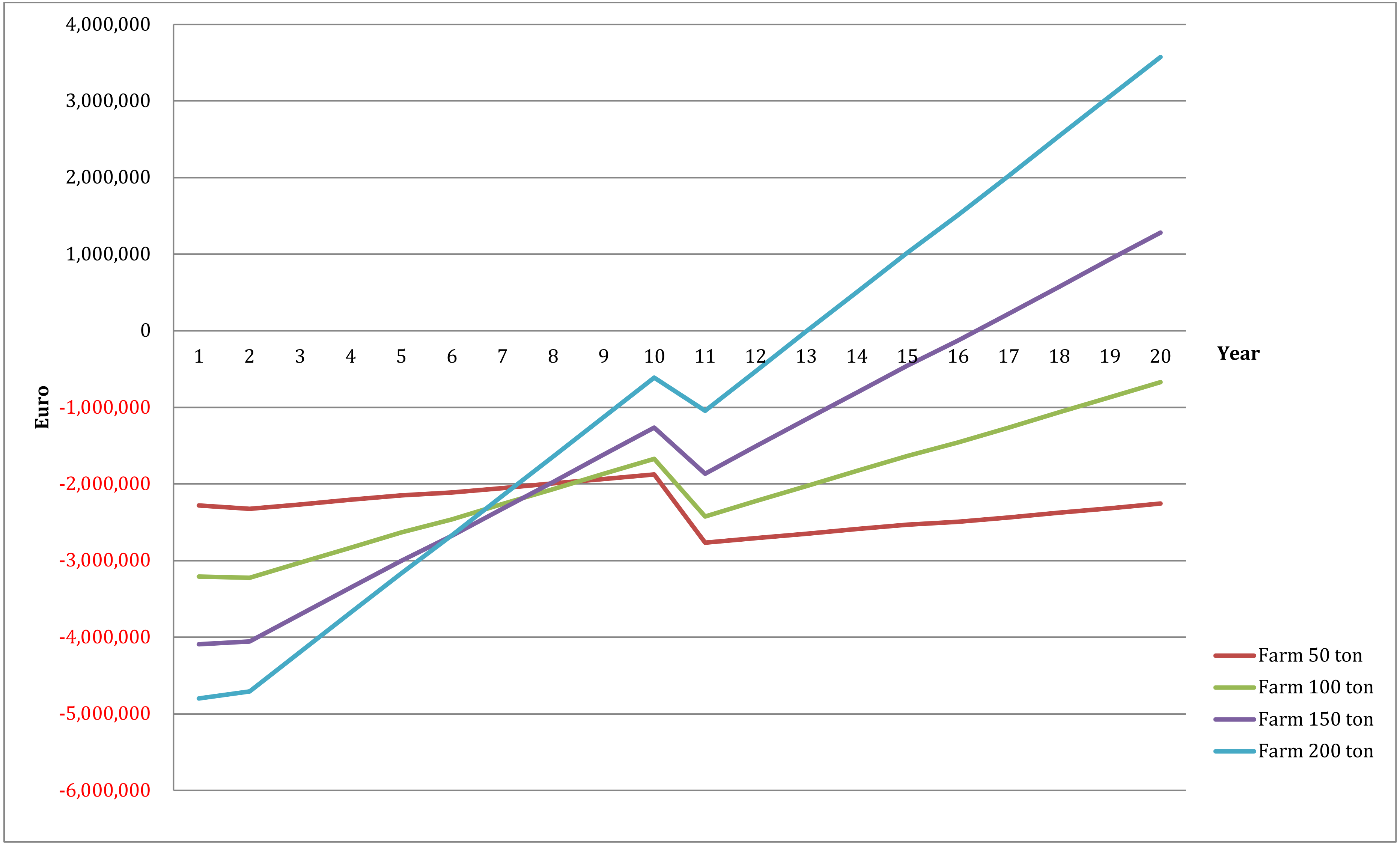

Figure 7.2 Cumulative cash flow for the out-grow production in in Recirculating Aquaculture Systems of pikeperch in France at 4 farms size over a period of 20 years.

After that the revenues from fish sales contribute to an increase of the cumulative cash flow, only interrupted by a small dip after 10 years because of supposed re-investments.
Figure 3.2 also shows that only the two farms with an annual production of 150 and 200 tons are able to generate a positive cumulative cash flow and offer a viable business proposition. The farm of 150 tons has an internal rate of return (IRR) of 3% and reaches break-even point after 17 years. The farm of 200 tons has an IRR of 6% and reaches break-even point after 14 years. The realized producer price is of overriding importance in these calculations and a 10% better price also makes the farm of 100 tons profitable.

7.2 Technological risks

Before the project several technical issues had to be solved for pikeperch (Fontaine et al., 2018):

- *Genetics.* There is lack of knowledge of the genetic variability of the used broodstocks. A genetic map comparing captive and wild broodstock was developed using microsatellite markers, to be used for breeding programs. In total 13 cultured and 8 wild populations are analysed and this shows that the majority of the populations show medium to low levels of genetic diversity and some of them even show inbreeding. The differences between domesticated broodstocks was high. The average values of heterozygosity and allelic richness are not significantly different between wild and domesticated populations. There are two genetically different groups: Northern Europe and Central Europe. In the Central group Hungary has genetically different pikeperch in relation to Czech Republic and Germany. Based on this data, the most important outcome is to develop breeding programs in order to improve growth and reduce production cycle duration.
- *Nutrition.* There are no specific feeds for pikeperch in the market yet. What is known is that it is essential that fatty acids are supplied in larval diets for normal development and to reduce stress sensitivity. DIVERSIFY learned that pikeperch requires a high level of PL in micro diets to sustain optimal growth. This reduced skeletal deformities. Essential fatty acids may not need to be incorporated in the PL fraction of the diet, and therefore EFA could be supplemented as triglycerides (in normal oil) to have a beneficial effect in larvae production. Ca/P, fatty acids and their interaction seem to be key nutritional factors. Next to that it is recommended that essential **Ω**-3 fatty (EPA + DHA) must be supplied to larvae for normal development and to reduce stress sensitivity. The results pointed out high occurrence of deformities and endochondral bones and increased incidence at higher salinities.
- *Larval husbandry.* Low larval survival (5 to 10%) due to cannibalism, high incidence of deformities and large size heterogeneity between larvae cohorts at various ontogenic development stages made that especially in this production phase research has been done. Studies have identified optimal combinations of environmental, feeding and population factors to improve survival (17%) and growth during larval rearing in RAS. However, it was still too low.
- *Grow out husbandry.* Pikeperch is very sensitive to stressors handling and husbandry practices that result in high and sudden mortalities. Red light spectrum at low intensity or white light spectrum at high intensity induced both a higher stress status. Low light intensity and red-light spectrum is less stressful and the effect was confirmed in RAS farm conditions. Domestication level was shown to influence stress responsiveness and immune response.

Further research is needed on:

- Larval nutrition, since the feed is very expensive and not optimal yet.
- Cannibalism in larval husbandry. The rates have been improved in Diversify but not enough to decrease costs at farm level.

- In the grow out husbandry tests the effects of light are found, but the immune status, humoral immune activities were only slightly impacted by some tested factors without conclusion.
- Improvement of growth performance
- Improvement of feeding strategy (decrease of feed costs)
- Increase survival rates during the nursery period (cannibalism), selection of populations
- Label the European pikeperch product
- Organise the exchange between fish farmers

The main technological risks for pikeperch are absence of tailor-made feed for pikeperch, what makes that production figures cannot be compared and improved. Next to that the cannibalism in the larval husbandry and the stress problems in the grow out husbandry have to be solved to make this a profitable species. Next to that sanitary risks have to be taken care of and production costs in RAS have to decrease.

7.3 Environmental impact

The larval rearing and grow out of pikeperch are mainly done in tanks and/or RAS systems. The environmental impact of these systems has been improved in the last couple of years due to water cleaning systems. In general, this type of system has the following environmental impact (Martin et al., 2010):
The larval rearing for Atlantic halibut is done in tanks and/or RAS systems. The environmental impact of these systems has been improved in the last couple of years due to water cleaning systems. In general, this type of system has the following environmental impact (Martins et al., 2010):

- A closed production system like RAS or a tank has the main advantage that the feed conversion efficiency is high. There is relatively low wastage of feed and the fish learn very quickly when and where feed is dispersed.
- For a RAS more energy is needed since water circulation is needed. Use of energy has environmental impact as such.
- In RAS and tank systems for on growing, manure of the fish has to be expelled from the tanks and be used somewhere else. It has no direct environmental impact, as long as there is a market for it.
- However, a RAS is a closed system in which everything can be controlled and in which pollution is controlled and no interference with the environment is needed.
- RAS systems and tanks are however controlled in ways that resemble a lot with industrial production of meat and eggs. Animal welfare organisations claim that fish in tanks or RAS system have lower animal welfare than fish in cages, since they are nearly in their own habitat. However, larvae perform better in RAS, which gives the impression that RAS is a good system for larval rearing. More research is needed to confirm that.

Some grow out of pikeperch is done in ponds. Grow out in ponds has other environmental issues (Braaten, 2007; Martinez-Porchas et al, 2012):

- A pond is a closed production system as a RAS and has the main advantage that the feed conversion efficiency is high. There is relatively low wastage of feed and the fish learn very quickly when and where feed is dispersed.
- In ponds manure of the fish has to be expelled or is a sediment on the bottom of the pond. In the first case it has no direct environmental impact, as long as there is a market for it. In the second case there is the risk of washing out of manure ingredients.
- However, as a RAS, ponds may be a closed system in which everything can be controlled and in which pollution is controlled and no interference with the environment is needed

- Pond systems resemble a lot with industrial production of meat and eggs. Animal welfare organisations claim that fish ponds have lower animal welfare than wild fish.
- Aquaculture can lead to eutrophication and nitrification of effluent receiving ecosystems.

7.4 Social impact

For social impact analysis we use the definition of Vanclay (2012) "Social Impact Assessment includes the processes of analyzing, monitoring and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programs, plans, projects) and any social change processes invoked by those interventions [...]."

According to this definition, introduction of pikeperch in the western European and mid-European countries, since it is a fresh water fish, might have the following social consequences:

- Pikeperch is already a well-known wild species in mid-EU. So, supply is mainly to be expected in the same region, since fresh fish supply is expected to have the highest margins. In central EU, traditionally meat is the main protein resource, but governments in the region are encouraging fish consumption.
- Pikeperch is a good species as alternative of *Pangasius* that has a profound market share in the region. Changing *Pangasius* for pikeperch might have a health impact, since production of pikeperch is controlled and produced according to EU regulations.
- Pikeperch has in the future the potential for good margins. The financial feasibility above doesn't show high margins yet, due to high cannibalism in the larvae growing phase and no optimal feeding, since there is no specific feed for pikeperch. Further research has the potential to increase the results in the future.
- Introduction of new whitefish species in the EU might result in decreasing employment in Asia in the aquaculture sector due to decreasing demand in the EU. However, the increasing demand for protein in Asia, might give them alternative market opportunities.

In general no essential large negative social impact of the introduction of pikeperch is expected.

7.5 Market impact

Market impact is defined as the impact of introduction on potential and current markets and impacts on market demand for fish (products) that are to be expected for Atlantic halibut (based on Kotler, 2003).

Pikeperch has in potential a medium market impact for the fish and aquaculture market:

- It has in potential a fresh and healthy alternative for *Pangasius*, since it is easy to process and a lot of potential products can be made with the species.
- White fish species are very wanted in the European market, and demand exceeds the local catch and production. Therefore, there is no doubt that this species has a good market future, if:
    - Cannibalism and feed conversion efficiency issues are solved
    - Production grows slowly according growth of demand
- For aquaculture farmers this species is interesting, since the margins are in potential attractive.
- Buyers in the retail are interested in new species, since they have the impression that the (cultured) fish assortment is too small. Consumers like *Pangasius*, but for retailers this is a risky species, due to the production risks in Asia. Fresh local produce from the EU is for their margins much more attractive than frozen meat from another continent.
- Supplier of other white fish species might feel more competition due to introduction of cultured pikeperch.

8 Conclusions

Greater amberjack and Atlantic halibut have currently the highest margins and therefore the best financial feasibility. The margins for pikeperch can be improved significantly when the cannibalism problems are solved and a specific feed with good conversion efficiency is developed. For meagre and grey mullet no financial information was available at the end of the project.

The environmental impact of the species was not researched in DIVERSIFY, but in general the impact of the different species on the environment is not better or worse than any other production in ponds, RAS or tank system or cages in the sea.

The social impact of introduction of the species is most likely to be highest in Norway and the Mediterranean. Greater amberjack and meagre are species that have potential in the south of Europe, while Atlantic halibut can be the diversification option versus salmon. Pikeperch is the central European option for aquaculture, but the margins are not high enough yet.

How large the market impact is of the species is mainly dependent of the acceptance by retail buyers and consumers. This can’t be quantified yet, but a good positioning can help a lot. All species need further research and effort on market positioning, marketing, and sensory research. On basis of this project all products have potential.

In Europe, **greater amberjack** shows the most promising market opportunities, given its large size, processing abilities and superior sensory characteristics. **Grey mullet** is a very interesting species due to the higher sustainability of its production methods. No specific preference region has been identified for this species. **Atlantic halibut** is especially interesting as alternative in the flatfish market since quota are decreasing and demand is still high. P**ikeperch** is especially interesting as the controlled and fresh alternative for Pangasius in mid-EU market and **meagre** has physical characteristics and is of interest in Southern Europe as start market. Wreckfish was not included in this study since it has no grow out yet.

9 Recommendations

All species need further technical and socio-economic research to be ready for full penetration in the market. In the technical paragraphs per species is indicated what the most important technical and market issues are that need further research. In general, further optimization of production and market development are the main attention points.

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