Current status on European lobster aquaculture in Europe

Report from the 3rd annual ELCE meeting held in Stavanger, Norway on 18 – 19 May 2015

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The main aim of the meeting was to organise a 3rd workshop in the ELCE network. ELCE wanted to continue the positive development within the network between Nordic companies and institutions carrying out research and commercial attempts with the European lobster. Due to a strong interest from countries outside the Nordic region, several European companies and research institutions were also invited in order to highlight status on lobster aquaculture in Europe. Another important aim, was to formally establish a steering committee of ELCE responsible for coordinating future activities and expansion of the network. Finally, it was an aim to discuss and optimise the utilisation of the existing database for knowledge sharing- and enhancement.

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Preface

On behalf of the network European Lobster Centre of Excellence (ELCE), Norwegian Lobster Farm hosted the 3rd annual meeting. Altogether 36 participants from a total of eight countries were present during the two days workshop.

The main aim of the meeting was to organise a 3rd workshop in the ELCE network. ELCE wanted to continue the positive development within the network between Nordic companies and institutions carrying out research and commercial attempts with the European lobster. Due to a strong interest from countries outside the Nordic region, several European companies and research institutions were also invited in order to highlight status on lobster aquaculture in Europe. Another important aim, was to formally establish a steering committee of ELCE responsible for coordinating future activities and expansion of the network. Finally, it was an aim to discuss and optimise the utilisation of the existing database for knowledge sharing- and enhancement.

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1 Introduction

The European lobster, *Homarus gammarus*,, is today one of the most valuable and preferred seafood in the world. Despite a vast distribution from Northern Norway to Greece and a small increase in volume recent years, the annual landings are currently less than 5,000 metric tons (MT), mainly from Ireland and Great Britain. The combinantion of marginal supply and an exclusive taste, the European lobster is today a promising candidate for aquaculture. Moreover, European lobster has a huge commercial potential in aquaculture due to its adaptable biology to aquaculture systems. They are relatively robust species to farm, there are no major problems producing huge quantities of IV larvae, and no weaning problems since the larvae eat formulated feed from day 1.

1.1 European lobster – an ideal candidate for aquaculture

Compared to other lobster species, the *Homarus* species are considered very hardy with a simple and abbreviated larval period. They feed readily on natural and artificial feeds, are resistant to disease and exhibit a very rapid and accelerated growth in warmed water (van Olst *et al*., 1980). Thus, temperature is the primary controller of growth and optimum water temperature has been found to be 20 ^{o}C (van Olst *et al*. 1980; Richards 1981; D'Abramo & Conklin 1985; Waddy 1988; Aiken and Waddy 1995; Drengstig & Bergheim 2013). Larval period in 20^{o}C water is around 12 days (Drengstig et al. 2005) compared to 35 days at 15^{o}C (van Olst *et al*. 1980). Furthermore, *H. gammarus* can reach 250-300g (total length 210 mm; carapace length 75mm) in 24 – 30 months as long as constant 20^{o}C water is provided (Wickins & Beard 1991; Drengstig et al. 2009). The extreme difference in growth rate experienced in heated seawater is a result of removing winter growth inhibition allowing for year-round growth and moulting.

Several different methods have been developed for culturing lobsters individually (further enlighted in Chapter 2). All of them attempt to provide a separate compartment for each lobster, a constant supply of oxygen saturated seawater to each individual, a method of providing food and removing solid and dissolved wastes, and in general an environment that will promote rapid, uniform growth and high survival (van Olst *et al*. 1980; Grimsen *et al*. 1987).

1.2 Historical perspective

Like many European coastal countries, the lobster fisheries in Norway have very long traditions and represented economically important fishery in many areas, especially in the south and southwestern coastal areas. In his comprehensive article (Dannevik 1936) Alf Dannevik provided historical information about lobster fisheries in Norway and also discussed the experiences from the early and numerous experiments with lobster cultivation.

The idea of lobster cultivation was motivated by the large variation in the lobster landings over time. In periods of low lobster catches the stocks are believed to be at low level and release of artificially produced lobster juveniles could have positive effects. This was clearly stated by Westhassel (Westhassel 1919): “If the stock size is small, release of hatchery produced lobster juveniles will contribute to an increase in population size and reproduction potential”.

The Society for Promotion of Norwegian Fisheries, Stavanger Section, was very concerned about the low lobster landing in Rogaland, and they therefore established and funded a lobster research activity at the Kvitsøy Islands in the beginning of the 1900s. Dr. A. Appelløf was leading the lobster work in the period from 1900 to 1915, and he established experimental facilities at Kvitsøy and conducted a number of studies. In his report (Appelløf 1900) he summarize the information available about lobster biology and distribution in Norwegian coastal areas, but also describe in details the various experimental studies conducted at Kvitsøy. Most remarkably, he and his local contact, developed lobster rearing floating units for juvenile production and adult cultivation.

Clearly, the early work of Appelløf and collaborators at Kvitsøy was focused on basic lobster research to evaluate the potential for future more large scale lobster releases. However, this work was not continuated until the establishment of a large scale lobster hatchery was built at Kyrksæterøra in 1982 by the commercial company Tiedeman Tobacco. The Tiedeman study was lead by Jens Glad Balchen and was based on a single lobster compartment hatchery design. Steinar Grimsen was responsible for the lobster hatchery with a capacity of producing 120 000 one year old lobster juveniles ready to be released. In 1985 and 1986, 31 000 lobster juveniles produced by the Tiedeman lobster hatchery were released around the Kvitøy Islands. Some of these lobsters was later identified in the fishery by the possessing two pincer claws and contributed significant to the lobster catches (Tveite and Grimsen, 1990). The Tiedeman lobster hatchery was, however, transferred in 1989 to the institute of Marine Research (IMR) in Bergen. As part of the Norwegian Sea Ranching Program (PUSH), large scale lobster enhancement was conducted at Kvitsøy in the period from 1990 to 1998 when about 126 000 microtagged lobsters where produced at the lobster hatchery at Kyrksæterøra and released at Kvitsøy. The experiments and the results have been reported in details elsewhere (Agnalt et al. 1999; Agnalt et al. 2004).

The promising results from the enhancement project also stimulated to develop a local lobster hatchery at Kvitsøy aiming on more permanent production of lobster juveniles for release in the area. Based on a hatchery design developed by Ingebrigt Uglem and funding from Norwegian Research Council, a small lobster hatchery was established. The local “Kvitsøy Lobster Hatchery” was in operation a couple of years, but the financial situation became a bottleneck for further operation. The hatchery was reorganized in 1999, and became the important experimental facility in the EU funded project "Genetics of European lobster", conducted in the period from 1999 to 2001. Several experiments based on single families produced larvae and juveniles were carried out and family identification was based on DNA profiling, as described in publication (Jørstad et al., 2007; Jørstad et al. 2009).

Asbjørn Drengstig and the commercial firm Norwegian Lobster Farm AS took over the Kvitsøy Lobster Hatchery in 2000. In this later period, they reorganized the hatchery and developed a number of new hatchery approaches, especially focussing on land based production on plate size lobsters of high marked value (Drengstig et al. 2009). There were, however, both interests the local community and scientific interests to develop a permanent lobster research activity connected to the "Kvitsøy Lobster Hatchery". Hence, during 2000 – 2004, several proposals were developed by Tore Kristiansen (IMR) and Asbjørn Drengstig (Norwegian Lobster Farm AS) focusing on development of production protocols for "release lobster" and production of "plate size" lobster. In addition, ideas like establishment of "Center for Lobster Research" and / or "European Lobster Center" were proposed at that time. Thus, the historical record of lobster research and scientific experiments at the Kvitsøy Islands is long and impressive. This is mainly based on the natural environment as an important lobster fishing area, the local society interests and scientific potential of studies to be conducted in the area. This potential should be further developed in the future.

2 Aquaculture production methods

Lobster aquaculture can be conducted in three forms: resource enhancement, product enhancement and full grow out. Interest in the resource enhancement aspect began more than a century ago and many hatcheries were built in Europe and North-America for the purpose of hatching eggs and releasing I or IV stage larvae into the wild (Nicosia & Lavalli 1999). In product enhancement, lobsters are kept in captivity in holding pounds and fed until their quality or prices increases (Aiken & Waddy 1995). Full grow out or closed-cycle culture is independent of fishery and involves rearing of lobsters from egg to market size.

In America, interest in full grow out culture peaked in the 1970s, when government funded research programs on intensive culture of American lobster were conducted in USA and Canada. As a result of this research and earlier studies, lobster biology became reasonably well understood (Factor 1995), seed stock could be produced on demand, and systems and strategies were in place for rearing lobster from larvae to market size (see reviews by van Olst *et al*. 1988; Aiken & Waddy 1995; Nicosia & Lavalli 1999). Several private companies in America started lobster production, but none of these projects proved to be commercially viable (Nicosia & Lavalli 1999). A large increase in landings of wild lobsters and an abrupt termination of governmental research programs before rearing technology and formulated lobster feeds were sufficiently developed contributed to this scenario (Aiken & Waddy 1995). Besides, the necessary computer and automation technology was too poorly developed in the 1970 – 1980s to achieve a sufficient automation level at a reasonable production costs. Today, there are no commercial land-based lobster farms in America due to too high production costs.

In Norway, interest in producing lobster juveniles for sea-ranching and stock enhancement gained high actuality during the 1990s and full grow-out in 2000. During the 1990's IMR conducted a research program on lobster sea-ranching which gave promising results (Agnalt *et al*. 1999) and a new law ensuring property rights to released sedentary invertebrates was approved by the Norwegian Parliament in 2000 and put into effect 1 January 2004. This law ensures exclusive harvesting rights in specific areas for decapods, molluscs and sea urchins to persons holding a proper license. This new act has promoted an increasing commercial interest in lobster sea-ranching in Norway, and several companies applied for licenses and start commercial sea-ranching. An important prerequisite for sea-ranching success is, among others, access to a large amount of cheap and high quality lobster juveniles for release.

During the last decade there were some significant breakthroughs in the development of automation and land-based aquaculture technology. Especially in the field of recirculation technology major progress occurred, making land-based aquaculture using heated water more economical realistic. A major research project was carried out on Kvitsøy between 2000 – 2009 by IMR and Norwegian Lobster Farm. These studies culimiated in a successful semi-commercial production with fully automated solutions controlling the entire value chain from brood-stock to market sized lobsters, including development of a live genebank with genetically tagged brood-stock and offspring (Drengstig et al. 2009).

2.1 Restocking, sea ranching and stock enhancement

Norway is the only country that has implemented an aquaculture act for sea ranching. This law opens up for issuing a licens releasing common property into commercial companies. The European lobster is an economically prized species widely over-exploited throughout its range, making European lobster to a very promising species for stock enhancement. As a consequence, the interest for lobster hatchery and stock enhancement grew up, giving born to research programs such as the "Norwegian Sea Ranching Program – PUSH" and the "Genetic diversity in the European lobster – GEL" (http://www.qub.ac.uk/bb-old/prodohl/gel/gel.html). These programs included several release experiments of tagged individuals, studies on the species ecology and a survey of its genetic structure through multiple markers.

In the Mediterranean basin the landings of *H. gammarus* have declined as in the rest of the range, with the landings from European Mediterranean countries dropping from 541 MT in 1995 to 94 MT in 2003, a trend followed also by the Adriatic and Tyrrhenian countries (FAO, 2010). In the northern Atlantic areas, the reply to stock decline was the implementation of stock enhancement programs successfully carried out during the last three decades in Norway, United Kingdom, Ireland and Germany (Browne et al., 2000; Burton, 2001; Hamasaki and Kitada, 2008; Schmalenbach et al., 2001). The data on both the commercial catches and the recaptured individuals demonstrated that the landings increased and that the released lobsters provided an appreciable contribution, but at rates that were frequently too low to consider profitable the results obtained with respect to the costs sustained (Hamasaki and Kitada, 2008; Ellis et al., 2014). However, the released females generally survived and reproduced at rates comparable to those of wild specimens suggesting the efficacy of restocking practices aimed at rebuilding the depleted wild populations in the mid-term (Agnalt et al., 1999; Tully, 2004). This perspective is supported by the finding that from a genetic point of view the released specimens neither replaced local individuals nor altered local gene pools, thus demonstrating that it is possible to implement massive release without causing genetic hazard (Le Vay et al., 2007). Opposite to the wide number of enhancement projects conducted in the Atlantic area, in the Mediterranean Sea no active management plans have been implemented so far for the European lobster.

According to the FAO, more than 80% of the world's fish stocks are fully exploited, over-exploited, depleted or recovering. In addition, there has never been as much pressure on the world's fish stocks as today. As global demand for captured/farmed marine products continue to grow, it is becoming increasingly desirable to have a more complete understanding of how we can enhance and re-stock populations of high value species. Efforts to increase recruitment to the fisheries by releasing hatchery-produced juvenile fish or invertebrates have been made for more than 150 years (Munro & Bell 1997, Nicosia & Lavalli 1999, Agnalt et al. 1999, Blaxter 2000, Bell et al. 2005, Agnalt et al. 2004). The European lobster is an economically important, high value species, with a relatively limited fishery and commercial farming has yet to be established. The consumer demand and market price is high in all market segments around the globe, causing increasing pressure on natural stocks and as such lobster populations are highly vulnerable. Several economically important populations have been harvested to the point where there is insufficient spawning biomass found within the population to sustain recruitment. An example of such overexploitation can be seen in Figure 1 which shows the reported landings of European lobster for UK, France, Ireland and Norway 1920 – 2011 and highlights the Scandinavian stock collapse from the 1930 – 1970. This led to preventative aspirations to prevent stock collapse by enhancing stocks and promoting sustainability where fishing pressure has potential to cause adverse effects on stock levels.

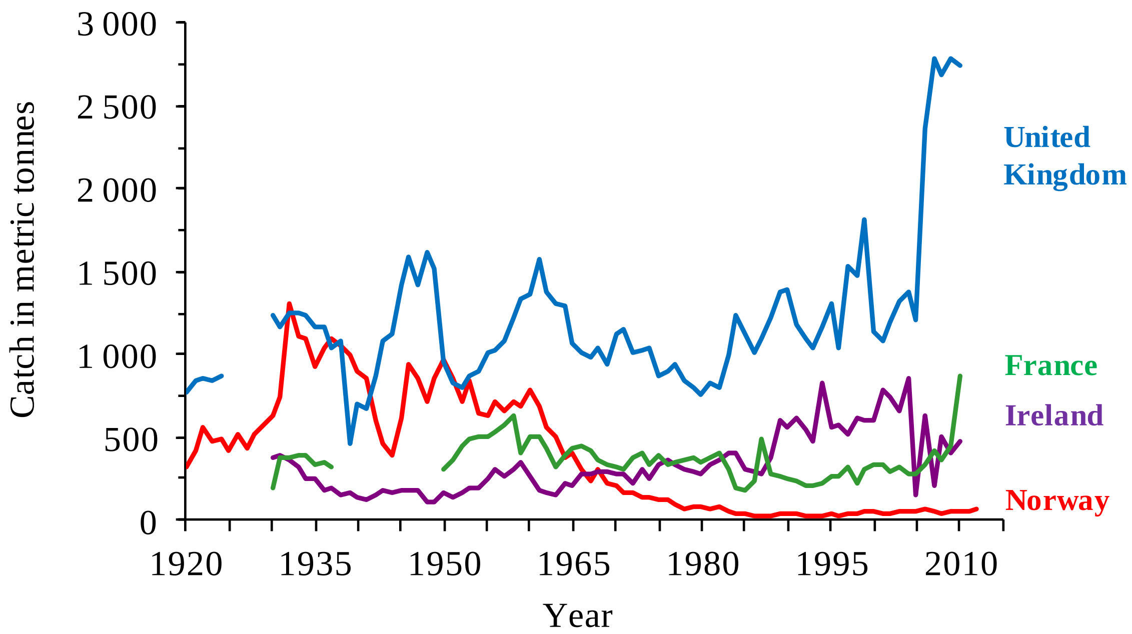


Figure 1. Reported landings of European lobster (*Homarus gammarus*) for the four most important nations in relation to lobster landings in the 1940's; United Kingdom, Ireland, France and Norway (data from Directorate of Fisheries in Norway, Dow 1980, FAO fistat 2012).

Despite this, stock enhancement efforts are increasing with many new programmes currently being implemented across the European lobster range. Programmes vary in size with regards to release number but also with regards to the size/age of release. Success will be dependent on specific factors of the given programme, but not limited to the environmental conditions related to release and sites. Most of these studies has established survival and recruitment into the fishery but many other questions relating to impact remain elusive and the growing number of stocking programmes remain hindered by a lack of clear evidence relating to impact (Ellis et al 2014). Table 1 summarises the past and present projects on stock enhancement.

Table 1. Summary of stock enhancement ventures for the European Lobster

Location	When reased (from – to)	Total number released	Release age/stage	Reference
United Kingdom (National Lobster Hatchery)	2000 - present	~175,000	Stage V-VIII	Dom Boothroyd – pers. Comm.
United Kingdom (Orkney Lobster Hatchery	2000 - pesent	~747,000 (plus whatever he told you he did last year)	Stage IV - X	D. Gouland, pers. Comm.
United Kingdom (Firth of Fourth)				
Norway (Norskhummer)				
Norway (Kitsvoy)	1990-1994	127,945	~1 year	Agnalt et al (2004)
France (Ile de Sein; Ile d'Yeu; Ile de Houat)	1972 - 1977	~265,000	Stage V to 1 year	Henocque (1983)
France (Ile de Sein; Ile d'Yeu; Ile de Houat)	1978 - 1983	1,300	~ 1 year	Latrouite and Lorec (1991)
United Kingdom (MAFF – Bridlington; NWSFC – Aberystwyth; SFIA – Ardtoe; Orkney)	1983 - 1990	90,925	~ 1 year	Bannister et al., (1994); Bannister and Addison (1998); Burton, (1993); Cook, (1995)
France (Ile de Sein; Ile d'Yeu; Ile de Houat)	1984 - 1987	25,480	~ 1 year	Latrouite and Lorec (1991)
Ireland (Galway; Wexford)	1993 - 1997	~292,000	Stage IV - V	Browne and Mercer (1998)
Germany (Helgoland)	2000 - 2005	~5,400	~ 1 year	Schmalenbach et al. (2011)
Italy (CISMAR – Viterbo)	2010 - 2013	~10,000	Stage IV +	G. Nascetti, pers. Comm.

Table modified from Ellis et al., 2014

2.2 On-growing

In the past, on-growing of European lobster in land-based systems has turned out to be difficult. Aiken & Waddy (1995) characterise and summarise the technological development like this: “The ideal tank for rearing lobsters individually would be inexpensive to construct and operate and simple to maintain. It would be self-cleaning, use space in three dimensions, conserve water, and permit access to the livestock for inspection and feeding. So far, no one has successfully incorporated all of these features into a single design”. Thus, the development of land-based lobster farming has been severely hampered by lack of suitable technology and production methods. The major constraints have also been the lack of high quality dry food, high labour costs, inadequate technological solutions for rearing in individual containers in an effective and profitable way and high investment costs.

During the last decade, R&D revealed that the use of technologies including recirculation of seawater (RAS) was a very efficient method. Biological re-circulation serves primarily two functions: the oxidation of ammonia by autotrophic micro-organisms and the oxidation of dissolved and some fine suspended organic materials by populations of heterotrophic micro-organisms. Autotrophic organisms feed on inorganic compounds (i.e. ammonia and carbon dioxide (CO_2) waste from lobsters) and heterotrophic organisms feed on organic compounds (i.e. lobsters eat feed). Thus, a successful re-circulation system operation requires an awareness of the possible changes in environmental conditions (key water quality parameters) occurring in a captive body of water. Desirable levels of water quality for clawed lobsters are temperature of 18 - 22ºC, salinity of 28 – 35 ‰, above 6 mg oxygen/L, pH of 7.8 – 8.2, less than 10 µg/L copper and less than 14 µg N/L as un-ionised ammonia (NH_3) (Wickins & Lee, 2002). However, for short periods, lobsters will tolerate considerably lower oxygen and higher ammonia concentrations than indicated as desirable levels.

Ammonia, which is quite toxic to lobsters, is the most limiting parameter in re-circulation systems for seawater. When lobsters are held and fed in closed systems for a long period of time, ammonia production and build-up will be enhanced. Sudden overloading of a system (high lobster to water ratio) may cause severe damage, and require a biological filter to mitigate the toxic effect. Lobster feed is high in protein and the ammonia excretion rates in the animals are correspondingly high – average rates of 0.1 – 0.5 g TAN/kg/day has been reported for adult lobster. In a re-circulation system, ammonia concentration is controlled by nitrifying bacteria in a biological filter. These bacteria (Nitrosomonas and Nitrobacter) convert ammonia to nitrite, which is less toxic, and then convert nitrite to nitrate. The system is considered to be balanced when the bacterial colony has grown large enough to keep the ammonia and nitrite level under control (Estrella, 2002).

3 European Lobster Centre of Excellence (ELCE)

The European Lobster Centre of Excellence was inaugurated during an international meeting at the National Lobster Hatchery, Padstow, UK in April 2013. It's mission is to share knowledge and experiences in order to fast track lobster aquaculture and lobster stocking programmes, utilising the following approaches:

- ✓ To develop mutually beneficial research programmes through consortium led funding applications
- ✓ To share knowledge and experiences through an annual workshop with partner presentations
- ✓ To share knowledge and experiences through a shared database
- ✓ To share experiences and knowledge through a website and email group

The group has membership from 8 European countries, consisting of Norway, Sweeden, Ireland, United Kingdom (Shetland, Scotland and Wales), Spain, Italy, Iceland and Denmark. The ELCE network has grown rapidly and today ELCE has more than 25 individual members (Figure 2).

Figure 2. Participants at the 3rd annual ELCE meeting in Stavanger (several particpants were not present while the picture was taken).

Members posess a diverse range of skills and experiences, consisting of a broad range of business, entrapreneurial, policy, regulatory, aquaculture, hatchery, technology, engineering, research and academic skills. Academic skills are also diverse with expertise in eco-physiology, nutrition, ecology, genetics, disease and molecular skills. ELCE members operate under a code of ethics and a set of members rules in addition to an executive comittee which makes executive decisions relating to membership and meetings.

The ELCE network aims at organising an annual meeting/workshop in the respective member countries including field visits to relevant operations and research institutes. The annual get-together also facilitates knowledge sharing and initiation of new cooperations between individual member as well as within the ELCE organisation.

4 Country status

4.1 Norway

Research on European lobster in the field of aquaculture includes sea ranching, stock enhancement and land-based farming. Activities focus on carrying capacity, how to improve survival after release and how genetics play a role in survival and growth i.e. selection, feed development, respiratory studies and system set-ups. Results related to carrying capacity was presented on the last meeting in North Berwick, Scotland October 2014. The presentation for ELCE in Stavanger focused on conditioning juveniles and genetics.

In this context conditioning is defined as a learning process in which something that not previously produced a particular response becomes associated with something that produces the response. In Eureopean lobster we want to assess if the behviour in newly released juveniles can be altered so that the survival rate upon release in the wild increases. Several experiments were conducted to elucidate the importance of substrate to promote digging behavour. Shell sand was selected as substrate but in addition shelter was added into the experimental units, thus providing an enriched environment. A summary of several experiements conducted over several years was presented at the workshop. The experiments ranged in complexity, duration and at different developmental stages in the lobster. Initially we started the conditioning phase from larval stages (IV to V) and it lasted several months but later we used ready-to-be-released juveniles and conditioned them for six weeks. Survival and growth rate was compared with control i.e. naïve individuals that were raised in single compartments without any stimulation from substrate and/or shelter, representing the situation in commercial production. To assess if the conditioning treatment had an effect a testing arena was set-up where an equal number of conditioned and naïve juveniles, as well size-matched, were released with number of shelter half of total number of juveniles. This was done to induce competition for shelter. The testing arena was made in the laboratory with tanks in some experiments and finally also in a semi-natural system in larger enclosures (meshed netting bags) set on the sea floor in a lobster holding park. It was clear in all experiemtns that a conditioning period in an environment with substrate and shelter for at least six weeks will promote survival, from two to five times compared with naïve juveniles. This work will be published later this year. Two master students have looked further into behaviour analysis of lobster undergoing a conditioning phase. Stian Aspaas looked into what behavior was most affected by substrate and shelter, and Henrik Trengereid analysed if juveniles could respond to predator smell. If they did, could this change the beavhour and if so can this be used as an advantage in releases? Both these studies will be published later this year.

Genetics is of great importance, both for sea ranching and for land-based farming. IMR is currently making a baseline study characterizing different brood stocks to be able to study local adaptations (north-south) and temperature tolerances. As well, IMR has been running different experiments focusing on familygroups and performance. In these studies, larvae from single mothers were kept separate and the juvenile offspring showed different traits in growth, survival and aggression (measured as claw loss). This gave clear indication the possibility for a selection program. A selection program was initiated in close cooperation with Norwegian Lobster Farms but unfortunate sircumstances with a fire in the hatchery precluded further analysis. The basis for a selction program was laid and will be given strong attention to in further R&D.

4.2 Sweden

The current Swedish efforts to culture the European lobster are focused on landbased culture in RAS systems for plate-size production. The Swedish wild stocks are not currently assessed yet according to the Swedish Agency for Marine and Water management (www.havochvatten.se), however fishing regulations are believed to uphold a sustainable wild population. Available data (catch diaries from a number of lobster fishermen in the area Smögen – Koster Islands) suggests that the lobster population increased from 1980 to a peak in the mid-1990s. After some years of decline, the population now appear to increase again. Thus the Swedish authorities see no urgent need to promote restocking of the wild populations by releasing juvenile lobsters. On the other hand, as the consumer request for lobsters is stable and high, the Government allow import and sale of live American lobsters. Since this species is alien to Europe and can hybridize with the European lobster, there are great concearns about this live import.

Aquaculture of the European lobster within the NOMACULTURE project:

The marine aquaculture in Sweden is currently only consisting of culture of blue mussels (*Mytilus edulis*) and trials on the European flat oyster (*Ostrea edulis*). NOMACULTURE is a nationally funded project that consists of several research groups who are working to develop a sustainable strategy for Swedish marine aquaculture with focus on environmental and economic sustainability. Two species are currently in focus: the European lobster (*Homarus gammarus*) and the spotted wolffish (*Anarhichas minor)*. The project gathers experts in biology, technology, food science, Life Cycle Assessment (LCA) and economics. NOMACULTURE will address the challenges of reducing dependence to fish oil and fish meal for aqua-feed, to develop high quality larval feeds and minimize nutrient leakage. This will ensure environmental and ecological sustainability of high-end products from marine aquaculture in harmony with the local communities. The lobster culture will be conducted at Sven Lovén Centre for Marine Science-Kristineberg, where the research group (led by Ass Prof Susanne Eriksson) has 25 years of experience working with (and culturing) crustaceans, mainly the Norway lobster (*Nephrops norvegicus*). NOMACULTURE is nationally funded by MISTRA (the Swedish Foundation for Strategic Environmental Research), the Swedish research council Formas and Region Västra Götaland during 2014-2018.

Facilities and current status:
The lobster culture within NOMACULTURE started in November 2014. The animals are cultured in a 150 m^2 culturehouse at the station, built for aquaculture purposes. The water used is currently flow through seawater taken from 32 m depth in the Gullmarsfjorden. The water is holding a salinity of 30-34 ‰ and can either be kept at ambient temperature or controlled up to 20°C. The water system will gradually be transferred into a fully or semi- RAS system over the course of the project. All equipment has been set up during the winter and spring of 2015 and the first experiments in the summer of 2015 were focusing on getting good survival and growth in the larvae using state-of-the-art equipment and feed. Berried females were creel-caught and brought into the Culturehouse from the fjord and allowed to acclimate to 18°C. Newly hatched Zoea larvae have been transferred to hoppers and initially measured for growth and survival using different types of feed, typically used in lobster culture (eg. copepods, Artemia). A novel feed based on protein extracted from rest products from the fishing industry is currently tested for palatability in juvenile lobsters.

4.3 Iceland

Based on earlier work by NLF and IMR on developing commercial farming of European lobster with a pilot unit in Kvitsöy of 2 metric tonnes per year Svinna-verkfrædi Ltd (Svinna) in Iceland started collaboration with Norwegian Lobster Farm (NLF) two years ago. The aim is to estimate if commercial land-based farming of European lobster utilizing geothermal water can become the next step for NLF´s development.

The group joined forces with DTU-Aqua in Denmark and started a three years Nordic Innovation funded "Solved" project with the aim to eliminate biological and technical risk factors before taking the next steps towards commercial farming. Collaboration partners in Iceland include the University of Iceland´s Research Centre in Sudurnes (UoI), Sudurnes Science and Learning Center (SSLC) and Saebyli Ltd.

European lobster juveniles were imported to Iceland in April 2014 from IMR and the National Lobster Hatchery in Padstow, UK (NLH), respectively. The lobsters were divided into two groups and kept in RAS and flow-through systems. Comparison of growth rate and survival of lobster juveniles, starting at stage IV have been carried out in both systems. Commercial available arctic charr feed from Fodurblandan in Iceland has been tested and compared with lobster feed from NLH. The results show similar growth rates and survival on both diets.

Soffia K Magnusdottir, master student in biology at the University of Iceland, has been taking care of the biological tests supported by Dr. Halldor P Halldorsson, Dr. Ragnheidur Thorarinsdottir and other co-workers. Respiration tests have been performed at different temperatures. Also two photoperiod treatments have been compared with regards to metabolic rates. The project has been presented at EAS2014 and ELCE meetings in New Berthwick in October 2014 and Stavanger in May 2015. Results will be released later this year.

4.4 United Kingdom

Lobster landings from UK vessels in the UK and abroad (Data from from Marine Management Organisation) is presented in Figure 3. Lobster landings in the UK have been relatively stable during the past 5 years, with catches recorded as being between 2,700 and 3,270 tonnes. Fishing effort is however very high and the stock is considered to be fully exploited.

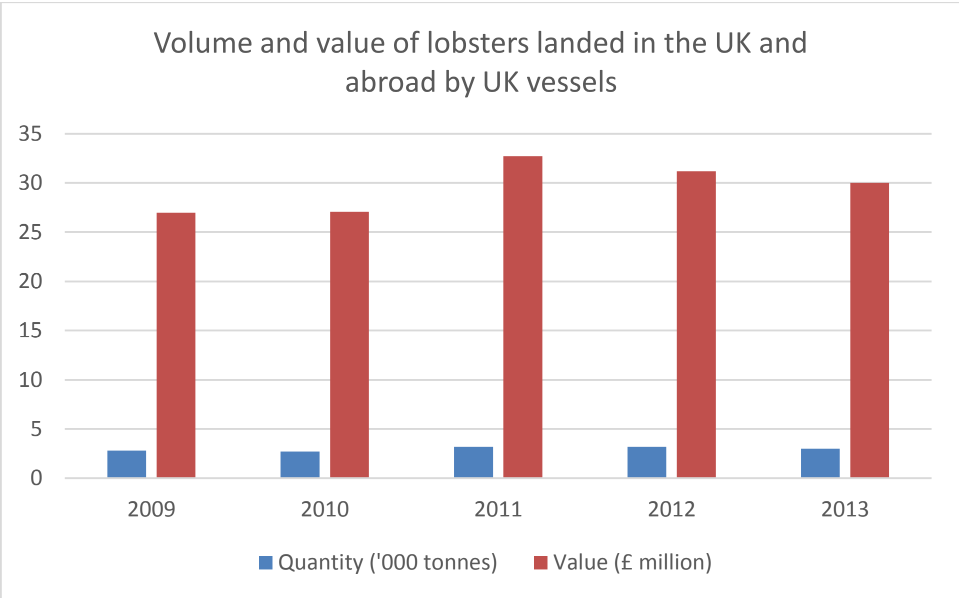


Figure 3. Lobster landings in the United Kingdom during 2009 – 2013.

All commercial fishing operations in the UK are subject to EU and UK regulations, with additional regulation in England being provided within the six nautical mile limit by the Ten regional Inshore Fisheries and Conservation Authorities (IFCAS). This regional approach provides additional technical management measures to be introduced on a regional basis. Therefore different regions have different technical measures in place to conserve stocks e.g. variations in minimum landing size, prohibition of landing of egg bearing females, V notching regulations, specifications on pot designs and pot limitations, amongst others.

Most inroads into lobster aquaculture in the UK are by hatcheries undertaking stock enhancement activity. These hatcheries include: The National Lobster Hatchery (NLH) in England, The Orkney lobster Hatchery & the Firth of Forth Hatchery in Scotland, the Anglesea Sea Zoo in Wales and Seascope in Northern Ireland.

The NLH was established in 2000 in order to enhance stocks locally (which had been showing signs of decline during the 1990's) and to operate a programme of industrial and public engagement and acting as a germ seed for UK based research on the species. The NLH received charity status in 2004 and is an accredited Social Enterprise. It operates programmes of research, stocking and education with a clear research strategy focused on developing the stocking programme, from both an asseeement and aquaculture development perspective. The charity currently employes in the region of 17 staff and has a team of approximately 20 volunteers. It hosts several postgraduate placements each year and is currently collaborating on 3 PhD studentships with the Centre for Environment Fisheries and Aquaculture Science (CEFAS) and the University of Exeter (UoE). A scientific committee has been established to guide the charity's research and to bring in academic skills from other institutes.

The stocking programme has developed over the past few years and in 2014 releases exceeded 54,000 juveniles between stage 5 and 8. Since 2013 the charity has been collecting both paternal and maternal tissue samples (from pleopod and egg clutches respectively) so that it can start to assess future contributions to the fishery, using genetic microsatellite markers. In collaboration with the UoE the NLH has been undertaking an assessment (within its release area) to identify the presence of population structure within wild stocks. This information is now informing hatchery operations and aligning NLH protocols with responsible practice guidelines.

Over the past ten years the NLH has been collaborating with the University of Plymouth and the University of Exeter to develop a formulated diet for post larvae, examining and trialing a different dietary component annually. Several studies have also focused upon the use of biotic supplements, both within feeds and added directly to the rearing environment to boost growth and survival in larvae and postlarvae. Studies have also examined the use of various disinfectants, notably the use of ozone and UV and more recently the use of ozone and UV in combination with biotic supplementation. The charity undertook work in 2010 – 2012 with the University of Swansea's Centre of Sustainable Aquaculture Research (CSAR) on the FP7 funded project 'Lobster Plant' specifically working on the use of disinfectants for hatchery production.

A recent collaboration with the European Centre for Environment and Human Health (ECEHH) has focused on developing a lobster specific bioassay to provide a simple and effective solution to water quality assessment.

Significant effort has been made during the past six years to examine potential sites around Cornwall for Sea based Container Culture (SBCC) of lobster. Various studies have examined survival and growth at different locations and more recent studies have looked at longer term survival and growth. Short term studies have shown high survival at some spots, with survival rates correlating to types and levels of fouling organisms found on the containers. A recent postgraduate project has been examining behaviourial differences between SBCC raised lobsters and hatchery reared lobsters, focusing on shelter seeking behaviour and interspecific competition.

'Lobster Grower' (LG), a collaborative project led by the NLH with CEFAS, UoE, Westcountry Mussels of Fowey, University of Falmouth and Fusion Marine has focused on the design and development of SBCC systems. It aims to make innovative designs and then test those designs within the laboratory. The project then aims to put in place the permits to establish a pilot scale lobster farm for testing these innovations.

'Lobster Grower 2' will be a collaborative poject led by the NLH with CEFAS, UoE, Westcountry Mussels of Fowey and University of Falmouth. It aims to set up and operate a pilot scale SBCC site over a three year period. It will test the innovations developed in LG and make further innovations relating to mooring systems and SBCC design. It will develop an aqua-economic model and assess the environmental impact of the pilot scale site as well as providing some road mapping for future innovations. Other projects will bolt onto LG2 and a PhD studentship (in collaboration with UoE and CEFAS) will examine the lobster microbiome.

The Firth of Forth Lobster Hatchery started off in 2010 with a small demonstration unit in a shipping container at North Berwick Harbour and now in 2015 after a grant from the Coastal Community Fund has released over 3000 juvenile back into the Firth of Forth. This exciting unique project has installed the latest equipment to incubate and develop eggs through larvae to juveniles in a large shipping container that is self sufficient in energy and is capable of working in remote locations. It is capable of being positioned around the coastal fishing communities and being run by them to promote a sustainable fishing future.

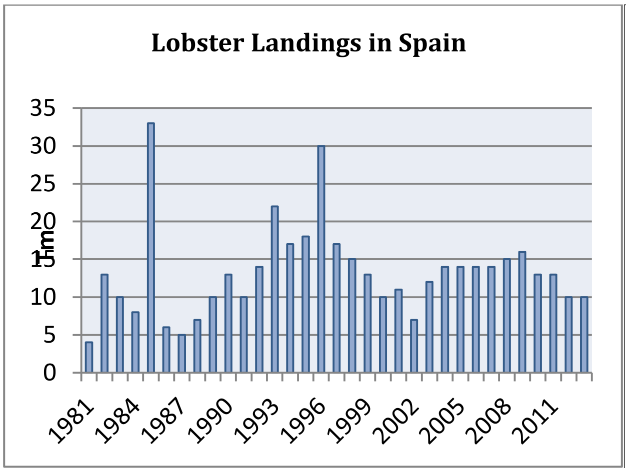
The Firth of Forth Lobster Hatchery employs 4 people to run and promote the facility which involves feeding three times a day. There are 12 broodstock containers capable of supporting 24 berried hens and a daily larval tub, with the main facility containing 16 larval incubation tubs and 4 aquahives for the stage 4 to juvenile development. It is the newest hatchery on the block and have already benefitted greatly from the information exchange and networking involved with the European Lobster Centre of Excellence.

The Firth of Forth Lobster Hatchery are constantly working with relevant investigations and research related to lobster aquaculture, and the hatchery currently carry out DNA sampling and other tasks for students research. The hatchery work closely with the local fishermen and business community to promote sustainable lobster fishing and are also a tourist attraction.

4.5 Spain

According to FAO Fisheries and Aquaculture Information and Statistics Service, *Homarus gammarus* landings in Spain for the last 30 years have been ranging between 10 – 20 metric tons (MT) per year. Statistics before the 1980s are less reliable, but it is inferred that landings have been in the range of 100 – 200 MT/year (Figure 4).

The lobster fishery in Spain, although being valuable, may be considered as a non-target fishery due to its scarcity and short allowed yearly fishing season. In that sense, longer annual fishing periods seem to increase total captures.



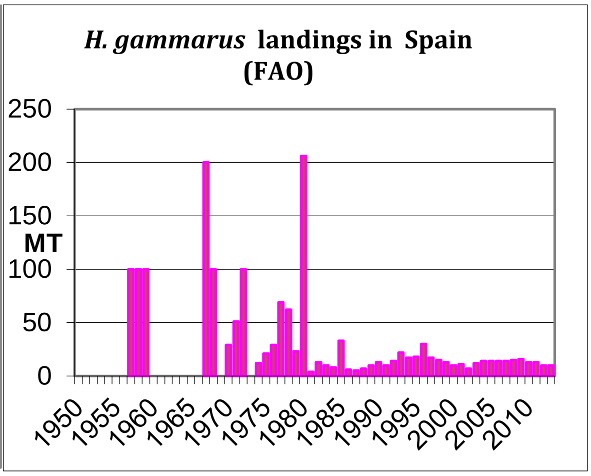


Figure 4. Lobster landings and landings of the European lobster in Spain between 1950 - 2013.

Regarding the spanish foreign trade for lobster, Spain is a net importer of clawed lobsters, mainly live animals. The total numbers have decreased over the last decades, probably due to the country`s financial crisis, whereas prices has remained fairly stable for live product. The relative contribution of the two clawed lobster species (*H. americanus* and *H. gammarus*), shows that import from the USA and Canada represents almost 80% of the total weight of live lobster trade in 2013 and 72.5% in terms of money (Table 2).

Table 2. Relative contribution of the two clawd lobster species (*H. gammarus/H. americanus*).

Live Lobster	**IMPORTS**			**EXPORTS**		
	MT	Thousands	€/Kg	MT	Thousands	€/Kg
TOTAL	**3 814**	**44 426**	**11.65**	**125**	**1 994**	**15.97**
USA	2 740	28 914	10.56	0	0	0
Canada	267	3 319	12.43	0	0	0
UE TOTAL	**780**	**11 740**	**15.05**	**119**	**1 900**	**15.97**
UK	651	9 949	15.28	2	30	14.71

There has not been any attempts on grow-out lobster aquaculture in Spain, but several attempts has been made on restocking/stock enhancement. During the 1980s and 1990s some trials on hatchery production of juveniles or post-larvae and release were done in several places of the north coast of Spain:

- ✓ 1981 NW of Spain, Galicia, release of several thousand of hatchery produced post-larvae
- ✓ 1988 – 1989 Basque Country, study on juvenile culture techniques
- ✓ 1994 Asturias, study on reproduction, larval rearing and juvenile growth and survival

In 2004 an INTERREG IIIC-Aquareg EU financed project started between three European regional partners; Galicia (Spain), Sør-Trondelag (Norway) and BMW (Ireland). The main goals of the project were:

- ✓ To develop cost effective production of lobster juveniles through active collaboration between research and training institutions
- ✓ To optimise the performance of lobster hatchery at Galicia for refining and adapting the larval rearing and the juvenile ongrowing techniques
- ✓ To evaluate and establish guidelines for a regional lobster restocking plan in Galicia and to adapt this plan for future transfer to BMW and Trøndelag

The methodology employed was based on rearing the juveniles from metamorphosis to a suitable size to release in the wild (40 – 60 mm total length) in individual baskets (oyster baskets) suspended from mussel rafts in the sea, with no tending or artificial feed supply (Figure 5).

Figure 5. Oyster baskets growing lobster juveniles without tending and feed supply.

At the end of the project, it was demonstrated that both survival and growth were good enough to represent a cost-effective method to produce lobster juveniles for restocking purposes.

In 2007, another 4-year project was initiated in Galicia focusing on lobster and turbot restocking. The main goals were:

- ✓ To evaluate the survival, growth and distribution of lobsters released in the selected area.
- ✓ To test transport and release methods

More than 20,000 juveniles were produced up to 50 mm total length (TL) using the methodology developed during the Aquareg project. Each year, approximately 5,000 juveniles were micro wire tagged and released over a five year period (2007 – 2011). In total only 51 individuals were recaptured, resulting in 0.1 – 0,46 % recapture rate between 2008 – 2011. At the end of the project (2012) it was concluded that recaptures showed a normal growth, some of the individuals attaining adult size but the percentage of recaptures was extremely low. Probably recapture monitoring procedures should be improved. From 2011 onwards, small and variable numbers of tagged juveniles produced for didactic purposes are still being released but no recapture has been reported since 2012.

4.6 Italy

The European Lobster is not a target species in Italian aquaculture. However, rearing techniques from berried females to the benthic stage, with juveniles reaching about 5 cm in total length, have been set up by CISMAR-UNITUS (Centro Ittiogenico Sperimentale Marino, belonging to Tuscia University of Viterbo; http://www.cismar.it). No other research centers nor aquaculture farms are equipped for European lobster aquaculture in Italy.

At present, Italy has no active management plans implemented for the European lobster. A pilot restocking project was conducted between 1996 – 1999 in the northern Adriatic Sea, to enhance the recovering of the local population after the severe anoxic crisis that caused massive lobster mortality in 1977 (Orel et al. 1993). Adult specimens were captured from northern Adriatic basin, marked and released on a selected beachrock outcrop. Also, some 120 days old juveniles reared from berried females were released in the same area. Although the first results highlighted the survival of the released adult specimens over time, the project did not go ahead (Burton 2001; Scovacricchi et al. 1998; 1999). At present, restocking pilot projects are running, concerning the enhancement of selected populations along the Italian Tyrrhenian coasts under the responsibility of CISMAR-UNITUS (European Fishery Fund: FEP Lazio 9/ACO/11/LA and FEP Calabria 03/BA/11) using juvenile lobsters reared from locally caught females and then released in the same area and including procedures to improve the behavioral phenotype of the released animals (Carere et al., 2012).

4.7 Denmark

Lobster Fisheries:
In Figure 6 below is shown registered catches of lobsters in Demark. In 1930s catches of lobsters peaked with yearly landings of around 150 MT. During the 1950s catches were up to 90 tonnes per year, but since then catches have declined dramtatically. An exception is the Limfjord where catches increased quite significantly from around 2009.

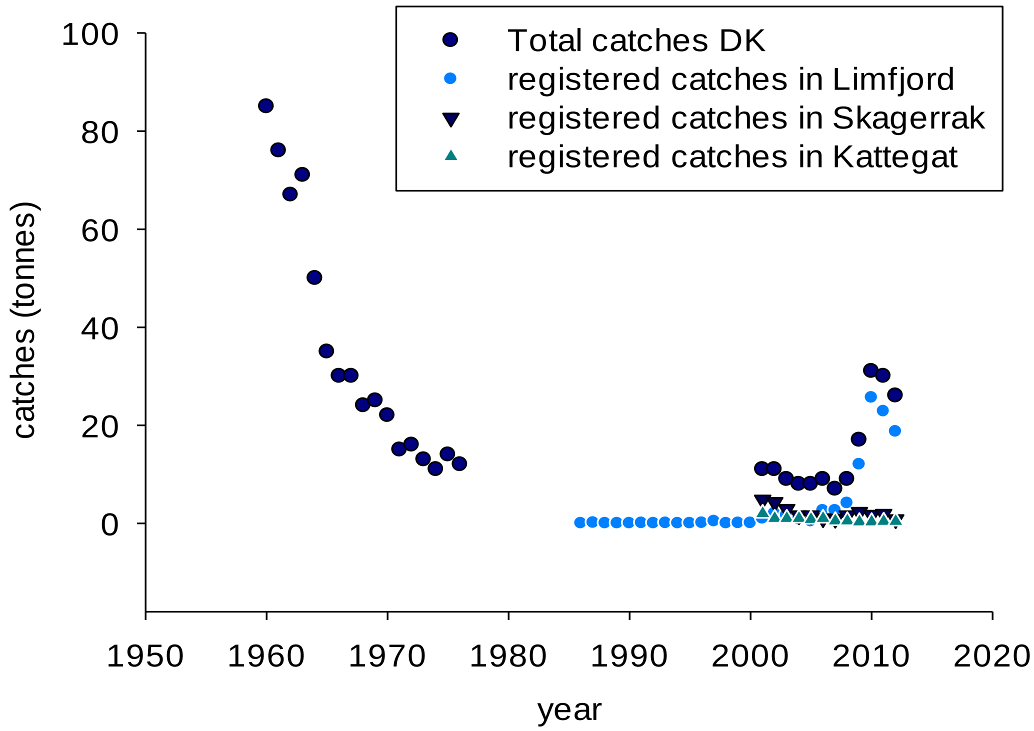


Figure 6: Registered lobster catches in Danish waters 1950-2012.

The cause of the decline in fisheries is probably multifactorial. Overfishing combined with the slow recruitment of lobster stocks (i.e it takes 6 – 8 years for a lobster to become mature), combined with the fact that no protective precautions apart from minimum size exist in Skagerrak and Kattegat are possible explanations, besides no total allowable catch quotas exists on lobsters in DK. However, on the other hand, fishery practices and methods have changed and there is no specific determined fisheries for lobsters in Skagerrak and Kattegat and landings are merely bycatches during fishing for other species (mainly brown crabs, *Cancer Pagurus*). During the period 2000 – 2008 a local ban protecting egg bearing females in the Limfjord may have been part of the the subsequent increase in catches in the period from 2008, or recruitment may have had some unknown successful environmentally favourable conditions. It is expected that illegal fisheries by divers and unregistered catches have a certain quantity, but whether this may have caused major deviations in yearly catching statistics is not known.

Figure 6 show that there is a potential for a much larger standing stock and a much larger fishery of lobsters in Denmark, but this should be regulated by national legislations as well as involving local associations of fishermen and eventually potential protection of certain areas or bans regarding collection of egg bearing females.

Lobster Aquaculture:
There are currently no funded restocking enhancement programmes in Denmark, or aquaculture production of juveniles for release. Restocking programmes have shown positive effects on lobster fisheries in various countries (UK, Norway, Skotland) and this might as well be be implemented in Denmark, especially in the habitats where lobsters are caught and used to be abundant. Similarly new potential habitats for release programmes are the many newly established Danish wind mill parks (Stenberg et al., 2011).

DTU Aqua (Dansih shellfish Centre is per 2015 part of DTU Aqua) is involved in a Nordic project project funded by Nordic Minister Council with focus on land-based culture of lobster dealing with commercial bottlenecks such as larval nutrition, larval survival, lobster physiology and rearing technology, besides together with Nordsøen Forskerpark, and Fiskeri Lag Nord (Hirtshals Fisheries Association) involved in getting regional funding to establish a rearing facility/ tourist center for production of juvenile lobsters for restocking and future sustainable fisheries in Northern Jutland.

5 Results from the workshop

A successful workshop were held in Stavanger where three questions were discussed. The results are presented below in chapter 5.1 – 5.3.

5.1 Identify challenges and obstacles for lobster aquaculture?

The main challenges and overall obstacles are all related to funding. Generally a lack of funding hampers development and growth of the industry. This relates to both public and private funding, and often a combination of the two sources in the cristical commercial stage of development. In addition, most funding is lacking the horizon required needed in order to develop the industry properly. Thus, most cases and projects are developed over a short period resulting in a lack of finances to implement R&D results into commercial and industrial stages. The targeted items and areas in need for more know-how is listed below:

Feed and nutrition:

- ✓ Feeding regime
- ✓ Nutrient requirements
- ✓ Dietary needs for lobster larvae and juveniles
- ✓ Feed composition
- ✓ Interaction with systems; e.g. RAS

System and technologies:

- ✓ Automated control
- ✓ Environmental control
- ✓ Release technologies
- ✓ RAS
- ✓ Logistics
- ✓ Sea based system - how to make them "more controlled"
- ✓ Lack of a “Best strategy” for production
- ✓ Water quality and treatment systems
- ✓ Cage designs and cannibalism

Hatcheries

- ✓ Coordinate research on system development
- ✓ Identify the best scale in upscaling production
- ✓ Standardisation of hatchery procedures – uniting knowledge to design the most optimal hatchery techniques
- ✓ Stable year-round production

Ongrowing technologies:

- ✓ Seabased and land-based containers

- ✓ Documentation of growth rates in "long cycles"
- ✓ Water quality and preventing fouling at high temperatures (20 C)
- ✓ Respiratory data

In addition legal issues, site availability, diseases and economics were discussed in terms of requirements for more funding and need for more research and know-how.

5.2 What solutions are needed to overcome these challenges?

After identifying bottlesnecks, the workshop tried to classify various solutions that may be appropriate to solve and overcome the challenges of the industry. It was unaminous that coordinating generic research would facilitate a higher pace in development and to gain commercial success. Moreover, based on the strength ELCE is representing at the moment, the organisation can do lobbying and involve politicians in a wider sense than members are able to individually. Initiatives to sustain and increase the number of players will also rise awareness of the industry, which in turn will increase Governmental commitment and attract private investors. The possible areas and solutions revealed are listed below:

Feed and nutrition:

- ✓ Cooperation
- ✓ Research Development
- ✓ Creating the perfect feed
- ✓ Automated high quality feeding

System and technologies:

- ✓ Increase the use of robotics and Omics technologies
- ✓ Identify state of the art equipment
- ✓ Fully utilise the ELCE database
- ✓ Develop integrated systems, enabling onshore production in combination with release of juveniles
- ✓ Increase knowledge base on habitat and release techniques
- ✓ Benchmark study on RAS technologies

Hatcheries:

- ✓ Develop a production norm – Best practice
- ✓ Reduce unit cost of production
- ✓ Continue the work with genetics – genetically tagged broodstock
- ✓ Biosecurity measures and increased knowledge on environmental control
- ✓ Increase collaboration within and between the industry/R&D, networking, exchange of know-how to enhance support to the industry

Ongrowing technologies:

- ✓ Increase the use of “research teaming” by challenges
- ✓ Identify and utilise test beds in commercial scale
- ✓ Identify the need for vaccination
- ✓ Goal efficient studies
- ✓ Understanding lobster genetics and use of next generation sequencing
- ✓ Market protection

In addition, visiability of ELCE, increase the number of application for research and commercial grants, and employ a train philosophy in the future development of the industry was pointed out as means to develop lobster aquaculture. Moreover, acceptance by improving public relations and awareness regarding the industry`s long term potential for local employment and socio-economic benefits could facilitate further growth.

5.3 Where do we go from here? Identify new possibilities/new projects

Before the workshop ended, it was important to determine the way forward and activities to be initated before the next annual meeting. Due to the complexity of the industry`s many challenges, it was natural to start in the beginning of the life cycle. Undepentant of production strategies, the industry in general are depending on a successful larvae and juvenile stage. It was decided to target a breeding program with the aim to intensify production in a joint effort from all hatcheries. The topics includes:

- ✓ Water quality
- ✓ Treatment technologies
- ✓ Nutrition and feed development/testing
- ✓ Production protocol – develop a European hatchery standard according to up-to-date know-how

It was also decided that ELCE should take lead to form a new application for EU funding under the Horizone 2020 programme. New applications should

- ✓ Utilise ELCE as brand and as a united European effort to create employment, innovation and growth
- ✓ Utilise ELCE as an effective tool to increase the number of new of players, and reduce costs for technolgy and equipment

6 Conclusions

The present workshop was a valuable contribution to the industry`s attempt to coordinate and commercialise lobster aquaculture. Lobster farming in any form is in its infant stage, and the present workshop revealed numerous challenges that needs to be solved. On the other hand, commercialisation of a new species in aquaculture cannot depend on R&D funding and solving all bottlenecks before initiation. Commercialisation will always reveal new bottlesnecks, often different then one expect. Thus commercialisation should permit development following a stepwise ladder where upscaling is done according to existing know-how and technological advancement. The workshop also focused on the hatchery part, since this part of the value chain is relevant for all aquaculture methods. ELCE will take lead in a future work trying to standarise hatchery techniques and procedures, and thereby establishing a Best-Practice based on the best part of existing solutions combined.

6.1 Steering committee and next workshop

The workshop also elected a steering committee to be in charge of further activities and coordination of the ELCE network. It is important to ensure that the network has a "driving force" and a commited leadership. The steering committee will organise the next annual workshop, suggested to be in August/September 2016 in Sweden.

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8 Appendix

8.1 Workshop programme

Programme 3rd annual ELCE meeting

Sponsored by:

18th May

16:00 - 16:40	Departure from hotel to Kvitsøy
16:50 – 17:30	Ferry to the island
17:30 – 18:50	Look around at the new Kvitsøy Lobster museum, Kvistøy lobster hatchery and Norwegian Lobster Farm old/new plate sized lobster technology/tank
19:05 – 19:45	Ferry back to main land
20:30 – 24:00	Dinner

19th May

Presentations (chair Ann-Lisbeth Agnalt and Carly Daniels)

08:30– 08:45 Welcome, very short presentation of VRI, NIC and delegates, by Asbjørn Drengstig

08:45 – 09:00 History lobster aquaculture/fisheries, by Knut Jørstad

09:00 – 11:00 Status lobster aquaculture (incl. morning break)

NOTE: *MAX 15 MINUTES EACH* – Q&A UNDER DIALOGUE CONFERENCE PART

- Iceland, by Ragnheidur Thorarinsdottir
- Sweden, by Susanne Erikson
- Denmark, by Ivar Lund
- Spain, by Gonzalo
- Italy, by Roberta Zimmaruta
- Norway, by Ann-Lisbeth Agnalt
- UK, by Carly Daniels, Dom Boothroyd

11:00 – 12:30 Formalisation of ELCE steering committee, election of board and president

12:00 – 12:45 Lunch

12:45 – 16:00 Dialogue conference including afternoon taste break – guidelines presented by Beth E. Iversen

1. "Identify challenges – what are the obstacles for further development of lobster aquaculture?"
2. "What measures are needed to overcome these challenges?"
3. "Where do we go from here? Identify new possibilities, project cooperation and organisation?"
   a. Who does what?
   b. Identify relevant calls

16:00 – 16:15 Sum-up, by Beth E. Iversen

16:30 Vote of thanks, end of seminar – return back home

8.2 List of participants

Below is a list over the attendees at the workshop and their contact information.

Confirmation of own contribution - ELCE 18-19 May

Country	Name	Institution	Signature
Norway	Jan Erik Jenssen	AqVisor	
	Jan Morten Homme	AqVisor	
	Asbjørn Drengstig	Norwegian Lobster Farm	
	Alf Reime	AqVisor	
	Beth Evensen	Blue Planet	
	Ann-Lisbeth Agnalt	IMR	
	Ellen Sofie Grefsrud	IMR	
	Geir Dahle	IMR	
	Knut Jørstad	IMR	
	Karl Chr. Baumann	Norsk Hummer	
	Frank Spetland	Norsk Hummer	
	Inge Reithaug	AqVisor	
	T. Kjetil Frøyland	Aegir	
UK	Domenic Boothroyd	NLH	
	Carly Daniels	NLH	
	Dennis Gowland	Shellfish Hatchery Systems	
	Jane McMinn	North Berwick Lobster Hatchery	
	Gareth Jones	North Berwick Lobster Hatchery	
	Ian Sheppard	Private start-up lobster	
Spain	Gonzalo Pérez Benavente	IGaFA	
Italy	Roberta Cimmaruta	CISMAR	
Iceland	Ragnheidur Thorarinsdottir	Svinna Engineering	
Sweden	Susanne Erikson	University of Gothenburg	
	Erik Bergwall	University of Gothenburg	
Denmark	Ivar Lund	DTU	