BELLONA REPORT 2013

Traditional and Integrated Aquaculture

Today's environmental challenges and solutions of tomorrow

BELLONA

The Bellona Foundation is an international environmental NGO based in Norway. Founded in 1986 as a direct action protest group, Bellona has become a recognised technology and solution-oriented organization with offices in Oslo, Brussels, St. Petersburg and Murmansk. Altogether, some 65 engineers, ecologists, nuclear physicists, economists, lawyers, political scientists and journalists work at Bellona.

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Bellona was established on 16 June 1986, and is an independent environmental NGO. Bellona focuses on limiting climate change, preventing pollution and working to increase ecological understanding and protection of nature, health and the environment. Bellona has 65 employees at offices in Oslo, Brussels, Murmansk and St Petersburg.

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Foreword

Aquaculture is an industry that provokes strong emotions in many people. While production and value creation is sizeable, the industry is criticised not least for spreading pollution, poor use of resources and threats to wild salmon.

In 2003 Bellona published the report "Environmental Status of Norwegian Aquaculture". Based on scientific fact, the report aimed to redress the misunderstandings and myths that had arisen, so that we could focus on the main challenges. The report still stands and has proved a useful reference for R&D, politicians, public agencies, the aquaculture industry and private individuals.

Ten years later, we are now launching a new report highlighting the key environmental challenges that the industry faces at this moment in time. These challenges must be tackled by further improving operations and procedures, and by investing more in innovation and new technology. At the same time, we are shining a stronger spotlight on aquaculture. The potential in the sea is enormous, and we are convinced that the fish farming industry will play a key role in future years when it comes to producing food, animal feed, energy and fuels. This will require even greater cooperation and dialogue between the industry, politicians, researchers and society at large.

The world is also facing enormous changes. The planet's population is rising, and the developing nations are rising out of poverty. Demand for food, water and energy is exploding. At the same time, the land available for food and energy production is shrinking due to desertification, which is a result of global warming. CO_2 emissions are climbing year by year, making the situation even worse.

But there are solutions to be had. The oceans cover ¾ of the planet, and the sea is thus the key to tackling our greatest challenges. In the sea we can produce biomass for use as food, animal feed, materials, fuels and pure bioenergy. Algae absorb CO_2, which combats ocean acidification and removes CO_2 from the atmosphere. Combining the production of bioenergy with carbon capture and storage creates a carbon negative result, which means that the more energy we consume, the more CO_2 is removed from the atmosphere.

Production of bioenergy in the sea can usefully be combined with production of food. Research around the world confirms that integrated aquaculture has incredible potential. Algae, blue mussels, lobsters and other resources can be cultivated alongside facilities for farming fish. The waste from one species becomes the resource for another, resulting in less disease in the fish, for example, and faster growth for the algae.

A great deal of money can be earned in solving the world's problems! Bellona has long maintained that integrated aquaculture and the cultivation of seaweed and kelp has the potential to become a green, environmentally responsible, billion kroner industry in Norway. Green jobs would be created along the Norwegian coast. Our country has a long and unique coastline that is perfect for commercial algae production and integrated aquaculture. There is the potential to produce millions of tonnes of macro-algae each year alongside the existing fish farms. This could, for example, cover a significant portion of the energy demanded by the road transport sector.

Frederic Hauge

Frederic Hauge, President of the Bellona Foundation

SUMMARY

The Norwegian aquaculture industry has seen significant growth since the 1970s, with Norway now the world's largest exporter of farmed salmon. Aquaculture in Norway is based on monocultures, which means that only one species is farmed at each marine site. The industry wishes to see a trebling of production by 2025, but this is an unsustainable target following current practices. There is, however, great potential for growth by opening the industry up to Integrated Multi-Trophic Aquaculture (IMTA), which can be run in a sustainable manner.

The trend at the moment is towards fewer units with larger production, something that may be pushing at the boundaries of what the ecosystems are able to tolerate. Although the aquaculture industry in general has made improvements in a number of areas, there remain considerable challenges. Escaping fish are a particular problem that can threaten wild populations of salmon and trout. Measures that are being tested include enclosed sites, more effective marking of fish, sterilising farmed fish to avoid dilution of the genetic integrity of wild salmon, and better nets in the aquafarms.

Salmon lice are another challenge. Large aquafarms produce considerable quantities of louse larvae, which are spread with the current. The same is true of the chemicals used to combat lice, which can threaten the ecosystems surrounding large farms. Several years have been spent trying to find good alternatives to chemicals, but the use of chemicals remains disturbingly high.

It is important to clear up environmental problems that can transfer to wild salmon. Impacts from the farms should be better monitored, different measures should be coordinated, and the results should be collated in order to identify gaps in knowledge.

Norwegian farming is a major consumer of fish oil and fish meal for feed. This contributes to pressure on wild fish stocks, which has led to increased use of vegetable ingredients. It is a challenge to source sufficient omega 3, which is necessary for the fish's immune system. One possible reason for an increase in infectious diseases may be reduced marine content in the fish feed. This problem can be solved with IMTA and algae cultivation.

Integrated Multi-Trophic Aquaculture marks a new approach to fish farming. IMTA can combat a number of the problems in today's fish farming industry, and is a sustainable system. Several species are put together in a way that creates an ecosystem, such that waste from one species becomes a resource for another.

There are many IMTA projects underway around the world, but Norway is lagging behind. One concern is a loss of profitability in the short term. There is also a lack of important knowledge, not least concerning IMTA's possible effects on the surrounding environment. Despite the challenges, Bellona is in no doubt that IMTA represents the future of aquaculture. The potential is enormous, but Norway ought to make better preparations for the transition. We require greater investment in research, pilot projects and eventually start-ups of commercial operations.

Only naturally occurring species should be used, in order to avoid unforeseen negative consequences for the ecosystem. In Norway there is considerable potential from blue mussels, algae (e.g. seaweeds) and invertebrates (lobsters, sea urchins, sea cucumbers, anemones etc.). Research has shown that blue mussels grow faster when they are cultivated alongside fish farming. They filter the water, and have proven helpful in reducing the spread of salmon lice and infectious diseases.

Algae are good sources of protein and omega 3, as well as being highly suitable as an ingredient in fish feed. Algae are also extremely interesting as biomass for the production of energy. The majority of what is produced from petroleum today, including plastics, could potentially be replaced by algae in the long term. Algae also absorb CO_2 and combat ocean acidification. The speed of growth can make algaculture an important climate measure.

In the long term, Bellona believes that a transition from monoculture to IMTA will increase profitability. It will be more viable to convert existing aquaculture than to start from scratch. In this respect, we should look to countries that have come much further than Norway, such as Canada, the USA and China. Bellona works with several research institutes in Norway to develop IMTA pilot projects, with partners including the Institute of Marine Research, the Norwegian University of Science and Technology (NTNU) and research organisation SINTEF.

1. Introduction

1.1 Challenges in today's Norwegian aquaculture industry

The aquaculture industry in Norway has grown considerably since the 1970s, when production came in at less than a thousand tonnes. In 2012, over 1.3 million tonnes of farmed fish and shellfish were produced, with a sales value of almost NOK 31 billion (Statistics Norway). There is no doubt that aquaculture is important to the Norwegian economy.

The trend in the aquaculture industry is towards fewer units with larger production. In recent years, salmon production has grown in volume by just over 10% per year, while the number of marine fish farming sites has seen a slight downturn (Johansen et al. 2013). The increase in production is achieved through greater biomass for each site. The technology has improved, but environmental challenges remain: Every year sees the escape of farmed fish that may be a threat to wild stocks; salmon lice, which continue to be a significant potential problem for wild salmon stocks; inefficient use of feed ingredients and pollution through discharges of nutrients, organic material and chemicals. Bellona believes that things do not have to be like this. There are options that can significantly reduce these conflicts.

The concept of sustainability has been introduced to show the necessity of ensuring a balance between environmental, economical and social dimensions. Unfortunately, the concept is complex and widely misused. There is a need for greater awareness of what sustainability is and how it can be achieved. Sustainability will be fundamental to the future of aquaculture. Aquaculture is important as part of the world's food production, it helps to reduce the fishing of wild stocks, and at the same time it creates jobs. Sustainable aquaculture should be environmentally friendly, ecologically efficient, diversified in terms of products, profitable and of benefit to society.

Traditional fish farm (Photo Annelise Leonczek)

1.2 The world needs more food

The global population continues to grow and is estimated to exceed 9 billion people by the end of 2050. Clearly the world requires greater access to healthy food. The sea's resources therefore need to be managed sustainably. The global trend has been to litter and deplete the seas in a way that limits the ecosystem's own capacity to recover. If we harvest the resources at a speed that is greater than nature is able to replenish them, we have to grow the food ourselves. Integrated aquaculture systems open up possibilities to jointly cultivate different species with huge commercial export value. Fish, algae and blue mussels can, for example, be combined with lobsters, crabs, sea urchins, annelids, prawns, sea cucumbers and tunicates. Many of these have biofiltration properties and contain proteins and omega 3. Some algae have a high nutrient content of proteins, vitamins, essential fatty acids, antioxidants and minerals (omega 3 oils in fish derive from algae that the fish have eaten). The aquaculture industry has an infrastructure that, with a few simple adjustments, has the potential to integrate a number of species with traditional farmed fish. Species from different trophic levels with different functions can operate together as their own small ecosystem, making better use of the ocean's resources.

1.3 The world needs more renewable energy

The need to find good alternative energy sources is rising as populations grow and pollution increases. The petroleum industry and the burning of fossil fuels have left us with major global and ecological challenges. Ocean acidification and warmer waters are impacting on biodiversity and habitats more quickly than researchers previously thought. Greater ocean acidification could lead to considerable financial losses for the aquaculture and fishing industry, as it can have a direct effect on organisms that are an important food source for fish, which in turn can directly affect fish larvae and fry. The hearing and balance organ of fish is made of calcium carbonate, and this organ can be affected by a lower pH.

With global challenges, it is particularly important to find innovative new solutions. Large-scale production of seaweed biomass in connection with fish farming offers great opportunities to produce renewable energy such as biogas or bioethanol. In this area, the aquaculture industry has huge potential to help absorb CO_2 and make the sea less acidic, renew habitats and produce renewable energy.

1.4 About the report

Bellona published the report "Environmental Status of Norwegian Aquaculture" in 2003 and an awful lot has happened since then. Better and more effective technological solutions have taken the industry to a level that allows it to be developed and integrated with sound environmental solutions. Bellona has been involved in the hunt for new solutions, new resources and new products that will be important for the future. The industry has high ambitions for growth, but it must happen in harmony with the ecosystem. This report is about how aquaculture can progress from salmonid monoculture to integrated and sustainable ecosystems. This progress depends on the aquaculture industry, research institutions and politicians working together. The potential for biomass production is enormous and the technologies are already available.

2. Today's fish farming and its challenges

2.1 Production

The farming of salmonids in Norway is currently based on monocultures (Fig. 1). This means that only one species is cultivated in large quantities. Production in the monocultures is high. In 2012, fish farms produced 1.2 million tonnes of salmon and 70,000 tonnes of rainbow trout (Statistics Norway). Salmon accounted for 93.6%, with rainbow trout making up 5.3%, with a total primary value of NOK 30.7 billion (Fig. 2). The aquaculture industry has improved in a host of areas over the past 10 years, but important challenges remain to be resolved.

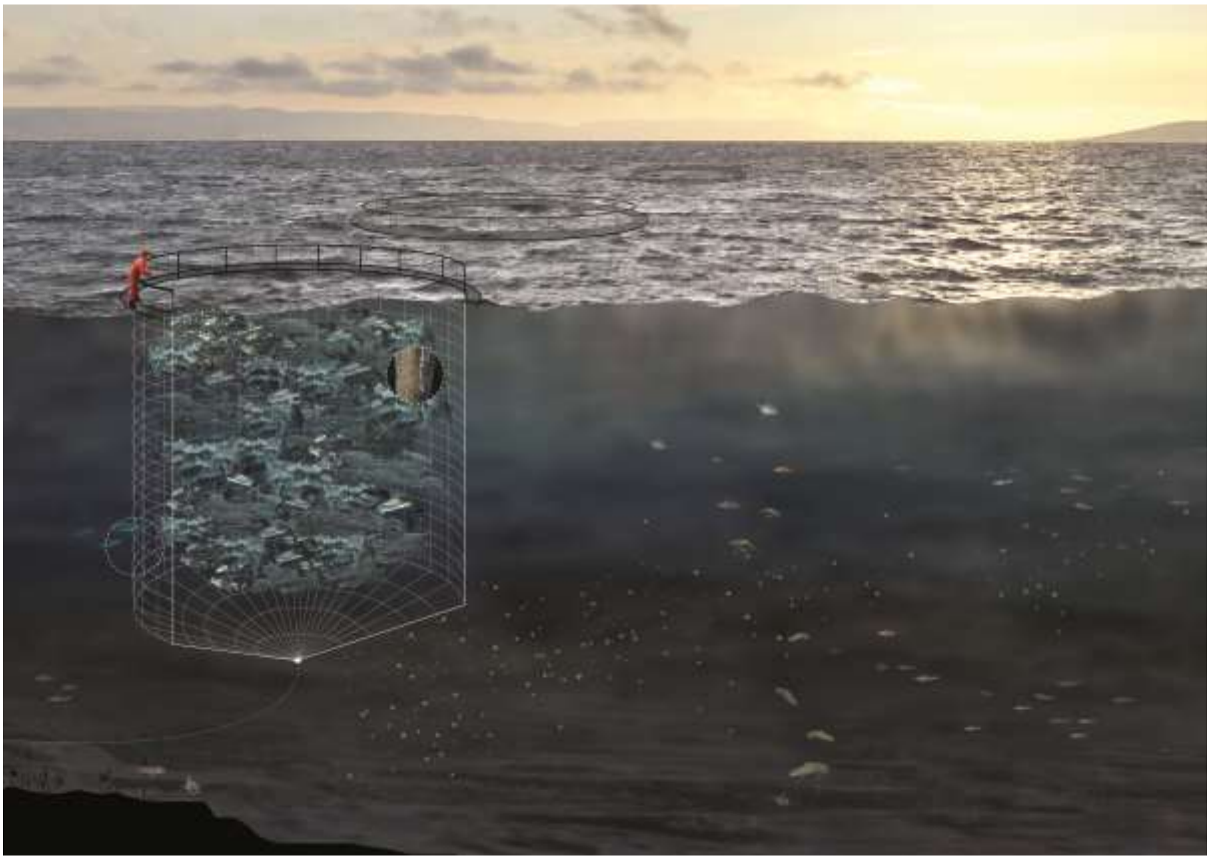


Fig. 1. The fish farming industry as it stands today with monocultures (illustration by Minsk & Bellona).

Monocultures allow for efficient, rational and mechanised operation plus high production levels. The problem is that such levels can overload the established ecosystem, putting the system out of balance and damaging its sustainability. Numerous factors contribute to this trend towards imbalance, including: escaped fish; parasites and diseases; discharges of nutrients and organic material; discharges of chemicals to combat salmon lice; copper antifouling for nets; poor use of feed resources.

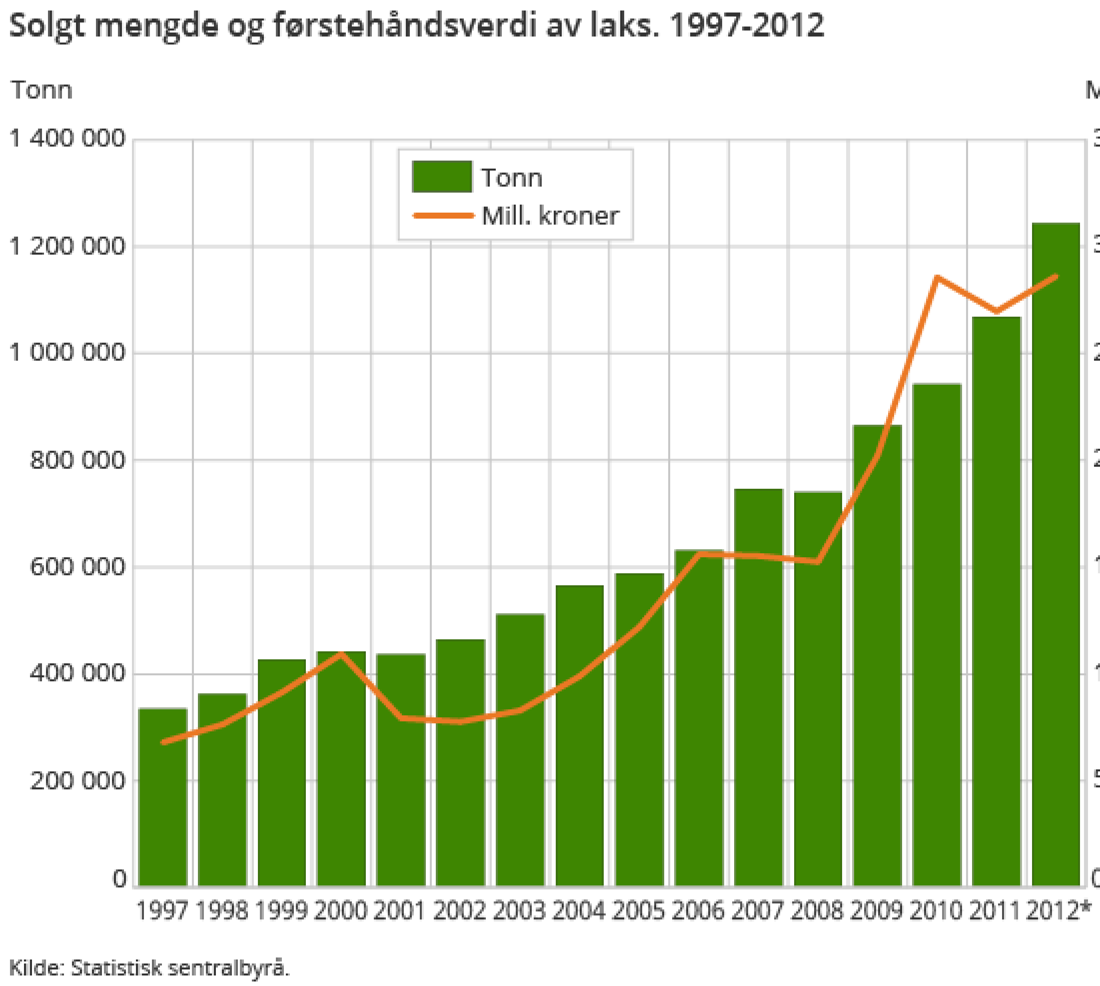


Fig. 2. Sales volumes for salmon and primary value (Source Statistics Norway).

2.2 Escaped fish

One of the aquaculture industry's greatest environmental challenges is the fact that farmed fish escape every year, and those escaped fish can pose a threat to wild stocks of salmon and trout. Allowing fish to escape is a criminal offence and can lead to considerable fines and punishments for companies and their employees (Thorvaldsen et al. 2013). The aquaculture industry and Norwegian authorities have a zero vision with regard to escaping fish. The operational objective is to reach a level where escaped farmed fish do not have a negative impact on wild fish. Unfortunately, this is quite a long way off. Figures from the Directorate of Fisheries (FD) show that escapes remain a problem. 2011 saw 365,000 salmon and 2,700 rainbow trout escape. Following a significant reduction in escapes in the years 2007/2008, there was an increase every year up until 2011. Although the figures are lower than in the period from 2002–2006, salmon (Fig. 3) and trout (Fig. 4) continue to escape. In 2012 there was a strong downturn in the number of escaped salmon and a strong upturn in the number of escaped trout. FD has had reports of incidents relating to a total of 170,961 individual salmonids. Of this number, salmon account for 38,199, and rainbow trout for 132,762 (Figs. 3 and 4). At the same time, overall production has risen. Taking a broad view of the statistics for escaped trout, it is clear that some years have seen almost no escapes, while individual incidents in certain years have had a notable impact on the statistics. 2012 confirms this trend. Rainbow trout is not a species that occurs naturally in our waters, and 30–40 years of farming has not led to these fish establishing themselves in our rivers as a result of escapees.

Fish farms are obliged to notify FD immediately as soon as they realise or suspect that fish have escaped. However, it is likely that some incidents have not been reported. FD suspects 10 episodes went unreported in 2012, and the actual number of escaped fish is therefore difficult to estimate. Today's situation remains unsustainable. Fish continue to escape from Norwegian fish farms and the potential damage to wild fish stocks is unacceptable.

Fish escapes are due largely to equipment failures as a consequence of poor weather and deficient procedures. Operational and human error are the main reasons, while rubbing from bottom ring chains causes major tears in the netting that can allow large-scale escapes. Escapes are reported throughout the production chain, from land-based facilities and transport to open water sites and processing plants. It is clearly the industry's responsibility to tackle the problem of escaped fish and if it is not up to the task, the authorities should consider implementing more measures of their own.

There are continuous advances in technological equipment for the fish farming industry that can reduce the danger of escapes. However, the degree to which the technology is used by the industry varies. The first thing to do is take simple measures and improve everyday procedures. The SINTEF research report of 2013 (Thorvaldsen et al. 2013) examines the human factor in escapes, and how important it is to adapt conditions at every level where there may be a risk of escape. Working on the fish farms can often be tough and demanding, and in bad weather it is easy to make a mistake. Under these circumstances, it is the people who fail rather than the technology. The report is intended to provide a greater insight into how the work can be organised and adapted in order to reduce the risk of escapes.

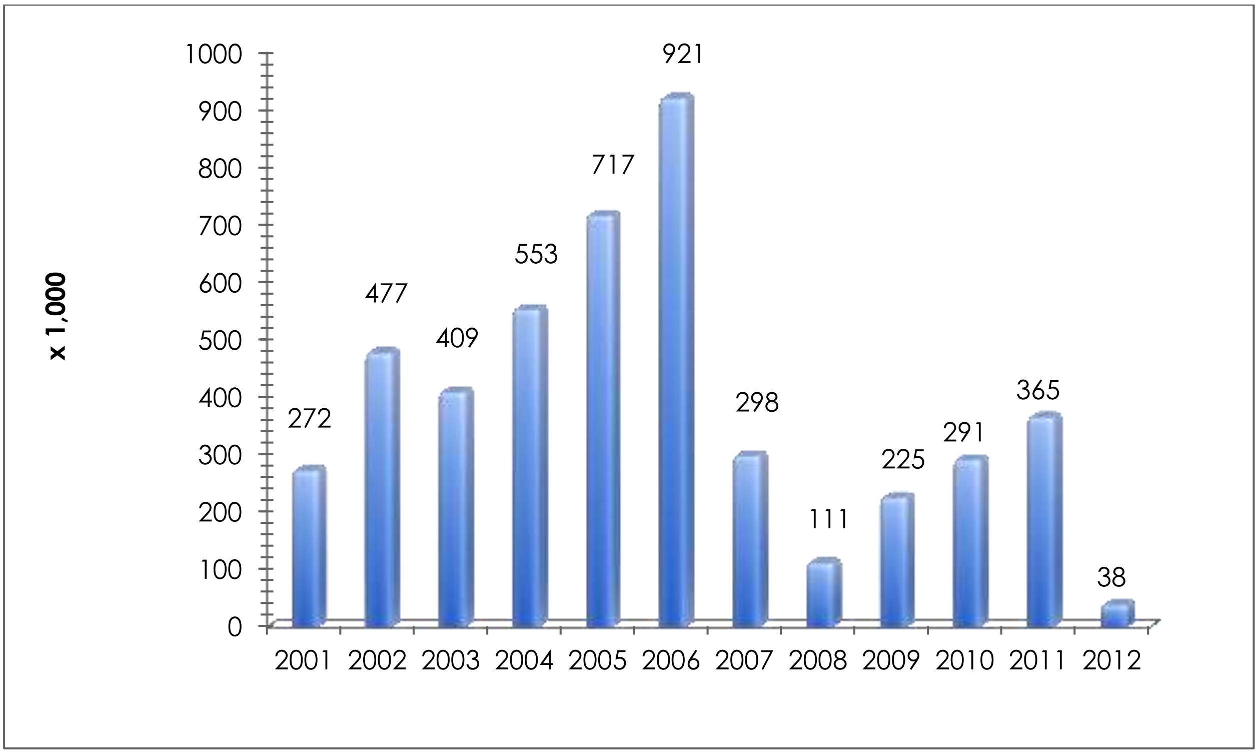


Fig. 3. Reported salmon escapes from 2001–2012 (Source Directorate of Fisheries)

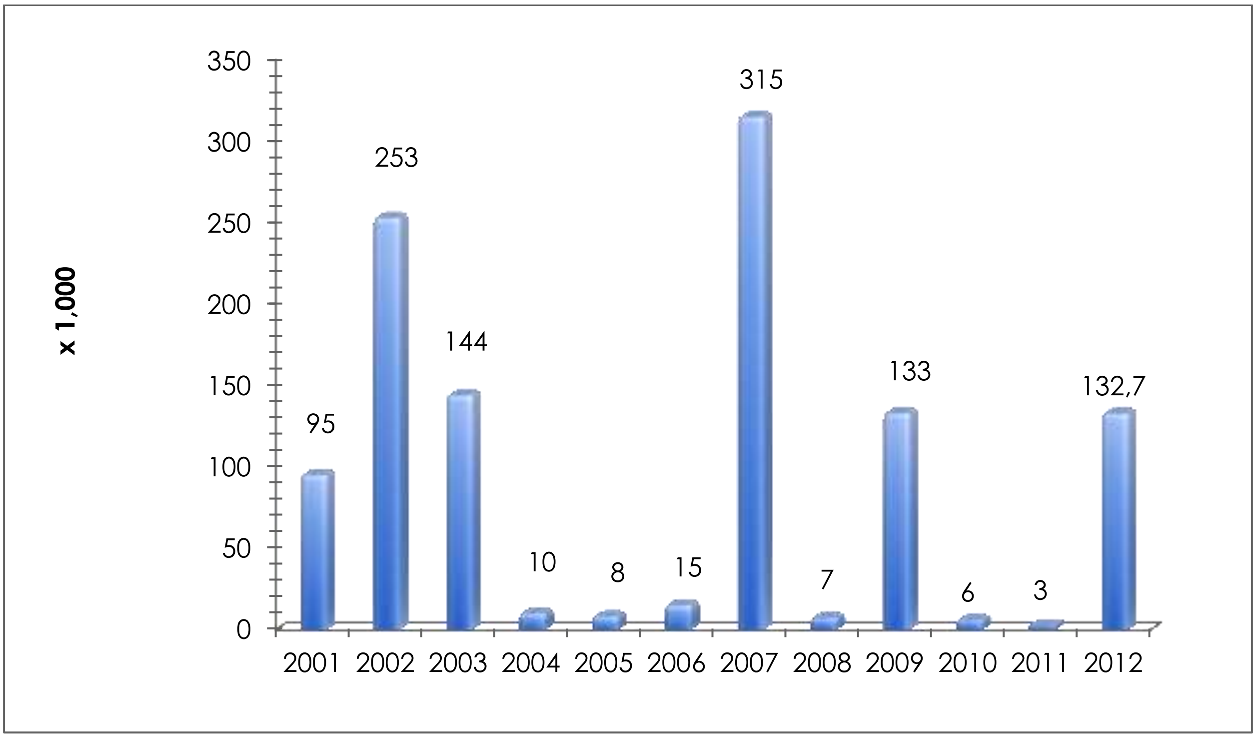


Fig. 4. Reported rainbow trout escapes from 2001–2012 (Source Directorate of Fisheries)

2.2.1 Closed system farming at sea

Closed systems are nothing new in the aquaculture industry. For several years now, smolt production has taken place in closed system facilities on land, because this part of the production uses freshwater. However, when it comes to the marine-based part of the process, this technology has not yet been fully developed for large-scale production. Closed system facilities may comprise steel, concrete, plastic, composite, fabric and netting in the water with a controlled entrance and exit. A number of new proposals have been put forward for closed systems in various materials and designs. In a report from 2011 (Rosten et al. 2011), SINTEF evaluated current methods for closed systems and concluded that there is insufficient scientific data on large-scale tests of closed system fish farming concepts. This was thought to be the case in the areas of technology, economics and biology. There is also no guarantee that fish will not escape, and a substantial amount of energy is needed to pump the water. Bellona believes, however, that closed system facilities should be tested on a large scale. Several stakeholders see numerous advantages in semi-closed systems for salmonids at sea in the early phase, where the danger of lice attacks, infections, mortality and escapes is reduced. Semi-closed systems for large fish appear unlikely at this point in time.

2.2.2 Closed system farming on land

There remains some debate over whether closed system fish farms on land with recirculation technology might be a solution for reducing the industry's challenges with regard to escapes and spread of disease. The technology is ideal for smolt production and post-smolt production (young salmonids with a length of 12–20 cm that are ready for migration to the sea), but there is little to be gained in terms of energy and financial benefit from using the system for adult fish. It would require large areas of land and is much less cost-effective than using the seas. Other countries have, however, invested in land-based production of salmon. Hvide Sande in Denmark, for example, produces salmon on land using recirculation technology. Production is estimated at 1,000 tonnes of salmon per year. There are also plans to build similar facilities in the USA and in the Gobi Desert. Such production on land may be viable in countries with lower costs than Norway, with little or no access to their own coastline, and with access to large areas of flat terrain where there is no conflict with culture, tourism or other industries.

2.2.3 Marking fish

In October 2011, Bellona and other environmental organisations issued a proposal for the double marking of fish. Such a measure would bring tighter controls to the fish farming industry and the possibility of tracing where the escaped fish come from. Double marking of fish would quickly be able to separate out the offenders to avoid punishing the whole industry. This would benefit both the serious fish farmers and the environment in the long term. Labelling of fish would be natural in connection with vaccination (Kristiansen et al. 2012).

There are several methods of marking fish, including the Coded Wire Tag, which is a tiny metal tag of just 1 millimetre that is inserted into the nose of the fish. A numeric code on the tag can easily be read using a microscope and, since each individual group of fish is given its own number series, it is easy to trace the origin of the fish. The objection is that every part of the fish is used and so the metal tag will get into food. Such a method could not be used to identify visually whether it is a farmed fish or a wild fish.

A method that has been discussed as a possible supplementary solution alongside marking to single out farmed fish is adipose fin clipping. The problem with the latter idea is that too little is known about how this affects the behaviour and health of the fish. There is relevant legislation in this area: 1) the Aquaculture Management Regulation (section 31 prohibiting the removal of body parts from live fish), and 2) the Norwegian Animal Welfare Act (section 10 on identity marking of animals). On behalf of the Norwegian Food Safety Authority and the Directorate of Fisheries, the Institute of Marine Research (HI) has evaluated adipose fin clipping as a marking method for farmed salmon (Kristiansen et al. 2012). The evaluation was unable to rule out the fact that there may be negative impacts on production and behaviour, and the decision was taken that adipose fin clipping should not be used in Norway.

Adipose fin clipping is a widely used method in the USA and Canada (Kristiansen et al. 2012) with generally little or no negative effect on growth and survival (Vincent-Lang 1993). In its experience, the Institute of Marine Research has also not observed any sores or infections in the area around the adipose fin afterwards or seen any evidence that the treatment has led to increased mortality. In total, several hundred million fish have their fins clipped in the USA and Canada, and over 50 million salmonids are also marked with a Coded Wire Tag (Kristiansen et al. 2012). It remains unclear what function the adipose fin has in nature. The adipose fin has not disappeared through evolution over many millions of years, which might suggest that it performs some function (Reimchen & Temple 2004). In terms of farmed fish which do not have to survive in nature, removal of the fin is likely to have little effect on behaviour in fish farms (Kristiansen et al. 2012).

The Norwegian Seafood Federation (FHL) and the Norwegian Seafood Research Fund (FHF) have initiated several projects to develop tools that will help trace escaped fish back to the original farm. These include the use of genetic methods to identify farmed fish with a high degree of probability (Karlsson et al. 2011). The process uses Single Nucleotide Polymorphism (SNP) as a genetic marker, as this helps to link progeny back to parents. The method is robust and cost-effective, and can differentiate farmed fish from wild fish.

2.2.4 Sterilising fish

The technology exists to produce sterile farmed salmon on a large scale. Sterilisation of farmed salmon is one of many measures that can reduce the risk of unwanted genetic effects caused by escaped farmed salmon (HI report 2012), but a number of challenges remain.

Aqua Gen, which produces salmon roe, has developed a new pilot plant for the large-scale production of sterile roe. The fertilised row starts out with three sets of chromosomes, which are normally reduced to two sets. Under high pressure, the roe retains three sets of chromosomes, which is what makes the adult fish sterile. Both young and adult sterile fish can easily be identified by analysing the DNA in their red blood cells using flow cytometry (Bakketeig et al. 2013). Aqua Gen's production facility has the capacity to sterilise a million salmon roe an hour. Research from the 1980s and 1990s has, however, shown that sterile salmon can suffer higher mortality rates, slightly poorer growth and skeletal deformations. From both a welfare and a financial perspective, the use of sterile salmon in farming has therefore been greeted with scepticism (Fjelldal et al. 2012, in HI 2012). Aqua Gen and the Institute of Marine Research have worked with the industry and international research institutions to examine how sterile salmon perform under different farming conditions. It was observed that sterile fish grow more quickly in freshwater, but there are divergent results concerning speed of growth in relation to non-sterile fish in saltwater. Other results from these experiments show there are still problems concerning the health and growth of sterile farmed fish:

- Sterile fish have a greater need for phosphorus in their diet to avoid skeletal deformations, but this can be reduced with lower water temperatures during the period from fertilisation to first feeding.
- Sterile salmon are more susceptible to faulty development of the pericardium. This can lead to reduced growth and increased mortality.
- There are generally more cataracts in sterile fish.
- Sterile fish are more sensitive to high temperatures in combination with poor oxygen levels. This might mean sterile fish are best suited to farming in areas where the temperature does not get too high in summer.
- The degree to which sterile males might affect spawning results in the salmon rivers remains uncertain, but laboratory experiments show sterile males to be just as aggressive during spawning as non-sterile fish.
- No matter what, sterile fish will never produce live young, and therefore cannot change the gene structure in the wild populations.

One important issue is thus whether escaped sterile fish are able to court and stimulate wild female salmon so that they release their roe without it being fertilised. In a worst-case scenario, escaped sterile fish could pose a major problem (Skaale et al. 2012, in the HI report).

2.2.5 Capsule and sonar technology

A new EU funded project led by Seafood Security is testing the possibility of monitoring fish farms with the use of patented capsule and sonar technology. This involves inserting a capsule into each fish and recording its movements via sound waves in the water, allowing large amounts of data to be captured. The object of the capsule is to optimise operation of the fish farm. If a fish escapes, it can be killed or immobilised via the capsule.

2.2.6 Dyneema netting

Better nets can reduce escapes. Dyneema netting uses the world's strongest fibre, making it 15 times stronger than steel and 40% stronger than nylon. The netting is lightweight and for cleaning it can therefore be air-dried. Aquaculture company Loch Duart in Scotland was one of the first to begin using Dyneema netting to reduce escapes. Loch Duart uses no chemical antifouling on the twine or moorings, as is common practice in the industry to prevent the growth of organisms. Instead, the nets are cleaned after natural drying in the sun and wind. Bellona has found that few fish farmers use this technology despite it being readily available. The causes may include the higher price compared with other nets on the market, and the fact that air-drying is cumbersome and impractical.

2.2.7 Salmon trap

New technology developed by BioSorts in collaboration with SINTEF can capture escaped farmed salmon in Norwegian rivers. This technology has not yet been used commercially, but may be able to play a key role in limiting the harmful effects of escaped farmed fish. The salmon trap is a fully automated system for clearing rivers of farmed salmon with immediate effect after installation. It sorts the salmon based on optical recognition. Escaped salmon are sent to a holding pool while wild salmon are allowed to pass through.

Salmon trap (Photo Biosort)

2.3 Salmon lice

Another major challenge that the aquaculture industry continues to battle with is salmon lice. Each year, the industry spends around one and a half billion kroner on fighting salmon lice. A number of trials are underway to limit/combat lice infestations in fish farms. These include thermal delousing, breeding resistance to lice, use of blue mussels, developing a vaccine against lice, use of currents, snorkels, plankton nets, lice skirts, mechanical delousing, louse traps, enclosed aquafarms, use of lasers, functional feed and use of an electric current. Many of these projects are described at lusedata.no. Some of the projects are also examined in more detail below (see sections 2.3.1–2.3.5). Current legislation states that there must be no more than 0.5 adult lice per fish. Even if there are few lice per fish and they are not harmful to the farmed fish, large quantities of salmon lice are produced in a fish farm. Making a rough estimate, a site with four cages and a total of 800,000 fish will have 400,000 mature female lice. Each of these lays between 7,000 and 11,000 eggs. Even if many of the eggs do not become fertilised and develop into new louse larvae, it is not difficult to appreciate the scale of production of planktonic salmon lice that are then carried away on the current. There may have been a downward trend over the past three years (Figs. 5 and 6), but there are still too many salmon lice. The areas from Trøndelag to Hordaland seem to be most affected by lice (Figs. 5 and 6).

Salmon louse (Photo Andreas Hagemann)

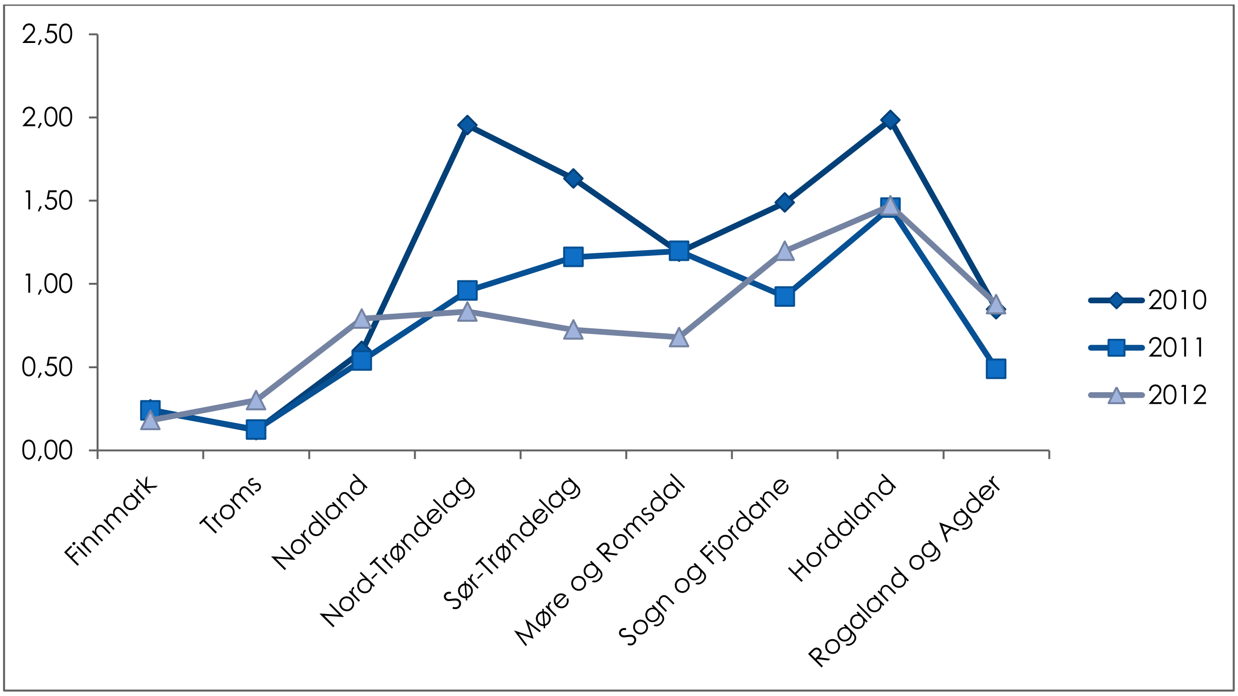


Fig. 5. Mobile lice over the past three years (Lusedata)

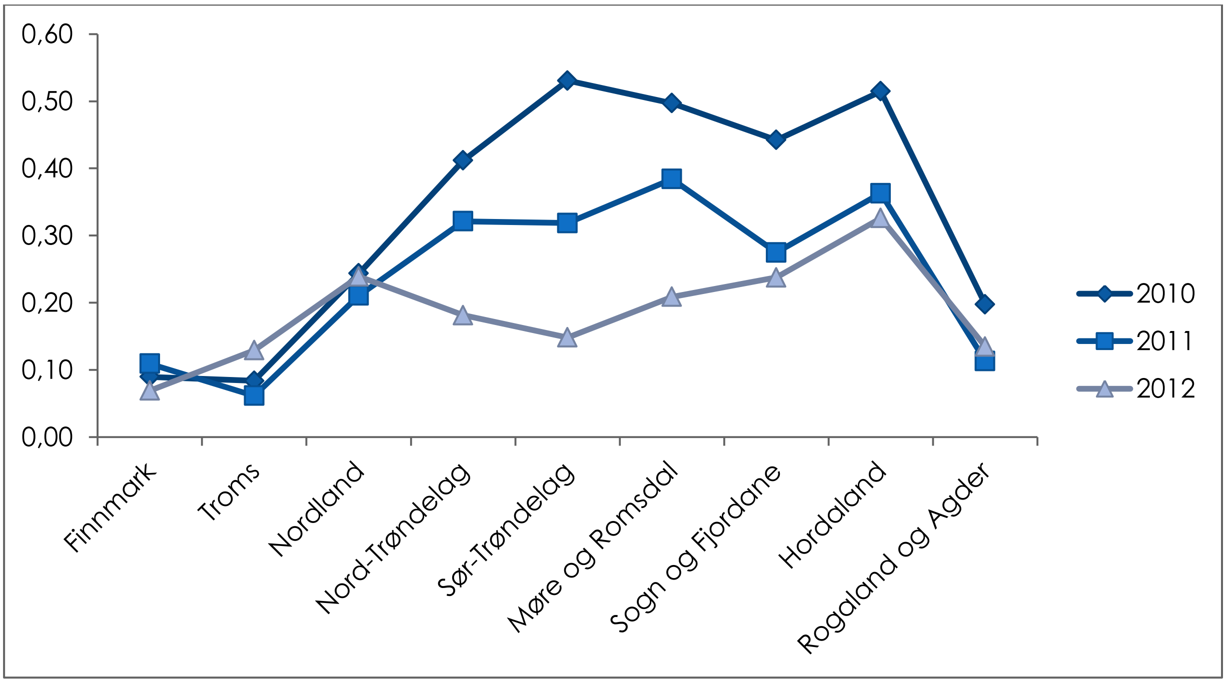


Fig. 6. Adult female lice over the past three years (Lusedata)

2.3.1 Discharges of chemicals against salmon lice

Treatments of lice-infested farmed fish can be divided into three main categories, which are usually used in combination: wrasse, delousing baths, and medicated pellets. The first, wrasse, has few environmental drawbacks, but certain limitations on practical use. The two others subject the fish and the marine environment to toxic substances. The chemical substances used to combat salmon lice in fish farms include substances that inhibit chitin synthesis in salmon lice, which prevents moulting. The medication is mixed into the feed or the water. The pharmaceutical Teflubenzuron is used against salmon lice, but the problem is that it also inhibits the synthesis of chitin in other crustaceans that live in the waters and on the seabed around fish farms (Samuelsen et al. 2013). As well as sinking to the seabed, the delousing medications are also dispersed across wide areas. Samples taken at three fish farms show how the delousing agents spread through the fjords (NIVA Report 2011 on behalf of the Norwegian Climate and Pollution Agency – KLIF). The chemicals are detected up to a kilometre away from the fish farms (Samuelsen et al. 2013). It has also been found on several occasions that salmon lice have developed resistance to the chemicals. Total consumption of chemical agents to combat salmon lice rose in 2009 and 2010, but went down slightly in 2011 (Table 1). There was a significant jump in the use of all agents against salmon lice in 2012 with the exception of Emamectin, compared with the previous year (Table 1). The greatest increase was in the use of chitin synthesis inhibiting Diflubenzuron and Teflubenzuron (Table 1). In 2012 chitin synthesis inhibitors were used in around 6% of the treatments.

The various chemicals that are used to combat salmon lice can have negative effects on the environment in high concentrations. Bellona's aquaculture report from 2003 describes the potential environmental effects, efficacy, degradation, dispersal and toxicity of the most commonly used delousing agents.

There have been concerns about whether it is healthy to eat salmon that has been treated with chitin inhibitors. Studies show that use of the delouser Flubenzuron is not a food safety problem in fish (Institute of Marine Research; National Institute of Nutrition and Seafood Research), but it has environmental problems that include significant negative effects on lobster larvae (Samuelsen et al. 2013).

Because there are other, better methods in the fight against salmon lice, Bellona believes environmentally harmful chemicals capable of disrupting the balance of the ecosystem should be reduced to zero.

A more eco-friendly delousing method in use is hydrogen peroxide (H_2O_2), which is a powerful oxidant often used as a bleach and disinfectant. Hydrogen peroxide decomposes spontaneously into water and oxygen. In contrast to the other delousing baths, hydrogen peroxide has largely been used for delousing in wellboats. The advantage is that hydrogen peroxide is more eco-friendly than chitin inhibitors. The disadvantage is that hydrogen peroxide is less effective (only working on the mobile stage of salmon lice) and that the lice only become detached without dying. The lice must then be collected and destroyed after treatment. There is also a greater risk of both escapes and stress when the fish are being transported to and from the wellboats for delousing.

Table 1. Agents against salmon lice measured in kg active substance from 2009–2012 (Source Norwegian Institute of Public Health)

	2009	2010	2011	2012
Azametifos	1,884	3,346	2,437	4,059
Cypermetrin	88	107	48	232
Deltametrin	62	61	54	121
Diflubenzuron	1,413	1,839	704	1,611
Emamectin	41	22	105	36
Teflubenzuron	2,028	1,080	26	751
Total	**5,516**	**6,454**	**3,374**	**6,810**
Hydrogen peroxide (tonnes)	308	3,071	3,144	2,538

2.3.2 Louse vaccine

Researchers have worked for many years on gene mapping the salmon louse (Bakketeig et al. 2013). This may prove to be a key tool in the task of finding new and better treatments against salmon lice. Identifying the genes essential to a salmon louse's survival allows identification of processes that make lice less successful and development of better treatment methods.

The Norwegian Veterinary Institute and the Institute of Marine Research are working together to produce a louse vaccine. This is being done by mapping the molecules from the salmon and the louse's own immune system. The aim is to find the right molecules that can be isolated and produced in a vaccine so that when lice drink salmon blood the fish's immune system recognises the lice and attacks while at the same time the louse's own immune system is suppressed (Lusedata). Potential vaccine antigens are to be tested on salmon during the course of 2013 (Bakketeig et al. 2013).

2.3.3 Louse-eating fish

There are many fish that eat sea lice. Wrasse is probably the best known example. The ballan wrasse (*Labrus bergylta*) is the most effective, as it eats lice at lower temperatures than the other wrasse species. It takes 2–5% wrasse in the cages to delouse the salmon. For example, a cage with 100,000 salmon requires 2–5,000 wrasse. The survival rate for wrasse in winter is low and the pressure on natural stocks is high. There has been a massive rise in the use of wrasse since 1977, from around 1,000 fish in 1988 to approximately 3.5 million in 1997, 4.4 million in 2009, and between 10 and 15 million in 2010 and 2011. In 2012 the Directorate of Fisheries set the minimum size for wrasse at 11 cm. From Trøndelag north, the minimum is 10 cm. Establishing a minimum size is a way of ensuring that a location is not depleted of wrasse, but allows the possibility of recruiting fish for delousing duties. The conflict between heavily pressurised natural wrasse stocks and the need to reduce lice in a growing salmon industry shows the considerable need for research into sustainable farming of louse-eating fish.

Launched in 2011, a three-year project financed by the industry's own research fund (FHF) sees SINTEF Fiskeri og Havbruk, the Institute of Marine Research, the Norwegian University of Science and Technology (NTNU), NIFES, Nofima and the industry itself investigating the scope for improving the farming of wrasse, with the aim of meeting 25% of demand for farmed wrasse by 2013.

Another louse-eating species has attracted a great deal of attention over the past year. Lumpfish (*Cyclopterus lumpus* L.) are widespread along the whole of the Norwegian coastline, and are better equipped for the cold winter climate than wrasse. Experiments have shown that lumpfish are more effective louse eaters than wrasse, and they have a shape that means they remain inside the nets even when small. There are reports and observations from the late 1990s about the lumpfish feeding effectively on salmon louse (Lusedata, Willumsen 2001). Despite the promising prospects, there is no commercial farming of this species at this time, although a facility for large-scale production is being established by Norsk Oppdrettservice and Arctic Cleanerfish.

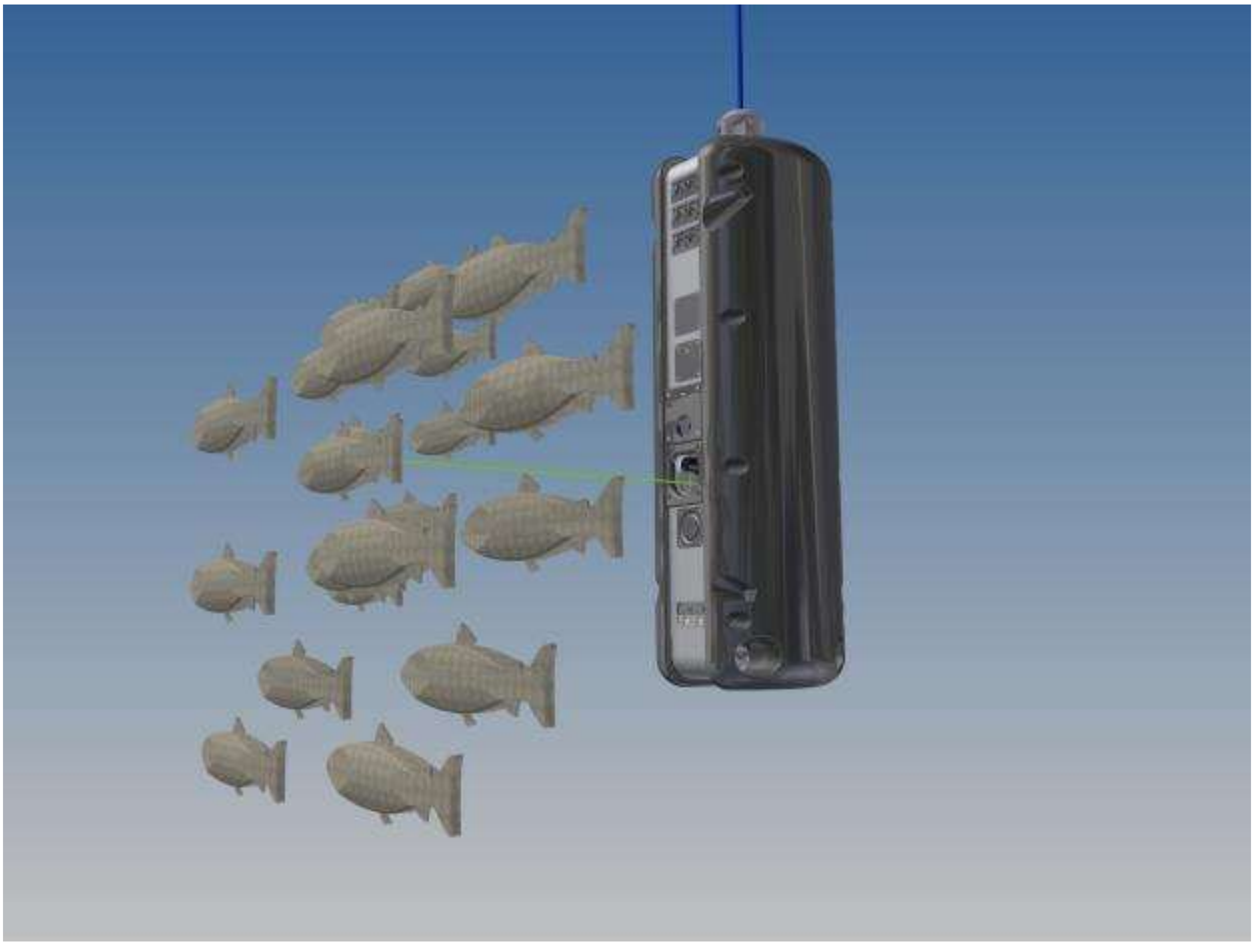
A lumpfish that has eaten salmon lice (Photo Gifas)

2.3.4 Electrification of cages

Electrical pulses in the water can be used to stop the escape of farmed fish and to prevent salmon lice, fouling and predators from entering the cage. The system, called Seafarm Pulse Guard, comprises a control system and an electrified skirt around the cage. Small-scale studies have shown that the technology can reduce new lice infestations by almost 80%. The method has been patented by the company Seafarm Development and will be trialled on a larger scale throughout an entire production cycle.

2.3.5 Laser

Fish farming companies Lerøy Seafood Group, Salmar and Marine Harvest are taking part in a joint project with the Norwegian technology company Beck Engineering to develop a system for optical delousing of salmon. This is a new technology that detects the salmon louse, measures its size and hits it with a laser. At a speed of up to five nanoseconds, this system can kill around 10 lice per second. The technology has the capacity to delouse 24 hours a day without causing the fish any stress. The project began in 2012 and will continue testing throughout 2013 before publishing the results.



Optical delousing of salmon (Photo Beck Engineering)

2.4 Infectious diseases

The fish farming industry continues to battle with a number of viral and bacterial diseases. Viral infections remain the greatest health problem nationwide for the aquaculture industry (Johansen et al. 2013). Infectious diseases can be spread by escaped infected fish and lice, but we still have little knowledge about the ecological consequences of infections transferring from farmed fish to wild fish (Institute of Marine Research).

2.4.1 Pancreas disease (PD)

Pancreas disease (PD) is caused by a virus known as the Salmonid Alphavirus (SAV). There are six known subtypes of PD that are designated SAV1–SAV6 (VESO & Norwegian Veterinary Institute 2007). SAV3 is common in Norway and occurs in salmon and rainbow trout. SAV2, which has been more common in Scotland, was found in Norway for the first time in 2010 (Johansen et al. 2013; Hjortaas et al. 2013), in Nordmøre and Sør-Trøndelag (Norwegian Food Safety Authority). PD was first observed in Norway in 1989. The virus has been found in several fish species, but outbreaks have only been recorded in salmon and trout. The disease affects the salmon's pancreas, as well as causing heart and skeletal muscle inflammation, and one of the early symptoms is that the fish stop eating. The consequences are reduced digestion, suppressed appetite, a weaker heart and poorer growth. This results in a slow death that can take 2–3 weeks. PD is highly infectious and is one of the most serious viral diseases that the fish farming industry currently has to contend with (Norwegian Food Safety Authority; Norwegian Veterinary Institute). The disease can easily spread to other neighbouring facilities. Outbreaks of the disease have only been recorded in the seawater phase and tend to occur once the fish have spent longer than 5–7 months in the sea. The mortality rate is high and the outbreaks can last a long time. Stress is a factor that increases the risk of a PD outbreak (McVicar 1987).

Incidents of PD affected between 75 and 89 locations from 2009–2011 (Table 2), but rose dramatically in 2012 to 132 outbreaks (Johansen et al. 2013). The northerly spread of PD was the worst health development in 2012 (Johansen et al. 2013). A PD outbreak at an open water site with 500,000 salmon leads to an average loss of over NOK 40 million. This is a huge financial blow for the industry.

A vaccine against PD has been developed, but has only a limited effect and vaccinated fish can still be infected. Nevertheless, the PD vaccine has been shown to produce lower mortality, milder outbreaks and reduced the length of illness, with the surviving salmon beginning to regain their appetite more quickly.

Table 2. No. of locations in the years 2005–2012 with infectious salmon anaemia (ISA), pancreas disease (PD), heart and skeletal muscle inflammation (HSMI) and infectious pancreatic necrosis (IPN) (Johansen et al. 2013).

	2005	2006	2007	2008	2009	2010	2011	2012
ISA	11	4	7	17	10	7	1	2
PD	45	58	98	108	75	88	89	137
HSMI	83	94	162	144	139	131	162	142
IPN	208	207	165	158	223	198	154	119

2.4.2 Heart and skeletal muscle inflammation (HSMI)

Heart and skeleton muscle inflammation (HSMI) is associated with a newly discovered reovirus in farmed salmon. The disease was first reported in Norway in 1999 and occurs along the whole coastline. Outbreaks happen over long periods and affected fish can be infectious for several months. HSMI predominantly causes inflammation and cell death in the heart. This damage arises early on in the cycle of the disease and can last for many months. An increase in the disease has been recorded in recent years (Table 2). In 2011 the disease was reported at 162 sites.

This is a 20% rise in the number of reports compared with 2010 (Fish Health Report 2011). In 2012 there were 142 reported incidents, slightly down on the previous year (Johansen et al. 2013). There is no treatment for the disease at the moment. In regulatory terms, the disease is on list 3 of national diseases that have to be notified to the Norwegian Food Safety Authority when they occur. Work on a vaccine is underway, but when this might be brought to market remains unknown (Kystlab).

2.4.3 Infectious pancreatic necrosis (IPN)

Infectious pancreatic necrosis (IPN) is caused by a resistant aquabirnavirus that can be passed on between individuals and from parents to young via roe and milk. The disease can affect various fish species, but mostly salmonids. Outbreaks can occur throughout the freshwater phase and the seawater phase. IPN is difficult to fight because the virus tolerates both high and low pH, heat and dryness, and survives in healthy fish. The mortality rate in an IPN outbreak varies a great deal, from almost nothing to nearly 100% with increased stress factors (Sandtrø 2011).

There is no treatment for the disease, but it can be combated through preventive health work. The number of IPN outbreaks reached a record high in 2009, with diagnoses at 223 sites (Table 2). Although registered outbreaks have almost halved over the past two years from 198 in 2010 to 119 in 2012 (Norwegian Veterinary Institute), it remains a problem for the industry. There have been great advances in breeding recently, and the disease appears to be reduced as a clinical problem where QTL roe has been used. The special QTL roe comes from parent fish that have tested positive for special gene markers and produce young with high resistance to IPN. This has helped to reduce the number of outbreaks. A vaccine is in widespread use but, given the figures above, it appears to have a limited effect.

2.4.4 Infectious salmon anaemia (ISA)

Infectious salmon anaemia (ISA) is a serious and infectious viral disease that has only been recorded in Atlantic salmon. The virus damages blood cells and blood vessel tissue and can cause serious blood loss. ISA occurs naturally in the sea. In Norway, ISA is classed as a type B disease, and is the only disease in salmon with an active control programme administered by the Norwegian Food Safety Authority. If the viral disease is discovered, all fish in the fish farm must be slaughtered within 80 days. A viral outbreak usually starts in one cage and over time it then spreads to other cages and sites. This disease causes considerable losses for the salmon industry, if it is not controlled and combated. Over the course of several years (2003–2010) researchers from the Norwegian Veterinary Institute gathered and analysed information from over 300 Norwegian salmon farming sites that had suffered an ISA outbreak, in order to understand more about what happens to infected fish. Knowledge of how this virus works is important if the industry and the authorities are to implement the necessary measures to prevent the disease and reduce the spread of infection. Geographically, the disease has appeared mostly in northern Norway in recent years, with most outbreaks in 2008 and 2009 (Norwegian Veterinary Institute 2010). Seven incidents of ISA were recorded in 2010 in the northernmost counties and only one incident of ISA in 2011, in Finnmark (Table 2). Two new outbreaks of ISA were recorded in 2012, both in Møre og Romsdal.

2.4.5 Causes of diseases in fish

Reduced immune defences and less than optimal fish health may be contributory causes of viral and bacterial diseases. The combination of stress and poor feed quality is a triggering factor in the outbreak of diseases. In Bellona's opinion, there needs to be more research into whether higher vegetable content and a lower level of good marine content in fish feed may be a key cause of reduced immune defences. In its Fish Health Report 2011, the Norwegian Veterinary Institute presents clear indications that smolt quality has been less than satisfactory over the past few years, and at the same time we have seen a rise in susceptibility to disease and poorer fish welfare. Another major problem is the spread of infection.

Wellboats that have not been disinfected increase the risk of infection (Johansen et al. 2013). Risk analysis from the ISA epidemic in Scotland confirm a heightened risk of ISA outbreaks from frequent wellboat contact (Murray 2002). The transmission of infection via wellboats may be due to (pdfri.no 2008):

1. Not knowing the infection status of fish coming from supposedly healthy farms

2. Not carrying out washing and disinfection in line with agreed procedures

3. Agreed procedures not being sufficient to ensure a clean boat, e.g. due to the physical/technical design of the boat

4. The wellboat taking shortcuts through more heavily infected areas, deviating from agreed routes, or taking on other types of transport assignment (e.g. transport of marine species, by-products or suchlike) before transporting hatchery fish

5. The boat being reinfected due to the intake of infected water before a new shipment

6. Fish from the previous assignment being stuck in the pipe system (rare, but it has happened)

There is currently no national register of wellboat transport assignments, so there is no oversight of how much biomass is being moved, and over what distances (Johansen et al. 2013).

2.4.6 Shrinkage

Shrinkage refers to fish that escape, have to be destroyed due to bacterial and viral infection, or suffer some other non-specific cause of death. Large-scale shrinkage remains a significant problem in the Norwegian fish farming industry (Norwegian Veterinary Institute 2011).

The death rate between fish egg and adult salmonid in nature is high, and is due in part to natural predation during the different life cycle phases, access to food, access to habitat and environmental conditions. With wild salmon, for example, survival from egg to smolt normally ranges from < 1% to around 5%. Progress from egg to smolt generally takes two to four years, depending on temperature and so on. The smolt age is lower in warm rivers than in the colder rivers further north. There is generally a gap of between one and three years between the smolt leaving the river and returning as an adult salmon to spawn. Survival at sea, represented by the proportion of smolts that return as salmon, varies widely from year to year – it can be as low as 1% in an extremely bad year and 10–20% in a very good year, averaging out at 3–8%.

Salmonid mortality in cages should not be compared uncritically with mortality in nature. In a cage there are no natural predators and environmental conditions ought to be of a standard that will not damage fish health. In addition, the fish always have access to food. In a cage therefore, the quality of food, environment and life are limiting factors. A rough indicator of poor fish welfare in salmon cages is the percentage mortality rate at the fish farms (Institute of Marine Research). A welfare indicator might apply the following levels: Extremely good welfare (< 3% mortality), Good welfare (6–10% mortality), Average welfare (10–15% mortality) and Extremely poor welfare (> 30% mortality) (Institute of Marine Research).

Number of fish, biomass weight, mortality and other losses are reported monthly to the Directorate of Fisheries. Shrinkage in this instance relates to farmed fish held out in cages. In Bellona's experience, the Directorate of Fisheries has no clear overview of what is recorded under shrinkage (discards or dead fish) apart from escapes. The rate of shrinkage stood at 22–26% from 2009–2011 (Fig. 7). From a total yield in 2012 of 248,383,374 salmon and trout, shrinkage accounted for 41,767,207 fish. This equates to a shrinkage of 17% in 2012, a significant reduction on the previous years (Fig. 7). This is certainly a notable improvement. However, we still need a better registration system for fish not being used for human consumption, so that concrete causes of death are specified. This is important information in mapping the actual situation and identifying primary causes. The Faroe Isles have shrinkage figures below 10% and good individual fish farmers have shown that it is possible to take the figure down towards 5% (Johansen et al. 2013).

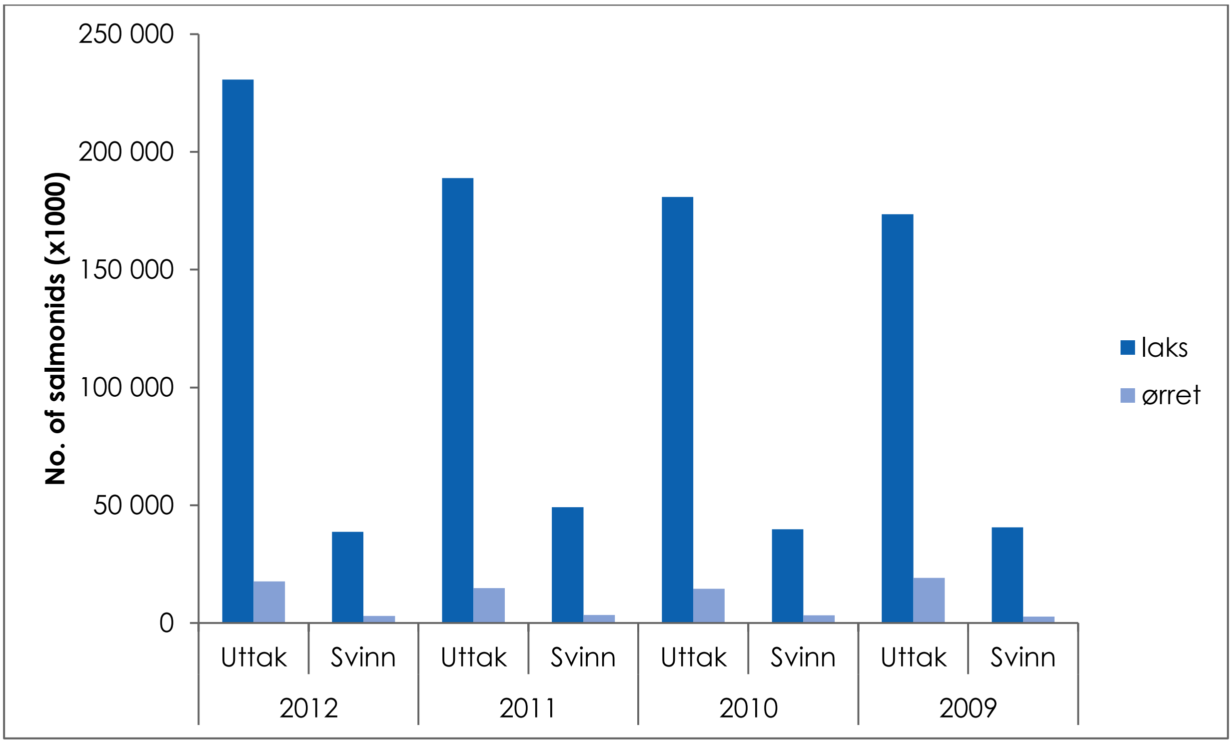


Fig. 7. Shrinkage and yield from 2009–2012 for salmon and trout (Source Directorate of Fisheries)

2.5 Feed resources

The Norwegian fish farming industry contributes to pressure on wild fish stocks by being a major consumer of fish oil and fish meal. In 2012 Norway consumed 1,594,932 tonnes of feed (Figs. 8 and 9). Around 20–30% of this feed becomes organic waste in the form of excrement and feed waste that sinks to the bottom and is consumed by bottom-dwelling organisms (Bakketeig et al 2013). It takes around 2.2 kg of wild fish to produce 1 kg of farmed salmon, but only around 1.46 kg of that wild fish is actually consumed (FHL; Mugås). This is around half of what used to be needed, but the figure remains too high. The marine raw material comes from industrial fishing and fish trimmings. It chiefly comprises a mix of fish such as herring, capelin, mackerel, blue whiting and anchoveta. The trend in feed consumption has changed with the increase in fish production. Recent years have seen producers include other sources in their feed. This has been prompted by the fact that fish meal and marine oils are limited resources, prices are high as with many other raw materials, and criticisms have been made about poor use of resources.

Farmed fish require good quality fish feed. An important nutrient in fish feed is omega 3. Fish meal and fish oil used to be predominant ingredients in salmon feed (Table 3), but today the content of marine ingredients varies depending on price and availability. In times of high prices and reduced supply, more oil may derive from vegetable sources. However, plant matter does not contain long chain omega 3 fatty acids. The content of omega 3 in fish feed has fallen because farmed fish are being fed plant oils. This drop in the available marine omega 3 means that fish now have levels around 50% lower than they had in 2003–2004 (National Institute of Nutrition and Seafood Research, Dr. Bente E. Torstensen). Nevertheless, salmon remains one of the best sources of omega 3 that we have.

Research has shown that poor quality fish feed suppresses a fish’s immune system and makes it more susceptible to disease (Miller 2002). There is thus traditionally a conflict between preservation of wild fish stocks and good quality fish feed. However, progress is being made concerning nutrition and feed, and there are many good marine sources of omega 3 and proteins that do not need to affect wild fish stocks. Marine raw materials do not need to be a limited resource. Plenty of proteins and omega 3 are available from lower trophic levels that make up the fish’s own natural food sources. This will be discussed in the next chapter (see Integrated aquaculture).

Table 3. Composition of Norwegian produced fish feed in % from 2007–2010 (Source FHL).

	2007	2008	2009	2010
Fish meal	30	30	31	25
Fish oil	20	15	20	17
Vegetable	50	55	49	58

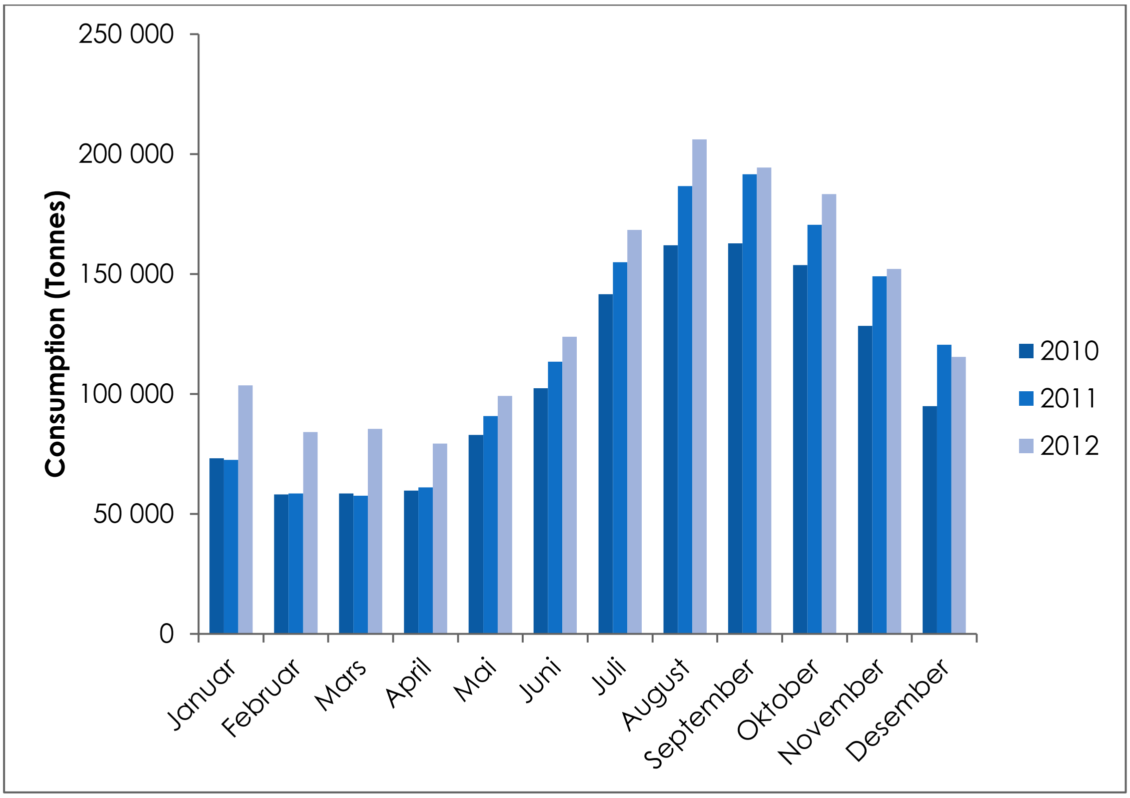


Fig. 8. Monthly consumption of fish feed in tonnes from 2010–2012 (Source Directorate of Fisheries)

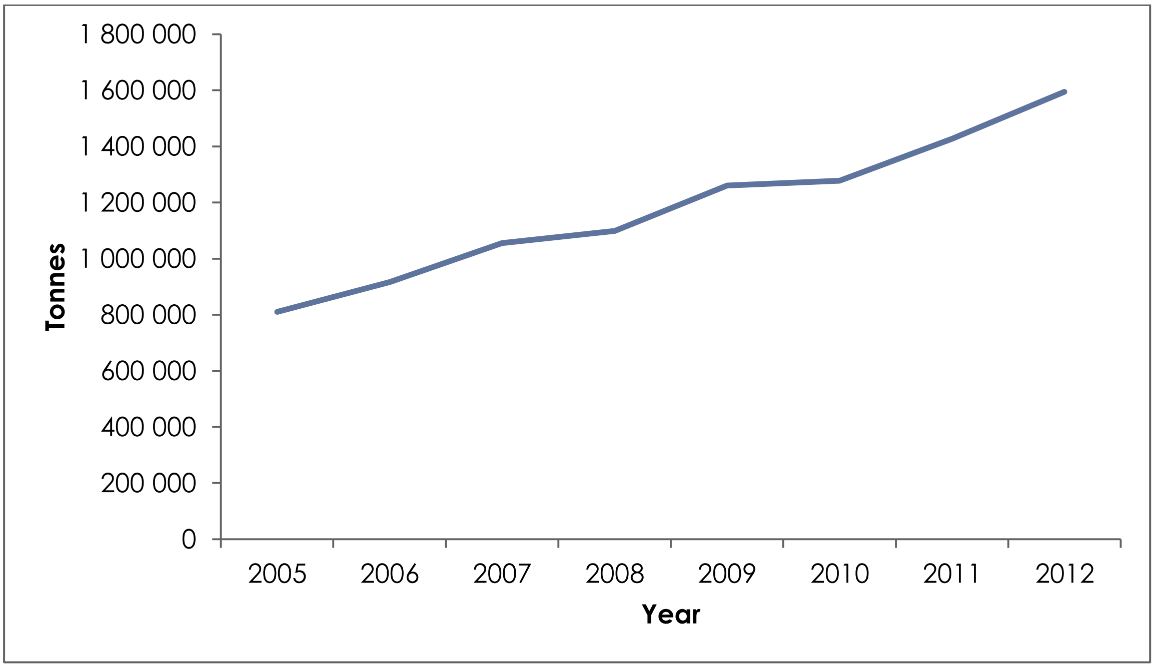


Fig. 9. Total consumption of fish feed from 2005–2012 (Source Directorate of Fisheries)

2.5.1 Environmental toxins in fish feed

Environmental toxins and farmed salmon have once again been in the spotlight recently. Today, all the world's oceans are polluted to varying degrees. Environmental toxins in the sea are becoming concentrated in the marine food chain and accumulating in fat. This means that predatory fish can contain high levels of environmental toxins. Traces of environmental toxins can unfortunately be found in almost all produced foods such as fruit, vegetables, seafood, meat and dairy products. Farmed salmon can have a significant level of environmental toxins if the feed contains high quantities of marine fat from severely polluted marine areas. Fish from Peru and Chile is preferred in part because it contains less environmental toxins. Danish feed producers catch fish from the Baltic Sea which has such high concentrations of environmental toxins (dioxins, PCBs, see below) that the oil must be purified if it is to be used in food production. The feed used in Norway has extremely low concentrations of environmental toxins. Good removal of low concentrations of environmental toxins in feed is difficult and expensive. Each year, the National Institute of Nutrition and Seafood Research (NIFES) measures environmental toxins in fish feed and they are found to be far below the limits laid down by the Norwegian Ministry of Health and Care Services. This is conducted as part of an EU-based (mandatory) monitoring programme concerning environmental toxins, which itself is founded in the requirements set out in Council Directive 96/23/EC. Directive 96/23/EC relates to both land animals and aquaculture, but the requirements are slightly different for the different animal groups. A 2011 report that NIFES drew up on behalf of the Norwegian Food Safety Authority indicated that there were low concentrations (below the limits) of legal pharmaceuticals and environmental toxins in farmed fish (Nøstbakken et al. 2012).

The most recent results of the monitoring by NIFES show that the level of heavy metals in Norwegian farmed fish lies below the limits by a good margin. Table 4 compares observed levels of heavy metals with limits set by the EU, and clearly illustrates that heavy metals in farmed salmon do not pose a consumer health concern. Mercury levels have fallen from 0.03 mg/kg in 2009 to 0.016 mg/kg in 2012. For lead and cadmium, the figures represent detection limits of 0.01 and 0.002 mg/kg respectively, so the actual values may be lower.

Dioxins (polychlorinated dibenzo-para-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF)) are organochlorine environmental toxins, which form as by-products of various industrial processes and during combustion. Dioxins accumulate in fatty tissue, are not readily degradable and are being concentrated in food chains – the marine food chain is particularly affected in this respect. People are exposed to dioxins via food, and the key sources are animal products such as fish, dairy products and meat. Levels of dioxins in foods are stated as nanograms TEQ/kg. Table 4 shows test results from samples of Norwegian farmed salmon from 2009 and 2012 (NIFES). The EU has set an upper limit for dioxins (PCDD and PCDF) in fish of 8 ng TEQ/kg and 4 ng TEQ/kg. Test results for farmed salmon show a concentration of 0.51 ng TEQ/kg (PCDD) and 0.22 ng TEQ/kg (PCDF) for 2012, a reduction compared with the previous year (Table 4).

Endosulfan is a pesticide found in vegetable oil made from soya, rice and maize. Endosulfan is no longer used in Europe, but it is used in other parts of the world that export food to Europe. To protect consumer health, regulations have been put in place that set limits on permitted pesticide residues in feed and food. In the EU the upper limit for endosulfan in feed for other animals is 0.1 mg/kg, while the maximum limit for fish feed is 0.05 mg/kg (Commission Regulation (EU) No 744/2012). Norway is in the process of introducing the same limits for fish feed as in the EU. A regulation on feed is now out for consultation, with a deadline for responses of 25 June 2013 (Norwegian Food Safety Authority). NIFES conducted a range of studies from 2006–2010 on endosulfan and farmed salmon. This data was used in a risk analysis conducted by the European Food Safety Authority (EFSA) in 2011. Based on this risk analysis, the maximum permitted level of endosulfan in feed for salmon was increased from 0.005 mg/kg to 0.05 mg/kg. Over the past six years, fish feed has contained between 0.0006 and 0.001 mg/kg, and in 2012 the average value was measured as 0.0008 mg/kg (Annual report on programme for monitoring fish feed from 2012, NIFES).

Table 4. Heavy metals and dioxins in farmed fish (Source NIFES). The figures represent average values from a number of measured samples (brackets) and the EU's limits (bold).

	EU limit	Measured value	2009	2010	2011	2012
Lead (mg/kg)	**0.2**		<0.015–0.1 (735)	<0.01–0.04 (615)	<0.03–0.04 (1505)	<0.01 (98)
Mercury (mg/kg)	**0.5**		0.03 (735)	0.03 (615)	0.02 (1505)	0.016 (98)
Cadmium (mg/kg)	**0.05**		<0.01 (735)	<0.002–0.02 (615)	<0.002–0.047 (1505)	<0.002 (98)
PCDD (ng TEQ/kg)	**8.0**		0.9 (270)	1.2 (183)	0.8 (140)	0.51 (98)
PCDF (ng TEQ/kg)	**4.0**		0.3 (270)	0.5 (183)	0.3 (140)	0.22 (98)

The values for environmental toxins are a long way below the limits and it remains safe and healthy to eat farmed salmon. Although it is a major challenge to keep the food plate clear of environmental toxin traces, it is important that the industry maintains a continuous focus on keeping concentrations as low as possible. This requires innovation, use/blending of new and pure feed sources and better, more effective cleaning methods.

Negative coverage of food safety and Norwegian farmed fish costs the industry a great deal of money. Divergent opinions from the industry create uncertainty and damage consumer confidence in food safety, but this can be reduced through clearer and more consistent communications from the industry.

2.6 Copper impregnation of nets

Another challenge for aquaculture is copper, which is used to prevent fouling of the nets. Impregnation is used to reduce this fouling on the netting, but it also has other functions such as stiffening the netting so that it remains taught in the sea, preventing UV radiation from damaging the netting and reducing/filling the space between the filaments in the netting so that these do not become overgrown (Bellona 2003). Fouling is a considerable problem for fish farmers as it increases the weight of the nets, which can easily cause tears to occur. Fouling also impedes water currents, which can bring oxygen levels in the cages below a critical minimum and lead to deaths among the farmed fish. When copper impregnated nets are new the antifouling works well, but after a few weeks they have to be cleaned to remove fouling, not least to ensure that water can flow through. After a few cleans, the copper ends up in the sea and on the seabed. Copper ions are released and copper compounds sink to the bottom, with the antifouling losing its effectiveness over time. Copper impregnated netting appears to be counterproductive, since it soon causes pollution and loses its effectiveness. Copper does not accumulate in the food chain, but it can reduce growth and reproduction in some aquatic species (Bakketeig et al. 2013).

Copper impregnation of nets is far too widespread, despite the existence of several alternative eco-friendly solutions. The discharge of copper into the environment from fish farming currently amounts to around 900 tonnes per year (Bakketeig et al. 2013). Copper is an environmental toxin and approximately 80–90% percent of the copper in the net impregnation agent leaks out as the nets sit in the sea, with the remaining 10–20% of the copper collected when the nets are cleaned. It is generally known that when nets are cleaned in the sea, the fish become stressed and the danger of escapes increases. Producing nets where the copper does not wash away is a step in the right direction. It doesn't solve the problems associated with copper, but it at least cuts back on the unnecessary environmental and financial costs. The environmental effects of copper discharges from fish farms are now widely documented, but considering the extent of the discharges there is a need to conduct exhaustive analyses of the effects that copper from fish farms has on the benthic fauna, phytoplankton and other organisms (Bellona 2003).

2.7 Discharges of nutrients

Fish farms discharge the nutrients nitrogen and phosphorus in both bound and loose form. Discharges of nutrients lead to increased algal growth and biomass production in the water, with the greatest effects occurring near the farms. The total discharges from several farms in the same area can, under extreme conditions, lead to eutrophication and reduced oxygen levels locally.

The Norwegian fish farming industry has changed a great deal since the 1970s. Farming facilities have been moved out to deeper, more open and exposed locations with better water exchange. Revised feeding procedures have led to discharges per tonne of fish produced halving over the past 15 years. However, increased production means that discharges remain high.

Anyone running a fish farm is required to monitor the environment around the site. MOM (Modelling-Ongrowing fish farms-Monitoring) is a system used to regulate the environmental impact from fish farms according to the holding capacity of the area. The monitoring programme is sanctioned by the Norwegian Aquaculture Management Regulation. The system has 4 status categories and differentiates between A, B and C surveys. Survey A is a simple measurement of the sedimentation rate on the seabed below the cages (not included in applicable standard NS-9410-2007). Survey B monitors bottom conditions below and around a fish farm. Survey C examines the bottom conditions that extend from the farm into the wider environment. Category 1 is for environments with good conditions, while the poorest fall into category 4. According to data from the Norwegian Ministry of Fisheries and Coastal Affairs, 93% fall into status categories 1 and 2 (representing 753 sites in 2012) (Fig. 10). Although this appears promising on the surface, there remains a large gap in our knowledge of ecological consequences. The Institute of Marine Research's 2012 report (Hansen et al. 2012) indicates that fish farming affects hard seabed ecosystems and that local eutrophication effects can occur in areas with poor water exchange. A surplus of nutrients that used to be seen as pollution could be used as a resource to cultivate other species. This is something that Bellona has focused on in recent years and Bellona is not alone in taking this approach. Several research institutions in Norway are currently examining how nutrients can become a key resource for other commercial marine species. Research has, for example, shown that seaweed and kelp, scallops and blue mussels grow better when nutrients are added. The Institute of Marine Research, NIVA and Uni Research at the University of Bergen are working together on a project (ECORAIS) describing both quantitatively and qualitatively how a supply of nutrients from fish farms affects communities, production and function within ecosystems. SINTEF and NTNU also have several projects underway, investigating the potential of surplus nutrients (see next chapter on integrated aquaculture).

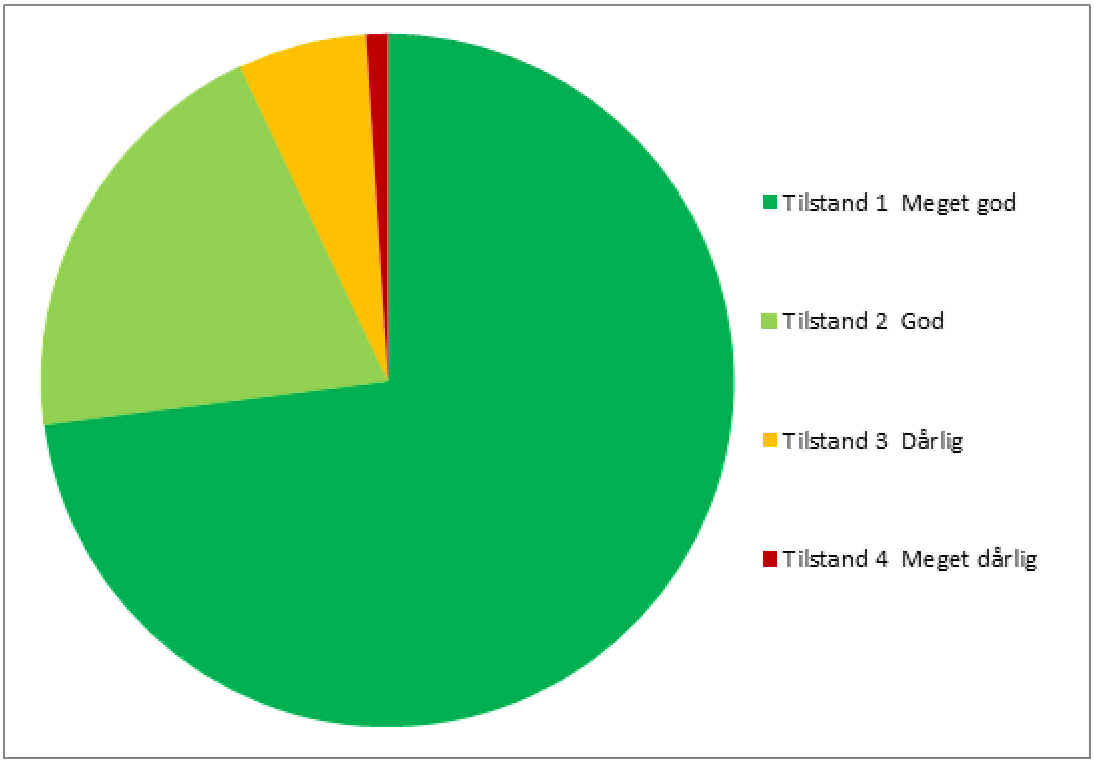
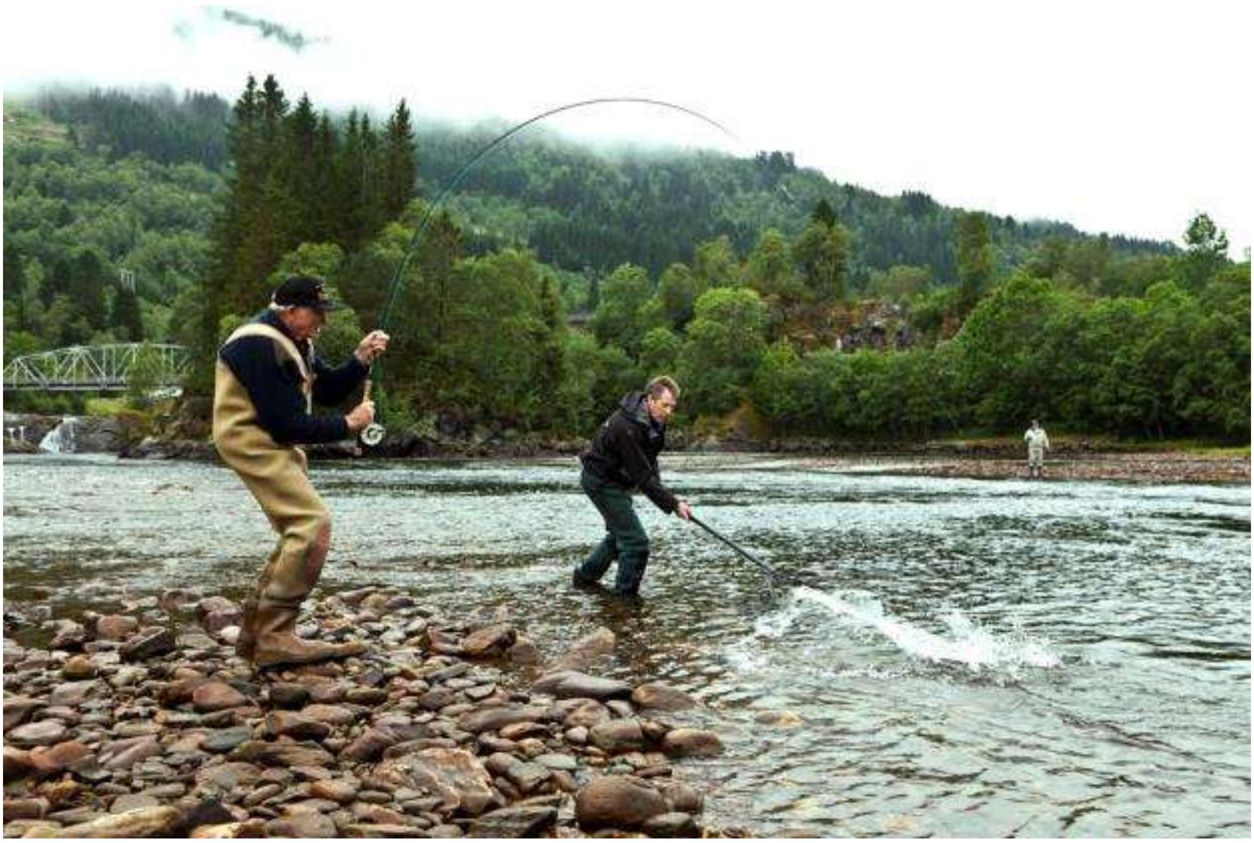


Fig. 10. Status categories for fish farms 2011–2012 (Source Directorate of Fisheries)

2.8 Status of wild salmon

The number of salmon that return to the rivers to spawn depends on conditions during the river phase, fjord phase and ocean phase. The national trend is most affected by the situation in the ocean. Conditions in the river and effects from the fish farming industry result in local variations. The report "Status of Norwegian salmon stocks 2012" from Norway's Scientific Council for Salmon Management (Anon 2012) states that in general the incidence of escaped farmed salmon is lowest in sport fishing in the rivers, higher in sample catches and brood stock catches in autumn before spawning, and highest in ocean catches. The lower incidence in sport fishing is attributed to the fact that farmed salmon tend to run up the rivers later in the year than wild salmon (Anon 2012). Although the incidence of escapes in salmon sportfishing, sample catches and brood stock catches has fallen in recent years, further measures are required to reduce the escape of farmed fish, if the genetic integrity of the fish stocks is to be safeguarded (Anon 2012).

In recent years, stocks of grilse in Norwegian rivers have become heavily depleted (Anon 2012), while quantities of medium-sized and large salmon have risen. In 2012, the recorded catch of salmon at sea and in the rivers was 173,000 fish, weighing a total of 696 tonnes. 14,300 salmon were reported to have been returned to the water (8% of the total catch). The total weight of killed and returned salmon is estimated at 758 tonnes. The catch statistics show a downturn in the number of salmon, but a large increase in average weight translates into a rise for the tonnage statistics. This is attributed to conditions in the sea.



Salmon fishing (Photo Atle Frøysland)

2.8.1 Ocean phase

Zooplankton is the most important food source for grilse. Compared with the average for the period 1997–2012, the estimated biomass of zooplankton per unit of area is now down by half in the North Sea (Fisken og Havet, issue 1-2013). Climatic conditions, changes in phytoplankton production, consumption by predatory animals, other zooplankton species and pelagic fish, or a combination of these may also play a role in the loss of plankton (Fisken og Havet, issue 1-2013). Little is known about salmon in the ocean phase and it is estimated that around 80–98% of the smolts that migrate from the rivers die at sea (van der Meeren 2013).

When salmon smolts reach the feeding grounds in the ocean, they are small and in poor condition. Instead of migrating back to the rivers as grilse the following year, they remain at sea feeding themselves up. They only come back to the rivers as medium-sized or large salmon. The salmon that survive the first critical winter at sea have good access to food, because they will be large enough to prey on pelagic fish. Consequently, the medium-sized and large salmon in Norwegian rivers have been of good quality in recent years (Norsk Villaksforvaltning (NVF)).

It is difficult to judge conditions for smolts in the ocean phase, with major global changes in the sea's chemistry and temperature due to global warming and ocean acidification. These changes affect the whole food chain and species composition, which can have consequences for particularly vulnerable smolts.

2.8.2 Fjord phase

Clearing up environmental problems that negatively affect wild salmon in the fjord phase is a political responsibility. The various impacts from fish farms must be better monitored than they are today, and the authorities need to set parameters for what is sustainable. There also needs to be more population-specific research into spawning stocks to identify the effects of natural variations, man-made effects and climate change. Genetic effects should also be investigated, since knowledge in this area is lacking. In 2012, the Institute of Marine Research published a risk assessment of Norwegian fish farms (Fisken og Havet, issue 2-2012), in which they assessed environmental impacts caused by Norwegian fish farms, based on new knowledge in the field of salmon farming. A preliminary assessment was made of animal welfare in Norwegian salmon farms, and of the risks in using wrasse as cleaning fish on the farms. The conclusion of the report was that infection pressures from salmon lice and genetic effects of escaped farmed salmon constitute the most problematic risk factors. In terms of lice, there was little infection pressure in spring, but this increased significantly with the spread of lice over the summer. The model used showed a correlation between the infection dynamic in fish farms and the increasing effect on wild salmonids that was observed in late spring and throughout the summer. With regard to other infection risks from farmed to wild fish, the Institute of Marine Research believes there is too little data to make a concrete regionalised assessment.

Millions of kroner are being ploughed into various wild salmon projects and other projects to improve conditions for wild salmon, for example through the Norwegian Seafood Federation's Environmental Fund and the Research Council of Norway. In addition, the industry itself is contributing many millions to a range of pilot projects. Bellona would like to see better coordination and a coherent overview of the results from these projects. Such an overview would be a great help in showing what has been tested, and would make it easier to identify any gaps in knowledge.

2.8.3 River phase

The production capacity of each river is established via a spawning target. The spawning stock target states the number of spawning fish or roe needed to fill the spawning and feeding grounds in the river in order to exploit the river's potential for fish production. In periods with few salmon, many rivers fail to achieve the spawning target due to overfishing of spawning salmon. This is put down to fishing quotas in Norwegian rivers being based on personal daily quotas irrespective of the size of the salmon. If the quota is exceeded, the smallest salmon will be put back, while the large spawning salmon that has the most roe will be killed. To resolve this issue, many rivers in recent years have introduced a personal seasonal quota for medium-sized and large salmon, alongside the personal daily quota. In rivers that have not achieved the spawning target, the authorities have reduced the length of the fishing season. These measures have little effect as long as there are no limits on how many people can fish in the river over the season (NVF).

In pilot trials by NVF, Sunnfjord introduced a new quota model in 2008 that has proven a great success. It is a combination of a seasonal quota for the whole river for medium-sized salmon and large salmon, and a personal daily quota for grilse. Deductions from the seasonal quota for medium-sized and large salmon are made for brood stock salmon for the hatcheries and a percentage to cover injured and dead salmon. What remains of a seasonal quota is split across three sections of river. The seasonal quota is adjusted annually according to the expected influx of medium-sized and large salmon. The seasonal quota can also be adjusted up or down during the fishing season as the level of spawning salmon becomes clear. The NVF quota model ensures that the spawning stock target is achieved, and that the salmon are well distributed among the landowners, giving several attractive fishing locations – all parties win.

Using seasonal quotas for medium-sized and large salmon at whole river level, combined with personal daily quotas for grilse, has major advantages over other quota models that have been tried. It is not the length of the fishing season that determines whether the spawning target is achieved, but the catch over the course of the season. As long a fishing season as possible also provides the greatest possible scope for landowners and other businesses to earn revenue (NVF).

Escaped farmed salmon in the rivers have been a concern for many years. A fishing project (funded by the Norwegian Seafood Federation's Environmental Fund) surveyed escaped fish in 62 watercourses in western, central and northern Norway, and found fewer escaped salmon in the rivers in 2011 and 2012 than was previously assumed. On a nationwide basis, this gives a figure for escaped salmon of 4.5% in 2011, with an improvement of 2.5% in 2012.

Wild salmon swimming upstream (Photo Alte Frøysland)

2.9 Current and proposed new measures

The aquaculture industry is constantly having changes and measures introduced to improve the environment. The huge growth in the industry has led to major technological advances. Many improvements have been made, but new rules and measures need to be drawn up to allow for further growth in the aquaculture industry.

2.9.1 New measures against salmon lice

The Norwegian Ministry of Fisheries and Coastal Affairs issued a modified regulation on spring delousing in 2012. This is a coordinated delousing from Rogaland up to Nordland to achieve the lowest possible infection pressure on migrating salmon smolts (Norwegian Food Safety Authority).

On 1 January 2013, a new salmon lice regulation came into force. The new salmon lice regulation contains a few new measures to combat salmon lice. The industry itself has been given greater responsibility for keeping down the number of lice in the cages. Although there are no statistics available, the modified new regulation has helped to reduce salmon lice.

In 2011, the Norwegian Ministry of Fisheries and Coastal Affairs paved the way for production of hatchery fish up to 1 kg. The background to the measure is a desire to cut the time the fish spend in the open cages, thus reducing the risk of escapes and exposure to salmon louse and diseases.

2.9.2 NYTEK regulation

A modification to the NYTEK regulation on technical requirements for floating fish farming installations entered into force on 1 January 2012. The purpose of the regulation is to help prevent escapes. However, the impact of this new regulation will only be known once figures for fish escapes are available over a longer timeframe.

2.9.3 Changes to Norwegian Aquaculture Act of 17 June 2005

The Norwegian Ministry of Fisheries and Coastal Affairs issued a consultation paper (19 September 2012) on a proposed act amending the Aquaculture Act. The consultation paper relates to changes in the environment chapter and the reaction and sanctions chapter, with proposals for stricter reactions, increased control and significant charges placed on the fish farming industry. Specifically, this means:

- Paving the way to require compulsory marking of fish.
- Joint industry responsibility for covering the costs of extracting escaped farmed fish from priority watercourses.
- The authorities can demand fees for environmental monitoring.
- Clearer and partially stricter sanction rules.
- The Directorate of Fisheries will be able to exchange information with other authorities that supervise the aquaculture industry.

2.9.4 Green concessions

The government has proposed awarding 45 new green salmon concessions in 2013. Of these, 35 will be redeemed against a current concession. This means that two new green concessions will be awarded against submission of one existing concession. Requirements are set concerning technological and operational solutions that reduce escapes and the incidence of salmon lice. Bellona is essentially positive about the proposal, but feels that the areas with the greatest impact should be singled out, for example areas with high lice levels combined with wild salmon migration. Tighter concession requirements might have been suggested here. The proposal has been sent out for consultation and the outcome remains to be seen.

2.9.5 The Salmon Aquaculture Dialogue

The Salmon Aquaculture Dialogue (SAD) was established as a research-based forum on the initiative of the WWF in 2004. The objective was to develop science-based measurable standards that could reduce the negative effects from salmon farming, while keeping the industry economically viable. This would be achieved by developing a credible certification system for farmed fish products, the Aquaculture Stewardship Council (ASC).

Over 500 stakeholders, including producers, environmental organisations, other NGOs, purchasers, researchers and others, have signed up to SAD. The dialogue participants have developed seven principles to resolve the key challenges of farming salmon, plus criteria that will mitigate the negative consequences. The voluntary standards are the result of an extensive multi-stakeholder process that has used innovative approaches to map environmental and social consequences.

These principles and their criteria constitute a framework of indicators to be used to measure the extent of the effect. The standards become quantitative performance levels that evaluate whether or not a principle has been achieved.

A steering group of representatives from bodies such as the Norwegian Seafood Federation, Marine Harvest, Skretting and the WWF has driven the work forward.

Work on the dialogue was completed in June 2012. SAD was wound down and the steering group handed the final standard plus a draft revision to the ASC, whose task is to certify the fish farms. The ASC will be working with independent third parties to certify fish farms that meet the final standard.

In autumn 2012, the ASC supervised trials of the standard and drew up a revision manual. Two members of the SAD steering group are part of the ASC's technical expert committee, a group that monitors implementation of the standard.

Evaluation of the field tests was conducted in winter 2012/2013. The results will determine whether the companies wish to commit to implementing in the standard. In spring 2013, several companies are expected to decide whether or not they are willing to abide by the standard.

A sustainability stamp from the ASC carries certain obligations, and the certification includes several requirements regulating water pollution, feed ingredients, transfer of infections between farmed and wild salmon, and working conditions at the fish farms. The new standard is intended to resolve the most important negative environmental and social consequences associated with salmon farming, while also allowing scope for the economic viability of the aquaculture industry, which has grown by over 50% in the past decade.

2.9.6 Indicators and limits

The Institute of Marine Research and the Norwegian Veterinary Institute have proposed indicators and limits for lice and escaped fish, on behalf of the Norwegian Ministry of Fisheries and Coastal Affairs. The goal is to assess the environmental sustainability of the Norwegian fish farming industry and to outline the probable consequences for wild fish. In the proposal, the Institute of Marine Research as described two sets of indicators – warning indicators and verification indicators for lice on wild salmon and for the genetic effects of escaped salmon. The warning indicators would give an early warning of the risk of negative environmental effects, while the status indicator would measure the actual status in a more robust manner. The Institute of Marine Research has suggested increasing monitoring along the coast to gather data and to improve and verify models that may prove useful in increasing environmental knowledge with regard to aquaculture and wild fish.

2.10 Future growth in the seafood industry

To be able to increase food production and manage resources properly, it is important to improve our knowledge of the ocean ecosystem. Several reports came out in both 2012 and 2013 with proposals to strengthen both R&D and the seafood industry (see below), and to improve management of Norway's coastal and offshore waters. All the proposals recognise huge potential in the marine industries that should be better exploited, but in a sustainable way. Achieving this requires a focus on marine management and resources to increase our knowledge.

2.10.1 Future ambitions of the seafood industry

The Norwegian Seafood Federation (FHL) published a report in 2012 on the industry's future vision of raising production to 2.7 million tonnes of salmon and trout by 2025 (FHL: SEAFOOD 2025, how to create the world's leading wild fish industry?). This represents a trebling of today's production. The report outlines six different actions required from companies, organisations and authorities to achieve this target. The main focus is on changing the industry's status to put food production on the same footing as energy production in the list of political priorities. Proposals for achieving the objectives include a greater focus on better use of resources, a long-term plan for resource management, greater efficiency and competitiveness, and a boost for ocean research and technological development.

2.10.2 Gaps in knowledge and future potential for the seafood industry

HAV21 is a national marine research and development the strategy. Norway has a responsibility as a centre of marine expertise, and needs to take a goal-driven approach to holistic ocean research. The HAV21 strategy sets out the recommended priorities required in order to fulfil commercial and political objectives for the marine sector. The strategy group for HAV21 was established in autumn 2011 by the Norwegian government and the Ministry of Fisheries and Coastal Affairs, and tasked with drawing up a proposed general research strategy for the whole of the marine field. HAV21 highlights and suggests what knowledge is required, and how it should be developed. Below is a brief summary of the areas that need strengthening:

- Public and private funding for marine research and development.
- Jurisprudence research and the establishment of a multidisciplinary research focus on future management principles, plus better organisation of marine and coastal management.
- Long-term research to understand the life and processes in the ocean, with a focus on: climatic effects; acidification; harvesting of biological and other resources; pollution and other human activity.
- A long-term investment in infrastructure to ensure the collection of data and effective monitoring, to provide the best possible warnings on different timescales.

- Marine research in the High North must be strengthened in line with the government's High North strategy.
- Research to highlight the potential and the need for knowledge and technology, plus a strategy for investment in new marine raw materials.
- Research into fish health and sustainable production of seafood, plus the documenting of sustainability and quality.
- Building up a marketing environment in Norway at a high international level in order to understand the importance of changes in existing markets, and what challenges new markets pose.
- Investing in technology within the fishing and aquaculture sector that draws on experience from technological developments in the maritime and offshore sectors, including biotechnology, nano/material technology and information technology.
- Organisation of multidisciplinary and cross-sector research projects in order to meet new management and commercial challenges.
- Establishing permanent research positions at universities and colleges, with a particular focus on scientific posts to provide more predictable career paths for young researchers.
- Communicating research results actively to administrators, the business world and the general public to ensure relevance and at the same time to help ensure the results are applied in practice.

2.10.3 Value creation based on productive oceans in 2050

A working group appointed by the Royal Norwegian Society of Sciences and Letters (DKNVS) and the Norwegian Academy of Technological Sciences (NTVA) produced the report "Value creation from productive oceans in 2050". The report describes considerable potential for marine value creation, putting it in excess of NOK 500 billion by 2050. The key conclusions and recommendations from the report are:

- The marine industries must be given higher priority in Norwegian political circles.
- Norway is uniquely placed to become a world leader in ocean technology, expertise and value creation. Norway has a responsibility to exploit its unique opportunities.
- There must be a focus on knowledge-based management of the oceans and coastal areas.
- There must be a strengthening of R&D and the marine-related educational sector.
- A coordinated technology strategy must be established in the field of the exploitation of marine resources.

2.10.4 The ministry's future ambitions for the seafood industry

In March 2013, the Norwegian Ministry of Fisheries and Coastal Affairs put a white paper before Parliament on becoming the world's foremost seafood nation (St. 22 (2012–2013)). One prerequisite for this is the need for profitability for all links in the value chain and for renewable marine resources. The government appears to have the political will to ensure its vision of Norway as the world's foremost seafood nation is achieved.

2.11 Conclusion

The fish farming industry as it is practised today is not sustainable, although progress is moving in the right direction. Levels of farm escapes and salmon lice remain too high. Organic pollution has the greatest environmental impact close to the farms. There is little to suggest that discharges of nutrients have a major ecological impact, but the nutrients could be put to better use. Many good technological solutions are available to mitigate the industry's environmental issues, but only a small proportion of these are used on a large scale. Many of the good solutions have only been tested in a laboratory setting and the need for large-scale testing is increasing as technology advances. Bellona believes the industry is important for the Norwegian economy, but new approaches and practices are required if the industry is to see further growth. Several reports published over the past two years have offered proposals for strengthening marine research and management of ocean resources. Integrated aquaculture has been mentioned many times as a possible alternative for future sustainable aquaculture.

3. Integrated Multi-Trophic Aquaculture (IMTA)

3.1 Introduction

Integrated Multi-Trophic Aquaculture (IMTA) (Fig. 11) appears to be able to provide considerable environmental and economic improvements compared with Norway's traditional monoculture fish farming. IMTA is a polyculture system where several species from different trophic levels (levels in the food chain) are cultivated together. Each species has different functions in the ecosystem that can benefit another species. The term "Integrated" refers to synergistic cultivation, using water-born nutrient and energy transfer. "Multi-Trophic" means that the various species occupy different trophic levels. Waste from one species thus becomes the food source of another species. One example has blue mussels and kelp being cultivated together with farmed fish. The mussels live on organic particles (e.g. plankton, fish waste, organic particles from fish feed) in the water, while kelp absorbs dissolved nutrients such as nitrogen and phosphorus (from sources such as fish faeces). As such, uneaten fish feed becomes a resource for the mussels. In addition, faeces from the fish are recycled as a food source for kelp. This process can bring significant environmental and economic benefits since blue mussels and kelp also have a commercial value (Fig. 12). It also makes for better use of the site and facilities, and greater diversity of production, which in turn brings higher profits from multiple products instead of one, plus more jobs (Chopin 2006; Troell 2009). A great deal of investment is being put into algae production and value chains globally. IMTA opens up many opportunities to produce more food, fatty acids, medicines and bioenergy in a sustainable and eco-friendly manner that can be incorporated into our own coastal system. Norway is one of the largest salmonid producers in the world, and yet Norway lags far behind Asia, the USA, Canada and several European countries when it comes to developing IMTA. Bellona believes it is important to consider the long-term future of renewable resources, food production and the environment.

Dr. Thierry Chopin and his research team in Canada have worked on IMTA for over 12 years, and report significant positive effects on the environment, both inside and outside the fish farming facility (Chopin 2006; Troell 2009). The research team has published several articles supporting the benefits of IMTA as relating to environmental impact, species response and economics. IMTA thus has the potential to achieve the goal of sustainable aquaculture (Chopin et al. 2001, Neori et al. 2004; FAO 2006; Ferreira et al. 2012) that satisfies the requirements for environmental, economic and social benefit.

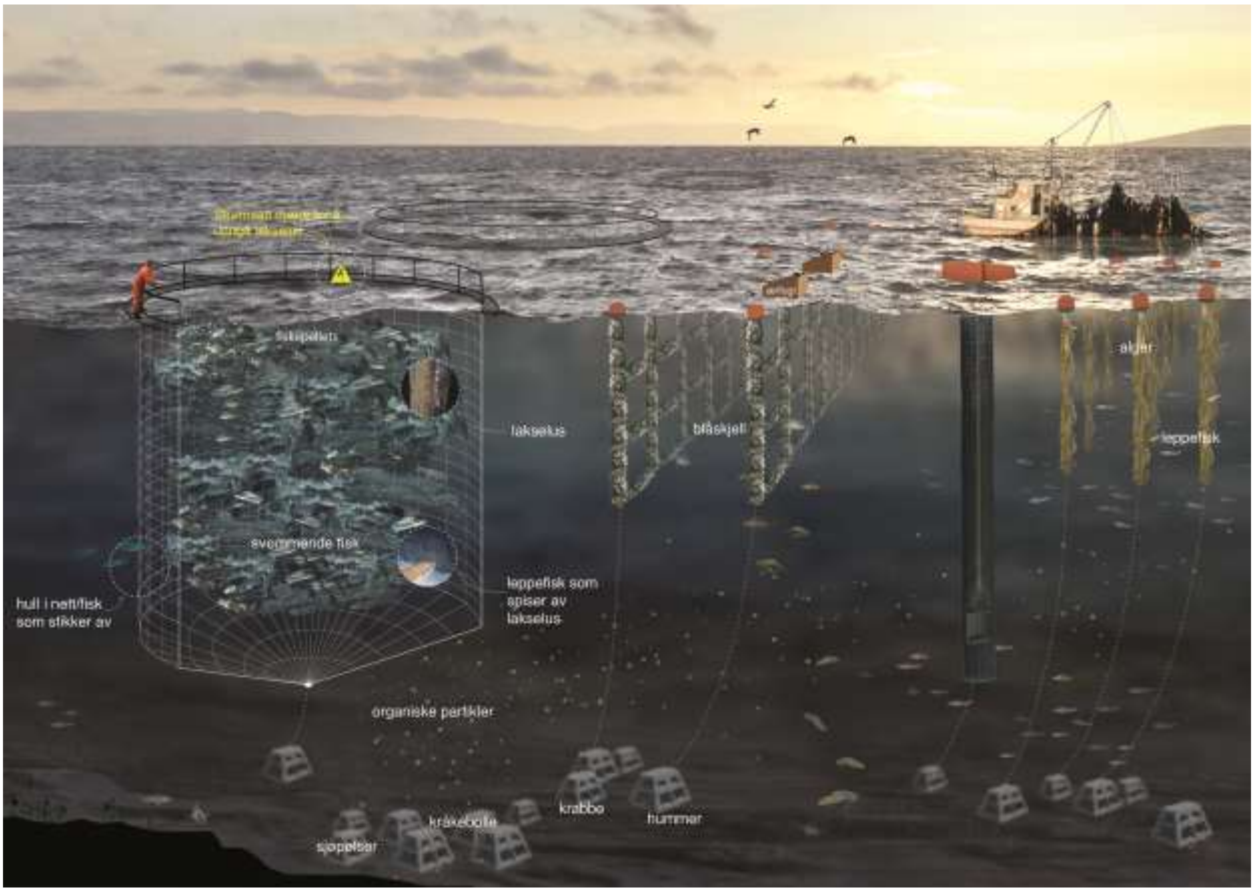


Fig. 11. IMTA with salmon, blue mussels, algae and invertebrates. Floating upweller technology is shown between blue mussels and algae (illustration by Minsk & Bellona).

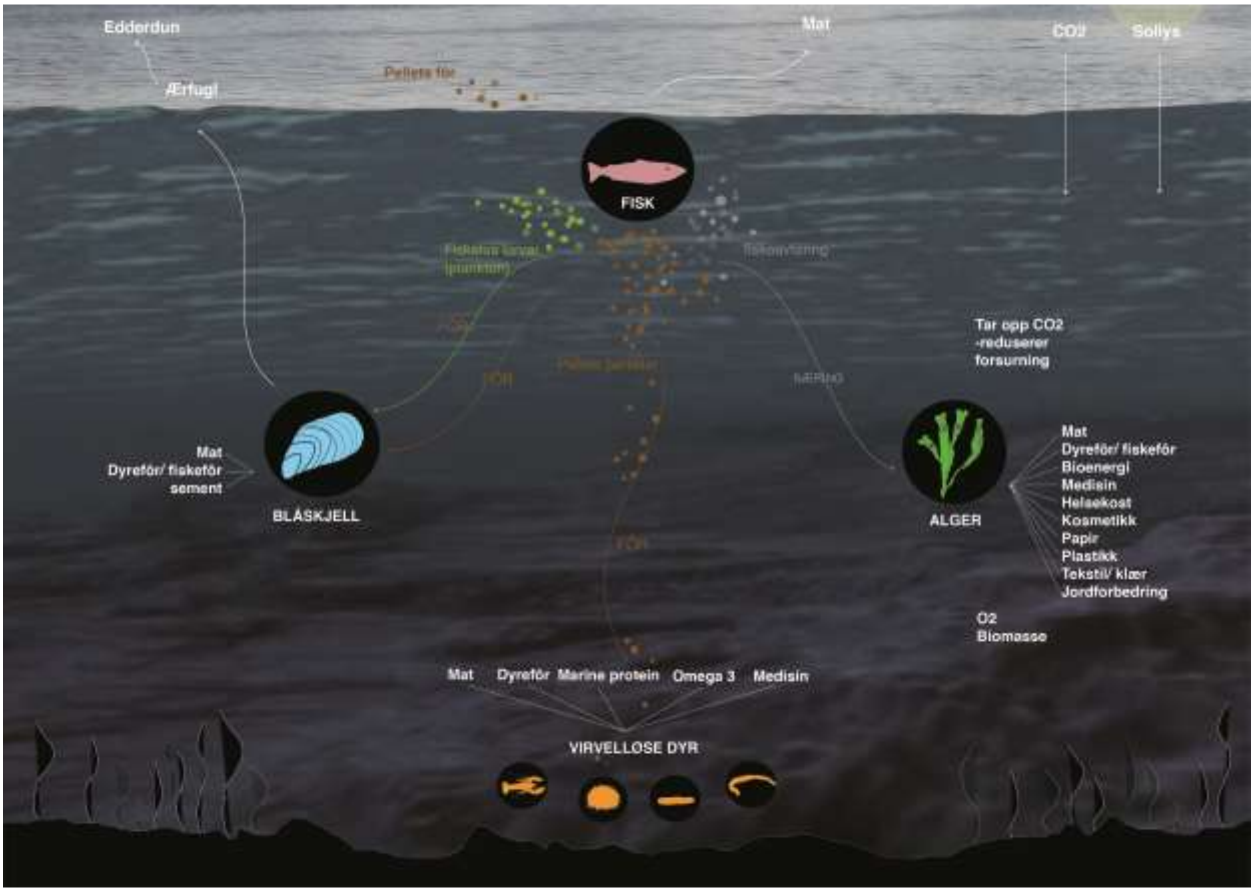


Fig. 12. Schematic explanation of IMTA. Surplus nutrients from fish farming can be used to cultivate other species of high commercial value (illustration by Minsk & Bellona).

3.2 Cultivating mussels in IMTA

Blue mussels (*Mytilus edulis*) grow naturally along the Norwegian coast and are an excellent species to integrate with fish farming. The mussels filter out plankton, small particles, which improves water quality and light penetration. A single 6 cm long mussel is able to filter around three litres of water per hour (Haamer 1996). A large quantity of blue mussels can therefore act as a "water treatment facility" for fjord sites that suffer from excessive levels of the nutrients nitrogen and phosphorus.

Several studies have shown that blue mussels and oysters grow more quickly when linked with fish farming (Wallace 1980; Jones & Iwama 1991; Buschmann et al. 2000; Lefebvre et al. 2000; Lander et al. 2004; Chopin et al. 2008; Handå et al. 2012a). Lander et al. (2004) studied the growth dynamic of blue mussels in an IMTA system in Canada. The aim was to investigate possible feeds and growth benefits for blue mussels when cultivated together with salmon. The results showed blue mussels reacting positively to an increased food supply from fish farms. They contained higher levels of omega 3 fatty acids and glycogen, and they grew larger in comparison with the reference group (blue mussels grown outside IMTA). Growth rates for blue mussels grown near a fish farm have been reported as being between 46% and 50% higher than for blue mussels that do not have the same access to food. Both taste tests and quality tests have been conducted to see whether blue mussels cultivated near salmon farms can be used for human consumption. The results showed no taste differences or quality differences between the blue mussels in IMTA and the reference mussels (Lander et al. 2004). The conclusion was that IMTA systems appear to offer a win-win situation for aquaculture with additional financial gains from the products.

SINTEF Fiskeri og Havbruk and NTNU have conducted laboratory experiments showing that blue mussels can metabolise waste substances from salmon farming (Handå et al., 2012b), and trials at sea have shown that blue mussels cultivated in IMTA can have higher nutritional content in autumn and winter than mussels grown in monoculture (Handå et al. 2012a).

In partnership with the Institute of Marine Research (HI) and Uni Research, NIVA has worked on a three-year project – supported by the Research Council of Norway – aimed at determining the ecosystem response to integrated aquaculture. As part of this research, blue mussels were tested at a depth of 200 m, directly under the fish cage. It was shown that blue mussels grew and subsisted well on nutrient particles originating from the fish farm (Karl Norling, NIVA pers.med.). This opens up the possibility of cultivating blue mussels at a greater depth, where particulate material from salmon faeces accumulates below the fish cage.

In another research project, MacDonald et al. (2011) researched feed responses in blue mussels and reported increases in the filtration rate with increased levels of fish feed (Fig. 13). It has also been shown that blue mussels are highly efficient in absorbing nutrients from salmon faeces (Reid et al. 2010) (Fig. 14).

Dr. Chopin and the Canadian Food Inspection Agency have been monitoring and analysing blue mussels and sugar kelp many years. No significant levels of pharmaceutical compounds given to salmon were recorded either in the kelp or blue mussel tissue (Haya et al. 2004). In addition, recorded values for heavy metals, arsenic, PCB and pesticides were below permitted limits (Canadian Food Inspection Agency, US Food and Drug Administration and EU Directive) (Chopin et al. 2009).

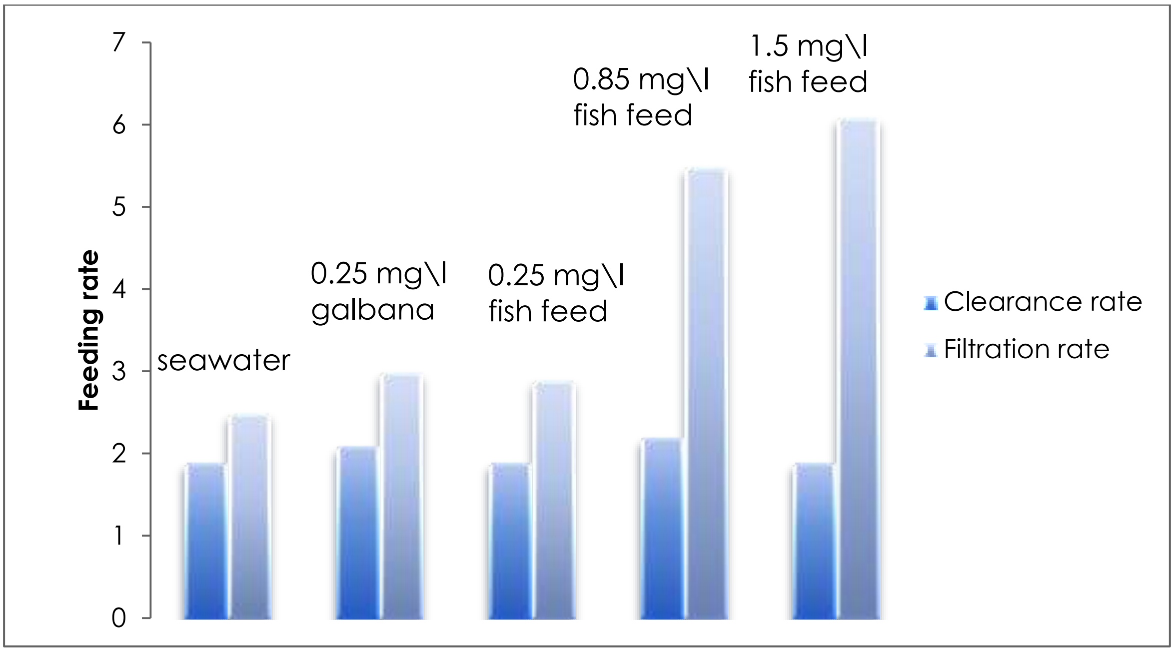


Fig. 13. Blue mussels increase the filtration rate with increased access to fish feed (MacDonald et al. 2011)

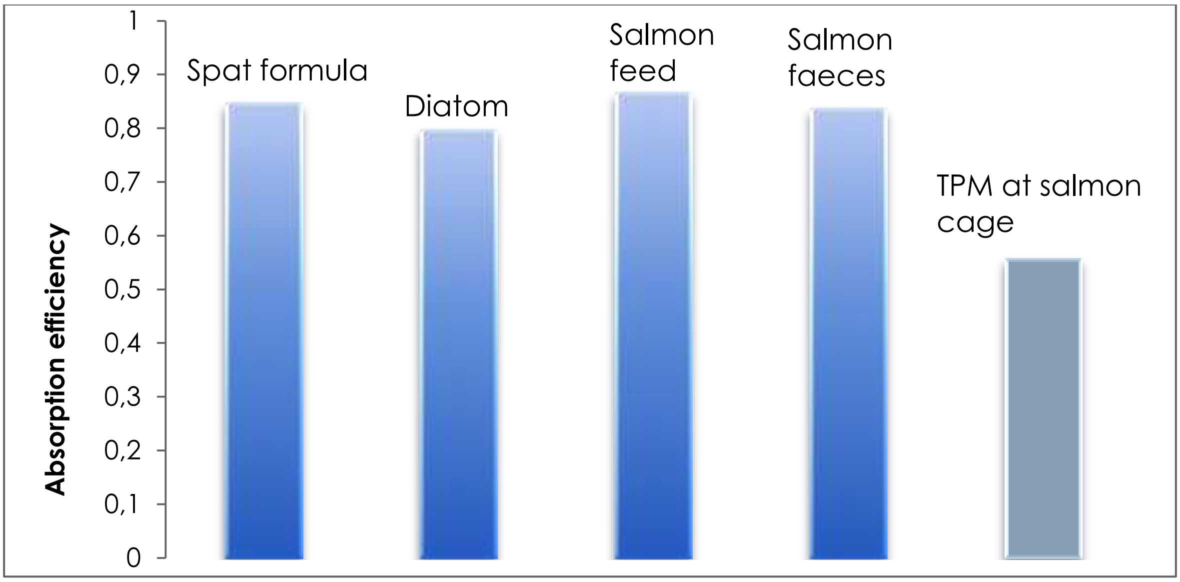


Fig. 14. Blue mussels absorb nutrients from fish faeces and fish feed (Reid et al. 2010)

3.2.1 Blue mussels can help reduce the spread of salmon lice

Salmon lice (*Lepeophtheirus salmonis)* currently pose the greatest parasite problem for Norwegian aquaculture. Nationally and internationally, huge resources are being pumped into research on combating salmon lice. Chemical treatments tend to be used to keep levels of lice in fish farms down (Chapter 1). Effective chemicals are available, with some added to the feed and others added directly to the water. A problem that is generating increasing concern is the fact that salmon lice are developing greater resistance to particular formulations. Some of today's formulations may therefore be losing their effectiveness. Some of the chemicals used have a negative environmental impact locally around the fish farm, while others are less environmentally harmful. Hydrogen peroxide is a good example of a substance in use that does not have negative environmental effects. It is currently used primarily in central Norway, but is also becoming more common in other parts of the country. Some fish farmers make use of biological delousing with the help of wrasse and lumpfish. There is a concern that salmon lice produce large numbers of planktonic young, which are then carried away with the current and infect wild salmon. However, experiments have shown that mussels can filter out planktonic stages of salmon lice. Molloy et al. (2011) researched this in the laboratory, by exposing blue mussels to planktonic stages of salmon lice for 30 minutes and 60 minutes. The blue mussels killed up to 62% of the free swimming copepodite stages of salmon lice. Analysis of the stomach contents of the blue mussels confirmed the presence of copepodites. If blue mussels cultivated alongside salmon are able to consume the planktonic and infectious stages of salmon lice, this could be a good method of reducing the level of salmon lice outbreaks in fish farms and their spread out into the fjord. A combination of grazing wrasse/lumpfish and filtering blue mussels may be the future answer to the salmon lice problem. Wrasse and lumpfish eat the mature females that are attached to the salmon, while the blue mussels reduce the further spread of planktonic salmon lice released from the mature females. The use of delousing chemicals in the feed and in the water that have a negative effect on crustaceans could then be significantly reduced.

Growing blue mussels in mesh bags (Photo Seafood.no)

3.2.2 Blue mussels can help reduce viral and bacterial diseases

Blue mussels have also been observed to reduce the incidence of infectious salmon viruses in the water (e.g. anaemia virus (ISAV) and infectious pancreatic necrosis virus (IPNV)). In a laboratory experiment, virus-infected salmon were tested together with blue mussels. After 35 days, blue mussel tissue tested negative for ISAV and IPNV (Huges & Maeve 2012). Blue mussels can accumulate ISAV for a short period. After 24 hours, only 5% of the blue mussels tested positive for the virus, but after 96 hours none of them had the virus (Huges & Maeve 2012). Blue mussels are not a host or vector for ISAV and IPNV, and it has been posited that blue mussels could act as a possible biofilter and prevent disease (Skar & Mortensen 2007; Chopin et al. 2009). This suggests that blue mussels in IMTA systems may provide health benefits for farmed fish (Haya et al. 2004; Chopin et al. 2009). Pietrak et al. (2010) tested a blue mussel model to investigate the potential risks or benefits for animal health in IMTA and found that blue mussels are able to remove both bacteria and viruses from the water. However, it has also been shown that blue mussels can accumulate other types of bacteria, such as the bacterium *Vibrio anguillarum* which causes the infectious disease vibriosis in fish. The bacteria are filtered out by the blue mussels and stored in their digestive gland. In this way, the mussels may act as a reservoir (Pietrak et al. 2010), although there is no evidence that fish can catch vibriosis from blue mussels.

3.2.3 Potential for Norwegian blue mussel production to return to a profitable market

Blue mussel production in Norway has shrunk in recent years, but IMTA could potentially bring an upturn. One problem with cultivating blue mussels has been identifying good areas with optimum growth rates. In 2010, SINTEF was commissioned to compile a strategy report for blue mussels in Norway. The report concluded that the Norwegian blue mussel industry had reduced dramatically. The production level has fallen from almost 5,000 tonnes in 2005 to less than 2,000 tonnes in 2011 (Fig. 15). There is little to suggest that this will improve in the near future. Poor quality and unreliable yields have laid the blue mussel industry low.

There are currently two commercial blue mussel enterprises, both located in Trøndelag. They have been in the industry a long time and mainly supply the domestic market with blue mussels. Problems with algal toxins have made it extremely difficult to produce mussels in both southern and northern Norway. The market depends on reliable deliveries and volumes have been small. It has also proven exceedingly difficult to export mussels to other mussel producing countries in Europe. High wage costs in Norway make it difficult to make a profit, while at the same time Norwegian mussels have no market advantage in Europe in the way that salmon does. A large increase in the production of blue mussels in years to come therefore requires good locations free from algal toxins, low cost levels and the development of new markets in step with growing production. The potential to use blue mussels for marine meal and oil in fish feed may generate increased demand for blue mussels in the future. The blue mussel industry could scale up production to a more commercially viable level by cultivating blue mussels in an IMTA system.

SINTEF has estimated that 30% of the nutrients discharged from salmon production in 2009 could have produced 64,000 tonnes of blue mussels. This gives a theoretical market value of NOK 3.2 billion, showing the enormous potential for blue mussel production in IMTA.

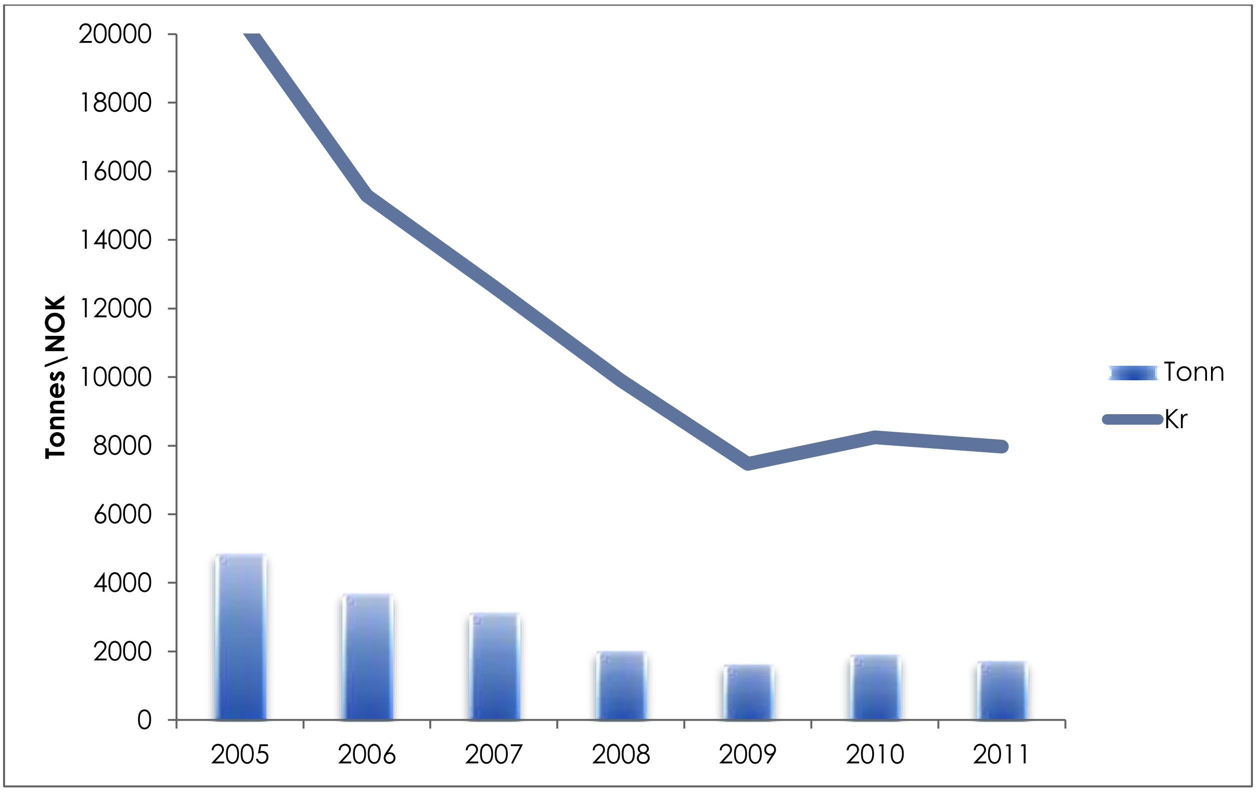


Fig. 15. Blue mussel production in biomass (tonnes) and sales value (1,000 NOK) from 2005 to 2011 (Directorate of Fisheries).

3.3 Cultivating algae in IMTA

In contrast to land-based plants, seaweed and kelp grow quickly, requiring no fertiliser, deforestation or use of heavy fuel technology. It has been discovered that kelp grown under optimum conditions (particularly high levels of nitrogen as found around fish farms) provides a good source of protein, amino acids, carbohydrates and minerals (Chopin 2006). Studies from both land-based and open water cultures confirm that nutrients released from fish farms are ideally suited for kelp growth (Troell et al. 2003; Lander et al. 2004; Chopin 2006; Troell et al. 2009; Handå et al. 2013). It has been documented that kelp can remove between 30% and 100% of the dissolved nitrogen produced by the fish (Troell et al. 2003, Sanderson et al. 2008). SINTEF Fiskeri og Havbruk has developed methods for year-round production of sugar kelp (Forbord et al. 2012), and shown that sugar kelp cultivated in IMTA can achieve much better growth than kelp cultivated in monoculture (Handå et al. 2013a).

Cultivation of sugar kelp in IMTA (Photo Silje Forbord)

The oceans absorb over 20 million tonnes of carbon dioxide (CO_2) each day, which has an acidifying effect. Large-scale cultivation of algae has many global benefits. Combustion of algae in combination with carbon capture and storage (CCS) could remove large quantities of greenhouse gases from the atmosphere (Bellona 2011). Reducing the amount of CO_2 released into the atmosphere is considered the only way to reduce the rise in ocean acidity. It is estimated that a hectare of macro-algae can remove up to 66 tonnes of CO_2. The Norwegian Parliament has declared that we must cut CO_2 emissions in Norway by 15–17 million tonnes by 2020, and algae cultivation might be able to help with this. CO_2 is emitted into the atmosphere during combustion, whether it comes from petroleum or algae. The difference is that using biomass such as algae combined with CCS produces negative emissions on the CO_2 balance sheet, with neutral emissions achieved from renewable energy (e.g. algae) without CCS, or fossil fuel combined with CCS, and positive CO_2 emissions coming from combustion of fossil fuel without CCS.

Sugar kelp is not the only important habitat. Kelp forests in general are the rainforests of the oceans. Kelp forest provides shelter and protection for many organisms. We often find fish species such as pollack, coley and cod above kelp forests. Species such as wrasse, coley and cod, and many species of small crustacean, can often be found in amongst the kelp plants. In addition there is a diverse range of life actually on kelp (epiphytes). These are organisms such as amphipods and isopods. The holdfast of cuvie (*Laminaria hyperborea*) is often home to annelids, bivalves, amphipods, isopods, crabs and squat lobsters. On the seabed between the cuvie plants roam bottom-dwelling fish, crabs, starfish, sea urchins, sea anemones, snails and annelids, to name but a few. However, the amount of kelp in the oceans is falling. The report on the sugar kelp project (Moy et al. 2008) estimated that 1.6 million tonnes of sugar kelp have been lost along the coast of Norway. In terms of CO_2, this represents a loss of 600,000 tonnes of captured carbon (Bellona 2011). Sugar kelp (*Laminaria saccharina*) generally grows in sheltered areas from the low tide zone down to a depth of 30 metres. It grows rapidly from early winter to April and takes 2–4 years to reach full maturity. There has been a major drop (around 40 to 80% (KLIF 2011)) in stocks of sugar kelp and cuvie along the southern and western coast of Norway. The loss of kelp is most likely due to temperature changes, grazing by sea urchins and eutrophication. Sugar kelp is an important habitat for coastal cod and the drop in biomass may be a contributory factor in reduced stocks of cod. The number of species of small crustacean, annelids and bivalves has fallen by 33%, while the number of animals (individuals of the species) is down by almost 75%. Reduced access to nutrition and shelter for organisms, including fish, is considered to be an important consequence of sugar kelp loss.

The NIVA CO_2 report (Gundersen et al. 2011) puts the loss of cuvie at around 20 million tonnes and sugar kelp at a huge 78 million tonnes, largely due to sea urchin grazing in the north. These GIS calculations were made in a rule-based model that calculates 10 kg kelp per m^2 on all beds from a depth of 0–25 m, which does lead to kelp being modelled on seabeds where it does not actually grow, making the figures heavily overestimated. Nevertheless, the Norwegian coast has a lot less kelp than it once did and, since so much has gone, it is difficult to gather data for new and better models. While recent years have seen growth/regrowth of kelp in Helgeland and Salten, it appears that sea urchins will dominate further north, and large areas of seabed will lose their natural vegetation in the foreseeable future. Consequently, cultivating sugar kelp in IMTA systems could give a boost to wild kelp and coastal cod stocks, as well as other organisms whose habitat is sugar kelp. Large-scale introduction of IMTA in Norway could help to increase the possibility of re-establishing kelp that has been heavily depleted along the coast.

Kelp forest (Photo Hartvig Christie)

3.4 Cultivating creatures other than fish in IMTA

There is potential to use other species (than those described above) that can bring environmental and economic benefits in IMTA systems. Sea urchin roe (gonads) is a luxury food in many countries. The Gonad Index should lie above 15% for success in the market. The sea urchins sold commercially must therefore often be fed after being caught in order to achieve sufficient quality. When sea urchins are cultivated in IMTA, the Gonad Index can exceed 20%. A combination of a high market price, strong demand and falling supply from other sources may give good grounds to integrate the sea urchins into Norwegian aquaculture. In captivity it is possible to feed them on waste from fish farms. Sixteen species of sea urchin have been recorded in Norway, the two best known of which are the common sea urchin (*Echinus esculentus*) and the green sea urchin (*Strongylocentrotus droebachiensis*). Sea urchins have mainly been caught by diving, which is both an expensive and a time-consuming process. Sea urchins are an exciting species and in the future they may become an even better used resource. Researchers at Nofima have developed a special feed that young sea urchins like, with seaweed as a key ingredient. Consistency, flavour and formulation have been tested, and the feed has worked well in farms.

Sea urchins (Photo Thinkstock)

Sea cucumbers belong to the class of echinoderms. They have a cucumber shaped body and no solid skeleton. There are 31 different sea cucumber species along the Norwegian coast. The red sea cucumber is probably the best known example. It has a red back and white flesh, and is usually around 25 centimetres long. Sea cucumbers are high in protein and can be eaten raw, fried and boiled. The seabed is full of sea cucumbers and historically these organisms have just been an undesirable bycatch for prawn and crab fishermen. Sea cucumbers have been cultivated in Chinese IMTA systems for many generations together with abalone and seaweed. There is high demand and thus a high market value for these organisms across the whole of Asia (although not yet in Europe). In the Far East it is common to eat sea cucumbers together with other seafood.

Sea cucumbers (Photo Thinkstock)

The lobster population has dropped significantly along the Norwegian coast in recent years (Bakketeig et al. 2013). This, combined with the high market value of lobster meat, may give good grounds to farm lobsters in IMTA systems. The challenge lies in developing a good technological concept for lobster farming in IMTA.

NIVA has been conducting a small-scale project for the County of Aust-Agder to release lobsters into artificial habitats under a shellfish farm to see whether this could increase lobster stocks and at the same time establish whether the lobsters could clean the bottom of discharges from the farm. The results were not good for profitable operations since there was a high mortality rate among the released lobster young. However, this first pilot project did show that the lobsters were happy under tiles, they dug in and cleaned up the sediment under the farm and lobster stocks in the area have increased considerably.

Lobster (Photo Thinkstock)

Annelids are segmented worms that live on the seabed and are an important food source for bottom-dwelling fish. There are around 12,000 recorded species of annelid around the world. Some of the annelids that live in mud have similar functions to earthworms on land. These include burrowing functions that help to turn over and exchange substances in the sediment. Annelids are rich in omega 3 and have a high protein content. Laboratory studies in Canada and Spain have shown that these worms can be successfully cultivated on a diet comprising fish feed and faeces. It can be beneficial to cultivate annelids and algae together in IMTA systems such that the biomass can be recovered as a food source for fish feed. Annelids are also sold as fishing lures (living, dried and imitation) in many countries, including Norway.

Annelid (Photo Thinkstock)

Tunicates are another interesting source of both fish feed and energy production that can be cultivated alongside other species. Tunicates belong to a subphylum of chordates. The body of a tunicate is covered by a "tunic" made from a cellulose-like polysaccharide, plus there is a notochord that is limited to the tail and is usually only present in larval stages. Tunicates stay attached to a substrate in their adult form and live by filtering out whatever comes past on the current. This has proven a problem for farmers, because the tunicates attach themselves to absolutely everything that offers a foothold and they grow and spread rapidly. Over several years of research, a team from the University of Bergen and Uni Research has found that tunicates can be used both as a renewable source of biofuel and as fish feed. The valuable substances in tunicates are the cellulose, which can be used as a biofuel, plus the proteins and the fatty acid omega 3 which are suitable for fish feed.

Tunicates (Photo Thinkstock)

3.5 Artificial reefs

An artificial reef is a man-made underwater structure, often intended to increase biodiversity in a particular area. Increasing biodiversity also increases the various functions of the species in the new habitat. In this context, function means species with different sizes, shapes, colours, ages, reproductive methods, movement, feeding systems and food preferences. These are just some of the functions from an endless list. All species have several functions in an ecosystem and complement each other. Species that do not establish themselves naturally fail to become part of the ecosystem or are displaced by other species. By setting up artificial reefs, several species with different functions are able to establish themselves after a short time and live together, turning the artificial reef into a small ecosystem. Some species eat small animals, other species consume waste products, some live as parasites or in symbiotic relationships, while others filter out small planktonic organisms. Artificial reefs are often created in areas that are totally protected from human activity, such as when restoring areas where habitats have been destroyed by dragnet fishing.

Artificial reef (Photo Hartvig Christie)

Fish farms attract other fish that graze on food waste, but there have been few studies into whether this is a good or bad thing. SINTEF Fiskeri og Havbruk and Nofima Marin have studied the interplay between fish farms and ecosystems at nine farms in three different locations in Finnmark, Trøndelag and Rogaland, and they found that on average fish farms attract at least 10 tonnes of wild fish. The study shows that both coley and cod consume large amounts of pellets and access to feed makes the condition of the fish better, with a much fatter liver. There is, however, uncertainty about what this means for the health and quality of the fish in the long term, and the spread of disease.

Fish that spend a long time around the farms and eat food waste would have a more natural habitat to graze on if artificial reefs were established locally, while at the same time species from the reef would clean up waste substances deriving from the fish farm.

NIVA has conducted several artificial reef trials in Norway that have proven successful in attracting kelp, fish, crustaceans such as crabs and lobsters, and other biodiversity. There have also been some small-scale projects in the Port of Oslo, Risør, Sandefjord, Lofoten, Hammerfest and Kirkenes.

Biodiversity after creating an artificial reef (Photo Hartvig Christie)

3.6 Upwelling may be a solution in areas with poor access to nutrients

Algae require nutrients, CO_2 and sunlight to grow. In particularly nutrient poor areas, it can be necessary or desirable to add extra nutrients to increase production. Setting the water in motion can lift nutrients up to the zone where there is access to light and thus increase the production of biomass. A trial conducted by the Institute of Marine Research in Lysefjorden showed that pumping brackish water in a pipe using a 60 kW pump down at a depth of 30 metres trebled algae production within a fjord area of 10 km^2 (average value of 900 mg C m^{-2} d^{-1}).

According to the Institute of Marine Research's 2012 report (Torrisen et al. 2012) this algae binds around 5,500 tonnes of CO_2 per season, accounting for 50% of CO_2 emissions in the municipality. Upwelling has increased production of macro-algae and blue mussels, and reduced production of toxic micro-algae (which have formerly been a major problem for blue mussel farmers). The Institute of Marine Research has now installed a larger and more efficient pump with a view to considerably increasing production. Use of bubble curtains and placement of distribution manifolds over submerged freshwater discharge pipes from power stations may be a way of creating upwelling (McClimans et al. 2010; Handå et al. 2013b).

3.7 Global challenges faced by the fishing industry

A whole host of species and stocks in the sea have been drastically depleted, which could have catastrophic consequences for all marine life. This depletion has a number of causes, including overfishing, loss of habitat, climate change, ocean acidification and chemical pollution (WHO 2012). All these factors could affect the fishing industry, but the greatest challenge is acidification.

3.7.1 The problem of acidification

Fossil energy is the leading cause of ocean acidification via combustion of oil, coal and gas. CO_2 becomes an acid when dissolved in water, as a consequence of which the top layer of water in all the world's oceans is becoming more acidic. Around a third of man-made CO_2 emissions are estimated to be absorbed by the surface of the world's oceans. As the pH drops, calcium carbonate dissolves, causing major changes in the marine ecosystem. Increased ocean acidification can have serious ecological consequences for marine species. The effect is particularly harmful to marine organisms that form calcium carbonate shells, such as: plankton, molluscs, echinoderms and corals (Doney et al. 2009). Since the time of the industrial revolution, the average pH value in the oceans has dropped from 8.21 to 8.1, with a change of 0.11 units representing a 29% increase in the concentration of H+ ions. If the current trend in CO_2 emissions continues and the CO_2 concentration in the atmosphere reaches 800 ppmv (parts per million volume) in the year 2100, the pH value will drop by a further 0.3–0.4 units (Orr et al. 2005; Doney et al. 2009).

Emissions (Photo Thinkstock)

The trend is moving more quickly in Arctic waters than anywhere else in the world. Gases dissolve more readily in cold water and so cold water absorbs more CO_2 than warm water. This is why the water is becoming more acidic in Arctic areas. This could have dramatic ecological consequences for these key marine areas. And these concerns also apply to our own Norwegian coast. Even if we cut all CO_2 emissions right now, concentrations in the atmosphere would increase for many decades and it would take tens of thousands of years for CO_2 to fall back to pre-industrial levels. It is therefore important to think strategically about how to reduce and "extract" CO_2 from the environment (see also Bellona reports "Norway's overall climate plan", 2009, "Carbon Dioxide Storage: Geological Security and Environmental Issues – Case Study on the Sleipner Gas Field in Norway", 2007 and "How to combat global warming", 2008).

Carbon negative solutions are a high priority focus area for Bellona. There are clear indications that the world will not achieve the necessary global reduction in emissions unless we develop solutions that can extract more climate gases from the atmosphere than we emit.

Algae account for the majority of the photosynthesis in the world's oceans and are part of the foundation for all marine life. Globally, these organisms are huge producers of oxygen and massive consumers of CO_2. Cultivation of algae will thus reduce the acidification of our oceans (Osinga 2010, International Coral Symposium in Wageningen). Osinga's proposal was to cultivate sea lettuce on a large scale below fish farms in order to reduce the level of acidity. He claimed that sea lettuce has the potential to reduce acidity by 10% in the Mediterranean if cultivated in a "marine field" of 180,000 square kilometres. This increase in alkalinity may appear small, but according to Osinga's calculations, it would be enough to compensate for the increase in acidity that has occurred since the start of the Industrial Revolution (Kleis 2010).

Ocean acidification is a global problem that requires global solutions, agreements and actions. The best way to reduce global ocean acidification is to cut CO_2 emissions. However, there is a lack of understanding and knowledge among politicians, and little has been done. New data is constantly being published, and the situation is proving to be much worse than researchers previously predicted. Over half of the corals on the Great Barrier Reef have been lost in the past 27 years, levels of diatoms – a phytoplankton – are down 40% in the South China Sea, and a mortality rate as high as 80% has been recorded for oyster larvae in the oyster beds along the north-west coast of the USA. Increased carbon concentrations have also now been documented in our own waters. How much devastation this increase is causing has not yet been established, but there is good reason to be concerned. We are beginning to see drastic results from our generation's CO_2 emissions. It is not just the marine ecosystems and biodiversity that are in the danger zone, but also the basic food supply of many nations. If the problem is not resolved now, the next generation will see a significant downturn in its resources. Norway has expressed an ambition to become the leading seafood producer in the world, but the conditions for the organisms we want to use may be damaged due to acidification. This could mean losses in the millions for the seafood industry and a drastic drop in the wild salmon population. The most important measure is quite simply a massive reduction in CO_2 emissions. To achieve this, we need a massive switch from fossil to renewable energy, more efficient use of energy, and success on the carbon capture and storage front. Good supplementary actions could be revegetation and large-scale cultivation of seaweed, kelp and seagrass. Large-scale cultivation of macro-algae could help to reduce ocean acidification, which would improve living conditions for calcium carbonate dependent marine organisms. Over the course of a year, the Norwegian fjord system is able to capture 10 million tonnes of CO_2 which equates to 10 carbon capture plants like the one planned for Mongstad, according to researchers at the Institute of Marine Research (article in Aftenposten July 2012).

3.8 What can we make from algae and other IMTA products?

Details of current algae production and use in Norway are contained in Bellona's algae report (2011). The majority of the products made from non-renewable crude oil can be replaced by products produced from algae. The potential for algae is huge and largely unexploited in Norway. Algae can be used for human food, animal feed, pharmaceuticals, nutritional supplements, as a source of industrial hydrocolloids, antifouling, plastics, paper and fuel.

In fact, few people are aware of the enormous potential that algae offer for the production of eco-friendly products. Algae perhaps tend to have more negative associations. Toxic algal blooms periodically make blue mussels poisonous, while seaweed and kelp are seen as something unpleasant we want to avoid on the beach as we head out to swim. There was, however, a Norwegian tradition of using algae for soil improvement, with the farmers gathering seaweed and kelp from the shoreline and spreading it over their fields. Cuvie and Norwegian kelp are the only algae species commercially harvested along the coast of Norway today. Each year around 150–180,000 tonnes of cuvie and around 15–30,000 tonnes of Norwegian kelp are harvested for the production of alginates and kelp meal. No-one in Norway cultivates these plants commercially, although interest has grown over the past couple of years and many pilot trials are underway. The process of cultivation is not particularly difficult, and the costs are small compared with other aquaculture species.

3.8.1 Algae can replace petroleum

There is no doubt that the petroleum industry plays an important role globally, but it has also had a devastating effect on nature. This includes particulate pollution, formation of acid rain through emissions of sulphur particles, NO_x compounds and CO_2 emissions that contribute to global warming. There is a great need for, and a global responsibility to find, alternatives to petroleum, coal and gas.

Algae are not currently used much as a replacement for petroleum products, but interest has grown in recent years as people realise the value and enormous potential of algae. The majority of products made from petroleum can be replaced with products from algae (Table 5). Methods have been developed on a small and large scale, and the technology is available. Global research is focusing in particular on how to extract energy and what capacity algae have to capture CO_2. Petroleum products are well established and industrialised, making them more cost-effective than algae at this point in time. For algae to reach a similarly profitable level, there needs to be a huge drive from research institutions, the business sector and politicians. If the investment in algae value chains and technological development had been as great as the investment in fossil technology, the world would have been a very different place, and the problems of global warming and ocean acidification would probably have been considerably less serious.

Table 5. Algae and petroleum

What it does/is/can be refined into:	Algae	Petroleum
Renewable resource	√	
Captures CO_2	√	
Reduces acidification	√	
Pollutes		√
Produces biomass	√	
Energy (fuel, power, heat)	√	√
Oil	√	√
Plastic	√	√
Paper	√	
Alcohol (wine, spirits, ethanol)	√	
Human/animal food	√	
Pharmaceuticals	√	√
Health food	√	
Cosmetics	√	√
Textiles	√	√
Fertiliser	√	
Antifouling	√	√
Silicone	√	√
Insulation	√	√
Asphalt/heavy oil	More research required	√

3.8.2 Biomass into bioenergy

Land-based cultivation has its limitations. Although a great deal of carbon is absorbed by forest biomass, the process is extremely slow compared with algae. It can take 10 years for trees to start being harvested, while it only takes a few months for a kelp harvest to grow. It is a challenge for the world to source enough biomass to achieve a carbon neutral society. On land, the desire for more biomass for energy purposes will often come into conflict with food production and preservation of crucial rainforest. A significant part of meeting this challenge is to identify and explore areas and opportunities for biomass production that does not impinge on viable agricultural land or important land-based biotopes.

Bioenergy is a major area of focus globally, with the production of algae playing a key role. To establish a competitive industry for trade in and production of algae-based products, sustainable production of algae must be in place. There are enormous potential opportunities which Bellona believes will benefit business and the environment over the long term. Algae are able to store large quantities of CO_2 in biomass. Kelp forests along the Norwegian coast have shrunk by 2,000 km² since the beginning of the 1970s. According to estimates from the Norwegian Institute for Water Research, this lost kelp forest could have stored 36 million tonnes of CO_2, as compared with Norway's annual emission of 40–45 million tonnes. The re-establishment of kelp forests could be an important component of Norway's efforts to capture CO_2.

The development of marine biomass production for energy purposes could establish an enduring new industry based on principles of sustainability. Cultivation in coastal areas could be established within a relatively short timeframe. This would make an important contribution to further investment. Large-scale cultivation in the open ocean, where the really huge potential lies, would require significant investment in research and development.

Biomass production for energy purposes could establish a new long-term industry (Photo Thinkstock)

Cultivating the equivalent of a hectare of macro-algae captures just under 9 tonnes of carbon. And from this algae, 7,500 litres of bioethanol could be produced. The potential is many times greater when there is better access to nutrients (for example, in conjunction with fish farming). Macro-algae have a maximum productivity of around 2 kg carbon per square metre per year. This is 2–3 times more than sugarcane, which is considered one of the best bioenergy crops. According to estimates by SINTEF, the yield lies between 3,800 and 10,500 kg carbon per hectare, which would convert to around 3,000–10,000 litres of ethanol (depending on when in the year the kelp is harvested) (Broch et al. 2013). And the potential could be even greater. It is calculated that an area the size of the County of Vestfold could produce the equivalent of 2–3% of the world's total bioethanol production. This is enough to meet half the demand in the EU.

Bioethanol is currently the most widely used biofuel, with sugarcane and maize the most commonly used raw materials. The USA and Brazil are the leading producers (Balat & Balat 2009). In Brazil almost all vehicles run on bioethanol in pure or blended form. Algae can produce the same yield of bioethanol in a smaller area and they grow more quickly than the plants traditionally used in bioethanol production.

Both micro- and macro-algae can be used to produce bioethanol. Algae primarily comprise carbohydrates, protein and oil. Ethanol can be produced from starch, cellulose and other carbohydrates in algae, possibly after extracting the oil to produce biodiesel. In contrast to land-based plants, algae produce no hemicellulose (group of polysaccharides) and lignin, which makes it much easier to ferment algal cellulose.

When producing fuel from algae, it is also possible to make various by-products such as biopolymers, protein and feed.

As with the production of biodiesel, the key is to find the ideal species of algae, and to optimise cultivation, harvesting and processing of the algae in order to make the process as energy- and cost-efficient as possible.

A blend of up to 10% ethanol can be used in ordinary petrol engines without any special adaptations. It is also easily possible to design engines that also run on pure ethanol or any other ratio of ethanol to petrol.

The added ethanol also improves the combustion of the petrol, thus reducing the organic emissions that are so harmful to health and the environment. Like biodiesel, bioethanol is much less toxic than petroleum-based fuels, and is readily biodegradable. Used as a petrol additive, bioethanol can also replace environmentally harmful octane improving agents such as PAH.

Thousands of experiments to manipulate algae have already been conducted at laboratory scale, as attempts are made to develop the best properties. These may include converting CO_2 directly into ethanol, or increasing the biomass growth rate of micro-algae. The question is to what extent genetically modified organisms (GMO) or their genes could diffuse into the natural environment, posing an ecological risk. We know little about the consequences due to a lack of knowledge in this field, while much of the in-house research activity is patented and therefore not in the public domain (Allison & Smith 2012). Lack of acceptance from the general public, as with GMO in agriculture, is another obstacle to large-scale use of GMO in algae cultivation.

There is currently no industrial production of bioethanol from algae.

3.8.2.1 Testing sugar kelp in biogas production

Biogas has been produced at FREVAR KF's wastewater treatment plant in Fredrikstad since it came on stream in 1989. The gas is a by-product from the plant's sludge treatment section. Up until 2001, the gas was used to meet the plant's need for building and process heating, with any surplus gas being burned off. Biogas based on waste resources is used to power road transport and in the production of energy and heat. To investigate the potential for kelp to be used in biogas production, SINTEF and FREVAR have conducted tests on sugar kelp grown outside Trondheim in one of SINTEF's kelp projects. The results show that sugar kelp responds extremely similarly to the pre-treated food waste that FREVAR usually uses (Fig. 16). Sugar kelp acts as a good biogas substrate together with other readily degradable organic material, and gives good gas production together with waste sludge that has been precipitated in the treatment plant (Fig. 16). Biogas is produced during anaerobic digestion (fermentation) of organic resources into biomethane (CH_4), and the residual product after digestion becomes a biofertiliser.

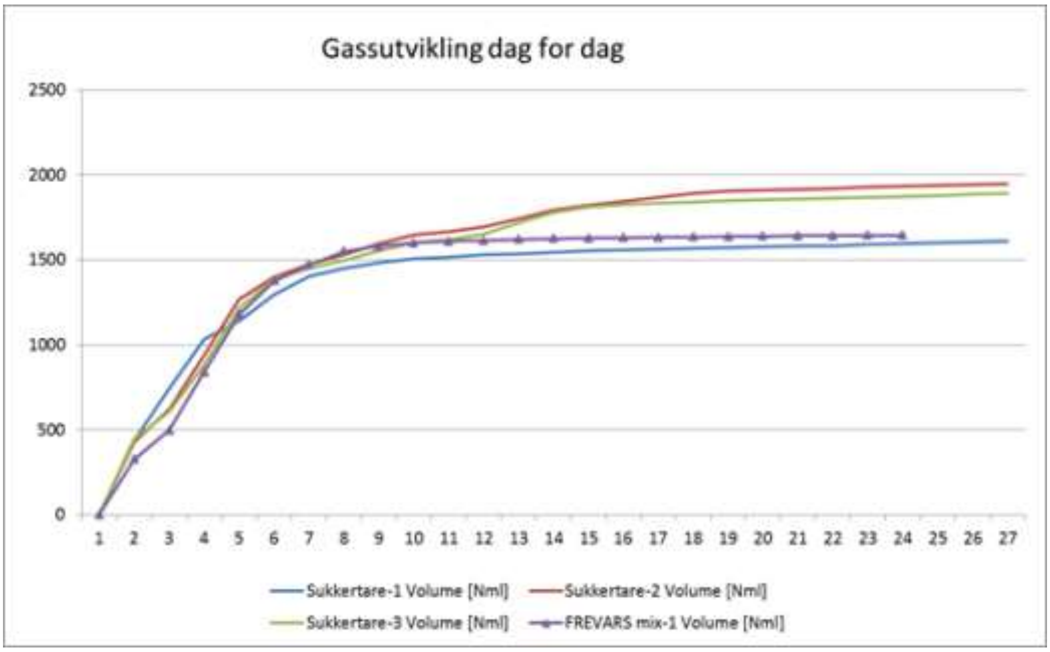


Fig. 16. Testing sugar kelp in biogas production (Source FREVAR, Knut Lileng and SINTEF, Jorunn Skjermo).

3.8.3 Supplements to our daily diet

With their high nutritional content, algae make a perfect dietary supplement. There are many types of algae that could be included in a daily diet. Seaweed and kelp can be eaten raw, boiled or fried, replacing regular vegetables or lettuces. Most people probably think of sushi when eating algae is mentioned, but there are many other options and good dishes from Norwegian cuisine that could be cooked too.

Fish cakes with algae (Photo Fremtidens Mat)

Algae are becoming a much sought after delicacy, but it is difficult to source the raw materials. You either have to collect it from the sea yourself or employ keen divers. Høyden restaurant in Bergen serves several dishes that include seaweed and kelp, and they use divers to gather the ingredients. More and more restaurants are now experimenting with making whole dishes from seaweed and kelp or using it as an accompaniment to other dishes.

Salmon and algae (Photo Fremtidens Mat)

Examples of seaweed and kelp that can be used in food:

<u>Green algae</u>

Sea lettuce (*Ulva lactuca*) and green sea fingers (*Codium fragile*)

Sea lettuce (Photo Thinkstock)

<u>Red algae</u>

Dulse (*Palmaria palmata*), laver (*Porphyra umbilicalis*), Irish moss (*Chondrus crispus*)

Dulse (Photo Christian Bruckner)

<u>Brown algae</u>

Sugar kelp (*Saccharina latissima*), badderlocks (*Alaria esculenta*) and Norwegian kelp (*Ascophyllum nododsum*)

Norwegian kelp (Photo Annelise Leonczek)

There are many good seaweed and kelp recipes on the internet (fremtidensmat.no) and books of recipes have also been published (Mortensen et al. 2004).

3.8.4 Pharmaceuticals, health foods and cosmetics

Marine bioprospecting is helping to identify interesting genes, biomolecules and organisms from the marine environment that may have potential commercial uses (Bakketeig et al. 2013). There is an abundance of documentation on the positive health effects of algae and marine invertebrates. Algae and marine invertebrates are used commercially in health food products and cosmetics in many places around the world. Algae, see anemones, bivalves, sea cucumbers, tunicates, sea urchins, crustaceans, annelids and hagfish contain biologically active components that can be used in pharmaceuticals, the chemicals industry or as food. Algae can be used medicinally for goiter, hormone therapy, obesity, hardening of the arteries, diabetes, allergies, HIV, digestive problems, breast cancer, candida, coughs, enlarged lymph nodes, fatigue, heavy metal poisoning, low blood pressure and rheumatism (e.g.: Borowitzka 1995; Okai & Higashi-Okai 1997; Watanabe et al. 1999; Higashi-Okai et al. 2000; Guerin et al. 2003; Venkata Raman et al. 2004; Habib et al. 2008; Gregory et al. 2012). Anemones contain substances that can be used both in pain relief medication and for chemotherapy. The stomach of sea cucumbers contains the molecule NGNA, which is highly effective against rhinovirus (common cold) and the influenza virus. The Norwegian company Scandinavian Clinical Nutrition (SCN) has now patented the substance NGNA, having proven its antiviral prowess.

Dietary supplement (Photo Thinkstock)

Vaccination is the most effective and environmentally friendly approach to combating diseases in fish farms, and is thus also an important element in the sustainable development of the aquaculture industry. In all, there are more than 760 vaccines available to fight human diseases, but there are only 30 vaccines commercially available for fish. This illustrates the need and the potential for development and cost-effective production of vaccines to manage fish health. The micro-algae *Chlamydomonas reinhardtii* is the most important model organism for use as a platform in the production of recombinant protein vaccines, therapies and industrial enzymes. The advantage of vaccines made from micro-algae is that they can be administered via fish feed. This is a very cheap way of vaccinating fish compared with traditional methods that include labour-intensive spraying and stressful anaesthesia. Bioresearchers are working with the industry to develop good fish vaccines.

3.8.5 IMTA species can help to reduce use of imported fish in fish feed

Farmed species are dependent on feed brought from outside the fish farm. Traditionally, all this feed has been based on marine ingredients from fisheries in the North Atlantic and the fish-rich waters off the west coast of South America. The growth in aquaculture has increased demand for feed and put serious pressure on feed resources. Today, around a quarter of everything fished in the world's oceans goes towards producing fish meal and fish oil.

However, there is good potential for Norway to produce its own fish feed from good marine IMTA sources. Research has shown that using algae and invertebrates in the production of sustainable fish feed has helped to boost fish health (Shields & Lupatsch 2012). The potential to use these products in fish feed makes them of both local and commercial value. Farmed fish require good quality fish feed. An important nutrient in fish feed is omega 3, which is in limited supply. There has been a reduction in the use of fish meal and fish oils in fish feed, and more widespread use of vegetable sources. Fish oil is a limited resource, but there are also other marine resources with high levels of omega 3 and protein that can be used in fish feed, and that can be cultivated in IMTA, such as bivalves, tunicates, crustaceans and annelids.

Algae in fish feed can also mitigate many of the environmental problems associated with today's aquaculture practices. Ocean Harvest Technology (OHT) in Ireland has developed fish feed with algae ingredients, replacing synthetic chemical additives and colourings. Research results have shown that fish feed containing algae reduces stress and improves the immune system (Shields & Lupatsch 2012). Fish feed with algae provides better resistance to viruses, bacterial infections and parasites (salmon lice infestation down 40% and mortality down 80%) (OHT). The cause of this reduction has not been fully established, but it appears as if the algae in the feed encourage the fish to produce a slime that lice don't like so they drop off the fish (Pers. med. Stefan Kraan).

Micro-algae can be cultivated in closed IMTA systems. Micro-algae have a higher proportion of omega 3 than macro-algae, and there are numerous international trials concerning the use of micro-algae in fish feed. Researchers are looking for algae that are able to produce oils with high levels of the marine fatty acids DHA and EPA. Alltech, an international company that develops nutritious feed, is working with various research and nutrition bodies in Norway, for example. Many studies have shown that micro-algae can produce up to 70% fatty acids. Alltech states that, once the right species of algae have been identified based on what the consumers of salmon are interested in and the production refined, it will be possible to supply the feed industry with marine oil from algae.

Marks & Spencer and the Scottish Aquaculture Research Forum (SARF) are collaborating on a project to investigate the use of both seaweed and micro-algae as commercially viable sources of fish feed ingredients.

Other companies such as AZTI-Tecnalia at the Ainia Technology Centre in Valencia are involved in projects testing sugars from algae for high-energy foods and fish feed.

3.8.6 Plastics

The majority of what we eat, drink or consume is packaged in petroleum-based plastic, which is a material made to last forever. Once we are done with the product, we discard it. This throw-away mentality is a relatively new phenomenon. Just two generations ago, we packaged our products in reusable or recyclable materials such as glass, metals and paper. Our seas, land and beaches are now waste dumps for plastic packaging. This is not only aesthetically ugly, but creates major problems for wildlife and biodiversity both on land and in aquatic environments.

It can take several thousand years for plastic to be broken down in nature. Plastic breaks down into small particles in the ocean over time, but it does not break down entirely. The plastic particles then act as "sponges" or emit environmental toxins such as PCB, DDT and other pesticides. These organic ecotoxins are called "POPs" and are consumed by marine organisms that may then be eaten by humans.

Plastic pollution (Photo Thinkstock)

2009 saw 230 million tonnes of plastic produced globally (Plastics – the Facts 2010). Enough plastic has been produced to wrap the planet in film six times over (Plastics – the Facts 2010).

What is known as the Great Pacific Garbage Patch is located in the Pacific Ocean gyre, where around 100 million tonnes of plastic float around (Marks et al. 2008). Fine particles of degraded plastic are eaten by invertebrates in the sea. These are then consumed by larger animals. A million seabirds, 100,000 marine mammals and countless fish die every year from the plastic that they take in (Plastic Planet). The majority of the plastic sinks, slowly dissolves and enters the food chain, where it is concentrated and ends up on our own plates.

Imagine if all the plastic around us was made from algae? It is a real possibility. Algae are a source of biopolymer products. The technology is available and has been tried and tested. Plastic producer Cereplast has spent several years working on alternative possibilities for making plastic from plants. They have conducted several experiments using algae, which have proven more suitable than land-based plants, due to the faster growth of algae. Bioplastics from algae have much less of an impact on the environment since they degrade within 180 days without leaving any harmful chemical residues behind.

There are various types of algae plastic. Hybrid plastic is biomass from algae that is added to the petroleum products polyurethane and polyethylene (Chiellini et al. 2008, Barghini et al. 2010). This reduces the quantity of petroleum, and the products gain new properties that speed up biodegradation. Green algae from the order of Cladophorales are particularly suitable for the production of hybrid plastic. Cereplast manufactures several products that are 50% algae and 50% petroleum, and their ambition is to use 100% algae in the future. Algae cellulose can also be used to make plastic.

3.8.7 Paper

Paper can be manufactured from algae (Chao et al. 1999; Chao et al. 2000; Seo et al. 2010). Using algae instead of wood pulp as the raw material in paper production can save large areas of forest and at the same time reduce CO_2 emissions. In addition, the price of wood pulp is expected to climb dramatically in the future. The use of algae to make paper has its origins in the Venetian lagoon (the Favini Group). The adverse algal bloom in the lagoon outside Venice has been harvested to make eco-friendly algae paper with varying algae content, thus solving the problem of storing the algae waste. The paper, called "Shiro Alga Carta", has a distinctive appearance with green algal flecks and is mainly used in graphic design and luxury packaging around the world. In addition, the firm has begun to use algae from the Brittany and Normandy coastline of France, which has the same algae problem caused by pollution.

Paper made from green algae can also be used to produce thin batteries. Algae cellulose has a surface capacity that is 100 times greater than plant cellulose. With 50-200% better charge capacity than polymer batteries, this could be the future of batteries (nanotechnology, Uppsala University in Sweden).

Chungnam National University in Korea has joined forces with electronics giant Samsung on a major project covering 500 hectares offshore with a view to making paper from red algae. They claim that paper pulp from red algae can be produced with less energy than for wood, and that it does not require the removal of lignin in the way that wood pulp does.

3.8.8 Textiles

China has started large-scale production of algae clothing after a research team at Qingdao University developed a method of producing fibre from certain species of algae. The algae fibres can be woven into fabrics and clothing, and are resistant to fire. In addition, the fibres contain metal ions that provide protection against electromagnetic waves and radioactivity. Algae clothing is ideal for firemen, for people who require protection against hazardous substances, and as ordinary clothing.

3.8.9 Fertiliser and soil improver

Seaweed and kelp have long been used as soil improvers, both by digging collected plants into the soil and via more modern methods of producing liquid algae extracts and seaweed meal for horticulture and agriculture. It is also possible to extract nitrogen and phosphorus from waste streams after production of biogas.

In many countries around the world, macro-algae are used as fertiliser. Macro-algae contain all the trace elements and plant nutrients needed for healthy crops, in addition to alginates, which are known to be an excellent soil improver.

In the 1940s-70s, oarweed was Norway's most important raw material for producing alginate (Photo Thinstock)

3.9 Economic potential of IMTA

IMTA can have a whole range of economic benefits compared with monocultures, including greater overall production, more product diversity and positive ecosystem services (Ridler et al. 2006; Knapp 2010; Ferreira et al. 2012). It is considered that the cost of setting up IMTA need not be insurmountable, if building on a monoculture setup. The infrastructure of fish farming is extremely well developed in Norway, and the cost of expanding this to IMTA is minimal due to the structure already in place. It is much more cost-effective to convert existing fish farms to IMTA than to build a brand new IMTA facility from scratch. The improved efficiency and the extra benefit of broader commercial and valuable products (e.g. salmon, blue mussels and kelp) instead of one product (salmon) could offset the start-up costs. The IMTA concept is highly flexible and can be developed in saltwater, freshwater, open and closed systems (Barringston et al. 2009).

3.9.1 Potential for production yield in Norway

SINTEF (2011) has estimated potential production yield for IMTA in Norwegian fish farms. The figures are based on the total production of trout and salmon from 2009 (1.016 million tonnes of fish, 28,650 tonnes of inorganic nitrogen and 14,100 tonnes of bound nitrogen) (SINTEF; NTNU; Wang et al. 2012). The nutrients could be used to produce 1.9 million tonnes (wet weight) seaweed and 64,000 tonnes of blue mussels. If IMTA facilities are moved offshore, the production yield could be improved many times over. No economic IMTA models have yet been developed for aquaculture in Norway. This must naturally be done for IMTA in order to move from pilots to commercial production. Economic models have been developed in several other countries, including Canada and South Africa.

3.9.2 Potential biomass production on large farms

The intention of the following estimates is to show the enormous potential that the sea offers, and how little we need of it to meet many different needs. The figures are calculated based on production per hectare and do not include distance calculations between species grown. The starting point is an area of 8,660 km^2 which amounts to 866,000 hectares (the size of Dogger Bank, where an offshore wind farm is planned). For comparison, this is smaller than the county of Rogaland, which measures 9,378 km^2.

Sugar kelp (growth season February–June) produces 160 tonnes per hectare per year, which gives 138.6 million tonnes per year wet weight for 866,000 hectares. The dry weight is around a third, which means 46.2 million tonnes (3.85 million tonnes per month dry weight). Around a third of kelp is stored carbon (NIVA 2010). As such, sugar kelp would capture 15.4 million tonnes CO_2 per growth season. In comparison, today's standing biomass of sugar kelp along the Norwegian coast is estimated at 20 million tonnes (NIVA 2011).

Micro-algae grow more quickly than macro-algae and with light and nutrients they can be harvested almost all year round. This gives annual productivity of up to 350 tonnes dry weight per hectare per year (SINTEF, varies with cultivation conditions). For an area of 866,000 hectares, this gives 303 million tonnes dry weight per year (25 million tonnes per month dry weight). Around half of the dry weight in micro-algae is bound up CO_2 (Oilgae). This amounts to 151 million tonnes CO_2 per year.

A new operational regulation that comes into force on 1 January 2013 states that the number of salmon in each cage must not exceed 200,000 fish. Under the current rules of max 25 kg/m^3 it is possible to have up to 1,000 tonnes (200,000 individuals of 5 kg in one cage). If one then calculates 1,000 tonnes harvestable fish every other year with 500 tonnes of fish per year per cage, this gives a yield of 433 million tonnes per year (36 million tonnes per month for an area of 866,000 hectares). In comparison, Norway's total salmon production amounted to around 1 million tonnes in 2011.

Blue mussels take around 2–3 years to become large enough for human consumption. This gives 60 tonnes per hectare per year. For an area of 866,000 hectares, this gives 52 million tonnes per year (4 million tonnes per month).

Are these figures realistic? They are realistic in terms of what can be estimated per hectare, but there is still a lack of knowledge on what we can produce on a large scale. Even if we deduct a certain distance between the IMTA systems and a certain distance between the various species in the IMTA system, there remains a huge potential for the production of biomass.

3.9.3 Benefits and challenges with IMTA-SWOT analysis

In 2010 a major IMTA workshop was held in Port Angeles, Washington, where researchers, industry players and public authorities met to discuss future opportunities and strategies. One of the days was spent analysing the ecological, economic and social benefits and challenges of IMTA through interviews with different groups of people.

A SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) was drawn up in advance for the various categories (see table below). Each of the categories was given an importance ranking, with each person giving a grade from 1–5 according to what they thought was most important, where 1 was unimportant and 5 was most important. With eight participants, the maximum score for a category was thus 40.

The tables (6, 7 and 8) show relevant factors that have been discussed in IMTA contexts around the world, where the gaps in knowledge lie and what concerns need to be taken into account. The SWOT analysis can thus be used to weight up the strengths against the weaknesses.

Totalling up the scores in the SWOT analysis (Tables 6, 7 and 8) shows that the highest points were given for the strength of recycling nutrients, and the weakness of lack of ecological knowledge. There are concerns over lower short-term profitability for IMTA compared with today's aquaculture, and the lack of public funding to develop a network of pilot projects and research. As of today, no effective technological solutions have been developed for large scale IMTA production. It is therefore reasonable to believe that monoculture offers greater profitability due to the absence of IMTA technology. On the other hand, the technology for large-scale IMTA production will not be developed until small-scale production solutions are up and running.

Other weaknesses of IMTA identified in the SWOT analysis appear to be centred around the complexity at different levels. For example, it was judged difficult to convey the technicalities to the public and the authorities. Other challenges are operational or relate to the cost of setup and maintenance. Many of the weaknesses come down to a lack of knowledge.

The aquaculture industry in Norway often provokes strong emotional reactions in people. When the ecological and economic status of the aquaculture industry is communicated to the general public, the focus tends to be more on the negative than the positive. It was therefore surprising to see the generally low score for social impacts in the SWOT analysis. As an example, conflicts over space were given a low score under weaknesses in the social impacts section. This score might perhaps have been higher under Norwegian conditions, where use of space for aquaculture continues to come into conflict with other users of the coastal waters.

The greatest threat comes from the fear that the IMTA concept will be wrongly communicated to the public, and this concern should not be underestimated. Negative media coverage of faulty or unsuccessful IMTA practices could quickly sink any prospect of further development. In a process that involves developing innovative new concepts, there has to be space to try and fail within acceptable limits.

The fact that IMTA could bring a whole new insight into aquaculture practices, with improved environmental consideration through the recycling of nutrients, was seen as the greatest strength. Another strength was the financial benefit of products that could be sold in new market areas and new niches. A sustainable image could have a major positive effect on the economics of the industry.

The SWOT analysis may be useful in showing what other countries think and what problems should be taken into account. It is, however, essential to analyse all aspects of the ecological, economic and social effects in relation to each other and to place this in a more explanatory context instead of individual analyses in these areas, as was done here.

Table 6. SWOT analysis of ecological impacts. Point scores are marked in red.

IMTA ecological impacts	
Strengths	**Weaknesses**
• Nutrient recycling (32) • Reduced demand for feed from pelagic marine fisheries and terrestrial crops (23) • Increased farm productivity (20) • Increased farm crop diversity (17) • Greater emphasis on quantifying ecological effects (15) • Can be used in many applications, e.g. freshwater, saltwater, closed and open systems (13)	• Lack of thorough understanding of environmental impacts (32) • Currently emphasises only high value products and thus less likely to contribute to world food needs (except seaweeds) (31) • Converts more resilient food webs to more vulnerable food chains (21) • Shifts nutrient flows in the environment to reduce natural production (18)
Opportunities	**Threats**
• Remediation of anthropogenic eutrophication (21) • If IMTA increases domestic production, decreased environmental costs (e.g. transportation) of imported seafoods (18) • Produce products (such as seaweed-based biofuels) that would reduce environmental impacts of fossil fuels (17) • Greater scope for decision-making for the aquaculture industry (14) • Potentially greater profitability compared to existing aquaculture systems (14) • Strengthens collaborative opportunities between different players (12) • Aquaculture research platform (8) • Specialised markets for IMTA products (4)	• Potentially lower profitability in the short term compared with existing aquaculture systems (31) • Not enough public funding (i.e. political will) for developing a network of demonstration and research sites to examine feasibility of IMTA (31) • Larger scale applications may have greater environmental impact and thus less social licence (28)

Table 7. SWOT analysis of economic impacts. Point scores are marked in red.

IMTA economic impacts	
Strengths	**Weaknesses**
• New image: differentiated coastal aquaculture (**28**) • Operational efficiencies: labour, operational rates, leasing (**23**) • Marketing advantages (**21**) • Effective use of nutrients and coastal space (**18**) • Ecosystem services increase revenue opportunities (**18**) • Diversified products = risk production (**13**)	• Complexity: marketing, operations, juveniles, business planning (**30**) • Regulatory complexity (**26**) • Site-specific criteria (due to multiple species): salinity, current, temperature (**20**) • Greater capital start-up costs (**20**) Risks: structural conditions, disease, operations (**18**)
Opportunities	**Threats**
• "Sustainable" image (**31**) • Market: pricing, high value products, packaging, niche opportunities (**21**) • Use IMTA as launching platform for national aquaculture vision (**20**) • Development platform: new products, innovation, feed, macro-algae, research (**18**) • Ecosystem services, potential revenue (**16**) • Accelerated innovation potential (**11**) • Adaptability (e.g. climate change) (**11**) • New partners (**3**)	• Social acceptance, public perception (**25**) • Natural threats: disease, parasites, storms (**25**) • Greater regulatory requirements (**25**) • Disappointment of expectations: failures could reflect badly on entire effort (**15**) • Market threats: overproduction, price cycles (**11**) • Competition from monoculture (**11**) • Cheap compared with IMTA (**7**) • New competing users (**1**)

Table 8. IMTA SWOT analysis of social impacts. Point scores are marked in red.

IMTA social impacts	
Strengths	**Weaknesses**
• Strong brand / green business (14) • Organic farming sounds positive (17) • Young industry – new model (11) • Commerce / jobs / wages (11) • Rewarding enterprise (11) • Scalable operation (10) • Healthy food (protein, omega 3) (10) • Improve environmental condition (9) • Year-round production, multiple species (8) • Educational opportunities (8) • Greater species diversification (7) • Opportunities for business development (niche) (7) • Preserve working waterfront (7) • Provide ecosystem services (5) • Good management (5) • Visual perception of aquaculture operations (4) • Scientific discovery (3) • Lease revenues (1) •	• Complexity (26) • Visual perception of aquaculture operations (18) • Fear of the unknown (18) • Capital intensity scale (16) • Economic viability (15) • Greater wildlife impacts and public perception thereof (15) • Potential to downgrade monoculture (10) • Poor examples and failures could colour overall perception (9) • Lack of critical mass (8) • Conflict of use (e.g. water, space) (6) • Young industry (5) • Maybe greater privatisation of public resources (3)
Opportunities	**Threats**
• Opportunity to culture new ecologically responsible species (17) • Jobs (17) • Social awareness (13) • Eco-food tourism (12) • Niches (11) • Optimise nutrient loads (10) • Increase healthy food supply (8) • Local buying (7) • Control environment (marketability) (7) • Education pathway (6) • Initiate partnerships (5) • Improve technology (5) • Regulatory design (2)	• Misinformation (30) • Financing (16) • Negative response to the label “farm-raised” (12) • Uncontrolled messages (e.g. on the internet) (10) • Shoreline development (10) • Lack of marine spatial planning (8) User conflicts over space (7) • Competition in the market (5) • Environmental degradation (2)

3.10 IMTA around the world

There are numerous IMTA projects around the world and interest is growing within the industry and at research institutions (Soto et al. 2009). There are countries that have farmed using the IMTA concept for several generations, and some have come as far as starting up commercial production. Norway, Sweden and Denmark remain at the pilot stage. It is not possible to describe all the many IMTA projects globally due to a lack of information. The results from various research projects remain unpublished and those involved in the industry are keeping their cards close to their chest. There are also many countries that have run commercial operations according to the IMTA concept for a long time, but that have not published any results.

3.10.1 Asia

Integrated aquaculture is not a new concept in Asia. Asian countries have practised polyculture of aquatic species for centuries in marine, brackish and freshwater environments (Neori et al. 2004; Ferreira et al. 2012). Asia is the world's biggest region for IMTA and has extensive commercial production, covering a wide range of species of fish, prawns, benthic organisms, bivalves and algae. One example from Kina is Sungo Bay, east of the Shandong peninsula. This site produces Zhikong scallops (*Chlamys farreri*), oysters (*Crassostrea gigas*), abalone (*Haliotis discus hannai*) and kelp (*Laminaria japonica)* in an area that stretches over 8 km with a water depth of 20–30 m.

Another example is the shallower area (10–40 m) around Zhangzidao Island, where the Zhangzidao Fishery Group Co has a licence covering 40,000 hectares for the cultivation of Yesso scallops (*Patinopecten yessoensis*), clams (*Scapharca broughtonii*), sea cucumbers (*Apostichopus japonicus*) and abalone (*Haliotis discus hannai*). The company has existed for 15 years and in 2005 its total production was worth over USD 60 million. The company has obtained a permit to expand the area farmed by 13,300 hectares to cultivate more species of algae and set up artificial reefs.

IMTA has also been implemented in several areas of Indonesia, including Cirebon and Indramayu, West Java, which farm prawns and seaweed, and Bali which farms fish, seaweed and oysters (Wibisono et al. 2011). IMTA on Bali has shown good results in terms of optimising feed use (Wibisono et al. 2011). An important part of the development process is submitting recommendations to the authorities (Astriana 2012).

Algae harvesting in China (Photo Silje Forbord)

3.10.2 Canada

Canada is streets ahead in IMTA research and commercial use in the western world. Dr. Thierry Chopin and his research team in Canada have been working on IMTA for over 12 years, and several farms have already implemented the IMTA model for commercial production. Of 96 sites in Southwest New Brunswick, five have developed IMTA and several others will soon begin commercial production. The main species farmed are salmon, kelp and blue mussels, but several other species such as sea urchins, sea cucumbers, scallops and annelids are now being evaluated for their ecological function and benefit to society.

An IMTA site has recently been established in Kyuquot Sound (Vancouver Island) to farm fish, kelp, clams, scallops and sea cucumbers (Cross 2007). The Canadian Integrated Multi-Trophic Aquaculture Network (CIMTAN) is involved in various projects together with research institutions and the industry.

IMTA in the Bay of Fundy, New Brunswick, Canada. Salmon is farmed in cages (front left), blue mussels are grown in bags and on ropes (front right) and kelp is grown on ropes (back right) (Photo Thierry Chopin).

3.10.3 USA

The USA already has several commercial land-based IMTA concepts, in addition to research projects. Söliv International is a skincare company that has developed a land-based IMTA system in partnership with the University of Washington, Seattle (Dr. Robert Waaland). They grow the red algae *Chondracanthus exasperatus* in separate tanks with seawater from the Pacific halibut (*Hippoglossus stenolepis*) and black cod that are farmed in other tanks. The algae grow under good conditions and, with maximum production of 75 kg wet weight per month, are then used in cosmetic products.

In Hawaii red algae and abalone are farmed in a land-based IMTA system (Soto et al. 2009) and along the coast of Massachusetts studies are being conducted into the viability of lobster farming and oyster production (Buttner & Leavitt 2003).

Matt Siskey & Ryan Baldwin (2011) from the University of New Hampshire investigated the possibility of farming sea urchins (*Strongylocentrotus droebachiensis*), sea lettuce (*Ulva lactuca*) and fish (*Tautogolabrus adspersus*) in IMTA on the west coast of the USA. They found that the presence of fish, sea urchins and sea lettuce in the same system produced a greater yield without them competing with each other for resources. The most interesting finding from the project was that the sea urchins that fed on fish faeces saw increased growth and larger gonads.

3.10.4 South America

Chile is one of the largest exporters of salmonids in the world and the IMTA potential is enormous (Soto 2009). There are several species of algae that are grown and harvested on a small scale, but only *Gracilaria chilensis* is the subject of large-scale commercial cultivation (Buschmann et al. 2005; 2006). IMTA has existed in Chile since the 1980s, but on a very small scale (Soto 2009). The main species farmed in this context have been rainbow trout (*Oncorhynchus mykiss*), oysters (*Crassostrea gigas*) and the agar-producing algae *Gracilaria chilensis*. Experience from many of the sites demonstrates better quality products, cleaner water and faster growth. IMTA development has been relatively limited due to the explosive growth in traditional production (monocultures) which has allowed IMTA little scope to grow and establish itself (Soto 2009). However, attitudes towards IMTA have begun to change due to the conflict between the considerable pressure on the environment and the drive for greater production. Alejandro Buschmann at the University of Los Lagos works on projects to improve the documentation of reduced environmental impact from salmonids in fish farms. The goal is to conduct more research into IMTA using trout, oysters and seaweed to identify the future potential of sustainable aquaculture. The greatest challenge lies in bringing on board the biggest industry players.

3.10.5 South Africa

Abalone (*Haliotis midae*), oysters (*Crassostrea gigas*), mussels (*Mytilus galloprovincialis*) and kelp (*Ecklonia maxima*) are a major industry in South Africa and are farmed together commercially in several locations. The kelp absorbs the surplus nutrients from the abalone (and possibly other species) and keeps the water clean. With its high content of nutrients and proteins, the kelp is then used to feed the abalone.

3.10.6 Australia and New Zealand

A three-year project off the South Australian coast involves nutrient-rich waste from tuna fish and yellowtail kingfish being used to grow seaweed. The project is a joint venture between the South Australian Research and Development Institute (SARDI), the University of Adelaide, authorities and commercial players.

The National Institute of Water and Atmospheric Research (NIWA) (2010) has developed an ecological IMTA model for establishing the optimum density between species and estimating products. The model has a dynamic energy budget at different trophic levels in an ecosystem model. New Zealand has been working with China on IMTA research since 2006 with a focus on ecological energy budgets, growth and ecological footprints for several species.

3.10.7 Middle East

Israel has at least three different IMTA projects in progress. SeaOr Marine Enterprises Ltd grows gilthead sea bream, seaweed and Japanese abalone. Waste products from fish are used to cultivate algae and the algae are then used to feed abalone. Nutrients are recycled and the water is effectively cleaned.

PGP Ltd is a small aquaculture farm in southern Israel that cultivates marine fish, micro-algae, shellfish and Artemia salina brine shrimp. Discharges from sea bream and sea bass are filtered by bivalves, Artemia salina and micro-algae from the water. The farm sells fish, shellfish and Artemia salina.

3.10.8 Europe

Loch Duart in Scotland farms sea urchins and seaweed together with salmon. Loch Duart has won various awards for its sustainable business, including the Gold Award for Best Food at the Taste of Britain Awards and the Vision in Business for Environment award (VIBES).

A range of IMTA research and pilot projects have been initiated in locations around Spain. In the Canary Islands, fish, bivalves, sea urchins and kelp are farmed together. Galicia, Catalonia and Andalusia are examining the potential for fish, bivalves and sea lettuce. Murcia farms fish, bivalves and sea urchins, while in the Balearics the focus is on the co-production of fish, bivalves, algae and bethnic organisms. Several of these projects are collaborations with various research institutions, the industry and the authorities. Trials in Galicia have shown that a kilo of sea lettuce meets the daily oxygen requirement for two kilos of fish in a recirculation system. Researchers from Galicia have drawn up criteria on how to choose the right species for an IMTA system. The choice of proper species is based primarily on growth potential, life cycle, resistance to disease, ecological function together with other species in the IMTA system, local species, biofiltration properties and commercial value. Over the course of several years, they have developed good design practices for IMTA with various species and evaluated the most suitable species for co-cultivation.

3.11 IMTA projects in Norway

Norway still has some way to go before IMTA can be brought to a commercial level. Despite Norway being the world's largest salmon exporter, we lag a long way behind in developing IMTA (Soto 2009). The farming of several different species together in Norwegian aquaculture has been met with scepticism due to fears of an increased risk in the spread of disease. In recent years, however, several research institutions have launched IMTA projects to examine the problems surrounding reuse of waste from fish farming. There is considerable interest among researchers and the first pilot project for blue mussels, kelp and salmon (INTEGRATE) has been rolled out on a small scale, with the accompanying development of IMTA models at SINTEF and NTNU. The research is based on new knowledge and technology. There are, however, some key problems that have not yet been studied, such as production capacity, risk of disease, fish welfare, escapes, operation, design costs and environmental impact.

The Institute of Marine Research, NIVA and Uni Research AS conducted a three-year project that concluded in 2012, studying IMTA and nutrient uptake. The objective was to investigate the response of ecosystems to induced stress and to evaluate nutrient uptake by macro-algae.

3.11.1 EXPLOIT

Bellona has entered into partnership with SINTEF (project manager), NTNU and the Institute of Marine Research to conduct an exciting new three-year research project (EXPLOIT) on integrated aquaculture, supported by the Research Council of Norway. The aim of the project is to survey the spread of nutrients deriving from salmon farms and to see what scope blue mussels, scallops and algae have to absorb these nutrients. The results of the project will hopefully increase our knowledge of the spreading mechanisms for nutrients and species productivity in integrated aquaculture. The project builds on the previous INTEGRATE project.

Sugar kelp from the EXPLOIT project in an early growth phase (Photo Annelise Leonczek)

3.11.2 DYMALYS

Lysefjorden in Rogaland is hosting the project DYMALYS – Dyrking av Makroalger i Lysefjorden (*Cultivating Macro-algae in Lysefjorden*). The core aim of the project is to develop optimal production technology adapted to Norwegian conditions for high quality macro-algae, through winter production of the species *Saccharina latissima*, *Laminaria digitata*, *Alaria esculenta* and *Porphyra spp*. The end products (the algae) are intended to be usable for human consumption, as a food and feed ingredient, for the uptake of nutrients from fish farms and CO_2 from other industries, for bioenergy and in fertilisers. The project was established in 2011 and over two seasons it has produced high quality macro-algae. As of 2013, *Saccharina latissima*, sugar kelp, has been tested in the restaurant market, for biogas production and in terms of nutrient absorption, with excellent results. Testing of algae as a raw material or ingredient in fish food has yet to be completed.

The project is a collaboration between Lerøy Seafood Group, Bicotec, Lysefjorden Forskningsstasjon, EWOS Innovation, Bellona, Sylter Algenfarm and IVAR. The project is partly funded through a Rogaland County Council regional development programme, and it is managed by Blue Planet.

Sugar kelp, *Saccharina latissima*, in a dish created by the Culinary Institute of Norway. The algae were grown as part of DYMALYS (Source Lerøy Seafood Group)

3.11.3 Hortimare and Salmon Group

Salmon Group AS and Sulefisk AS began integrated farming in 2010 in partnership with Dutch firm Hortimare. The salmon are farmed together with three different types of kelp (not blue mussels) close to the fish farm so that the kelp grows more quickly. The idea behind the project is to use the kelp as a vegetable source of fish food. The results show that it is possible to produce 6 kg per square metre with a further potential to produce 12–16 kg under optimum conditions. Achieving that sort of volume could make production economically viable. At the moment, the kelp is harvested manually, but the stakeholders behind the development project are waiting for the issuing of regulations for integrated aquaculture, in order to make large-scale cultivation a possibility.

Salmon Group AS sees the investment in kelp as an important element of a sustainable focus on new raw materials for fish feed production. Salmon Group AS is part of the network behind the CO_2BIO AS project in Mongstad, aimed at developing full-scale production of omega 3 from micro-algae, with CO_2 from a local water treatment plant as an input.

Harvesting sugar kelp (Photo Øyvind Kråkås)

3.11.4 Val algae project

Knowledge development is important in establishing a sustainable future for the aquaculture industry. In this regard, Val upper secondary school, the Royal Norwegian Society for Development, Bioforsk and Bellona have joined forces on a pilot project to farm algae. Val upper secondary school has courses in aquaculture as an elective subject. The school owns and runs its own salmon farm, and is also principal shareholder in the company Follaskjell AS, which cultivates blue mussels. This gives the school a unique opportunity to pass on knowledge of the seafood industry to the next generation, through a combination of theoretical knowledge and practical exercises on their own farm. For the coming academic year, there are around 40 students who have chosen aquaculture at Val. As a private school, Val has students from across the country, and is thus involved in building up the nation's aquaculture expertise.

There is currently a lack of knowledge about the cultivation of algae in Norway, and if this is to be developed into a viable industry along the Norwegian coast, targeted work is required in both R&D and the dissemination of knowledge. Establishing a pilot facility linked to Val upper secondary school will play a key role in this area, with short paths from trials to publication of results.

Val fish farm (Photo Halvor Mortensen)

3.11.5 IDREEM

Bioforsk and GIFAS AS are working together on an exciting four-year research project – IDREEM (Increasing Industrial Resource Efficiency in European Mariculture). The project involves 14 partners from aquaculture and research institutions in seven different countries and is coordinated by the Scottish Association for Marine Sciences (SAMS) in the UK. The focus of the project partners is on helping to secure a future for IMTA in Europe. The project will be conducted over several phases, including pilot testing, field research and modelling. Interdisciplinary research within IDREEM will examine the obstacles and risks to the use of IMTA systems and develop tools to overcome these constraints, whether they are economic, environmental, technical, social or regulatory. IDREEM will deliver tools and evidence to support the adoption of IMTA across the aquaculture industry, helping create employment and widening a market niche for IMTA-grown seafood products.

3.12 Taking the IMTA process forward

In order to drive the position of IMTA in Norway forward from pilot and research level to commercial viability, several phases of development will be required within different categories. Acceptance from the public, the industry and politicians is important to future development. Clear rules, strategies and economic models must be developed, and here we can learn from other countries that are further down the line. Canada has come a long way in developing these processes, and has proposed strategies for developing good infrastructure and models for IMTA systems (Barrington et al. 2009).

3.12.1 Establishing economic models

There is sufficient data from various IMTA projects around the world to declare that the IMTA concept has a bright future. An important step towards large-scale production is the establishment of good economic models based on choice of species and what social benefits these bring to Norway.

IMTA farms should be planned well and designed as complete systems. Economic analyses must be integrated into the general modelling of the IMTA system, to provide a better understanding of the economic effects on local communities along the coast. This will make it possible to compare profitability and economic consequences.

These models must be sensitive to different conditions, and have an inbuilt flexibility that is adapted to the environmental, economic and social data applicable to the location where the IMTA system is to be installed.

There are numerous reference works on good models regarding biomass production and the environmental impact of monocultures (Corner et al. 2006; Cromey et al. 2002; Skogen et al. 2009; Stigebrandt et al. 2004) but there are very few who have put together IMTA models. Ferreira et al. (2012) have created a model where they compare monoculture of cusk and integrated aquaculture with cusk and oysters. The purpose of the model is to establish production capacity, environmental effects and economic potential. The model thus helps when choosing good locations for maximum yield and minimum environment impact.

Ren et al. (2012) have developed an ecosystem model based on which species' functions are most ideally suited for optimal growth. The model is a tool for comparing monoculture with IMTA systems, and can provide a greater understanding of the species' functions in relation to each other, as well as giving good estimates of production capacity and biofiltration performance.

3.12.2 Suitable species for IMTA

It is important that the organisms in the IMTA system are chosen based on the functions they have in the ecosystem, their economic potential, and their acceptance among consumers. The criteria for choosing the right species are as follows (Barrington et al. 2009):

- Rule number one is to use local species that already exist in the area. This will help to prevent the risk of introducing species that could cause damage to the ecosystem.
- Use species that will complement each other at different trophic levels, for example by using each other's resources. One species' waste can become a nutrient source for another species' growth. Not all species can be cultivated effectively together. It is therefore crucial to be familiar with the life cycle of the species.
- Choose species that grow quickly and where the biomass yield is large, possibly species with high market value per kilo, or with great potential for value chain development. Market surveys should be conducted and customers should be canvassed before making investments.

- Use species that make it easier for both the authorities and industry players to promote value chain development.

3.12.3 Understanding the ecosystem and local conditions

Each aquaculture site has its own unique oceanic and biological profile, and these factors will affect the species that can be cultivated. The area should be surveyed for natural plankton communities, habitats, current and seabed conditions, natural variations in nutrients, oxygen levels, ice formation, depth and temperatures through the year, in order to maximise the success of the IMTA structure.

3.12.4 Guidelines, frameworks, regulations and criteria

As of today, no guidelines, frameworks, regulations or criteria have been developed for IMTA in Norway. However, these need to be in place in order to allow the development and exploitation of commercial products from IMTA systems. Responsibility for this lies with the authorities. The authorities have ambitious plans for the future of Norway as a seafood nation, but growth is self-limiting due to the methods currently used, and the new environmental constraints that the aquaculture industry has been obliged to operate within. IMTA requires a new approach. A number of changes are needed if Norway is to compete with other countries that practise IMTA.

3.12.5 Need for more space

The use of marine sites in the coastal zone is regulated through the municipal planning system, in accordance with the Norwegian Planning and Building Act. There is an ongoing debate about whether the space given over to fish farming should be reduced, increased or set at zero growth. Greater use of the coastal zone and additional players could lead to conflicts of interest. In 2011 the Area Commission published a major report (Gullestad et al. 2011) addressing the use of marine sites in the coastal zone. The Commission proposed various measures for establishing a new site structure in the aquaculture industry. The report stressed that the industry must be ensured sufficient access to marine sites and that these areas must be used effectively with the least possible environmental impact. It was proposed that the coast should be divided up into separate production areas, and that one licence would belong to one production area, while also establishing fish farm free areas. The separate production areas would then be divided into zones with coordinated stocking and coordinated fallowing.

If the value creation potential for algae is to be realised, access to cultivable sites must be ensured. Norway has huge potential to be one of the world's biggest players in aquaculture. It is important to understand that size has nothing to do with sustainability. A site could be small and unsustainable. It could also be large and sustainable. The fish farming industry currently occupies only 0.5% of the Norwegian coastline. As long as the marine sites are run sustainably and managed correctly, there should be no problem in increasing this figure.

3.13 Conclusion

IMTA offers huge potential. But how can we acquire the necessary competencies? And what about the authorities, legislation, research, value chain development and economics? The normal linear approach starts with research, then come political decisions and finally there is investment. Just such an approach lingers on in Norway. Most of those who farm fish know nothing about growing algae or mussels. Different stakeholders possess different competencies. It is crucial to bring these competencies into a system that can work effectively. Effective collaboration between industry, business, research and politicians is necessary in order to ensure effective development of sustainable aquaculture. Such a partnership should be established simultaneously for both pilot projects and industrialisation.

There remains some way to go before it is possible to establish large-scale production and achieve substantial profitability. However, it could all happen quickly given sufficient resources. The technology needs to be developed, and here there is no other option but trial and error.

The focus should be on the overall potential. Bellona believes the future of fish farming lies in Integrated Multi-Trophic Aquaculture, and it is entirely possible to increase both area and production through such practices. Good innovation concepts must be created. We should think about what we want for our valuable coastal areas. Whatever we humans do will leave some traces. The important thing is to find solutions that keep those traces to a minimum. We should develop a holistic understanding and come up with holistic solutions that work with the ecosystem rather than against it.

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IDREEM (Increasing Industrial Resource Efficiency in European Mariculture) is an IMTA project under the EU's 7th Framework Programme: http://www.longline.co.uk/IDREEM/

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