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Pre-project: Climate Change as an Opportunity towards Adaptive Sustainable Aquaculture (CADINAL)

Norwegian Institute for Water Research
– an institute in the Environmental Research Alliance of Norway

REPORT

Main Office
Gaustadalléen 21
NO-0349 Oslo, Norway
Phone (47) 22 18 51 00
Telefax (47) 22 18 52 00
Internet: www.niva.no

NIVA Region South
Jon Lilletuns vei 3
NO-4879 Grimstad, Norway
Phone (47) 22 18 51 00
Telefax (47) 37 04 45 13

NIVA Region East
Sandvikaveien 59
NO-2312 Ottestad, Norway
Phone (47) 22 18 51 00
Telefax (47) 62 57 66 53

NIVA Region West
Thormøhlens gate 53 D
NO-5006 Bergen Norway
Phone (47) 22 18 51 00
Telefax (47) 55 31 22 14

NIVA Region Mid-Norway
Høgskoleringen 9
NO-7034 Trondheim
Phone (47) 22 18 51 00
Telefax (47) 73 54 63 87

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Author(s) Trine Dale, NIVA Nathaniel B. Dkhar, TERI Debashish Goswami, TERI Anke Weber Smit, NIVA Åse Åtland, NIVA	Topic group Aquaculture	Distribution Open
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Cultured food fish currently accounts for nearly 50 % of the global consumption. India and Norway are the world's second and seventh largest aquaculture producers respectively, thus aquaculture is considered to be a sector which provides immense opportunities in both adaptation and mitigation under climate change realm in both countries. India and Norway is located in the tropical, and in the cold temperate zone respectively. Furthermore, freshwater aquaculture dominates in India, while in Norway marine water aquaculture dominates. While feed inputs for Indian carps mainly stems from agriculture, the salmon still depends on feeds input from fisheries. Thus the two countries aquaculture industries could be regarded as two extremities within world aquaculture, and a comparison will be highly valuable. The overall objective of this pre-project was to build a holistic and integrated knowledge base that would enable a future quantitative analysis of the dynamic two way interactions between climate change and the aquaculture sector. This report sums up the knowledge basis on the impacts of climate change on Norwegian aquaculture, assess the feasibility for an in-depth quantitative analysis on the impacts of climate change on Norwegian aquaculture, and sums up common research challenges between Norway and India. The knowledge basis on the impacts of climate change on Indian aquaculture is summed up in a separate report.

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Åse Åtland	*Mark Powell*	*Kristoffer Næs*
Project Manager	Senior Adviser	Research Director

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Pre-project:

Climate Change as an Opportunity towards Adaptive Sustainable Aquaculture (CADINAL)

Preface

The current pre-project was financed under the INDNOR programme (Research cooperation with India). The project was started in January 2011, and the original plan was to finish by the end of the year 2011. Due to changes in project personnel both in TERI and in NIVA the project period was prolonged until July 2013. The project was led by Anke Weber Smit from the start of the project period until the end of 2012, when she left NIVA and I took over the role as project manager. From NIVAs side we would like to thank The Norwegian Research Council for this opportunity and special thanks also to our colleagues at TERI for the constructive collaboration during the project period and the hospitality during our visit to India in December 2012.

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Åse Åtland

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Summary

Cultured food fish currently accounts for nearly 50 % of the global consumption. India and Norway are the world's second and seventh largest aquaculture producers respectively, thus aquaculture is considered to be a sector which provides immense opportunities in both adaptation and mitigation under climate change realm in both countries. India and Norway is located in the tropical, and in the cold temperate zone respectively. Furthermore, freshwater aquaculture dominates in India, while in Norway marine water aquaculture dominates. While feed inputs for Indian carps mainly stems from agriculture (e.g. organic manures from cattle supplemented with a mixture of rice/wheat bran and oil cake) the salmon still depends on feeds input from fisheries. Thus the two countries aquaculture industries could be regarded as two extremities within world aquaculture, and a comparison will be highly valuable. The overall objective of this pre-project was to build a holistic and integrated knowledge base that would enable a quantitative analysis of the dynamic two way interactions between climate change and the aquaculture sector. The overall objective was addressed through three main work packages with individual part objectives. Part objective 1, was to evaluate the feasibility for an in-depth, quantitative assessment of the climate change impacts on the aquaculture industry in India and Norway. Part objective 2, was to evaluate the feasibility for an in-depth, quantitative assessment of the aquaculture industry's impacts on climate change in India and Norway. The final part objective was to formulate a first draft of an overall design for future adaptive strategies aimed to strengthen the sector's resilience towards less expected climatic challenges. This report sums up the knowledge basis on the impacts of climate change on Norwegian aquaculture, assess the feasibility for an in-depth quantitative analysis on the impacts of climate change on Norwegian aquaculture, and sums up common research challenges between Norway and India. The knowledge basis on the impacts of climate change on Indian aquaculture is summed up in a separate report.

1. Introduction and approach

1.1 Background

It is now widely accepted that at least part of the earth's 0.6 ° C warming during the 20th century is due to emissions of greenhouse gases caused by human activities (IPCC 2001), and the research effort on the impacts of climate changes has increased the last 15 years. In the same period the importance of aquaculture for food production and food security has been increasingly acknowledged. Surprisingly, very little research has been undertaken to link aquaculture and climate change (Handisyde et al., 2006, De Silva & Soto 2009), and studies are few, especially compared to all other primary production sectors (De Silva & Soto 2009). According to Handisyde et al., (2006), the major direct drivers of climate related changes in aquaculture production are changes in temperatures (air, inland and sea surface), oceanographic variables (currents, wind velocity and wave action), sea level rise and increase in frequency or intensity of extreme events and water stress. These changes may in turn result in physiological changes (e.g. growth, reproduction and frequency/virulence of parasites and pathogens), ecological changes (organic and inorganic cycles, ecosystem services) as well as operational changes (e.g. species selection, site selection and technology) (Handisyde et al., 2006). Furthermore, climate impacts may work indirectly through important inputs to aquaculture, where the most obvious and commonly discussed indirect impact is related to fisheries, both their role in supplying fish meal and oils, and their role as competitors with aquaculture products in the market place (Handisyde et al. 2006, De Silva & Soto 2009). Thus changes in fisheries caused by global climate change may cascade into aquaculture systems, particularly that of carnivorous species like the Atlantic salmon.

Aquaculture occurs in fresh water, brackish water and marine waters, and is distributed throughout a span of climatic regimes. Thus the different elements of climate change are likely to be manifested to varying degrees in different climatic zones. For example, it is predicted that global warming and a consequent increase in water temperature could impact significantly and negatively on aquaculture in temperate zones because temperatures could exceed the optimal range of organisms currently cultured. The optimum temperature range for maximal growth rate of Atlantic salmon, for example, is 15-16 ^{o}C, where values above and below this range cause decreased growth rates (Koskela et al., 1997). On the other hand, temperature related negative impacts temperate zones may be balanced with enhanced growth and production in tropical and subtropical zones, as well as in the northern temperate regions (Lorentzen 2008). Unfortunately, positive impacts are likely to occur in concert with potential negative impacts arising from other climatic change elements (e.g. increased eutrophication in inland waters).

The Norwegian aquaculture industry has grown steadily over the past 30 years. Although marine finfish such as cod and halibut, and shellfish such as blue mussels are in the process of becoming commercialised, salmonids are the backbone of Norwegian aquaculture industry. Farmed salmon is one of the most important export commodities of Norway (ranking behind oil and aluminium), with an export value of about 4.8 billion US dollars in 2011 (www. ssb.no). Hence, aquaculture contributes substantially to the country's economy. Salmon and rainbow trout are both anadromous species. The starting point is the production of brood stock fish for the collection of eggs and milt. Hatching takes place in onshore tanks, while a grow-out phase is almost exclusively based on intensive cage culture in the sea. Exclusively formulated feeds are used.

Indian aquaculture has demonstrated a six and half fold growth over the last two decades, with freshwater aquaculture contributing over 95 percent of the total production. The production of carp in freshwater and shrimps in brackish water forms the major areas of activity. The three Indian major carps, catla (*Catla catla)*, rohu *(Labeo rohita*) and mrigal (*Cirrhinus mrigala*) contribute the bulk of production with over 1.8 million tonnes. The brackish water aquaculture has been confined to a single species, *Penaeus monodon* with a production of approximately 115 000 tonnes. While carp and other fin fishes are grown for the domestic market, a large proportion of prawn production is exported. Production of cold-water fish species, contributes little to the total aquaculture production in India. However, some production of

Rainbow trout (*Oncorhynchus mykiss*) occurs especially in the states of Jammu & Kashmir and Himachal Pradesh, and the total production was in 2012 estimated to be around 500 t/year (Meenakumari and Mahanta 2012). In a recent workshop it was stated that this type of aquaculture has a huge potential for growth. Aquaculture in India, in general, is practised with the utilisation of low to moderate levels of inputs, especially organic-based fertilisers and feed. Considering the substantial contribution aquaculture makes towards socio-economic development in terms of income and employment, environmentally friendly aquaculture has been accepted as a vehicle for rural development, food and nutritional security for the rural masses. It also has immense potential as a foreign exchange earner.

1.2 Objectives

The main objective in this pre-project was to build a holistic and integrated knowledge base that would enable a quantitative analysis of the dynamic two way interactions between climate change and the aquaculture sector in a future full-project.

1.3 Implementation

The project was started in January 2011, and the original plan was to finish by the end of the year 2011. Due to changes in project personnel and project managers both in TERI and in NIVA, new personnel were included and the project period was prolonged until July 2013. As stated in the objectives, the project was a pre-project with the goal of creating the scientific fundament for a full project application on aquaculture to the INDNOR-programme. However, after the project start-up, the focus was somewhat shifted in the INDNOR programme, and aquaculture was no longer included in the INDNOR calls for researcher projects. In spite of this, the project group decided to still focus on the climate change challenges for the aquaculture industry in the two countries, and based on that to identify specific areas of research where we would benefit from cooperation between TERI and NIVA in the future. This has been pursued both by reviewing some of the most relevant literature (published and grey literature) in Norway and in India, and also through joint Norwegian-Indian projects meetings and workshops where stakeholders were included in addition to climate-change and aquaculture researchers.

2. Results

2.1 Introduction

According to FAO, aquaculture is the farming of aquatic organisms: fish, molluscs, crustaceans, aquatic plants, crocodiles, alligators, turtles, and amphibians. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated (FAO 2002). This is very much in accordance with the definition used by the Norwegian authorities where aquaculture is understood as the "Production of aquatic organisms where production is understood as any measure to alter the weight, size, number, characteristics and quality of living aquatic organisms." (Salmon Allocation Decree, 2004, Norwegian Ministry of Fisheries and Coastal Affairs). In 2010, global production of farmed food fish was almost 60 million tonnes, where almost the entire production destined for human consumption (Table 1). Aquaculture is the fastest growing food production sector, presently accounting for over 40 % of the world’s food fish (FAO 2012). Globally aquaculture is carried out in freshwater, brackish waters and seawater environments. While finfish production dominates aquaculture production in freshwater, crustacean culture is dominating aquaculture in brackish waters and mollusc culturing dominates mariculture (FAO 2012).

Table 1. World aquaculture production in 2010 (FAO 2012).

World	Tonnes	Percentage
China	36 734 215	61.35
India	4 648 851	7.76
Viet Nam	2 671 800	4.46
Indonesia	2 304 828	3.85
Bangladesh	1 308 515	2.19
Thailand	1 286 122	2.15
Norway	1 008 010	1.68
Egypt	919 585	1.54
Myanmar	850 697	1.42
Philippines	744 695	1.24
Other	7 395 281	12.35
Total	**59 872 600**	**100**

Most aquaculture systems are open systems, where success is depending on favourable environmental conditions. Climate change is likely to have disadvantageous economic consequences on aquaculture, at least regionally. It is likely to impact fisheries and aquaculture because of changes in temperature, ocean currents, winds, nutrient supply, rainfall, ocean chemistry and extreme weather conditions. Climate change and climate variability have occurred throughout history, and natural systems have developed a capacity to adapt which supposedly will help them mitigate the impact of future climate changes. However, two factors currently limit the adaptive capacity of the fisheries and aquaculture sector:

(I) The rate of future climate change is expected to be at a pace far greater than previous natural changes.
(II) Species and ecosystems are not as resilient as they used to be because of the synergistic effect of a number of anthropogenic pressures like loss of genetic diversity, habitat destruction, pollution, introduced and invasive species and pathogens.

2.2 Norwegian aquaculture; history and present production

Aquaculture in Norway dates back to 1850 when the first brown trout (*Salmo trutta*) were hatched. By around 1900 rainbow trout (*Oncorhynchus mykiss*) were imported from Denmark and the first attempts at pond culture were initiated. An increase in interest was shown after World War II, followed by a breakthrough in the early 1960s when for the first time rainbow trout was successfully transferred to sea water. The first successful on growing of Atlantic salmon (*Salmo salar*) also took place during this same period. A technological breakthrough came around 1970 when the first sea cage was constructed. On growing in cages proved to be safer and provided much better environmental conditions than onshore tanks or the various enclosures that had been used earlier, particularly with regard to salmon farming. The long and sheltered coastline of Norway, with its thousands of islands and inlets, as well as the Gulf Stream providing a reliable and stable temperature, has been proven to provide excellent opportunities for this kind of intensive fish farming (Gjedrem 1993).

Together with China and Thailand, Norway is one of the top three fish exporters in the world (FAO, 2010). Norway is the world´s leading aquaculture producer of salmonids, accounting for 36% of the world production (FAO, 2010). In 2012 the total production of salmonids exceeded 1.3 mill tonnes (*Figure 1*).

Intensive farming of Atlantic salmon is by far the most important species in Norway, and the accounting for more than 80 % of the total Norwegian aquaculture production. Salmon is followed by rainbow trout (10-15%) and cod (SSB 2010). Other marine finfish such as halibut and shellfish species (blue mussel, oysters) are produced in small quantities. The first hand value of the Norwegian aquaculture production exceeded 31 billion NOK in 2012, and this was "all time high"(SSB 2012)

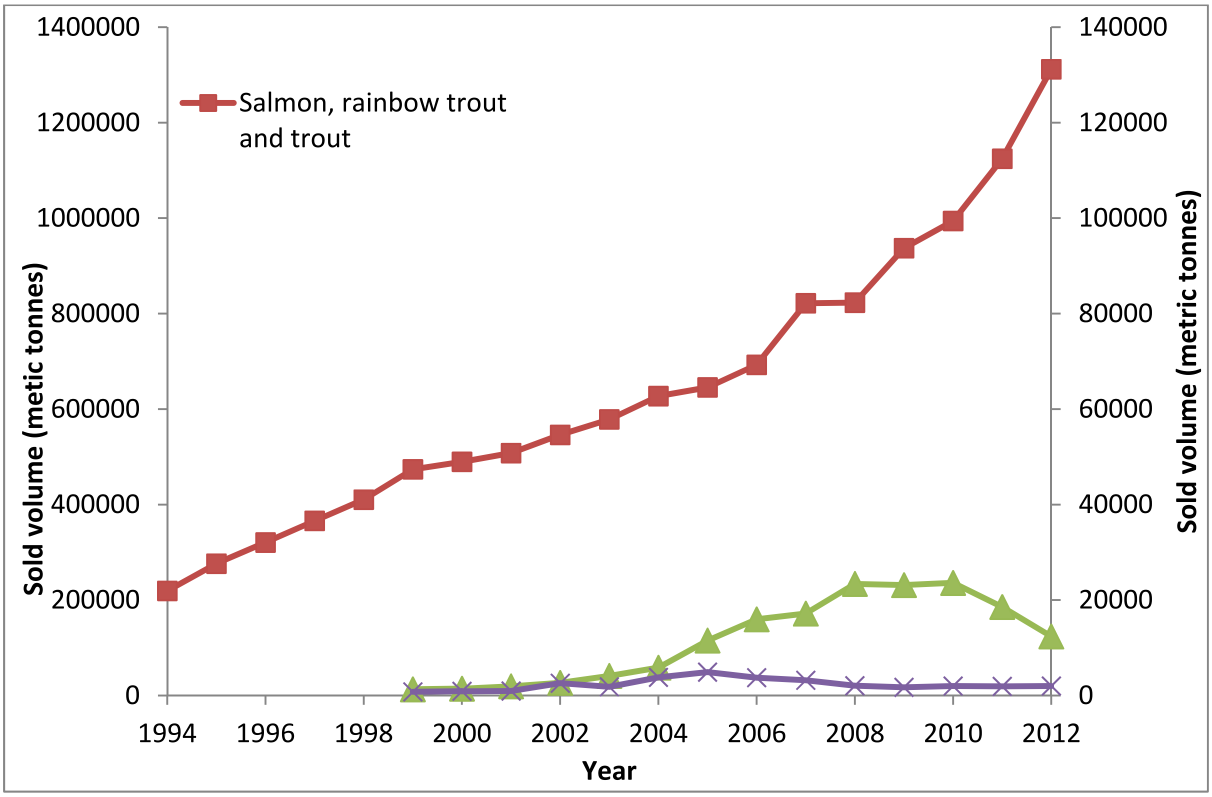

Figure 1. Norwegian aquaculture production in the period 1994-2012. The numbers for salmonids are given on the left axis while marine fin-fish and shellfish is read on the right hand side axis (source: Directorate of Fisheries, www.fiskeridir.no).

Ninety-five per cent of Norwegian aquaculture production is exported, with the EU being the main market. Salmon products however are exported all over the world. Farmed salmon is now one of the main export commodities from Norway and aquaculture and related industries contribute substantially to the country's economy and it is believed that there is still considerable potential for future growth. The major challenge to the industry is to develop a profitable aquaculture industry based on species other than salmon and to establish a sustainable supply of raw materials for the feed industry (Olafsen et al. 2012)

2.2.1 **Human resources**

As a result of high labour costs in Norway, aquaculture is a highly industrialized sectors in comparison to Africa and Asia where small-scale operations are dominant (FAO, 2010). The number of employees was about the same in 2010 as in 1994 in the case of salmon, rainbow trout and trout aquaculture (*Figure 2*).

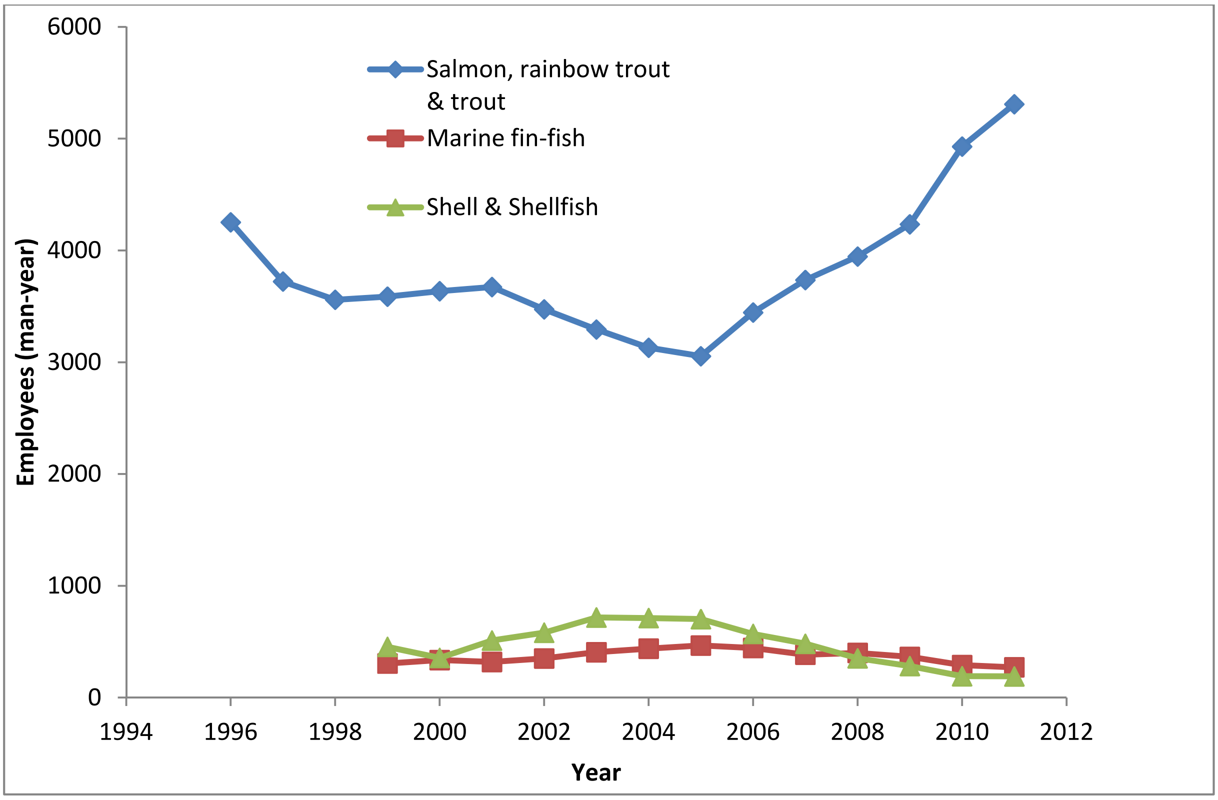

Figure 2. Number of employees in the period 1994 (1999)-2012 (Directorate of Fisheries, www.fiskeridir.no)

This means that the productivity (production per person) was increasing considerable over the last decades (SSB, 2009). Today around 5000 are directly employed in fish-farming, but many more are indirectly linked to the fish-value-chain e.g. as deliverers of technical equipment, or in further refining of the fish (*Figure 2*) (for an in-depth analyses see e.g. Sandberg et al., 2010). Since the industry is located along the entire coast, many rural communities are depending on the industry for revenue and employment.

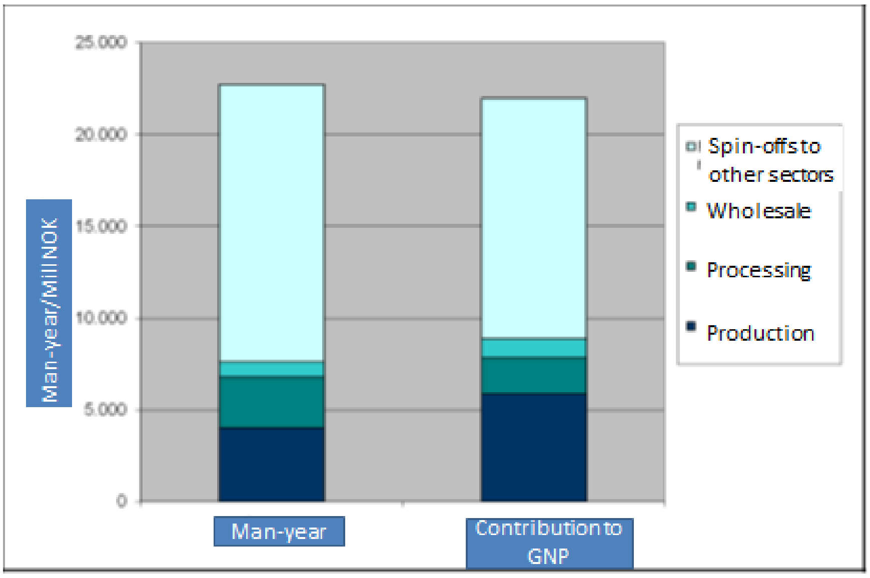

Figure 3. Employees in the wider aquaculture value chain and their contribution to Gross National Product (GNP)(modified from Sandberg et al. 2010).

The industry has become a major contributor to employment, as have suppliers of i.e. technical equipment, services, logistics, research and consulting (termed spin-offs to other sectors in *Figure 3*). While employment in production has been declining over recent years, this has not been the case with the administration and service sector to the industry where a major change from an unskilled to a skilled labour force has taken place and the number of employees with academic qualifications has increased.

2.2.2 **Species, cultivation and culture systems**

Salmonids
Salmon and rainbow trout are anadromous species, meaning that they spend a portion of their life in fresh water and a portion in seawater. Atlantic salmon (*Salmo salar*) is native of Norwegian waters, where spawning and smoltification has taken place in the country’s rivers since the last glacial period. The freshwater phase is followed by an ongrowing period at sea. Wild stocks of Atlantic salmon have been caught since ancient times, both in rivers and in the open sea. Along with the halibut, salmon has probably been the most valued fish species of all by people living along the coast. The rainbow trout (*Oncorhynchus mykiss*) is not native. The species was introduced into Norway around 1900 and was produced in freshwater until the early 1960s. Transfer to sea water following smoltification became then a successful process and intensive ongrowing of fish to between 2-6 kg in sea cages has subsequently come to dominate rainbow trout production. Farming of Atlantic salmon and rainbow trout takes place along the entire coast from Agder in the south to Finnmark in the north. Since 1975, production has been regulated by government licensing. In addition to Atlantic salmon and rainbow trout, there is also production of arctic char (*Salvelinus alpinus*). For this species there has been a small but stable production of 300-500 tons a year in the period 2007-2011 (Directorate of Fisheries 2012).

Marine fish
There are several species of marine fish that are/has been considered interesting for aquaculture in Norway, such as Atlantic cod (*Gadus morhua*), halibut (*Hippoglossus hippoglossus*), turbot (*Psetta maxima)* and spotted wolfish (*Anarchichas minor*). The Atlantic cod has always been the most important species in Norwegian capture fisheries. As a result of seasonal variations in availability and annual fluctuations in the wild catch, interest in farming the species has been shown for a long time. During the last decades there have been several attempts to engage in cod farming in Norway, with varying success.

In the Old Norse language, the halibut was called ‘the holy fish’. The fish is highly valued due to its taste and relative scarcity from the wild caught fisheries; it is therefore very interesting with respect to its prospects for aquaculture. The species has however, a complex biology and it has been very difficult to establish a stable production of high quality fry. Improvements are being made and today volume is increasing especially due to its high price making production profitable, and it is now a small but growing commercial production. In the period 2007-2011 there has been a production in the range 1500-2500 tons of Halibut per year (Fiskeridirektoratet 2012).

In the southern part of the country, one farm is producing about 600 000 turbot fry (*Psetta maxima*) and about 250 tons of market size fish per year. The spotted wolffish (*Anarchichas minor*) is a very promising aquaculture species which thrives in cold waters and is therefore very well adapted to production in northern regions.

Shellfish
The blue mussel (*Mytilus edulis*) is found along the entire Norwegian coast from the Swedish to the Russian borders. Various experiments in the extensive culture of this species have been carried out over the last 50 years; however, production has not reached commercial viability. The main reasons

for this are a low price, logistical problems as well as problems with bird predation and marine biotoxins caused by algal blooms. Possibilities for high volume production are enormous along the long and highly productive coastline if a commercial breakthrough does occur one day. Production of the European flat oyster (*Ostrea edulis*), both of juveniles and market size oysters, has a long tradition in Norway, and the Pacific cupped oyster (*Crassostrea gigas*) has also been imported for aquaculture purposes, but neither of these have reached any significant production volume. Experiments in the cultivation of the great Atlantic scallop (*Pecten maximus*) has also been on-going for a number of years but again no commercial production has yet been established.

2.2.3 **Production cycle**

Broodstock
The starting point in fin-fish production is the production of broodstock fish for the collection of eggs and milt. The breeding is now almost entirely based on participation in genetic breeding programs. For farmed salmon, the original breeding population was a selection of wild salmon caught from Norwegian rivers some Rainbow trout now has around nine to 10 generations of family and individual based selection behind it. Farmed cod in Norway is also descended from wild local stocks. After a few generations of development, it is now feasible to control the quality of the brood stock. Breeding programs are established both for cod and halibut.

Hatching
For salmon and rainbow trout, fertilized eggs are incubated hatched and feeding begins using formulated feed in intensive systems. The fry will usually spend 8-18 months in fresh water tanks before it is ready for smoltification and transfer to net pens in the sea. The smolt weighs 70-100g when it is transferred to the sea. Some freshwater production facilities include both hatcheries and smolt production while others purchase juvenile fry and produce smolt stage. Unlike salmon and trout, which are fed pellets from an early stage cod larvae have to be fed live plankton (rotifers, *artemia*) as a starter feed. Throughout the different larva stages, cod need prey of increasing size. After some time, the larvae are adapted to pellets. This commonly takes place in intensive hatcheries. In halibut farming, all phases of production require special solutions compared to farming of other species such as salmon. The larvae of the halibut are very fragile and hence there are stringent demands in regard to hygiene and gentle handling during production. As with cod larvae, halibut larvae are dependent on live feed after the yolk sac phase.

Ongrowing
Ongrowing at sea is now almost exclusively based on intensive cage culture for all finfish species, some halibut is still produced in onshore tanks, but cage culture seems to dominate for this species also. In the case of salmon, ongrowing at sea takes from 15 to 24 months, and is carried out in very large-scale production systems.

All licenses for ongrowing are given with an upper limit for "maximum allowed biomass" (MTB)(http://www.lovdata.no/cgi-wift/ldles?doc=/sf/sf/sf-20041222-1799.html). This biomass is the maximum biomass that can be held at any given licence at any given time. The standard MTB is 780 tons (900 tons in the two northernmost counties). Several licenses can be operated at the same site, and the biggest sites may today contain up to 7000 tonnes MTB. A farm of this size will typically have 8-10 net-pens each with a perimeter of 157 m.

Formulated dry feed account for almost 100 percent of the feed used. Feeds are administered automatically by centralised feed systems that blow the feed directly from the feed silos to the fish. Cameras and various sensors are monitoring the feeding sessions and feeding is terminated when the fish are satiated. In addition to the licenses, farmers must have permission to utilise specific sites for production. These production sites are required to operate on a single year class basis. In other words, when smolts are put to sea cages at one site in any particular year, the farmer is not allowed to stock new smolts into the same site before the original fish is harvested. The site should then have a fallowing period (left empty), usually for a period of at least six months, before new smolts can be transferred into the site again. With an ongrowing production period varying between 15 to 24 months, one farm should have at least three ongrowing sites available.

Shellfish
All mussel farming is based on natural spat collection. Spat collection is carried out using hanging collectors. These are sometimes left for ongrowing, but it has become a more common practice to replant or thin the spat as it grows. Mussels are not fed at any point, but live on natural populations of algae in the sea. European flat oyster spat is usually produced in specific small, narrow inlets which have a freshwater layer on top, with this layer providing a 'greenhouse' effect with a temperature high enough for the oyster to spawn. Spat will then settle on collectors and can be transferred to hanging baskets for ongrowing. Intensive production of scallop and oyster spat has also been researched.

2.2.4 **Freshwater**

Arctic char (*Salvelinus alpinus*) is the only species farmed entirely in freshwater. Most of the farms are small scale, and located in the northern part of the country. In 2009 the production of arctic char was 600-700 tonnes and most of the production is aimed for domestic markets. There is also a minor, although not insignificant, production of portion size rainbow trout in freshwater ponds or tanks (FAO, 2011).

Although freshwater aquaculture in the strictest terms (the entire production is carried out in fresh water) is rather limited in Norway, freshwater aquaculture is very important on the wider terms since there is a freshwater stage of the production cycle for anadromous fish like Atlantic salmon (*Salmon salar*) and rainbow trout (*Oncorhynchus mykiss*)(see above). The freshwater phase ranges from hatching until the smolt stage, where the fish is ready for transfer to seawater. Some freshwater production facilities include both hatcheries and smolt production while others purchase juvenile fry and produce smolt stage salmon (FAO, 2011).

2.2.5 **Brackish Water**

Technically, brackish water contains between 0.5 and 30 grams of salt per litre (0.5 to 30 parts per thousand, ppt or ‰). Thus, brackish covers a range of salinity regimes and is not considered a precisely defined condition. It is characteristic of many brackish water bodies that their salinity can vary considerably over space and/or time. Norwegian fjords and coastal waters are influenced by freshwater run-off. In Norwegian fjords there is typically a top layer of salinity < 30, overlying a layer of more saline water. The depth and the salinity of the brackish water layer vary between fjords, along fjords and seasonally within a fjord. In inner part of the fjords the salinity in the brackish layer is low but the brackish layer is shallow. Further seawards the salinity decrease and the brackish water layer gets deeper. At some point the top layer is no longer defined as brackish. On a specific site the lowest salinity coinciding with snow/glacier melting during spring and summer. Norwegian fish farms (sea cages) are located in fjords and coastal water could thus be defined as brackish water aquaculture. However, since far from all farms have brackish conditions in the top layer and many only have brackish water close to the surface, we choose to define the sea stage of Norwegian fish farming as mariculture (see below).

2.2.6 **Mariculture**

The ongrowing phase of the most important species of fin-fish (salmon, rainbow trout and cod) is now almost exclusively based on intensive cage culture in the fjords or coastal areas (see above). In addition all shellfish production is carried out in the same areas. Thus mariculture is dominating Norwegian Aquaculture. In early stages of the Norwegian aquaculture industry, sea cages were often located inside sheltered fjord areas and bays. As the farms have grown bigger and the sea cage technology has grown more robust, farms have moved towards more open coastal waters. Ongrowing at sea takes from 14 to 30 months (depending on species and region), the production at one site usually varies from 800 to 4 000 tonnes in one production cycle, thus making this a very large-scale production system (FAO, 2011).

2.2.7 **Geographical distribution**

The Norwegian coast is lined with aquaculture facilities (*Figure 4*). In 2010 there were 1565 allowed seawater sites (http://www.fiskeridir.no/statistikk/akvakultur/statistikk-for-akvakultur/totalt-hele-naeringen). It is however important to note that not all of these are in operation at the same time, since every site have a fallowing period after each production cycle (see above). There were 213 licences for juvenile production of salmon, rainbow trout and trout on land. Furthermore there are 10-15 landbased full cycle farms producing Arctic charr and trout (Winther et al. 2010). The Norwegian coastline spans from around 58 to around 71°N and from around 4-31°E, hence Norwegian aquaculture is carried out under very different climatic conditions.

Figure 4. Distribution of aquaculture sites in Norway (Source: Norwegian Directorate of Fisheries, www. fiskeridir.no)

For more detailed information on the main aquaculture production sites please see *Table 2* which lists the production sites from per county.

Table 2. Distribution of seawater sites (intensive ongrowing in sea cages) for all species, and land based (intensive hatching/smolt production in tanks) juvenile production sites for salmon, rainbow trout and trout in 2010 (Source: Norwegian Directorate of Fisheries, www. fiskeridir.no).

	Sea sites (ongrowing)			Land sites (hatchery/smolt production)
	Salmon//rainbow trout/trout	*Other species [1]*	*Shellfish*	*Salmon/rainbow trout/trout*
County	**Number**	**Number**	**Number**	**Number**
Finnmark	62	15	1	3
Troms	110	11	5	11
Nordland	196	81	64	31
Nord-Trøndelag	69	3	39	16
Sør-Trøndelag	94	4	22	19
Møre og Romsdal	107	30	14	32
Sogn og Fjordane	96	32	44	22
Hordaland	203	25	76	51
Rogaland	73	16	15	16
Vest-Agder	11	1	8	
Aust-Agder	2	0	22	
Other counties	0	0	14	12
Total	**1 023**	**218**	**324**	**213**

[1]=Cod, Atlantic halibut, turbot

2.3 Impacts of Climate Change on Norwegian Aquaculture

Surprisingly, very little research has been undertaken to link aquaculture and climate change, especially compared to all other primary production sectors (De Silva & Soto 2009). According to Handisyde et al., (2006), the major direct drivers of climate related changes in aquaculture production are changes in temperatures (air, inland and sea surface), oceanographic variables (currents, wind velocity and wave action), sea level rise and increase in frequency or intensity of extreme events and water stress. These changes may in turn result in physiological changes (e.g. growth, reproduction and frequency/virulence of parasites and pathogens), ecological changes (organic and inorganic cycles, ecosystem services) as well as operational changes (e.g. species selection, site selection and technology) (Handisyde et al., 2006)(summed up in table 3). Aquaculture occurs in fresh water, brackish water and marine waters, and is distributed throughout a span of climatic regimes. Thus the different elements of climate change are likely to be manifested to varying degrees in different climatic zones.

In a recent review of climate change impacts on marine aquaculture in the UK and Ireland, Callaway et al. (2012) concluded that natural environmental variability and the pace of technology development may have overshadowed possible effects of climate change, and it is therefore difficult to assess whether climate change is presently is affecting aquaculture in UK and Ireland. There are many similarities between Norwegian salmon aquaculture and salmon aquaculture in the UK and Ireland and we believe that the comprehensive review given by Callaway et al. (2012) bear much relevance for Norwegian conditions as well.

In the following section we will address some of the drivers listed in *Table 3* in some more detail with focus on the ones we believe will impact Norwegian aquaculture most heavily. Since fin-fish, in particular salmonids, is presently dominating the Norwegian aquaculture industry focus is on fin-fish.

Table 3. Impacts of climate change on aquaculture (Modified from Handyside et al., 2006). The impacts we believe is most relevant for Norwegian Aquaculture is given in italic.

Drivers	Impacts on culture systems	Operational impacts	Impacts on sustainability
Sea surface temperature changes	• Enhanced growing season • Enhanced growth rates and feed conversion • Decreased dissolved oxygen • Lower winter mortalities • Increased incidents of diseases and parasites • Harmful algal blooms ?	• Changed geographical range • Relocation of farming areas • More fouling on nets • Need for new technology	• Increased incidents of diseases and parasites (threat to wild stocks) • Longer transportation distances
Changes in other oceanographic variables as wind velocity, currents, wave actions	• Alternations in water exchange and dispersal • Changes in abundance and/or range of capture fisheries used for meal and oil production	• Changed densities, feeding routines etc	• Different pattern of waste dispersal • More pressure on wild fish stocks
Increase of frequency and/or intensity of storms	• Large waves and storm surges	• Needs for new technology • Damage to facilities • Loss of stock • Increased insurance cost • More expensive constructions	• Loss of stock (escapes)
Innland water temperature increase	• Reduced water quality: less oxygen (both in sea facilities and on land) • Enhanced growth rates and feeds conversions • Harmful algal blooms ?	• New water treatment systems • Less energy spent for water heating during winter (some regions) • More energy spent in water cooling summer (some regions)	
Changes in precipitation (freshwater runoff)(intensity,frequency, seasonality)	• Changes in fjord circulation • Increased toxic aluminium • Harmful algal bloom	• Relocation of farms	

2.3.1 **Changes in seawater temperature**

The seawater temperatures are estimated to increase with 0.5°C along the western coast the next 70 years, while the increase will be more pronounced in the southern parts with an estimated increase of 1.4°C the next 100 years (North Sea regions)(Hanssen-Bauer et al. 2009). All cultured aquatic animal species are poikilothermic, and water temperature affects poikilothermic through effects on the rate of biochemical reactions (Angilletta et al. 2002). Thus temperature influences physiological characteristics such as rates of development and growth and traits associated with these (e.g. Jonsson and Labee-Lund 1993, Elliott and Hurley 1995). Furthermore, temperature have the capacity to affect endocrine function and either advance or retard gametogenesis and maturation (e.g. Hoang and Lee 2002, Pankhurst & King 2010). In salmonids the timing of the smoltification process is believed to be mostly determined by photoperiod (McCormick 1994), but also temperature has a substantial impact (McCormick and Shrimpton 2002, McCormick and Moriyama 2000).

Salmonids are cold water species with relatively narrow temperature optima (Atlantic salmon 13-17ºC, Rainbow trout 9-14ºC and Arctic char 6-15ºC, Ficke and Myrick 2007). If temperatures increase outside the tolerance limits there will be significant negative effects. Even when tolerance limits are not exceeded, a temperature increase significantly outside temperature optima will reduce feed intake and feeds conversion ratios and feed inputs cannot compensate for increased metabolism. On the other hand, if the temperature increase is within the optimal range, one can expect increased growth rates and overall production increase provided that the feeds input required for compensating the enhanced metabolism are met (and that other associated factors such as diseases do not become more detrimental). A positive effect is therefore more likely for species that are fed such as fin-fish, compared i.e. to shellfish that are depending on the availability of natural resources such as phytoplankton. In southern Norway, the summer temperatures already exceeds the temperature optimum in a number of farms (*Figure 5*), hence some of the present farm sites may be unsuitable for salmon production in the future. On the other hand, the anticipated temperature increase may also open for new species not presently grown in Norway. In mid and northern Norway summer temperatures are presently well within the optimum range (*Figure 5*) for salmon, and this will be the situation even with the temperature increase estimated for Norwegian water (see above). A temperature increase within the optimum range is beneficial for the growth rate and feeds conversion efficiency (Lethonen 1996), and has the potential to extend the growing season and reduce winter mortality (Handisyde et al. 2006). A positive impact may therefore be anticipated in mid and northern Norway (Lorentzen 2008).

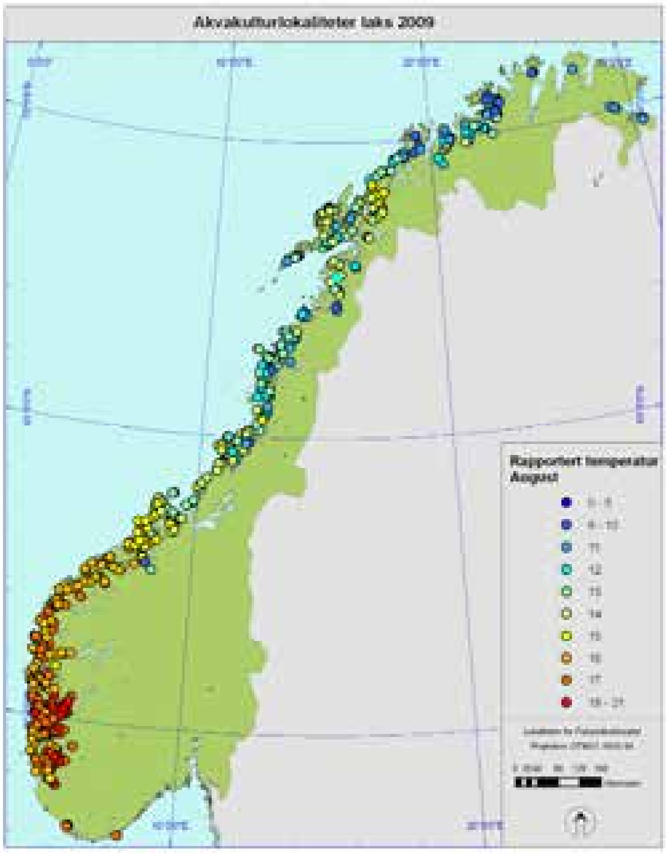

Figure 5. Reported August temperatures in Norwegian salmon farms in 2009.

Increased water temperatures reduce the oxygen solubility, and the effect is more pronounced in seawater than in freshwater as oxygen solubility is salinity dependent. Furthermore, Ficke and Myrick (2007) suggested that climate change could lead to more strong stratification and eutrophication in upper layers, and result in oxygen depletion during dark hours. These authors also suggested that changes in rainfall and wind patterns could result in upwelling bringing deep oxygen depleted water to the surface. Because the aerobic metabolic rates of most cold-blooded organisms increase with temperature, increased temperature both decrease DO concentrations and increase the oxygen demand (Kalff 2000). Pörtner & Knust (2007) suggested that the main physiological effects of climate change are related to thermal limitations of oxygen, and that larger individuals may reach their thermal aerobic limit sooner than small individuals and hereby be more vulnerable. Many sea cages for ongrowing (large fish) are located in fjord areas where the thermal reduction of oxygen levels may be enhanced by changed patterns in freshwater runoff, making the stratification stronger in parts of the season. In Norwegian sea cages, low oxygen content during summer is already a commonly occurring situation in stratified fjord locations (see Oppedal et al. 2011).

There is an ongoing discussion on the effects of climate change and health in cultivated animals. Many pathogens of terrestrial and marine taxa are sensitive to temperature, rainfall, and humidity, creating synergisms that could affect biodiversity. Climate warming can increase pathogen development and survival rates, disease transmission, and host susceptibility (Harwell and Mitchell 2002). In their summary Handisyde et al. (2006) suggested that temperate regions in general will be more adversely affected with increased prevalence of pathogens caused by temperature increases. In high latitudes, occurrence and transmission of aquatic parasitic diseases are driven by temperature and primarily take place during the warm summer months (Rintamäki-Kinnunen & Valtonen 1997, Rintamäki-Kinnunen et al. 2005a,b), thus an increased temperature in either end of the transmission season may also result in a wider “time window” for spread of the disease in the host population (Karvonen et al. 2010).

Although most host-parasite systems are predicted to experience more frequent or severe disease impacts with warming, a subset of pathogens might decline with warming, releasing hosts from disease (Harwell and Mitchell 2002). A recent time series study from Finland (Atlantic salmon and sea trout facility) showed that while the prevalence of some disease -causing agents increased with increased temperature, some decreased while others again did not show any relationship with temperature (Karvonen et al. 2010). These authors emphasized that the complexity of pathogen ecology, and interactions with local conditions make it difficult to determine the magnitude and direction of temperature effects. It is difficult to quantify the possible effects of increased seawater temperatures on fish health in Norwegian aquaculture. The use of antibiotics may be considered an indicator of the health status with regard to bacterial diseases, and in Norwegian aquaculture there has been a low consumption of antibiotics the last decade (*Figure 6*). Before this period, development of vaccines and an active disease reducing policy including zoning, spatial rearrangement and mandatory fallowing had reduced the use of antibiotics with 90% compared to the 1980’s (Midtlyng et al. 2011). Presently the biggest losses to disease within Norwegian Aquaculture are due to viral diseases such as pancreas disease (PD), heart and skeletal muscle inflammation (HSMI), infectious salmon anemia (ISA), and infectious pancreas necrosis (IPN)(http://www.fisheries.no/aquaculture/Sustainability/An_Environmentally_Sustainable_Aquaculture_Industry)

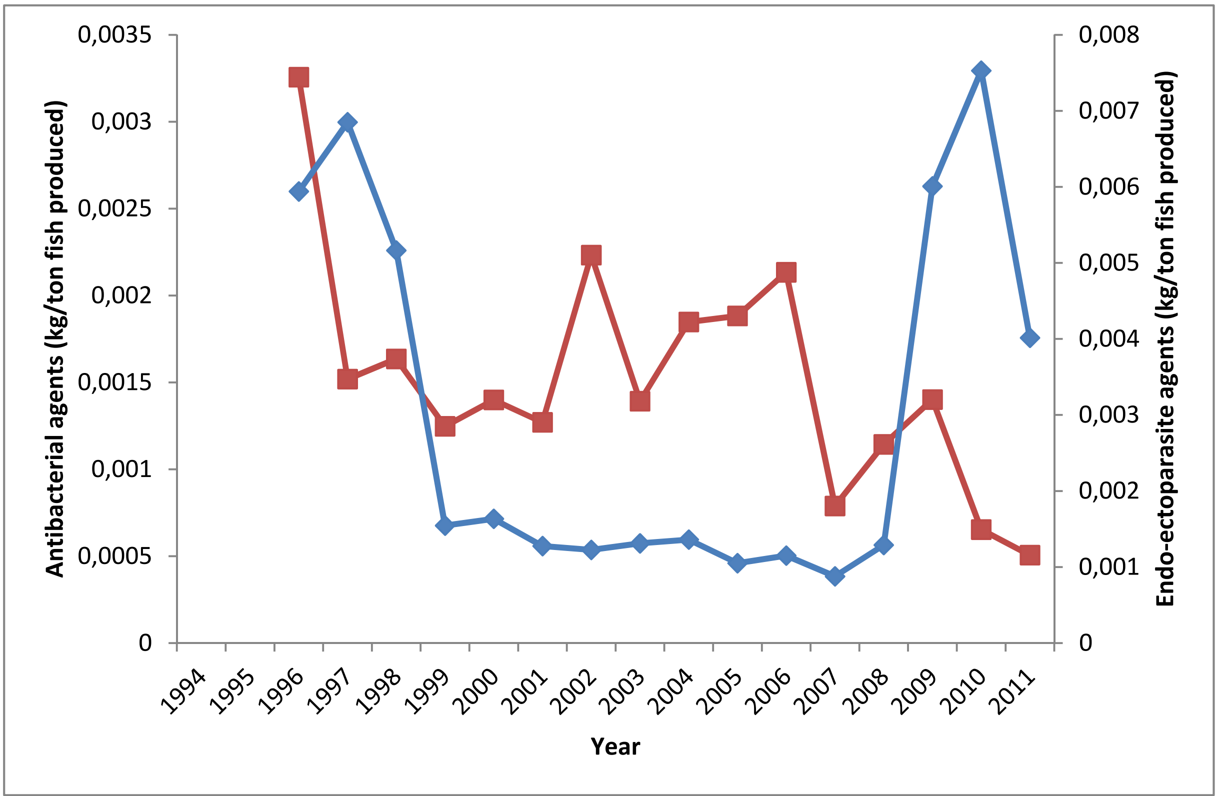

Figure 6. Consumption of antibacterial (left axis) and anti-parasite drugs (right axis) in the period 1996-2011 (source www.fiskeridir.no).

2.3.2 **Changes in other oceanographical variables and freshwater runoff (wind, currents, waves and precipitation)**

There has been an intensification of storm events in the NE Atlantic over the last 50 years (Jones et al. 1999, Alexander et al. 2005, Yan et al. 2006). However, the confidence in wind and storm projections is generally low, and different models give different results for the same area (Wolf & Woolf 2010). Since wave heights are depending on the intensity of storms, and/or on their tracks, there is correspondingly low confidence in projections of wave heights (Frost et al. 2012). For Norway, models suggests little or no change in the mean wind conditions, but the frequency of high wind speeds may increase (Hanssen-Bauer et al. 2009). Extreme wave heights are estimated to increase 6-8% towards 2100 in the southern areas (Nordsjøen & Skagerrak), while small changes are anticipated in the remaining part of the coast where aquaculture is carried out (Hanssen-Bauer et al. 2009). Both wind and waves can potentially cause structural damage to aquaculture infrastructure, and make operational routines like anti-parasite treatment and live fish transport more difficult. A scenario with intensification and increased frequency of storm events will therefore lead to loss of fish, reduced welfare for the fish, higher capital cost required to build more robust infrastructure and more expensive insurance. The escape of farmed fish in one of the major environmental concerns in Norwegian salmon aquaculture In Norway, structural damage on equipment caused 68% of all escapes in the period 2006-2009 (Jensen et al. 2010). Most of the escapes occur during autumn months where coastal storms are most frequent and intense, and extreme weather conditions are considered to be an important cause (Jensen et al. 2010).

In terms of precipitation, the entire region is expected to be wetter, with an increase in the average annual precipitation in the range 5-30% towards the end of the century (Hanssen-Bauer et al. 2009). Wintertime precipitation is estimated to increase with 40% in the southern regions, with an increase in the number of days with heavy rain/snow. Floods are difficult to estimate precisely. In general the size of the floods are estimated to increase in Norway, but large local variability is expected. Higher air temperatures give earlier snow melting and earlier spring floods (Hanssen-Bauer et al. 2009). Altered hydrology will have complex effects on water quality, involving altered water column stratification (see above), turbidity, nutrients and contaminant loads. Increased soil temperature speed up decomposition of organic matter and hence increase availability of inorganic nutrients through mineralization. The effect of increased temperature on leaching of NO_3 was demonstrated experimentally on a whole-catchment scale in Risdalsheia in southernmost Norway. Here, a 3.7 °C increase in annual air temperature over three years induced a three-fold increase in the leaching of inorganic N (van Breemen et al. 1998, Wright 1998). A modeling study from the Bjerkreim river in south western Norway also indicates increase in NO_3 concentrations and fluxes, with a corresponding increase in fjord primary production of 15-20 % (Kaste et al. 2006).

Acute mortality of Atlantic salmon due to acute aluminium toxicity has been described from fjord-based fish farms in Western Norway (Bjerknes et al. 2003). This is caused by aluminium transported from acid rivers into the fjords during snowmelt and heavy rainfall. Increased precipitations in Northern Europe predicted by climate change will cause increased river inflow of freshwater into high latitude seas including Norwegian fjords. A recent study documents depositions of Al on gills of Atlantic salmon smolts exposed in 12 different stations surrounding the island Osterøy, Western Norway (Groison *et al*. submitted). The highest accumulation of gill-Al occurred at salinities ranging from 1.5 to 7.0 ppt defined as the salinity window where the Al toxicity effect is the greatest. The compilation of data showed that the risk for Al accumulation in smolt gills is fully correlated to freshwater runoff patterns.

Aquaculture activities in brackish waters may be affected by changes in salinity (increasing or decreasing), again depending on local conditions of runoff, marine circulation, etc. in addition to cultured species suffering from physiological stress.

2.3.3 **Nuisance and harmful species**

Harmful algal blooms (HAB's)

For the aquaculture industry, blooms of both toxic and non-toxic species may be harmful. For the shellfish industry the problems are connected to the accumulation of phytotoxin in bivalves feeding on toxic phytoplankton. Toxic species include the dinoflagellates *Alexandrium* and *Gymnodinium* both associated with the production of paralytic shellfish poisoning (PSP), diarrheic shellfish poisoning (DSP) producing species such as *Dinophysis,* or diatoms such as *Pseudo-nitzchia* associated with amnesic shellfish poisoning (ASP).

There is a number of species that are known to cause problems for fish, most of these are flagellates belonging to the genera *Heterosigma*, *Chattonella (Pseudochattonella)*, *Prymnesium*, *Chrysochromulina* and dinoflagellates such as *Karenia mikimotoi* (Hallegraeff 2010) and *Alexandrium* (Cembella et al. 2002, Martin et al. 2010, Burridge et al. 2010). Furthermore, diatoms particularly species belonging to the genera *Chaetoceros* are increasingly acknowledged as a cause of gill disorders (Rodger et al. 2011). In Scandinavian waters, some of the best documented events of mortality in farmed fish were caused by haptophyte species belonging to the genera *Prymnesium* (Eikrem and Throndsen 1993, Johnsen et al. 2010) and *Chrysochromulina* (e.g. Dahl et al. 1989, Eikrem and Throndsen 1993, Gjøsæter et al. 2000). Furthermore *Pseudochattonella* (Lu and Göbel 2000, Edvardsen et al. 2007, Skjelbred et al. 2011) and *Karenia mikimotoi* (Dahl and Tangen 1993) have been held responsible for several fish mortality events in the North Sea and Skagerrak. *Heterosigma akashiwo* is another well-known fish killer (Clément & Lembeye 1993, Connell et al. 2001, Taylor and Harrison 2002, Rensel et al. 2010), but enigmatically mortality of farmed fish during *H. akashiwo* bloom events in Scotland and Norway are very rare (unless under-reported) events, if not absent.

Generally HAB's seems to have become more frequent, more intense and more widespread the past three decades (Hallegraeff 1993, Van Dolah 2000). Unfortunately, very few long-term records of phytoplankton composition on any single locality exist (Hallegraeff 2010). Data from one of the few long time series, the Continuous Plankton Recorder (CPR), shows a decrease in the abundance of dinoflagellates (both HAB and non-HAB species) relative to the abundance of diatoms (both HAB and non-HAB species) in the north-east Atlantic and the North sea (Hinder et al. 2012). An analysis of data from a long-term monitoring program (IMR monitoring program) in the Norwegian Skagerrak, also show a decrease in the abundance of selected dinoflagellate species including *Dinophysis* the last decade (Naustvoll et al. 2012). These authors also reported changes in the phenology of this species, with a trend towards a narrowing of the peak season. Further north, in the areas where the aquaculture activities are carried out, data are scarce and no long-term records exist.

The Directorate of Fisheries collect data from the aquaculture industry, but all fish mortalities are lumped together, and the proportion caused by algae is not discernible in the statistics. Hence the information about fish-kills due to algae is anecdotal, and makes no basis for an evaluation of the magnitude of the problem and whether or not mortalities due to algal blooms is an increasing problem.

The relationship between climate change and HAB's is complex, and predictions of the impacts of climate change are fraught with uncertainties (Hallegraeff 2010). Typical traits of climate change such as increased sea surface temperature, enhanced surface stratification, changes in local nutrients upwelling, stimulated photosynthesis by elevated CO_2 levels, increased precipitation and storm events causing increased freshwater and nutrients runoff from land are all traits that may produce contradictory species responses (Hallegraeff 2010). Furthermore, the coastal areas where Norwegian aquaculture is carried out are differently affected by a combination of terrestrial and marine processes, something that make general predictions even more difficult.

Jellyfish

Jellyfish are gelatinous zooplankton including scyphozoa, siphonophores and hydrozoans (Richardson et al. 2009), and swarms of jellyfish are significant causes of production loss in the aquaculture industry (Rodger et al. 2011). Many jellyfish have cnidocytes which contain stinging structures (nematocycts) that can damage both the gills and the skin of the fish. The nematocysts discharge as a response to chemical or mechanical stimuli elicited by prey organism (Kass-Simon & Acappaticci 2002). It is shown that the toxin mixture released cause detachment, clumping and lysis of gill cells as well as a drop in vitality (Helmholtz et al. 2010). The gill damage is evident after relatively short time (Helmholz et al. 2010), and even relatively short term exposure could cause persistent gill damage (Baxter et al. 2011). High numbers of jellyfish, even species without nematocysts, may also cause mortalities due to clogging of gills and subsequent suffocation (Båmstedt et al. 1998). In European water, the lion's mane jellyfish (*Cyanea caplillata*), the moon jellyfish (*Aurelia aurita*), *Pelagia noctiluca, Phialidium sp, Leukartia raoctona, Catablema vesicarium* and *Apolemia uvaria* and *Solmaris corona* have all caused problems for the aquaculture industry (see review Purcell et al. 2007).

As far as we know there is no monitoring of jellyfish in Norwegian waters. As for algae, the proportion of mortalities caused by jellyfish is not discernible in the Directorate of Fisheries statistics. Hence, there do not exist data that can elucidate the magnitude of the problem. As for harmful algae blooms, the potential relationship between climate change and abundance/distribution of jellyfish is a complex one. It has been an on-going debate whether or not jellyfish blooms are becoming more frequent on a global scale (Condon et al. 2012, Condon et al. 2013, Gibbons and Richardson 2013). However, in some areas such as the North Atlantic shelf area, there seems to be a significant increase (Condon et al. 2013).

2.3.4 **Indirect effects**

For aquaculture of carnivorous species, the most obvious and commonly discussed indirect impact of climate change is related to supplies of fishmeal and fish oil (De Silva & Soto 2009). Aquaculture's share of total fish meal has increased since the 1980s and was estimated to be around 50% in 2010 (Naylor and Burke 2005). The fish oil marked has a similar trend only with an even higher aquaculture share (Naylor & Burke 2005). According to FAO, aquaculture is the fastest growing food sector, but unlike livestock that can readily substitute vegetable proteins when fish meal availability decrease, carnivorous aquaculture species require a certain amount of fish meal and oil for energy, health and palatability (Naylor and Goldburg 2000). Industrial fish-meal and fish oil production is typically based on a few fast growing short lived productive stocks of small pelagic fish in subtropical and temperate regions. Important stocks are anchovy and sardines from Chilean and Peruvian waters, menhaden and capelin from Mexico, USA and Canada, and herring, mackerel and blue whiting from Scandinavian waters. These stocks represent finite and limited resources. Predictions on how all these species and their ecosystems will respond to climate change is difficult to make. However, any of the above mentioned stocks like e.g. the Peruvian anchovy are based on upwelling ecosystems that are highly vulnerable to changes in climate. Annual catches of Peruvian anchovy have fluctuated between 1.7 and 11.3 million tons within the past decade in response to El Niño climate disruptions (Daw et al. 2009), and climate change is likely to amplify these natural variations (Galloway et al. 2012). Independent of the climate change aspects, the dependency of a finite and limited resource has been a concern for the aquaculture industry for a long time. This has prompted considerable research (Naylor et al. 2009), where focus has been on finding replacements for fish meal and oil (e.g. Tocher et al. 2009). This R&D effort has resulted in a fish meal/oil proportion 30% (15% meal and 15% oil) in modern feeds compared to 80% in 1990 (www.Skretting.com). Norwegian aquaculture is almost exclusively salmonids and is dependent of formulated feeds. Availability of feeds ingredients either land based crops or marine meal and oils is most likely to be influenced by climate change, hence indirectly affecting Norwegian aquaculture.

2.3.5 **Data availability for an in-depth assessment**

According to Norwegian regulations (Forskrift om drift av oppdrettsanlegg FOR 2008-06-17 nr 822 http://www.lovdata.no/cgi-wift/ldles?doc=/sf/sf/sf-20080617-0822.html) it is obligatory for sea farms to report a list of production information to the Directorate of Fisheries monthly. This list is **a)** the number of production units **b)** new fish in the sea (species, numbers and age group) **c)** standing stock of fish (species, numbers and age group), **d)** biomass **e)** quantity of fish slaughtered (species, numbers, weight and condition) **f)** quantity of live fish moved to other site (species, numbers, name of new site) **g)** loss (mortality and other, species, numbers) **h)** feeds consumption (weight and type) and **i)** volume. These data are publically available on county level (although given on farm/sea cage level), and can be accessed from the Directorate of Fisheries. Furthermore all escape incidents shall be reported to Directorate of Fisheries, and the escape incidents are subject to an investigation where the course of events and causes are clarified and analysed. The numbers of escapes and their causes are also publically available on county level. Furthermore, more than 150 Norwegian land based farms participated in the “VK-undersøkelsen”(WQ 99-06) that were carried out in the period 1999-2006 (Rosten et al. 2007). Inlet-water quality was also evaluated in WQ 99-06 and included measurements of parameters such as temperature, ion composition, organic content and particles and metals (Kristensen et al. 2012). The availability of reliable data provides excellent opportunities to perform an in-depth assessment of the possible impacts of climate change on Norwegian aquaculture.

2.4 Indian aquaculture and climate impacts

The history and present production in Indian Aquaculture and the possible effects of climate change on Indian aquaculture is summed up in a separate report.

2.5 Meetings and workshops

During the project period two Workshops were held (see Appendix A for invitation/programmes). The first project meeting was held in Bergen, Norway from May 2nd until 4th 2011, and the second meeting was held in New Dehli, India from December 10th until 14th 2012. Dr. Sreelakshmi and Ms. Tanvi Vaidyanathan were the representatives from TERI during the workshop in Norway in 2011.

The first workshop was intended to be a stakeholder workshop where the aim was to systematically collect different stakeholder's perception on the impacts of climate change on the sustainability of Norwegian aquaculture. People from industry, management, NGO's and academia were invited, and their inputs were to be organized using the **DPSIR** (**D**rivers-**P**ressures-**S**tate-**I**mpacts-**R**esponse) framework. **DPSIR** framework is a causal framework for describing the interactions between society and the environment (e.g. Sekovski et al. 2012). A second goal of the workshop was to get stakeholders inputs on important scientific questions to be addressed in a full-scale project. However, few stakeholders registered for the workshop, and the workshop was cancelled. Instead there was meeting where Norwegian and Indian project group members and a representative from one of the biggest salmon feeds producers attended. The visit of the Indian project partners also included visits to one smolt production facility and a visit to the Matre Research Station.

Trine Dale and Åse Åtland from NIVA visited TERI and India in December 2012. During this week an open meeting was held in TERI on December 13th where researchers from the Department of Zoology at the University of Delhi, the G. B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand and also from the Indian Council of Agricultural Research (ICAR) participated and gave presentations –see Attachment II for program and details.

During the visit to New Dehli the project group also visited the ISRMAX India which is a large agriculture fair that brings commercially available technologies and industry expertise together. In this fair the "Directorate of Coldwater Fisheries Research" also was present, and a lot of information was gathered. This research institute is part of ICAR – the Indian Council for Agricultural Research.

3. Discussion and conclusions

3.1 Main similarities and differences between Norway and Indian aquaculture

Freshwater aquaculture in tropical and subtropical regions of Asia has been identified as focal areas for adaptive strategies related to climate change because world aquaculture production is concentrated here (De Silva & Soto 2009). Fin-fish aquaculture in temperate areas could also be seen at targets for adaptive strategies due the high value of the products (4% of global fin fish production, but almost 11 % of global total value)(De Silva & Soto 2009). India and Norway is located in the tropical, and in the cold temperate zone respectively.

Furthermore, freshwater aquaculture dominates in India, while in Norway marine water aquaculture dominates. While feed inputs for Indian carps mainly stems from agriculture (e.g. organic manures from cattle supplemented with a mixture of rice/wheat bran and oil cake) the salmon aquaculture still depends on feed inputs from fisheries. Thus the two countries aquaculture industries could be regarded as two extremes within world aquaculture, and a comparison will therefore be highly valuable.

3.2 Common research challenges

The research challenges related to the increase of food-output from aquaculture as well as decreasing the climate impact from the industry in a changing climate are many and complex. The solutions to these challenges can only be found by breaking down barriers between research fields (Godfray et al 2012), and through international cooperation in coordinated efforts.

Based on this work, as well as the literature we see the most important research challenges as the following:

- Managing conflicting use of resources
- Feeds: availability of Fishmeal and Fish Oil
- Aquaculture ecosystem impacts
- Negative anthropogenic impacts on aquaculture; e.g. climate change and industrial pollution
- Improved biosecurity and health management

In addition to these we also see the following major challenges related to knowledge transfer and financing systems:

- Poor technology and knowledge in many nations an regions
- Financing and investment specially for small farmers
- Promotion of ecosystem approach aquaculture management at all levels from feed to harvest

Even though the environmental challenges for aquaculture production are different in Norway and India, we believe that joint research efforts are important. In Norway we have a lot to learn from India and Asias long-term experience with multi-trophic aquaculture and combined aquatic and terrestrial food production. We also believe that the potential for the use of Norwegian aquaculture technology is way beyond only salmon farming. In a recent seminar in Norway, it was stated by FAO that a huge potential for growth exists especially for marine aquaculture in Asia and also other tropical and sub-tropical regions.

As mentioned in the introduction freshwater production of cold-water fish species could have a huge potential for growth in India, and it is also interesting for tourism purposes. However such production of e.g. Rainbow trout in the mountainous regions of Northern India will be highly vulnerable to water stress and also to rapidly changing water quality under extreme events. We believe that this is an area of research where which could benefit from cooperation between TERI and NIVA.

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Appendix A.

Invitation to Workshop in Norway:

Climate change as an opportunity towards adaptive sustainable aquaculture (CARDINAL)

Interessent Workshop

Hotell Terminus, Bergen, 3. May 2011

Verdens befolkning antas å nå 9 milliarder i 2050, og verdens matvareproduksjon må øke i takt med befolkningsveksten. I lys av de forventede klimaendringene vil kapasiteten til å produsere nok mat avhenge av om produksjonen skjer på en *effektiv* og *bærekraftig* måte.

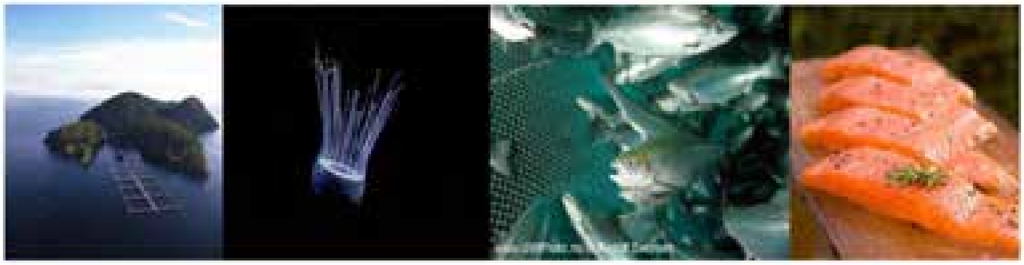
Oppdrettsfisk utgjør nesten 50% av verdens konsum av fisk, og oppdrettsnæringen står overfor store muligheter og utfordringer under et fremtidig endret klima både når det gjelder effektivitet og bærekraft. Norges forskningsråd (NFR) har finansiert en studie hvor målet er å bygge en kunnskapsbase som gjør det mulig å vurdere forholdet mellom akvakultur, klima og bærekraft. Vi vil sette fokus på to akvakulturnasjoner, India og Norge, som representerer to ulike klimatiske soner og sosioøkonomiske forhold.

I prosessen med å bygge opp en kunnskapsbase ønsker vi innspill fra interessenter innenfor næring, forvaltning og frivillige organisasjoner.

Påmelding:
Linda Skryseth, NIVA Vestlandsavdelingen, Thormohlensgate 53D
Tlf: 97 95 87 10
E-mail:linda.skryseth@niva.no

Climate change as an opportunity towards adaptive sustainable aquaculture (CARDINAL)

Interessent Workshop, Hotell Terminus, Bergen, 3. May 2011



Målsetningen med workshopen er å samle innspill fra interessenter, og plassere disse inn et rammeverk som på en systematisk måte kan belyse effekter av klimaendringer på akvakultur. Ulike interessenters kunnskap og ekspertise er helt nødvendig for å danne et best mulig bilde av hvilke utfordringer klimaendringer kan skape for akvakulturnæringen, og hvordan disse påvirker næringens bærekraft. Gjennom workshopen ønsker vi også at interessenter skal bidra med å identifisere og spisse aktuelle forskningsproblemstillinger som skal inngå i et større oppfølgningsprosjekt.

Program

0900-0915	Presentasjon av CARDINAL prosjektet (v/Anke Weber Smit, NIVA)
0915-0930	Klimascenarier for norske farvann (v/Anke Weber Smit, NIVA)
0930-0945	Klimaeffekter på norsk oppdrettsnæring og betydning for bærekraft (v/Trine Dale, NIVA)
0945-1000	Fôrproduksjon i et klima og bærekraftsperspektiv (v/Luise Buttle, EWOS Innovation)
1000-1015	Kaffe-pause
1015-1045	Introduksjon av DPSIR metoden; et verktøy for kunnskapsdeling (v/Isabel Seifert, NIVA)
1045-1145	Bærekraftig akvakultur i et endret klima; analysert med DPSIR metoden (v/Isabel Seifert, NIVA)
1145-1230	Oppsummering og identifisering av kunnskapshull (v/Trine Dale, NIVA)
12.30	Lunsj

Climate change as an opportunity towards adaptive sustainable aquaculture (CARDINAL)

NIVA

Interessent Workshop, Hotell Terminus, Bergen, 3. May 2011

Programme Workshop in India:

Workshop: Climate Change as an Opportunity towards Adaptive Sustainable Aquaculture (CADINAL)

Organized by
The Energy and Resources Institute (TERI)
in association with
Norwegian Institute for Water Research (NIVA)
13 December, 2012
New Delhi

Time	Details	
9:30-10:00 am	Registration	
10.00 am - 10.10 am	Opening remarks by **Dr. Ligia Noronha**, Executive Director, TERI	
10:10 am - 10:20 am	Introduction of the speakers	
Technical sessions –Moderator: **Dr. Shresth Tayal**, Fellow TERI		
10.20 am - 10.30 pm	Introduction of the Project by Ms. Tanvi Vaidyanathan, The Bay of Bengal Programme- Inter Governmental Organization (BOBP-IGO), Chennai	
10.30 am - 10.45 am	Tea	
10:45 am - 11:15 am	Project Presentation by NIVA	
11:15 am - 11:40 pm	**Dr. Neeta Sehgal**, Professor, Department of Zoology, University of Delhi, Delhi	Talk on 'Quality of fish seeds'
11:40 am - 12:05 pm	**Dr. R.S. Chauhan**, Professor and Head, Department of Aquaculture, G. B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand	Talk on 'Earning sustainable livelihood for rural communities through organic recycling based integrated fish-livestock aqua-farming'
12:05 pm - 12:30 pm	**Dr. S.K. Singh** Senior Scientist, Soil & Crop Management (Fish & Fisheries), Central Soil Salinity Research Institute (ICAR), Karnal, Haryana	Talk on 'Role and importance of aquaculture in the integrated fish farming system'
12:30 pm – 12:50 pm	Open Discussion	
12:50 pm – 1:00 pm	Closing Remarks by **Dr. Debashish Goswami**, Fellow TERI	
1:00 pm	Lunch	

NIVA: Norway's leading centre of competence in aquatic environments

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Norwegian Institute for Water Research

Gaustadalléen 21 • NO-0349 Oslo, Norway
Telephone: +47 22 18 51 00 • Fax: 22 18 52 00
www.niva.no • post@niva.no