



# Work programme

Large-scale  
Programme on Aquaculture Research – HAVBRUK2



## Large-scale Programmes

The RCN initiative  
to meet national  
research priorities

# Work programme

From 2016

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Large-scale  
Programme on Aquaculture Research – HAVBRUK2

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# 1 Summary

The Large-scale Programme on Aquaculture Research (HAVBRUK2) is the Research Council of Norway's most important funding instrument for aquaculture-related research, and consolidates and coordinates activities in this field. The programme is open-ended. The HAVBRUK2 programme is also a key instrument in the Research Council's efforts targeting the blue bioeconomy.

Norway is currently in a very strong position and is well-equipped to exploit the wide-ranging commercial, societal and research opportunities that are emerging in the aquaculture industry. A number of reports and national strategies point to the major potential for further growth in the industry. The HAVBRUK2 programme is intended to provide knowledge that will enable Norway – as an exporter of salmon and other seafood products and a supplier of knowledge, equipment and technology – to achieve its ambitious growth targets.

The primary objective of the HAVBRUK2 programme is to generate knowledge and solutions for socially, economically and environmentally sustainable growth in the Norwegian aquaculture industry, and to maintain and further develop Norway's leading position in aquaculture research. During the initial phase of the programme, priority will be given to research in the following thematic areas:

- Thematic priority area 1: Societal perspectives, management and markets
- Thematic priority area 2: Healthy fish
- Thematic priority area 3: Production biology
- Thematic priority area 4: Aquaculture technology
- Thematic priority area 5: Nutrition and feed ingredients
- Thematic priority area 6: Production of marine species lower in the food chain (low trophic-level species)
- Thematic priority area 7: Genetics and selective breeding

The HAVBRUK2 programme will keep a steady course in the ongoing effort to maintain Norway's leading position in aquaculture research. The programme will attach importance to basic research in key thematic areas, focus on researcher recruitment, work to ensure commercial relevance and provide an open arena for innovation projects in the aquaculture industry.

At the same time, the programme will seek to take advantage of new opportunities. Activities in this context include stepping up the level of research activity to develop marine production of new species lower in the food chain, strengthening aquaculture technology development and intensifying efforts to exploit the potential inherent in new biotechnological tools, nanotechnology and ICT. The use of experimental calls for proposals to fund projects involving new, high-risk ideas will also be of relevance. International cooperation is essential, and will be given priority when it enhances project quality and research activities.

The programme targets the entire research system, from universities, university colleges and publicly-funded research institutes to private companies in the producer and supplier segments. The programme will encompass the entire spectrum of research activity, from fundamental knowledge development to problem-solving and innovation. Combined, this will help to build a sound knowledge base for the aquaculture industry and the government administration.

To realise sustainable growth in Norwegian aquaculture the industry must achieve greater social acceptance, nationally and locally. The HAVBRUK2 programme will strengthen social science-based

research to increase knowledge about relations between the industry and society. In cooperation with related programmes and instruments, the HAVBRUK2 programme will also improve dialogue between the aquaculture research community and society at large by drawing attention and helping to find solutions to complex, divisive issues.

The HAVBRUK2 programme shares an interface with a number of programmes and funding instruments at the Research Council, and will actively collaborate with these on funding announcements as well as advisory, internationalisation and communication activities. The programme will also collaborate with other agencies in the research and innovation system, such as the Norwegian Seafood Research Fund (FHF), Innovation Norway and the regional research funds. This will increase both the impact and the scope of activities and promote inter- and multidisciplinary cooperation and network-building.

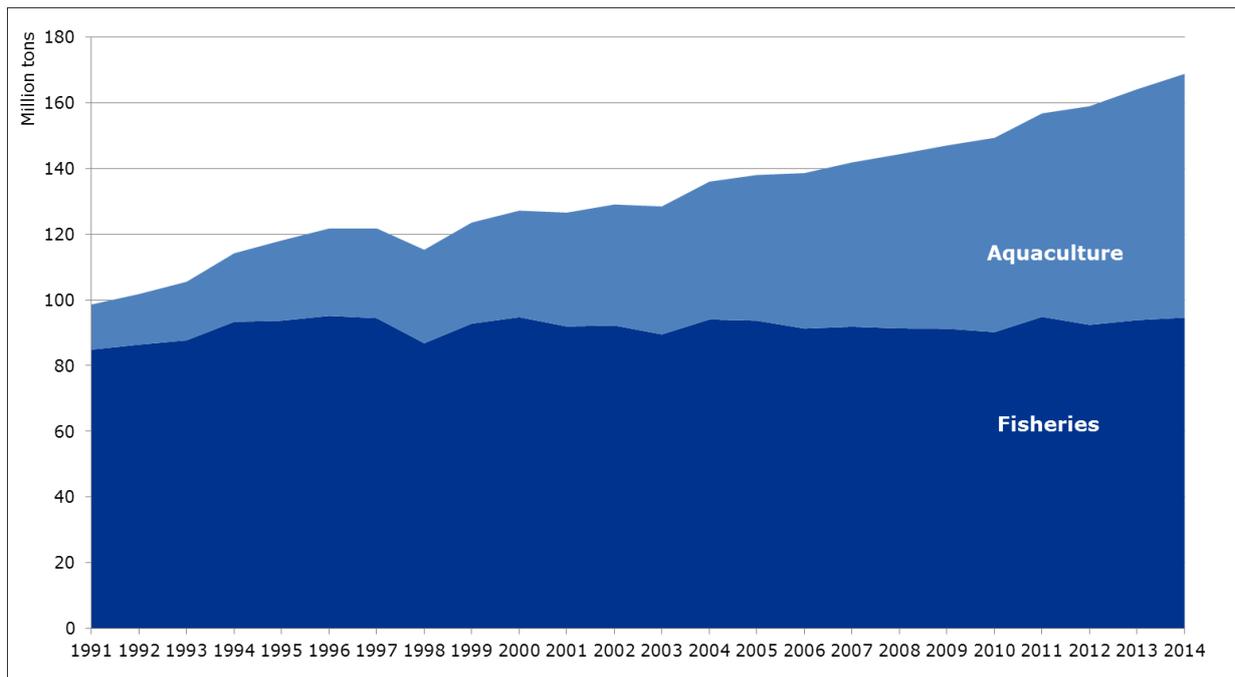
## **2 Background**

### **2.1 Strategic perspectives – Blue growth**

The aquaculture industry is a key component of the Norwegian bioeconomy, and will together with the fisheries industry form an important foundation on which Norway can build a post-petroleum economy. Thanks to geographical, climatic and societal competitive advantages there is still potential for continued growth in the marine industries. Norway has access to some of the world's most productive ocean areas as well as a coastline, infrastructure and traditions that provide unique opportunities for aquaculture activities. The country is currently the world's leading producer of salmon and rainbow trout, and the aquaculture industry creates extensive export value and provides a basis for employment and settlement in coastal areas.

Global development trends and other international trends influence investment in marine research. New ways to use the ocean and marine resources have been given a place on the agenda. Greater attention is being directed towards new energy sources, new maritime access routes, seabed mineral deposits and marine bioprospecting and on harvesting more food from the sea. This is opening up new opportunities for increased value creation from marine-based activities, while escalating competition for the use of ocean and coastal areas is giving rise to new challenges.

The Final Report of the United Nations Conference on Sustainable Development, Rio+20 (2012), represents the first time the oceans and seas are specified as an important resource for future food production. The sea covers more than 70 per cent of the earth's surface, but currently accounts for only two per cent of food production. While global wild fish capture has remained relatively stable at roughly 70–90 million tonnes annually for the past 30 years, the volume of farmed fish has increased about 12 times, with an annual growth of roughly nine per cent. In 2014, global aquaculture production of fish, crustaceans and molluscs totalled nearly 74 million tonnes (see figure) and nearly 100 tonnes including aquatic plants. Aquaculture will become an increasingly important means of ensuring an adequate supply of nutritious food for a growing population.



**Developments in global capture and production of fish, by fisheries and aquaculture sectors, 1991–2014.**

**Source: Food and Agriculture Organization of the United Nations (FAO).**

The aquaculture industry is one of Norway’s most internationally oriented industries. Over 90 per cent of the fish produced in Norway is exported. *The aquaculture industry currently accounts for 70 per cent of the total value of Norwegian seafood exports.* Norwegian salmon will help little to feed impoverished people in the Third World. Nevertheless, it is an important supplement to overall global food production and for population groups with growing purchasing power for whom high-quality seafood is in demand. In addition, Norway has aquaculture expertise and technology that can contribute significantly to boosting production of fish and seafood in other parts of the world.

Norwegian aquaculture researchers are at the forefront of the research field, and Norwegian aquaculture research groups have a high profile and a strong international standing. Investment in knowledge and technology development has been a key driver of the rapid expansion of the Norwegian aquaculture industry. Continued growth is dependent on a sound knowledge base that will enable the industry to take advantage of new opportunities and tackle new challenges. Aquaculture research is an important part of marine research, which also includes research on the management and use of marine resources, including problems related to the coastal zone and global issues.

The development of aquaculture in Norway has been a successful industrial venture, and farmed salmon sells well in the global and domestic market alike. Nevertheless, social acceptance for aquaculture is surprisingly weak compared with other types of food production. The public at large displays a generally low level of knowledge about aquaculture, and the industry encounters vacillating political legitimacy for decisions relating to increased growth at the local and regional level.

To achieve sustainable growth in Norwegian aquaculture the industry must have greater social acceptance, nationally, regionally and locally. This will require more knowledge about and a deeper understanding of aquaculture among the population. At the same time, the industry must be more attentive and flexible in light of public opinion and conflicting interests.

We still have only limited knowledge about the effects of Norwegian aquaculture activities in the context of international food production and resources. We need to know more about how increased demand for marine and vegetable raw materials affects the resource base and how increased consumption of e.g. farmed salmon directs demand towards protein-rich foods (that are based on the same raw materials to a certain extent).

Achieving the five-fold growth envisioned in the follow-up report on marine value creation in 2050 will require a coherent, global perspective on what sustainable growth will involve.<sup>1</sup> Achieving this ambitious target will also be dependent on major technological advances, and aquaculture production will have to be expanded to encompass many more species, such as seaweed and molluscs. This is reflected in national strategies and plans, including the HAV21 national marine research and development strategy and the Norwegian Government's Long-term plan for research and higher education 2015–2024. The latter identifies the seas and oceans as a long-term priority area, and recommends the use of funding instruments such as thematic initiatives in areas where Norway enjoys strategic advantages, e.g. marine research.

On 20 March 2015 the Norwegian Government presented a white paper on growth in the aquaculture industry in which regulation of growth in production is linked to environmental sustainability. The follow-up to the white paper involves the introduction of production areas where growth will be regulated by environmental status. This new production structure may have major ramifications for the organisation of the industry. The master plan for marine research presented on 1 September 2015 attaches particular importance to strengthening research activities targeting technology development and the development of new marine industries. In November 2015 the Government introduced a scheme for development licences for testing new aquaculture technologies. Both measures will open the door to increased activity in the supplier industry in particular.

Since around 1990, a major proportion of the public funding for aquaculture research has been channelled through the Research Council. The programme *Aquaculture – An Industry in Growth* (HAVBRUK) (2006–2015) was launched in 2006 as one of seven under the Research Council's Large-scale Programme initiative to address national research priorities. The HAVBRUK programme was evaluated by Oxford Research in autumn 2013. The evaluation report concluded that the programme should be continued, with primary focus on the same thematic priority areas and essentially the same profile as regards the ratio of basic research, applied research and innovation activities.<sup>2</sup>

At its meeting no. 3/2014, the Research Board of the Division for Energy, Resources and the Environment agreed to launch the process of planning a new (large-scale) programme on aquaculture research. At the same time, it was decided to shift the division of responsibility between the programmes as follows:

- Research on the production of marine biomass would be moved from the Large-scale Programme for Energy Research (ENERGIX) to the HAVBRUK2 programme;
- Research on the impacts of aquaculture on the natural environment would be moved from the HAVBRUK2 programme to the Research Programme on Marine Resources and the Environment (MARINFORSK);

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<sup>1</sup> The Royal Norwegian Society of Sciences and Letters and the Norwegian Academy of Technological Sciences: "Value created from productive oceans in 2050", 2012.

<sup>2</sup> Oxford Research: Fast i fisken. Evaluering av Norges forskningsråds program HAVBRUK – en næring i vekst, 2013. ("An evaluation of the Research Council of Norway's programme Aquaculture – An Industry in Growth (HAVBRUK)", in Norwegian.)

- The MARINFORSK programme would be given primary responsibility for research on management of coastal waters.

On 25 September 2014, the Executive Board of the Research Council decided that aquaculture research activities would be organised under the Large-scale Programme on Aquaculture Research (HAVBRUK2). The new programme is designed to advance the achievement of the following political objectives:

- Develop cost-effective, sustainable seafood production;
- Develop new knowledge in areas where Norway has special advantages;
- Develop export-oriented industrial activities in areas where Norway has special advantages;
- Contribute to global knowledge development for marine food production.

The Norwegian aquaculture industry is currently in a very strong position and is well-equipped to exploit the wide-ranging commercial, societal and research opportunities that are emerging. The HAVBRUK2 programme is intended to provide knowledge that will enable Norway – as an exporter of salmon and other seafood products and a supplier of knowledge, equipment and technology – to achieve its ambitious growth targets.

## 2.2 Scientific perspectives

In 2014, Science-Metrix conducted a bibliometric analysis of Norwegian research on commission from the Research Council.<sup>3</sup> The analysis showed that Norwegian research groups are at the international forefront in a range of marine disciplines. They hold a leading position in key areas of fisheries and aquaculture research such as nutrition, genetics and selective breeding, fish health, welfare, technology and interactions with the surrounding environment. Norwegian research efforts have been crucial for seafood production in Norway, and Norwegian researchers have also made important contributions to the global knowledge pool to further develop aquaculture activities worldwide.

The HAVBRUK2 programme targets the entire research system, from universities, university colleges and publicly-funded research institutes to private companies in the producer and supplier segments.

The HAVBRUK2 programme will expand on the results from the HAVBRUK programme, with continued focus on high research quality and relevance and benefit to industry. It has been given special responsibility for laying a foundation for socially, economically and environmentally sustainable growth. In keeping with the recommendations of the Research Board of the Division for Energy, Resources and the Environment, the new programme will help to build a sound knowledge base for the aquaculture industry and the government administration based on research on sustainability, fish health and welfare, safe and healthy seafood, technology development, and production of “new” marine raw materials for use in feed, for energy purposes and as food. The programme will also encompass societal aspects of aquaculture activities, nationally and globally.

The Research Council’s aquaculture research efforts encompass several programmes, centre schemes, open competitive arenas, infrastructure initiatives and other funding instruments. This ensures flexibility in follow-up and fosters integrated knowledge development. The HAVBRUK2 programme is an open-ended programme and will consolidate and coordinate aquaculture-related research activities at the Research Council.

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<sup>3</sup> Science-Metrix: Bibliometric Study in Support of Norway’s Strategy for International Collaboration, 2014. (Positional analysis of selected countries in Fisheries & Aquaculture with the mapping of their collaboration rate with Norway, 2003–2012.)

### 3 Objectives of the programme

Programme name: Large-scale Programme on Aquaculture Research  
Acronym: HAVBRUK2

**Vision:** A knowledge-based, sustainable and world-leading Norwegian aquaculture industry.

#### Primary objective

The HAVBRUK2 programme will generate knowledge and solutions for socially, economically and environmentally sustainable growth in the Norwegian aquaculture industry, and will maintain and further develop Norway's leading position in aquaculture research.

#### Secondary objectives

The programme will fund both basic research and applied research activities in order to:

- Generate knowledge for promoting *social acceptance* for and good governance in aquaculture;
- Generate knowledge for developing sustainable methods to improve *fish health*;
- Develop a fundamental understanding of the *lifecycle and biology* of fish to ensure reliable production;
- Cultivate knowledge for developing solutions and *technology* for sustainable production;
- Cultivate knowledge for developing and utilising safe, healthy and globally sustainable raw ingredients for *fish feed*;
- Generate knowledge for increasing *new aquatic bioproduction*;
- Generate fundamental knowledge for *genetic improvement* of aquatic organisms.

#### Focus

The HAVBRUK2 programme will be an important instrument with regard to realising the Research Council's efforts involving the bioeconomy. The programme has a clear industry focus and targets the entire aquaculture value chain all the way to the market for lightly processed products, where it shares an interface with the Research Programme on Sustainable Innovation in Food and Bio-based Industries (BIONÆR).

The primary focus of the programme is on the value chain for salmonids, but it also encompasses production of other species, with a focus on lower trophic levels. Other forms of production, for example, at land-based and freshwater fish farms, are also covered under the programme.

The HAVBRUK2 programme is responsible for knowledge development to ensure the most environmentally sound operation of aquaculture facilities possible as regards technology, delousing, escapes, environmentally hazardous substances, waste feed, use of medicines, sedimentation around the facilities, and more. Here the programme shares an interface with the Research Programme on Marine Resources and the Environment (MARINFORSK), which is responsible for research on the impacts of all types of industrial activity, including aquaculture, on marine ecosystems.

Fundamental to all programme activities is the need to ensure good fish welfare, ethical production, and safe and healthy food. At the same time, it will be important to generate knowledge for promoting social acceptance for and good and reliable governance in aquaculture. The programme is a key instrument for implementing the Research Council's Research Strategy for the Arctic and Northern Areas and will help to generate solutions for mitigating the impacts of climate change. The

programme has also been charged with facilitating efforts to take advantage of the potential inherent in the use of new generic technologies and tools.

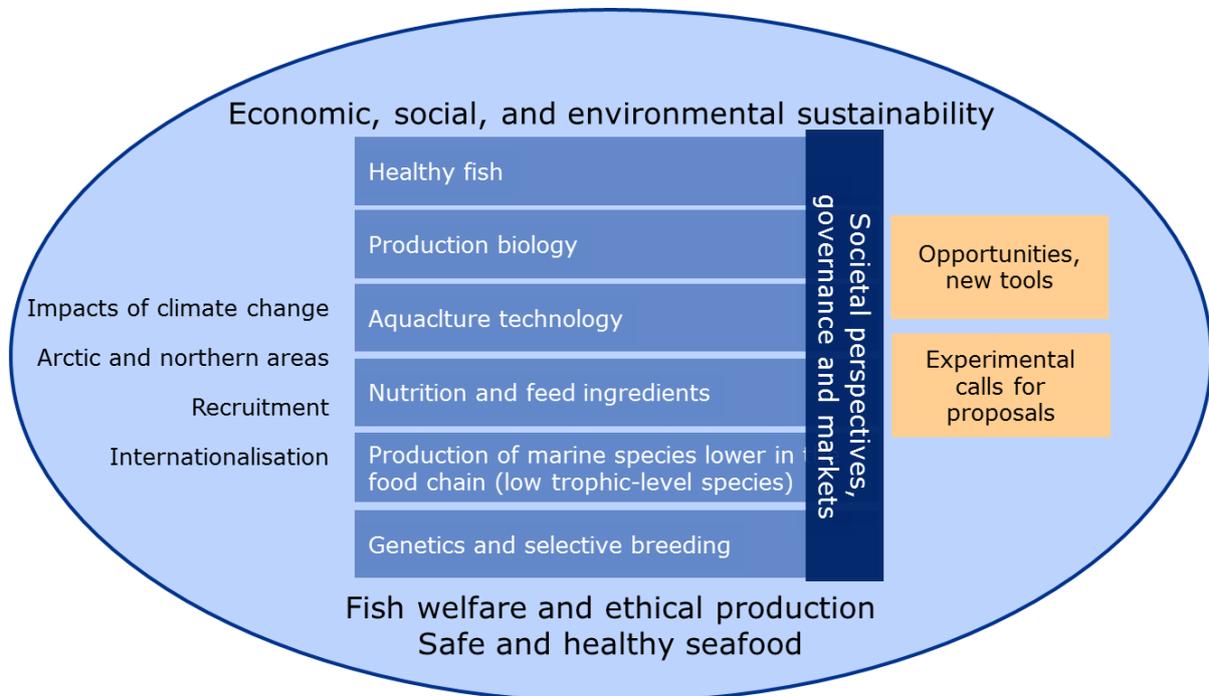
## 4 Priority research tasks

### 4.1 Thematic priority areas

One of the tasks of the HAVBRUK2 programme is to help Norway to maintain and further develop its position as the world’s leading seafood nation. In order to generate knowledge and solutions to promote socially, economically and environmentally sustainable growth in the Norwegian aquaculture industry, the programme will give priority to research in the following thematic areas:

- Thematic priority area 1: Societal perspectives, management and markets
- Thematic priority area 2: Healthy fish
- Thematic priority area 3: Production biology
- Thematic priority area 4: Aquaculture technology
- Thematic priority area 5: Nutrition and feed ingredients
- Thematic priority area 6: Production of marine species lower in the food chain (low trophic-level species)
- Thematic priority area 7: Genetics and selective breeding

These areas address the key priorities of the HAVBRUK2 programme at start-up and in the longer term. This work programme can and should be revised at regular intervals to ensure that the programme has the most appropriate scientific and operational focus at all times and promotes the greatest possible scientific and societal relevance.



## 4.2 Strategic priorities

The message of the HAV21 national marine research strategy can be summed up in the slogan: “**steady course and new opportunities**”. The HAVBRUK2 programme has based its strategic priorities for the next 10 years on the recommendations of the HAV21 strategy report.

### Steady course

Today, Norwegian research activities and research quality are of high international standard. Setting the right thematic priorities and attaching importance to basic research has helped to build a knowledge-based aquaculture industry. Maintaining an internationally leading position in key areas such as fish health/basic fish biology, feed/nutrition, genetics/selective breeding and technology will be critical for continued sustainable growth in aquaculture. Norwegian researchers lead the field in several of these areas. Thus Norway itself must take responsibility for moving the research front and cultivating innovations to achieve ambitious industry targets.

The evaluation of the programme *Aquaculture – An Industry in Growth* (HAVBRUK) points in the same direction. The evaluation report concluded that the research community, the authorities and the industry alike still want and need basic research, and that the Research Council takes a special responsibility for long-term research. The report also supported continued competence building through the use of instruments to increase recruitment. Basic research is also of relevance for the aquaculture industry, and the HAVBRUK2 programme will facilitate the active participation of industry partners in both user-driven projects and researcher projects. The programme will also serve as an important open competitive arena for innovation projects in the aquaculture industry and help to reduce the risk carried by the supplier industry in its research and development activities.

If Norway is to maintain its leading position in key areas of aquaculture research, efforts must be continuously intensified, both qualitatively and quantitatively. The HAVBRUK2 programme will therefore help to step up the level of research activity and keep a **steady course** by:

- Attaching importance to basic research in key thematic areas;
- Focusing on researcher recruitment in projects and in special funding instruments;
- Working to ensure commercial relevance and providing an open competitive arena for innovation projects in the aquaculture industry.

### New opportunities

There is significant potential for developing other types of aquaculture activities than salmon farming along Norway’s long, productive coastal strip. The 2012 report “Value created from productive oceans in 2050” points to the special potential for production of marine biomass lower in the food chain, such as macro- and microalgae and molluscs. This type of production at lower trophic levels will not put pressure on limited feed resources. It can also make use of discharges of nutrients and organic matter from fish production. The HAVBRUK2 programme will have responsibility for the Research Council’s increased investment with regard to low trophic-level marine biomass production.

The supplier industries to the maritime and offshore sectors are highly competent and lead the field internationally. There is tremendous potential for further developing Norwegian aquaculture technology in the interface between “Norway’s three most complete industries” (*Et kunnskapsbasert Norge*, Torger Reve et al. 2012). Until now, the marine supplier industry has had limited instruments at its disposal. Together with relevant Research Council programmes, the HAVBRUK2 programme will bolster aquaculture technology-related efforts. In addition to providing funding for industrial

research, the programme will be open to providing financial risk mitigation for the testing, demonstration and piloting of new technology.

The rapid evolution of the three enabling technologies biotechnology, nanotechnology and ICT may provide the aquaculture industry with new and “unexpected” solutions to many challenges.

The sequencing of the salmon genome has opened up new opportunities to enhance our understanding of fish capacity to adapt to different environmental and production conditions, the genetic basis for this capacity, and how gene expression can be influenced. New technology enables researchers to study epigenetic effects, e.g. how environmental conditions during one life stage may affect adaptive capacity later in life, which may be significant for factors such as smolt quality and ability to cope with stress. Applying a systems biological approach, including the use of model organisms, will be valuable in generating more basic knowledge to implement in further salmon research.

Several of the factors limiting the growth of the aquaculture industry are related to society’s response to the rapid expansion of this relatively new industry. There are issues involving e.g. ownership rights, use of sea areas and environmental impacts. Further growth in the industry requires social acceptance and good governance models. The HAVBRUK2 programme will therefore work to enhance understanding of relations between the industry and society, thereby promoting socially sustainable development under knowledge-based, reliable and robust governance. The Research Council has a special responsibility as an objective funding source in this context.

The evaluation of the Research Council conducted in 2012 identified the need for funding instruments to promote novel, innovative, high-risk ideas. The HAVBRUK2 programme will therefore provide funding for ambitious, creative, high-risk projects in its own funding announcements, in addition to providing funding in thematically open arenas to make room for new concepts and solutions. Cooperation with related programmes/activities may also be of relevance to fostering creative thinking on specific topics in the interface between programmes.

Therefore, in addition to focusing on keeping a **steady course**, the HAVBRUK2 programme will promote and take advantage of **new opportunities** by:

- Stepping up the level of research activity to develop marine production of new species lower in the food chain;
- Strengthening aquaculture technology development, particularly in the supplier industry, to exploit the extensive competency of the maritime and offshore supplier industries, which is one of Norway’s competitive advantages;
- Intensifying efforts to exploit the potential inherent in new biotechnological tools, nanotechnology and ICT;

#### **Types of projects under the HAVBRUK2 programme**

- Researcher Projects
- Knowledge-building Projects for Industry
- Innovation Projects for the Industrial Sector
- Personal Post-doctoral Research Fellowships
- Project Establishment Support (international cooperation)
- Personal Visiting Researcher Grants
- Personal Overseas Research Grants
- Support for Events
- Support for strategic positioning activities

#### **Programme-specific schemes:**

- Knowledge platforms
- Projects for top young investigators in aquaculture research

- Increasing the use of experimental calls for proposals to fund projects involving new, high-risk ideas;
- Enhancing the participation of trade and industry in research activities by stipulating requirements for the involvement of industry partners in researcher projects and issuing separate funding announcements for innovation projects;
- Bolstering efforts to increase understanding of the relationship between the aquaculture industry and society at large.

## 5 Cross-cutting cooperation with related funding instruments

The Research Council works to promote integration and effective coordination among its research programmes, and encourages binding cooperation between research programmes and other funding instruments. Knowledge needs may extend across several programmes (such as interactions between wild salmon and farmed salmon) and some extend beyond the framework of the programmes themselves (such as the bioeconomy, effects on ecosystems and sea/land area-related processes), or may be given inadequate focus in the current programme structure (such as the need for knowledge about major restructuring processes).

In the years ahead, a more open and flexible structure will be employed to facilitate cooperation between different activities. Programme activities will be planned in cooperation with related programmes to ensure that research needs extending across the individual programmes' area of responsibility are covered. In keeping with the Research Council's routines for planning cooperation between programmes, programme coordinators for related programmes will meet together annually to plan concrete collaborative activities.

### 5.1 Relevant forms of cooperation

**Role as funder** – Scientific and/or financial cooperation on funding announcements

- Contribute funding to another programme's funding announcement, with thematic guidelines.
- Collaborate scientifically and financially with several programmes on a targeted funding announcement with a limited thematic focus.
- Collaborate with several programmes on larger-scale funding announcements with a broad thematic focus.

**Role as a meeting place** – Develop joint communication and meeting-place activities to promote more integrated, synthesised and targeted communication with user groups (see also Chapter 7. Communication and dissemination activities).

- Make use of the Research Council's role as a meeting place to direct focus towards relevant, complex issues where there are differences of opinion between research groups or between researchers and users, or conflicting interests between user groups.

**Role as advisor** – Strengthen cooperation between Research Council programmes

- Scientific and strategic cooperation, for example in budget and planning processes, to promote integrated thinking and lend greater weight to the Research Council's input.

### Role as an international driving force

- Increase cooperation between programmes on international activities and boost mobilisation for participation in international efforts.

## 5.2 Topics for cooperation with other programmes

The HAVBRUK2 programme shares an interface and areas of overlap with a number of other programmes, centre schemes, open competitive arenas, infrastructure initiatives and other Research Council instruments. The most important partners for cooperation are the BIONÆR, MARINFORSK, BIOTEK2021, MAROFF, PETROMAKS 2, ENERGIX, KLIMAFORSK and MILJØFORSK programmes.

The HAVBRUK2 programme may, for example, cooperate with:

- the BIONÆR programme on seafood to cover the entire aquaculture value chain, to view the environment and resource utilisation on land and in the sea in the same context, to develop technology and systems for live holding that ensure good fish welfare and product quality, and to promote an integrated bioeconomic perspective across the blue and green sectors.
- the MARINFORSK programme on the management and use of coastal areas and the environmental impacts of the aquaculture industry on the marine ecosystem.
- the MILJØFORSK programme on genetic interactions between farmed salmonids and wild salmonids.
- the MAROFF and PETROMAKS 2 programmes (and Innovation Norway) to increase coordination of efforts in marine technology.
- the ENERGIX programme on marine biomass for biofuels.
- the KLIMAFORSK programme on knowledge development to predict the effects of projected climate change and to plan relevant mitigation measures for the aquaculture industry.
- the BIOTEK2021, IKTPLUSS and NANO2021 programmes to exploit the potential inherent in new technologies. It is vital to develop methods and technology of relevance for the Norwegian seafood industry in collaboration with these three technology programmes and to implement the results of generic research in industry-oriented projects.

### Relevant partners

- BIONÆR – Research Programme on Sustainable Innovation in Food and Bio-based Industries
- MARINFORSK – Programme on Marine Resources and the Environment
- MILJØFORSK – Programme for Environmental Research for a Green Transition
- MAROFF – Innovation Programme for Maritime Activities and Offshore Operations
- BIOTEK2021 – Large-scale Programme on Biotechnology for Innovation
- ENERGIX – Large-scale Programme for Energy Research
- PETROMAKS2 – Large-scale Programme for Petroleum Research
- KLIMAFORSK – Large-scale Programme on Climate
- NANO2021 – Large-scale Programme on Nanotechnology and Advanced Materials
- IKTPLUSS – Initiative for ICT and digital innovation
- JPI Oceans – Joint Programming Initiative for Healthy and Productive Seas and Oceans
- SFF – Norwegian Centres of Excellence Scheme
- SFI – Centres for Research-based Innovation Schem
- INFRASTRUKTUR – National Financing Initiative for Research Infrastructure
- FORNY2020 – Programme for Commercialising R&D Results
- VRI – Programme for Regional R&D and Innovation
- SkatteFUNN R&D Tax Incentive Scheme
- PROFORSK – Programme for the profiling of research

## 5.3 National cooperation with other agencies in the research and innovation system

The HAVBRUK2 programme also shares an interface and cooperates with other agencies in the research and innovation system:

- **Innovation Norway:** observer on the HAVBRUK2 programme board and cooperation on events and participation in industry trade shows;
- **Regional research funds:** cooperation on innovation projects for the industrial sector, with common application deadlines and joint application review process;
- **The Norwegian Seafood Research Fund (FHF):** joint funding announcements targeting specific topics/thematic areas and scientific follow-up of projects co-funded by FHF.

## 6 International cooperation

The bibliometric analysis from 2014 showed that Norwegian research in the field of fisheries and aquaculture is at the international forefront with regard to quality and expected volume (specialisation). Norwegian research groups are attractive partners for cooperation and have a high score in the citation index. Several other countries also performed very well in this field (including Denmark, Portugal and Canada), and research cooperation with these countries should be further developed.

The evaluation of the HAVBRUK programme confirmed that Norway is a global leader in aquaculture research and that the programme was instrumental in achieving this position. The evaluation report nonetheless raised the question of whether the requirement of incorporating international cooperation into research projects is actually necessary in cases where national partners are better suited.

The HAVBRUK2 programme will maintain a high level of international cooperation, and will give priority to projects incorporating such cooperation when it enhances project quality and research activities. Internationalisation of the research is positive in and of itself as it promotes the evolution of Norwegian research groups and international network-building. The programme will work to enable a greater number of Norwegian researchers to benefit from research and study periods abroad, and correspondingly enable more international researchers to spend time at Norwegian institutions.

Norwegian participation in the EU Framework Programme for Research and Innovation, Horizon 2020, may substantially boost the volume of aquaculture-relevant research in the coming years. The HAVBRUK2 programme must create a framework for greater Norwegian participation in Horizon 2020, both as partners in and coordinators of research projects, in order to deal with challenges facing the aquaculture industry. It is also important to strengthen Norwegian participation under the ERA-NET scheme, particularly the ERA-NET Cooperation in Fisheries, Aquaculture and Seafood Processing (COFASP). Similarly, it will be important to work closely with the European Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI Oceans) and have close contact with the European Aquaculture Technology and Innovation Platform (EATiP).

Research Council programmes are responsible for implementing the Research Council of Norway's strategy on international cooperation and for enhancing the ability of Norwegian research groups to successfully compete for funding under EU framework programmes. The HAVBRUK2 programme will

assess the need for dedicated instruments to encourage increased participation in the EU framework programme.

The allocation letters from the funding ministries also set guidelines for international research cooperation in various sectors. In terms of aquaculture, the USA, Canada, Chile, Brazil, India, China and Japan are the most important partner countries outside the EU. The HAVBRUK2 programme will give priority to cooperation with these countries in its funding announcements for project establishment support (PES) and mobility grants.

With regard to Nordic cooperation, the HAVBRUK2 programme will coordinate activities in connection with the Nordic Marine Innovation Programme.

The HAVBRUK2 programme will employ the following instruments to encourage international cooperation:

- Project establishment support (PES) for cooperation with countries outside the EU (there are designated instruments for research cooperation with EU countries);
- Personal visiting researcher grants (for incoming researchers);
- Personal overseas research grants for Norwegian researchers;
- Prioritise international cooperation in project allocations where such cooperation will enhance research quality;
- Specific stimulation measures to increase Norwegian participation in the EU framework programme, as needed;
- Assess opportunities for issuing bilateral joint funding announcements with priority countries.

## **7 Communication and dissemination activities**

Communication activities are to draw attention to the Research Council's initiatives in marine research and aquaculture research. The Research Council's communication strategy underlies the programme's communication activities targeting researchers and other users of the programme.

The programme will also motivate and pave the way for more and better dissemination from the projects, which is primarily the responsibility of the researchers/institutions. Communication and dissemination activities will be crucial to achieving the programme objectives and this will be reflected in the funding announcements and project follow-up.

### **Objectives**

Communication activities under the programme will:

- Improve dialogue between the aquaculture research community and society at large, and help to give a more visible profile to and simplify complex issues within the programme's area of responsibility;
- Highlight the strategic role of the Research Council in generating value creation for society and ensuring aquaculture research of high scientific merit;
- Promote targeted communication on aquaculture-related issues in cooperation with related funding instruments and research groups;
- Ensure an adequate number of high-quality grant proposals in response to the programme's funding announcements.

### **Target groups**

- Trade and industry, and business organisations;
- Politicians and the public authorities;
- The research community;
- The general public and the media.

### **Main principles**

- Cooperate with related programmes/funding instruments to communicate with and disseminate results to various user groups at the overall or thematic level (see Chapter 5. Cross-cutting cooperation with related funding instruments);
- Cooperate on international instruments to give a more visible profile to Norwegian participation in international research efforts;
- Cooperate with research groups to publicise good examples of research results;
- Cooperate with user groups;
- Facilitate targeted communication efforts in projects and following up the activities;
- Recycle texts and other material that have already been produced by disseminating them through more channels.

### **Instruments**

- Organise the HAVBRUK conference (every other year);
- Provide meeting places for different target groups, from wide-ranging conferences and dialogue meetings on topics relevant to the public debate to dialogue meetings and purely scientific conferences/meetings;
- Use the press/media, including the national media, scientific media and the Norwegian-language popular science website forskning.no;
- Use the Research Council's own channels, including English-language channels and social media.

Based on this, the programme will provide input to the Division for Energy, Resources and the Environment's annual communication plan(s) for, for example, marine research, marine technology and the bioeconomy.

The division management will determine the communications-related tasks for which the programme administration will be responsible. Responsibilities will be distributed in dialogue with the programme administration.

## **8 Budget**

The HAVBRUK2 programme is a large-scale programme at the Research Council and is funded by allocations from the Ministry of Trade, Industry and Fisheries and the separate budget item from the Ministry of Education and Research. At start-up, the programme budget totalled NOK 166 million: NOK 147 million from the Ministry of Trade, Industry and Fisheries and NOK 19 million from the Ministry of Education and Research. With zero growth, the HAVBRUK2 programme will annually have roughly NOK 150 million at its disposal for funding research projects.

In its evaluation of the HAVBRUK programme, Oxford Research recommended that the programme be continued, but with an expanded financial framework that would allow it to fulfil its obligations

vis-à-vis the government administration and help to build world-leading research groups. According to Oxford Research, the programme has insufficient economic muscle in relation to its ambitions and the size of the industry.

After several years of zero growth, the aquaculture field has been given higher priority and experienced moderate budget growth in recent years. Given the priorities set out in the Long-term plan for research and higher education 2015–2024, continued growth in funding for aquaculture research and innovation activities to further develop the industry can be expected.

There is no set budget for the individual thematic priority areas under the HAVBRUK2 programme. This gives the programme the latitude to strengthen research in strategically important areas in response to emerging needs and changes in the industry. In keeping with the Research Council's new programme model (Research Council 3.0) funding announcements encompassing all of the thematic areas in the work programme will be issued annually. Funding announcements that rotate on an annual basis between each of the thematic priority areas and funding announcements with an open thematic framework will also be issued. This will be specified in the three-year action plans.

To ensure that research areas located in the interface between the HAVBRUK2 programme and other programmes are covered, the need to issue joint funding announcements should be assessed on an annual basis. Without binding the HAVBRUK2 programme to cooperation, roughly 5–10 per cent of the programme budget should be allocated to joint funding announcements over time. In the same way, funding should be set aside for activities in international arenas such as the ERA-NET scheme and the like and for the programme's own activities to encourage international cooperation. Over time this should account for a corresponding share (5–10 per cent).

### **Zero-growth budget**

With zero growth, the HAVBRUK2 programme will mainly have to focus on strategic basic research in core areas in order to maintain adequate expertise and recruitment. The programme will also have to focus on areas which only receive public funding, e.g. research activities targeting the needs of the government administration.

### **Budget increase**

With budget growth in the years ahead, the HAVBRUK2 programme will be able to launch larger-scale efforts to realise new opportunities for marine cultivation in the broad sense. Industrial production of marine biomass for consumption and as raw materials for feed and energy will require large-scale, long-term R&D activity.

Similarly, targeted efforts involving new technology can make new marine areas accessible for aquaculture production. Technology development and testing are costly, however, and both industrial R&D and risk mitigation will be required before the technology is ready for implementation by the industry. Testing is also necessary to safeguard the environment and fish welfare.

With a more ample budget, the programme will also be able to issue more experimental calls for proposals to realise the potential inherent in innovative thinking and new enabling technologies.

## 9 Organisation

### Programme board

The HAVBRUK2 programme board is appointed by and reports to the Research Board of the Division for Energy, Resources and the Environment. The programme board is responsible for achieving the programme's objectives using the specific instruments available. Activities are to be carried out in accordance with the intentions and objectives of the Research Council's strategies and guidelines, the guidelines from the Council's Executive Board and the Research Board of the Division for Energy, Resources and the Environment, and the guidelines from the funding ministries and other funding sources.

The programme board acts on behalf of the Research Council and reports to the research board via the executive director.

### Programme administration

The HAVBRUK2 programme administration is responsible for carrying out the day-to-day tasks of the programme, performing the administrative functions of the programme and facilitating the implementation of the programme board's decisions.

### Application review process

Funding announcements will be in compliance with the Research Council's applicable rules and established application submission deadlines. The HAVBRUK2 programme may employ all Research Council application types. Any additions to the requirements or assessment criteria for grant applications will be specified in the individual funding announcements.

Researcher projects will be assessed by panels of international referees that convene for discussion and assess the grant proposals in accordance with Research Council guidelines. Innovation projects will be assessed by national referee panels.

When assessing grant applications, consideration will be given to the scientific merit of the grant proposal, the relevance of the grant proposal relative to the call for proposals, the relevance and benefit of the grant proposal to society, the authorities and industry, and the substance of the grant proposal in relation to relevant ongoing projects.

The programme administration will submit a recommendation for projects to be awarded funding to the HAVBRUK2 programme board. The programme board is responsible for final approval of grant allocations.

## 10 Evaluation

The HAVBRUK2 programme will follow the development of the programme towards achieving its stipulated scientific and strategic objectives. With regard to the scientific secondary objectives, analyses of the project portfolio will show the extent to which the programme is funding research that addresses the knowledge challenges described in Chapter 4. These secondary objectives will be translated into concrete actions in three-year action plans.

Below is a list of operational measures for achieving the programme's scientific secondary objectives:

<b>Secondary objectives to be achieved through basic and applied research activities</b>	<b>Researcher projects</b>	<b>Innovation projects for the industrial sector</b>	<b>Interface with other thematic programmes</b>	<b>Other measures</b>
- Generate knowledge for promoting social acceptance for and good governance in aquaculture	+++		Discussion meeting Integrated projects Follow-up research	
- Generate knowledge for developing sustainable methods to improve fish health	+++	+		Experimental calls for proposals
- Develop a fundamental understanding of the lifecycle and biology of fish to ensure reliable production	+++	+	BIOTEK2021	
- Cultivate knowledge for developing solutions and technology for sustainable production	+	+++	MAROFF, PETROMAKS 2, DEMO2000, BIONÆR	Experimental calls for proposals
- Cultivate knowledge for developing and utilising safe, healthy and globally sustainable raw ingredients for fish feed	++	++	BIONÆR	Experimental calls for proposals
- Generate knowledge for increasing new aquatic bioproduction	+++	++	MARINFORSK	Knowledge platform
- Generate fundamental knowledge for genetic improvement of aquatic organisms	+++	++	BIOTEK2021	Experimental calls for proposals

The HAVBRUK2 programme will not employ the application type knowledge-building projects for industry initially, but instead will strongly encourage the involvement of the industry in researcher projects. The programme will assess the use of knowledge-building projects for industry on an ongoing basis.

The strategic objectives of the programme will be followed up and assessed regularly, both qualitatively and through the use of statistics and analyses. Information on the strategic role of the HAVBRUK2 programme, the manner in which the programme is being implemented, the actions taken and work methods selected, and the collaborative platforms developed will be set out in the programme's annual report. Furthermore, the programme board will assess the programme's performance achievement on an ongoing basis and introduce new concrete measures in the programme's action plans, funding announcements and communication activities.

### **Performance targets and performance indicators**

Performance achievement under the programme will be expressed and assessed on the basis of performance targets and performance indicators. Key consideration will be given to the following:

<b>Performance targets (Success criteria)</b>	<b>Performance indicators</b>
<b>High scientific merit</b>	<ul style="list-style-type: none"> <li>• Articles published in journals and series</li> <li>• Articles published in anthologies</li> <li>• Monographs published</li> <li>• Reports, memoranda, articles, lectures at meetings/conferences oriented towards the project's target groups</li> <li>• Number of knowledge platforms established</li> </ul>
<b>Strengthen researcher recruitment</b>	<ul style="list-style-type: none"> <li>• Number of completed doctoral degrees wholly or partially funded under the programme</li> <li>• Number of doctoral fellowships (within the framework of the project and personal) wholly or partially funded under the programme</li> <li>• Number of post-doctoral fellows (and work-years) wholly or partially funded under the programme</li> <li>• Number of projects for top young investigators in aquaculture research</li> </ul>
<b>Promote innovation</b>	<ul style="list-style-type: none"> <li>• New/improved methods/models/prototypes finalised</li> <li>• New/improved products finalised</li> <li>• New/improved processes finalised</li> <li>• New/improved services finalised</li> <li>• Patents applied for</li> <li>• Licensing agreements signed</li> <li>• New companies launched as a result of the project</li> <li>• New business areas in existing companies as a result of the project</li> <li>• Companies participating in projects that have introduced new/improved methods/technology</li> <li>• Companies participating in projects that have introduced new/improved work processes/business areas</li> </ul>
<b>Strengthen international cooperation</b>	<ul style="list-style-type: none"> <li>• Proportion of projects in collaboration with international research groups</li> <li>• Volume of internationally oriented funding (project establishment support, support for positioning activities)</li> </ul>

<b>Emphasise dissemination of research results</b>	<ul style="list-style-type: none"> <li>• Number of projects established under European joint funding announcements (ERA-NETs, JPIs)</li> <li>• Number of fellowship-holders/researchers on a longer research stay at an international research institution</li> <li>• Number of international guest researchers involved in projects</li> </ul> <p>From the projects</p> <ul style="list-style-type: none"> <li>• Popular science publications (articles/books, debate books/articles, publications circulated for review, exhibitions, fiction, etc.)</li> <li>• User-oriented dissemination activities: lectures, articles in scholarly journals</li> <li>• Mentions in the mass media (newspapers, radio, television, etc.)</li> </ul> <p>In addition, under the auspices of the HAVBRUK2 programme:</p> <ul style="list-style-type: none"> <li>• Open scientific seminars and workshops, courses</li> <li>• Dissemination measures targeting the general public</li> <li>• Number of events awarded support</li> <li>• Press, radio and television coverage of the programme</li> </ul>
<b>Collaboration across types of research, subject fields and sectors</b>	<ul style="list-style-type: none"> <li>• Number of joint funding announcements within the division</li> <li>• Number of joint funding announcements across divisions</li> <li>• Number of joint funding announcements with funding instruments outside the Research Council</li> </ul>

The HAVBRUK2 programme is an open-ended programme. After five years of operation, the need for an evaluation of the programme, or segments of the programme, will be considered in light of the changes that have emerged and the challenges facing the programme. After 10 years of operation, the need for a major revision of the knowledge base should be assessed. Consideration should also be given to whether the programme should be subject to an ongoing evaluation.

## Attachments to the work programme

- Thematic priority area 1: Societal perspectives, management and markets
- Thematic priority area 2: Healthy fish
- Thematic priority area 3: Production biology
- Thematic priority area 4: Aquaculture technology
- Thematic priority area 5: Nutrition and feed ingredients
- Thematic priority area 6: Production of marine species lower in the food chain (low trophic-level species)
- Thematic priority area 7: Genetics and selective breeding

# Thematic priority area 1:

## Societal perspectives, management and markets

### Objective

*The HAVBRUK2 programme will generate knowledge for promoting social acceptance for and good governance in aquaculture.*

### Challenges

To realise sustainable growth in Norwegian aquaculture the industry must achieve greater social acceptance, nationally and locally. This is a two-way process in which society's knowledge about and understanding of the field must be enhanced, while the industry must at the same time be attentive and flexible in light of public opinion and conflicting interests. For the aquaculture industry to grow, it will need predictable framework conditions and knowledge-based management – which in turn entails developing reliable indicators for assessing sustainability from a number of standpoints.

We have only limited knowledge about the effects of Norwegian aquaculture activities in the context of international food production and resources. Socially, economically and environmentally sustainable development are key goals, but much work is needed to develop reliable indicators of sustainability as well as principles of integrated management and criteria for assessing the environmental impact of salmon farming at the local, regional and global levels. Achieving a value chain-based, integrated global perspective on sustainability will require insight from both the social and the natural sciences and an interdisciplinary approach.

Modern aquaculture extends beyond traditional cultural and management-related distinctions between coast and land, between utilisation and preservation, and between common and private property. Restricting access to coastal areas by issuing aquaculture licences and sites to companies, and commerce with these companies (including the sale and purchase of companies possessing licences) are examples of management areas that pose challenges of a legal, economic, practical and political nature. More knowledge is needed about framework conditions and governance systems that take all these factors into consideration. More knowledge is also needed about the complex governance system that encompasses the environment, food quality, fish welfare, industrial policy, and more.

Norwegian aquaculture companies also have large-scale operations in other countries such as Canada, Scotland and Chile. In addition, the salmon industry is a major consumer of global natural resources for fish feed. The HAVBRUK2 programme must therefore be opened to research that highlights societal aspects of these activities. The Norwegian knowledge system, with extensive public funding of research and a high degree of transparency, has laid the foundation for Norway's success in aquaculture. Restructuring and internationalisation of the industry may affect this, and it is therefore essential that the HAVBRUK2 programme maintains a global perspective on societal sustainability.

For certain coastal communities, the issues of settlement, jobs and value creation are closely linked to the development of aquaculture activities. Compared to agriculture, aquaculture is a relatively new form of production that challenges cultural, political and legal paradigms. Social science research on aquaculture is still in its early phases, and promoting development in this field will require relatively open calls for proposals that accommodate new theoretical, thematic and interdisciplinary connections and also incorporate gender perspectives.

## **Priority areas**

- Knowledge about the aquaculture industry's sustainability in an integrated global perspective, including reliable sustainability indicators;
- Knowledge about legal issues associated with ownership and transfer of licences;
- Knowledge about access to utilising coastal areas;
- Knowledge about governance systems affecting the industry;
- Insight into the relationship between fish and people – culturally, ethically and practically – and about conditions and methods for safeguarding fish welfare during daily aquaculture operations;
- Knowledge about the interaction between quality differentiation and consumer interests in the market, the use of quality as a competitive parameter, and about certification schemes for e.g. the environment, feed, fish welfare, contaminants and nutritional content;
- Knowledge about the market situation for Norwegian salmon in terms of customs barriers, market access and trade conditions for the industry as a whole;
- Insight into Norwegians' attitudes about and understanding of salmon farming and aquaculture in general;
- Knowledge about special characteristics of Norwegian aquaculture in regard to the relationship between science, industry and policy design (legitimacy).

## **Sustainability perspectives (social, environmental, economic)**

Growth in the aquaculture industry brings new challenges and requires research cooperation across scientific boundaries. By developing reliable indicators for and expanding scientific knowledge about what constitutes environmentally, economically and socially sustainable development, the programme is designed to help the industry to develop more safely and quickly in the right direction. At the same time, it will be easier to better document that solutions are sustainable, which would likely improve the industry's reputation in the public eye.

## **Cooperation and shared interfaces with other Research Council programmes**

The HAVBRUK2 programme shares an interface with a number of programmes at the Research Council regarding social science issues in aquaculture – particularly the BIONÆR, MARINFORSK, MILJØFORSK, KLIMAFORSK and BIOTEK2021 programmes.

## Thematic priority area 2: Healthy fish

### Objective

*The HAVBRUK2 programme will generate knowledge to develop sustainable production that ensures good fish health and welfare.*

### Challenges

Fish diseases remain one of the aquaculture industry's main challenges, causing major annual losses due to higher mortality rates, reduced fish growth and diminished product quality. Sub-optimal fish health has negative impacts on profits, animal welfare and the environment, while also damaging the industry's reputation. Fish health can also be important for market access. To minimise losses and ensure the industry's sustainability, it is vital to continue giving priority to preventative fish health.

Pathogens and parasites become established and quickly multiply and spread in conditions of intensive fish farming. Experience indicates that new diseases will continue to emerge in the industry. Innovative technological solutions may reduce some of these problems, but new production practices and new species will bring new problems. Treatments for salmon lice, for example, are difficult as well as problematic from a fish welfare perspective, and salmon lice are acquiring a high level of resistance to existing medicines. In addition, certain medicines can have undesirable impacts on the environment. Solving these challenges requires development and testing of many different measures to complement medicinal treatment, preferably in combination with one another.

There is ample evidence that the way the industry has organised production is not optimal for preventing the transmission of infection between marine fish farms. It is important to gain more insight into optimal buffer zone size, delineation/division of coastal areas and potential measures to develop improved location of farm-sites and operational/management structure.

Safeguarding fish health will require more knowledge about the fish immune system, different pathways of infection, pathogenic organisms and host-agent interactions. New vaccine technologies and strategies need to be developed. Since a number of factors can affect the natural and acquired resistance of fish, more knowledge is needed about the roles played by e.g. co-infections, carrier states, epigenetic effects, stress and nutrition.

Farmed fish are currently regulated under the Animal Welfare Act. How do fish farmers, researchers and consumers, respectively, perceive fish/animal welfare? In this context knowledge is needed about how best to safeguard fish welfare and develop reliable, understandable welfare indicators with practical applications in daily operations.

In Norway a relatively large number of fish are sacrificed for scientific purposes, not least in experiments to improve fish health. Thus more research is needed to improve the design and implementation of experiments. In addition, the stress on individual fish needs to be reduced by improving sampling methods and other procedures. For ethical reasons, Norway is seeking to reduce the number of fish used in experiments and to develop good alternatives.

### Priority areas

- Basic studies of immunology, infectious agents and host-agent interactions in order to develop new vaccine concepts and strategies;
- Controlling salmon lice and other parasites and pathogens while minimising the impact on the environment and safeguarding fish welfare;
- Epidemiology, population medicine and health management;

- Insight into reservoirs of key infectious agents among wild fish stocks;
- Research on how to prevent health problems associated with new production practices, new species and new feed ingredients;
- 3-R animal welfare methods (replacement, reduction and refinement) for the use of fish in research;
- Knowledge about cleanerfish use – welfare, infection transmission and optimal use for delousing salmon.

### **Sustainability perspectives (social, environmental, economic)**

More environmentally sustainable development requires sound solutions to limit the transmission of infection between farmed fish and wild stocks. Preventing disease will enhance fish welfare while consuming fewer resources in producing fish that die or exhibit poor quality. This would save the Norwegian aquaculture industry billions and improve its reputation among the public. Furthermore, developing non-medicinal treatments will reduce discharges of toxins.

### **Cooperation and shared interfaces with other Research Council programmes**

The thematic priority area *Healthy fish* shares an interface with the MILJØFORSK programme with regard to research on disease in wild salmonid stocks and impacts of salmon lice and pathogens from aquaculture sites on wild salmon and sea trout; with the MARINFORSK programme with regard to effects of medicines and other medications on the natural environment, and to zones and structure of the industry; with the BIOTEK2021, IKTPLUSS and NANO2021 programmes regarding potential application of new technologies in epigenetics, vaccine development and new diagnostic methods; and with the KLIMAFORSK programme for generating knowledge to predict effects of projected climate change on the spread of pathogens to new areas.

## Thematic priority area 3: Production biology

### Objective

*The HAVBRUK2 programme will develop a fundamental understanding of the lifecycle and biology of fish to ensure reliable production.*

### Challenges

Salmon farming has undergone a rapid development and rationalisation process, in which knowledge about salmon developmental biology, environmental requirements and coping strategies in the various life stages has led to greater productivity, higher profitability and improved fish health. Increasing emphasis is being placed on fish welfare, where deeper insight into salmon physiology and behaviour will facilitate the development of welfare indicators as well as solutions for aquaculture technology and operations that also safeguard fish welfare.

To deal with the environmental problems in salmon farming, such as those related to open net-cage production, it is necessary to test out a variety of new technologies, production regimes, and operational and handling routines. Fish welfare and adaptive capacity must be documented for these new solutions. In order to produce robust fish that at the same time are domesticated enough to thrive under production, it is vital to generate knowledge about genetic diversity in farmed salmon and the role of environmental conditions and production practices in relation to new and existing production methods and technologies. Effective new solutions will reduce production time and help to streamline operations. To safeguard fish welfare as well as product quality during the slaughtering process, knowledge related to handling, transport, stunning and slaughtering procedures will be essential.

Through systematic efforts towards producing marine species over the last 20–25 years, Norway has built up substantial international know-how in this area. Currently there is only marginal production of marine species other than salmonids in Norway, and demand for this expertise has fallen significantly. Production of cleanerfish (such as ballan wrasse and lumpfish for delousing farmed salmonids) is an example of rapidly industrialised production of two new marine species, thanks in large part to earlier promotion of knowledge development. Many challenges remain and new research is needed, however, before these cleanerfish can serve optimally as lice eaters with their welfare safeguarded. In the future, production of new marine coldwater species may become viable, in addition to which today's relatively low-volume production of marine fish needs more knowledge to draw upon. For these reasons it is important for Norway to maintain and cultivate the knowledge base for producing marine species, particularly regarding the earliest and most complex life stages.

### Priority areas

- Basic biological knowledge about different life stages and processes of salmon such as sexual maturation, early-stage development, growth, exercise and smoltification in relation to different environmental pressures – aimed towards more resilient production of healthy fish;
- Knowledge about environmental requirements, adaptive capacity, stress mechanisms, behaviour and learning – to ensure good fish welfare and develop better welfare indicators;
- Interactions between different production technologies/practices and fish physiology and behaviour;
- The effects of handling, transport, stunning and slaughtering procedures on both fish welfare and product quality;
- Interactions between the fish, technology and farmers, and tools to improve production control and monitoring;

- Knowledge about production of cleanerfish;
- Production of marine fish, emphasising the life stages up to completed start-feeding.

### **Sustainability perspectives (social, environmental, economic)**

Sustainable growth in the aquaculture industry requires solutions that better address the environmental problems of e.g. salmon escapes and the spread of salmon lice, while also safeguarding fish welfare. Developing such solutions depends on a deeper understanding of the salmon lifecycle and adaptive capacity and the interactions between salmon biology, production technologies, operations and farmers. Solutions that safeguard salmon welfare will improve the industry's reputation in the public eye and lead to higher profits.

### **Cooperation and shared interfaces with other Research Council programmes**

The thematic priority area *Production biology* shares an interface with the BIOTEK2021 programme with regard to utilising the salmon genome and other innovations in biotechnology; with the MARINFORSK programme with regard to environmental impacts and coastal ecology; and with the KLIMAFORSK programme regarding development of knowledge to predict the effects of projected climate change on salmon welfare and adaptive capacity.

## Thematic priority area 4: Aquaculture technology

### Objective

*The HAVBRUK2 programme will cultivate knowledge for developing solutions and technology for sustainable production.*

### Challenges

The use of open net-cages in suitable locations has been a critical success factor for Norwegian aquaculture. Open net-cages, however, lead to environmental challenges such as escaped fish, discharge of undesirable substances, and the transmission of salmon lice and other diseases between farmed fish and wild stocks. Large fish farms and other facilities with dense populations of fish involve operational challenges related to e.g. monitoring, precise feeding, and treatment for outbreaks of parasites and diseases – and require locations with good currents, depth and water quality.

Higher productivity, improved fish welfare and reduced environmental impact are drivers for developing tomorrow's technology in the aquaculture industry. Knowledge about fish behaviour and physiology constitutes an important basis for technology development. Knowledge and solutions are needed for monitoring, observation, automation and less-intrusive handling of fish in order to safeguard their welfare and ensure predictable, cost-effective production. More knowledge about the impact of waves and currents on aquaculture sites and solutions for decreasing the chances and consequences of operational and human error will help to reduce the risk of escapes.

Continual advances are being made in the aquaculture technology platform, while several new concepts and production methods are under development, such as the use of recirculation technology, production in closed and semi-closed cages, and open-ocean aquaculture sites. Pilot testing and demonstration are essential to implementing new technologies. Knowledge and solutions are needed for documenting fish welfare, biological performance, environmental impact and technical robustness of new and existing production practices.

In catch-based aquaculture, fish and crustaceans can be held in captivity, fed and sold when their quality and markets are favourable. This raises both the quality and value of the catch. A number of challenges still need to be solved to optimise this kind of production and adequately safeguard animal welfare with regard to handling during catch and transport, live holding, feeding and slaughter.

### Priority areas

- Knowledge and technology for reducing discharges (including escapes, salmon lice and other parasites/pathogens) and for utilising waste as a resource;
- Knowledge about measuring and monitoring biological and environmental parameters;
- Knowledge and technology related to cleanerfish;
- Knowledge and technology for new production practices (offshore, closed/semi-closed/treated, land-based/RAS) and improvement of the current platform;
- Know-how and technology for raising the efficiency of work operations and for reduced and less-intrusive handling of fish;
- Knowledge and technology for increased control, documentation and monitoring of biomass in new and existing production systems;
- Knowledge and technology for more controlled, efficient feeding;

- Knowledge about aspects of health, safety and environment for personnel, including design of equipment and procedures for minimising risk;
- Catch-based aquaculture emphasising handling, technology, feeding, slaughter and animal welfare.

### **Sustainability perspectives (social, environmental, economic)**

Refining existing technical solutions and production practices and developing new ones will help to safeguard fish welfare, create safer working conditions, reduce the negative environmental impact of aquaculture practices, and improve the industry's reputation. The automation and rationalisation resulting from technological development will contribute to the industry's economic sustainability.

### **Cooperation and shared interfaces with other Research Council programmes**

The thematic priority area *Aquaculture technology* shares an interface with the MAROFF programme with regard to areas involving maritime transport and marine operations, e.g. knowledge and technology related to service boats and well boats; with the MARINFORSK programme with regard to use of the coastal zone/area and environmental impacts; and with the MILJØFORSK programme as regards fish escapes.

## Thematic priority area 5: Nutrition and feed ingredients

### Objective

*The HAVBRUK2 programme will cultivate knowledge for developing and utilising safe, globally sustainable raw ingredients for fish feed and for achieving healthy products and food security.*

### Challenges

With global population growth and a rapidly increasing middle class, the world's resources and food supply are under pressure. As a general rule, ingredients should be used for direct human consumption when possible, while animal feed and energy should be based on raw materials unsuitable to human diets. The need for seafood from aquaculture is expected to rise sharply, requiring greater access to suitable feed ingredients.

Access to marine feed ingredients is limited, so these must be utilised in the best possible ways. At the same time, new ingredients must be developed, in particular using lower trophic-level species as feed ingredients and increasing the proportion of them in fish farming. Examples of relevant feed ingredients include by-products and discards from fisheries and aquaculture activities, insects, algae or other low trophic-level species, and ingredients from plants that are currently scarcely available on the world market. Production and refinement of these raw materials for use as feed ingredients are priority areas for research. More knowledge is needed about the nutritional requirements of fish and their tolerance of contaminants in order to safeguard fish health and welfare using new feed ingredients.

No matter what feed ingredients are used, it is always vital to ensure good end-product quality and food safety and to satisfy consumer demands in different markets.

Norwegian farmed salmon is currently produced with a feed conversion ratio of roughly 1.2. This ratio is affected by the choice of feed ingredients. Changes in the feed composition can alter the bioavailability of the nutrients and the degree to which the feed satisfies the daily nutritional requirements of salmon.

Under practical conditions of large-scale production, it is a major challenge to incorporate the daily dietary variation needed to provide the fish with optimal feed rations.

The sequencing and publication of the salmon genome paves the way for new understanding of how individual feed components may affect the fish immune system, fat deposition, muscle formation and product quality. A systems biological approach could lead to more targeted fish nutrition and make it possible to customise feed composition to a far greater degree than is currently possible.

All raw materials utilised in fish feed are a potential source of contaminants. When introducing new, non-traditional feed ingredients, knowledge about relevant contaminants, the bioavailability and bioaccumulation of these contaminants in the flesh of the fish, and health risks to fish and humans is crucial.

### Priority areas

- Develop alternative, environmentally sustainable feed ingredients not currently used for direct human consumption, including their production, processing and implementation, in feeds for salmon and rainbow trout;
- Utilising new raw materials in fish feed such as by-products and low trophic-level marine species;

- More knowledge about the fundamental biological mechanisms that may be affected by individual feed components;
- Knowledge about how to optimise feeding practices in order to develop practical feeding recommendations;
- Contaminant and nutrient levels in feed and feed ingredients, potential effects of these on the ecology of the seabed, interaction effects of these and how to reduce such levels;
- Insight into the nutritional requirements of fish to ensure the production of healthy, robust fish;
- Develop methodology for quantifying digestion and discharge of nutrients in aquaculture production.

#### **Sustainability perspectives** (social, environmental, economic)

New feed ingredients must be assessed from a sustainability standpoint, including lifecycle analyses and natural resource accounting. It is a clear objective that new raw materials used in fish feed should not be suitable for direct human consumption.

#### **Cooperation and shared interfaces with other Research Council programmes**

The thematic priority area *Nutrition and feed ingredients* shares an interface with the MARINFORSK programme with regard to sustainable harvesting of marine organisms as feed ingredients; with the BIONÆR programme on the significance of feed for safe and healthy food and other effects on end-product quality; and with the BIOTEK2021 programme on bioprocessing of raw materials and genetic aspects of feed utilisation.

## **Thematic priority area 6: Production of marine species lower in the food chain (low trophic-level species)**

### **Objective**

*The HAVBRUK2 programme will generate knowledge for increasing marine bioproduction.*

### **Challenges**

The report “Value created from productive oceans in 2050” anticipates that by 2050 Norwegian aquaculture will encompass far more species than Atlantic salmon and that species at lower trophic levels will account for the bulk of production. Low trophic-level species, with few exceptions, command relatively low prices per weight, which in turn will require industrial production with low production costs. There may turn out to be many application areas for low trophic-level species, including as fish feed ingredients, sources of bioenergy and other industrial purposes traditionally based on fossil sources, and as products for direct human consumption. These are markets and processes that are currently underdeveloped.

Internationally, new production methods that emphasise recirculation of water and nutrients are on the rise. Efforts are underway to develop intensive production of species with high resource efficiency and nutritional value. This is a trend that may emerge in Norway as well, so it is important to focus on resource-efficient production species, and preferably species that can be produced in closed, environment-controlled systems, which also include collection of waste/discharges or utilisation of discharges in new production.

### **Priority areas**

- Production biology for low trophic-level species;
- Knowledge and technology for industrial production of low trophic-level biomass;
- Harvesting technology for low trophic-level biomass;
- Continued development of new production systems;
- Preliminary studies on utilising low trophic-level biomass in feed;
- Knowledge about the sea area needed for production of low trophic-level species;
- Knowledge about the genetic effects of selectively bred low trophic-level species;
- Insight into measurable environmental impacts (positive and negative) and public opinion regarding the introduction of integrated aquaculture/production of low trophic-level species.

### **Sustainability perspectives (social, environmental, economic)**

The world towards 2030 is facing major challenges to produce food not only for a growing global population but also for an increasing proportion of people rising from poverty to the middle class. This entails a food production that must make less use of resources which are currently used for direct human consumption.

### **Cooperation and shared interfaces with other Research Council programmes**

The thematic priority area *Production of marine species lower in the food chain (low trophic-level species)* shares an interface with the ENERGIX, BIOTEK2021 and BIONÆR programmes regarding development and utilisation of marine biomass for various uses (including energy production); and with the BIONÆR programme with regard to catch-based aquaculture and live holding.

## Thematic priority area 7: Genetics and selective breeding

### Objective

*The HAVBRUK2 programme will generate fundamental knowledge for genetic improvement of aquatic organisms.*

### Challenges

Selective breeding work has helped to make Norwegian and international aquaculture more cost-effective while producing more robust fish with increased disease resistance. The classical, systematic selective breeding carried out on Norwegian salmon since the mid-1970s has been a main factor in developing new production species in Norway as well as internationally. New, more precise selection methods such as marker-assisted selection have also proven effective in e.g. boosting resistance to costly diseases such as infectious pancreatic necrosis (IPN).

Selection methods will be complemented by and quality-assured using sequenced genomes. Now that the salmon genome has been sequenced, classical selection methods will be complemented by methods based on deeper biological insight. Non-additive effects (gene-gene interaction), gene-environment interaction and gene expression (epigenetics) can also be better understood and utilised. This new biological insight will help to develop new tools to combat infectious agents and parasites and to safeguard fish welfare and the environment as the aquaculture industry expands. This kind of knowledge puts the industry in a better position to face the challenges of sustainability: utilising new feed ingredients as conventional ones become scarcer, preventing disease and negative impacts on wild fish stocks.

The sequencing of genomes opens up new opportunities across disciplines, for instance by offering deeper insight into host-pathogen interactions, selecting for vaccine response and customising vaccines to fish selected for resistance to various diseases. Genomic information also offers new insight into nutrition and metabolism and thus opens up the possibility of customising feed and feeding regimes to different groups of fish with differing genetic backgrounds and under different environmental and production conditions. This would also enable producers to meet the market demand for seafood with specialised nutritional benefits.

Still, less than 10 per cent of aquaculture worldwide uses systematic selective breeding. International cooperation on selective breeding and genetic research is indispensable, particularly for technology development and knowledge sharing.

### Priority areas

- Enhance fundamental biological knowledge for more precise genetic selection;
- Refine methods for more precise and reproducible recording of phenotypes, e.g. by applying “Big Data” to selective breeding;
- Develop next-generation selection methods that also promote sustainable selective breeding;
- Make use of gene-gene interaction and gene-environment interaction (epigenetics);
- Produce sterile fish in a new way; expand the knowledge base for production of sterile fish that safeguards fish welfare, productivity and the environment;
- Research on the selection of important traits for robust fish;
- Develop genomic tools and apply new selection methods to new species in Norwegian production systems and for international knowledge transfer.

**Sustainability perspectives (social, environmental, economic)**

Targeted selective breeding work has greatly helped the industry to achieve economic sustainability. New knowledge and technology makes it possible to develop new breeding objectives for aquaculture. Greater precision in phenotype recording and the inclusion of multiple traits will add balance and reliability to selective breeding. Efficient feed utilisation, even with the use of new feed ingredients, will be a key selection trait. There is now more and more focus on traits such as health, resilience, product quality, low stress response and tolerance for domestication under new and special environmental conditions. The use of sterile fish may emerge as an important measure for preventing accidental interbreeding with wild stocks.

**Cooperation and shared interfaces with other Research Council programmes**

The thematic priority area *Genetics and selective breeding* shares an interface with the BIOTEK2021 programme with regard to generating basic new knowledge and developing and using genetic tools in the wake of the sequenced genomes; with the BIONÆR programme with regard to the practical utilisation of tools and methods of quantitative genetics, marker-assisted selection and genomic selection; with the MILJØFORSK and MARINFORSK programmes as regards research on genetic interaction between wild and farmed fish.



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