The Research Council of Norway

HAVBRUK Work programme

Applicable from 2018

Large-scale Programme

Aquaculture Research – HAVBRUK

Large-scale Programmes

The RCN initiative to meet national research priorities

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The report can be ordered and downloaded at
www.forskningsradet.no/publikasjoner

English translation: Darren McKellep/Carol B. Eckmann
Graphic design cover: Melkeveien Designkontor AS
Photo cover: Geir Helge Solevaag

Oslo, May 2018

ISBN 978-82-12-03704-5 (pdf)

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1 Summary

The Large-scale Programme on Aquaculture Research (HAVBRUK) is the most important funding instrument for aquaculture-related research at the Research Council and will consolidate and coordinate activities in this field. It is an open-ended programme and a key instrument in the Research Council's efforts targeting the blue bioeconomy, and will follow up the Council's strategy "Research for Sustainable Societal and Industrial Development".

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 HAVBRUK 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, while at the same time safeguarding the environment.

The primary objective for the HAVBRUK programme is to generate knowledge and solutions for socially, economically and environmentally sustainable growth and development in the Norwegian aquaculture industry, and to maintain and further develop Norway's leading position in aquaculture research. Activities under the programme are divided into the following five research areas, each with its own set of objectives:

1 – Societal perspectives, governance and markets
2 – Fish health
3 – Production biology, nutrition, selective breeding and genetics
4 – Production technology and processing technology
5 – Targeted initiatives: Low trophic-level species, Sustainable feed ingredients and Safe and healthy seafood

The HAVBRUK programme will keep a steady course in the ongoing effort to maintain Norway's leading position in aquaculture research. The programme will continue to attach importance to basic research in key research areas and focus on researcher recruitment while working to ensure commercial relevance and provide an open competitive arena for Innovation Projects in the aquaculture industry. At the same time, the programme will seek to take advantage of new opportunities, including boosting research to develop production of low trophic-level species, new sustainable feed ingredients and safe and healthy seafood. 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 scope of the programme covers the entire aquaculture value chain, from selective breeding and feed ingredients to processing and markets. 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 programme will continue to fund social science-based

research to increase knowledge about relations between the industry and society. In cooperation with related programmes and instruments, the HAVBRUK 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 HAVBRUK 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 and challenges

2.1 Strategic perspectives – Blue growth

The sea covers 70 per cent of the earth's surface, but currently accounts for less than five 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 roughly 12-fold, with an average annual growth of approximately nine per cent. Norway 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.

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 who are seeking high-quality seafood. 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.

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. 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.

Further growth in the aquaculture industry is dependent on the development of new knowledge to take advantage of new opportunities and tackle new challenges. In recent years, the production of salmon and rainbow trout has stagnated due to major problems with salmon lice. In autumn 2017 Norway's coastline was administratively divided into production areas, and management of the aquaculture industry now reflects their respective salmon lice situations. This new production structure may have major ramifications for the industry.

The bulk of Norwegian-produced salmon is currently processed outside Norway. Greater efficiency and automation in the seafood industry will be crucial in raising the share of seafood processed in Norway and enhancing the competitiveness of the Norwegian processing industry. It may also reduce waste and improve utilisation of raw materials, in keeping with bioeconomy principles.

In Norway, social acceptance for the aquaculture industry is surprisingly weak compared with other types of food production. The public at large displays varying levels of knowledge about aquaculture,

and the industry encounters vacillating political legitimacy for decisions relating to increased growth at the local and regional level. There is a need for more knowledge about the aquaculture industry among the general public.

There is also limited knowledge about the effects of Norwegian aquaculture activities in the context of international food production and resources. More knowledge is needed 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).

In 2015 the Executive Board of the Research Council decided that aquaculture research activities would be organised under the *Large-scale Programme on Aquaculture Research (HAVBRUK).* The 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 programme is designed 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

A bibliometric analysis of Norwegian research, conducted by Science-Metrix in 2014 and with figures updated from 2017, 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 have made important contributions to the global knowledge pool to further develop aquaculture activities worldwide.

The Large-scale Programme on Aquaculture Research (HAVBRUK) targets the entire research system, from universities, university colleges and publicly-funded research institutes to private companies throughout the entire value chain.

The programme is responsible for promoting research that lays a foundation for socially, economically and, in particular, environmentally sustainable growth. The programme will help to build a sound knowledge base for the aquaculture industry, the government administration and society at large.

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 HAVBRUK programme is an open-ended programme and will consolidate and coordinate aquaculture-related research activities at the Research Council.

3 Objectives for the programme

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

Primary objective

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

Secondary objectives

1) *The programme will fund both basic research and applied research activities for developing technology and know-how to ensure that Norwegian aquaculture:*
    - is a profitable industry with *knowledge-based governance* and *good social acceptance;*
    - is structured to *prevent the transmission of infection, promote good fish welfare* and ensure that *vaccines for costly diseases are available*;
    - is *based on the organisms' biology and nutritional and environmental requirements, and on utilising and developing the organisms' genetic potential;*
    - has *sustainable, efficient production technology for every life stage* and that a large proportion of production is *processed nationally;*
    - includes production of *low trophic-level species*, is based on *sustainable feed ingredients* and produces *safe and healthy seafood.*

2) *Projects funded under the HAVBRUK programme will promote good fish welfare* and *sustainable and ethical production* and *bring new strengths to Norwegian research groups.*

4 Thematic and scientific priority areas

The HAVBRUK programme has a clear industry focus and targets the entire aquaculture value chain, from selective breeding and feed ingredients all the way to the consumer, including processing and markets. The programme is an important instrument with regard to realising the Research Council's activities relating to the bioeconomy.

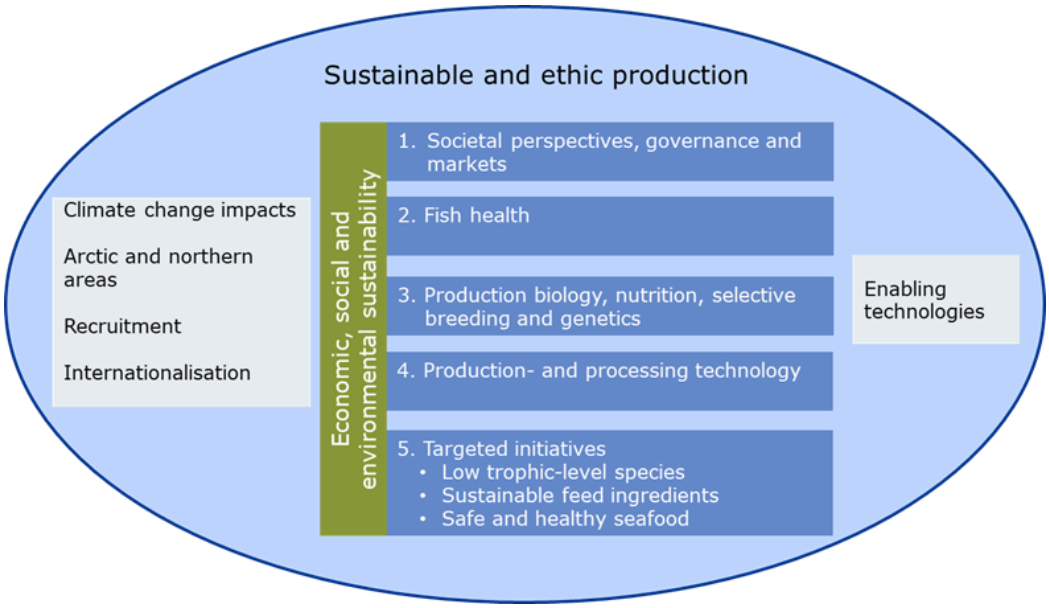
The primary focus of the programme is on the value chain for salmonids, but it also encompasses production of other species, with a focus on lower trophic levels. Other forms of production, for example, at land-based and freshwater fish farms, are also covered under the programme. Good fish welfare and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

The HAVBRUK programme is responsible for knowledge development to ensure the most environmentally sound operation of aquaculture facilities possible. 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. Within the relevant research areas, the programme will intensify efforts to exploit the potential inherent in new biotechnological tools, nanotechnology and ICT.

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. Sustainable, ethical production is a fundamental principle for all programme activities.

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:

- Research area 1 – Societal perspectives, governance and markets
- Research area 2 – Fish health
- Research area 3 – Production biology, nutrition, selective breeding and genetics
- Research area 4 – Production technology and processing technology
- Research area 5 – Targeted initiatives: Low trophic-level species, Sustainable feed ingredients and Safe and healthy seafood



These research areas address the key priorities of the HAVBRUK programme. 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 fosters the greatest possible scientific and societal relevance.

5 Priorities for structuring the research effort

Maintaining Norway's leading position in key areas of aquaculture research requires continually bolstering efforts in terms of both quality and quantity. Therefore, the HAVBRUK programme will:

- attach importance to basic research in key research areas;
- focus on researcher recruitment in projects and in special funding instruments;
- work to ensure commercial relevance and provide an open competitive arena for Innovation Projects in the aquaculture industry;
- use experimental calls for proposals to fund projects involving new, high-risk ideas;
- enhance the participation of trade and industry in research activities by stipulating requirements for the involvement of industry partners in Researcher Projects and by issuing separate funding announcements for Innovation Projects.

To realise opportunities and promote sustainable growth, the HAVBRUK programme will identify priority areas for research. These may vary over the course of the programme period. The three priority areas for research currently selected are:

- step up the level of research activity to develop marine production of new species lower in the food chain;
- boost research on developing sustainable aquaculture feed;
- intensify research on producing safe and healthy seafood.

Sustainability

In order to secure enough food for a steadily increasing global population, marine aquaculture production must expand. Norwegian salmon production and related technology and expertise can help to make seafood an important part of future sustainable food production. To realise sustainable growth in the Norwegian aquaculture industry, however, the industry must ensure that growth does not compromise the environment in the form of unacceptable impacts or unsustainable consumption of resources. These are key challenges for the aquaculture industry and have been a factor in keeping the volume of Norwegian salmon production stable at the 2012 level, without any increase.

Several of the UN Sustainable Development Goals are highly relevant for Norwegian aquaculture productions and associated research and development activities. This applies to food security, nutrition and health, climate change, the oceans and marine resources. The Research Council's Strategy for Sustainability states that research and innovation are necessary for producing the knowledge and solutions needed to address the challenges set out in the sustainability goals. The Research Council plays a vital role in ensuring that the research it funds leads to more sustainable development by incorporating this into its steering documents, funding announcements and selection of projects for funding. The HAVBRUK programme will target its calls for proposals and selection of projects towards finding solutions to the aquaculture industry's environmental challenges and achieving sustainable growth and development in Norwegian aquaculture production.

Internationalisation

Internationalising research activities is important for promoting the evolution of Norwegian research groups and building international networks. The HAVBRUK programme will give priority to projects incorporating international cooperation that enhances the quality of research.

The HAVBRUK programme creates a framework for greater Norwegian participation in the EU framework programmes, both as partners in and coordinators of research projects, and in the ERA-NET scheme. 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).

The priority partner countries outside the EU are the USA, Canada, Chile, Brazil, India, China and Japan. With regard to Nordic cooperation, the HAVBRUK programme will coordinate activities in connection with the Nordic Marine Innovation Programme.

To encourage international cooperation, the HAVBRUK programme will employ specific funding schemes for: Project Establishment Support (PES) for cooperation with countries outside the EU; Personal Visiting Researcher Grants; and, Personal Overseas Research Grants. The programme also employs specific stimulation measures to increase Norwegian participation in the EU framework

programmes, as needed, and when relevant takes part in bilateral joint funding announcements with priority partner countries in addition to participating in the European Research Area (ERA).

Gender balance and gender perspectives

The Research Council seeks the best possible balance between men and women in research activities. The gender balance in the projects funded under the HAVBRUK programme has been relatively good in recent years. This needs to be followed up and maintained. At the same time, it is important to assess whether gender perspectives can be better incorporated into activities under the programme.

A satisfactory balance between the genders ensures a broader perspective in research questions and promotes research that reflects the significance of gender and gender differences in society. It is also important to remain aware that research results may have different implications for women and men.

For the HAVBRUK programme it may be relevant to apply a gender perspective when assessing factors such as ownership and inheritance, consumption and demand, willingness to take risks, the design of jobs and equipment, considerations relating to the environment and fish welfare, the impact of environmentally hazardous substances on fish and on the fish for human consumption, gauging of acceptable threshold limits, etc.

Social dialogue and meeting places

Communication activities are to draw attention to the Research Council's initiatives in aquaculture. The researchers are responsible for publication and dissemination of research results, and the HAVBRUK programme will facilitate communication from the projects by encouraging the researchers to take part in the public debate. The programme's calls for proposals will stipulate more stringent requirements for scholarly publication and the dissemination of research results to users and the general public.

Important communication activities under the programme will include:

- organising the HAVBRUK conference (every other year);
- organising annual gatherings for research fellows;
- providing meeting places for different target groups, from wide-ranging conferences and dialogue meetings on topics relevant to the public debate to dialogue meetings, start-up meetings and purely scientific conferences/meetings;
- using the press/media;
- providing information to the programme's users via programme webpages and social media.

6 Cooperation with related instruments

The HAVBRUK 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 Research Programme on Sustainable Innovation in Food and Bio-based Industries (BIONÆR), the Research Programme on Marine Resources and the Environment (MARINFORSK), the Research Programme on Biotechnology for Innovation (BIOTEK2021), the Innovation Programme for Maritime Activities and Offshore Operations (MAROFF), the Large-scale Programme for Petroleum Research (PETROMAKS 2), the Large-Scale Programme for Energy Research (ENERGIX), the Large-scale Programme on Climate

Research (KLIMAFORSK) and the Programme for Environmental Research for a Green Transition (MILJØFORSK).

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

- **Norwegian Seafood Research Fund (FHF)** – cooperation on funding announcements and events and participation in industry trade shows, and observer on the HAVBRUK programme board;
- **Innovation Norway** – cooperation on events and participation in industry trade shows, and observer on the HAVBRUK programme board;
- **Regional research funds** – cooperation on Innovation Projects for the Industrial Sector, with common application deadlines and joint application review process.

Internationally, the HAVBRUK programme will implement specific stimulation measures to increase Norwegian participation in the EU framework programmes, as needed, participate in bilateral joint funding announcements with priority partner countries where relevant, and engage in relevant cooperation on joint funding announcements within the EU framework.

7 Anticipated results, impacts and societal outcomes

The aquaculture industry and public administration both have a need for relevant research to encourage the development of Norwegian aquaculture in sustainable ways. It is therefore essential that the results from projects funded under the HAVBRUK programme are disseminated to relevant user groups so that new knowledge may be implemented. For this reason, the programme's secondary objectives are formulated as impacts and societal outcomes rather than as deliverables and general quantifying mechanisms at the project level.

The programme logic model (see attachment, page 22) shows the connections between the primary objective, secondary objectives, research areas and priorities for structuring the research effort and the anticipated results, effects and societal outcomes. The programme will perform an initial evaluation of its status in 2018 as a basis for comparison for subsequent evaluations.

8 Resources and budget

The HAVBRUK programme is funded by allocations from the Ministry of Trade, Industry and Fisheries and the Ministry of Education and Research. For 2018, total revenues for research and innovation activities amounted to NOK 189 million.

At the end of 2017 the programme had a funding transfer of 14 per cent due to the launch of the new programme. According to the budget, transfers will become negative in 2019, and the budget provides for allocating 10 per cent above funding in a zero-growth budget. In the HAVBRUK programme's long-term budget, the amount of funding announced is expected to stabilise within the coming years, with NOK 180–190 million available for annual calls for proposals. Detailed plans for the programme's budget, activities and calls for proposals may be found in the annual action plans.

9 Governance and organisation

Programme board

The programme board of the HAVBRUK programme is appointed by and reports to the Research Board of the Division for Energy, Resources and the Environment. The programme board is charged with administering the instruments at its disposal to achieve the programme's objectives. 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 division research board. A list of programme board members may be found on the programme's webpages: https://www.forskningsradet.no/prognett-havbruk/Programme_board

Programme administration

The HAVBRUK programme administration is responsible for carrying out the day-to-day tasks of the programme and performing the administrative functions of the programme.

Application review process

Funding announcements will be in compliance with the Research Council's applicable rules and established application submission deadlines. Requirements and assessment criteria for grant applications will be specified in the individual funding announcements.

Researcher projects and doctoral research fellows 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.

During assessment of grant applications, marks are assigned for the scientific merit of the grant proposal, the relevance of the grant proposal relative to the call for proposals, the benefit of the grant proposal to society, the authorities and industry, and the substance of the grant proposal in relation to relevant ongoing projects.

Based on the marks assigned by the panels, the programme administration will submit a recommendation for projects to be awarded funding to the HAVBRUK programme board. The programme board is responsible for final approval of grant allocations.

10 Attachments to the work programme

- Research area 1 – Societal perspectives, governance and markets
- Research area 2 – Fish health
- Research area 3 – Production biology, nutrition, selective breeding and genetics
- Research area 4 – Production technology and processing technology
- Research area 5 – Targeted initiatives:
    - Production of marine species lower in the food chain (low trophic- level species)
    - Sustainable feed ingredients
    - Safe and healthy seafood
- Key documents
- The HAVBRUK programme logic model

Research area 1:
Societal perspectives, governance and markets

Objective: *The programme will fund both basic research and applied research activities for developing technology and know-how to ensure that Norwegian aquaculture is a profitable industry with knowledge-based governance and good social acceptance.*

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 aquaculture industry must be enhanced, while the industry must at the same time be attentive to public opinion. The aquaculture industry should have the ability to adapt to the many conflicting interests involved in the coastal zone. In addition to being environmentally sustainable, continued growth in the Norwegian aquaculture industry will need social acceptance, predictable framework conditions and knowledge-based governance. This in turn entails developing reliable indicators for assessing sustainability from a number of standpoints (social, economic, environmental, biological and management-related). The Norwegian aquaculture industry is export-oriented, and adequate knowledge and understanding of the requirements and demands of different authorities and markets will be essential to sell large volumes at optimal prices. At the same time, the Norwegian aquaculture industry is a major international actor when it comes to e.g. import of feed ingredients. The Norwegian aquaculture industry has a social responsibility and must remain aware of equity effects and social sustainability, both nationally and internationally.

Relevant research topics include:

- Norwegian social acceptance for the aquaculture industry;
- The aquaculture industry's use of sea area, the sea area needed, and competing interests for sea area;
- The aquaculture industry's use of society's resources and its contributions to society locally, regionally and nationally;
- The significance of the ownership structure for operating conditions and the industry's reputation and framework conditions;
- The significance of ownership structure and other structural factors;
- Markets, financial matters and profitability throughout the aquaculture sector;
- Opportunities and limitations in national transport infrastructure;
- Effects of framework conditions and regulation;
- The government administration's need to weigh different societal interests against the industry's need for efficiency and predictability;
- Companies' responsibility for social and environmental sustainability;
- Updating and transferring knowledge in the aquaculture sector – between industry, public authorities and other industries.

Environmental relevance

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 will 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 HAVBRUK programme shares an interface with a number of programmes at the Research Council regarding social science issues in aquaculture – particularly the MARINFORSK programme in connection with use of sea area in the coastal zone and effects of anthropogenic pressures on ecosystems.

Research area 2: Fish health

Objective: *The programme will fund both basic research and applied research activities for developing technology and know-how to ensure that Norwegian aquaculture is structured to prevent the transmission of infection, promote good fish welfare and ensure that vaccines for costly diseases are available.*

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.

Relevant research topics include:

- Relevant infectious agents (both known and unknown) that lead to diseases with significant impacts on animal welfare, the environment and profitability;
- New methods/strategies to combat salmon lice;
- Specific research questions related to cleanerfish;
- Immunology, agent characterisation, host-agent interactions, boosting fish immune systems, and development of new vaccines and vaccine concepts and strategies;
- Transmission of infection between farmed fish and wild stocks;
- The environment as a depot for pathogens;
- Methods to replace, reduce and refine the use of fish in research;
- Safeguarding fish welfare should be based on fundamental knowledge, practical indicators and an understanding of the impacts of different farming systems/routines on fish welfare.

Environmental relevance

More environmentally sustainable development requires sound solutions to limit the transmission of infection between farmed fish and wild stocks. Preventing disease and mortality will better safeguard fish welfare and the environment as well as improve profitability. 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 research area *Fish health* 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 medications on the natural environment, and to zones and structure of the industry; with the BIOTEK2021 programme, the IKTPLUSS Initiative for ICT and Digital Innovation (IKTPLUSS) and the Research Programme on Nanotechnology, Microtechnology and Advanced Materials (NANO2021) regarding opportunities to develop 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 and about disease resistance in farmed fish.

Research area 3: Production biology, nutrition, selective breeding and genetics

Objective: *The programme will fund both basic research and applied research activities for developing technology and know-how to ensure that Norwegian aquaculture is based on the organisms' biology and nutritional and environmental requirements, and on utilising and developing the organisms' genetic potential.*

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.

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.

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. 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.

Relevant research topics include:

Selective breeding and genetics

- Develop and take advantage of knowledge about the overall genetic material in the environment;
- Opportunities to apply epigenetics in sustainable Norwegian aquaculture;
- Take advantage of the possibilities opening up through gene technology, e.g. new genome editing tools, for use in selective breeding and the production of healthy, profitable production organisms that are safe to consume;
- More efficient selection by taking advantage of new phenotypes and genomic information;
- Opportunities for customisation of different traits and production strategies.

Nutrition

- Nutritional requirements in different species, life stages and production environments for producing resilient fish;
- Sustainable feeding strategies adapted to species, facility type and site;
- Functional components in feed;
- Safe feed for producing healthy, resilient fish;
- Gene technology for producing sustainable feed;
- Characterise high-quality smolt/fry adapted to their environment, and size at transfer to sea;
- Technical feed quality with good digestibility and minimal waste.

Production biology

- Production of sterile fish that safeguards fish welfare, productivity and the environment;
- Effects of the environment on the production organism;
- Optimal environment in various facility types through all life stages;
- Efficient use of resources (water, land/sea area, feed, etc.)
- Multi-trophic aquaculture for good resource utilisation.

Environmental relevance

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

This research area 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; with the KLIMAFORSK programme regarding development of knowledge to predict the effects of projected climate change on salmon welfare and adaptive capacity; and with the BIONÆR programme with regard to the bioeconomy.

Research area 4:
Production technology and processing technology

Objective: *The programme will fund both basic research and applied research activities for developing technology and know-how to ensure that Norwegian aquaculture has sustainable, efficient production technology for every life stage and that a large proportion of production is processed nationally.*

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. Land-based production of salmon as well as other species now comprises a significant portion of the value chain. Large fish farms and other facilities with dense populations of fish, whether on land or at sea, involve operational challenges related to e.g. monitoring and management, precise feeding, and treatment for outbreaks of parasites and diseases – and require suitable locations with good currents, depth and water quality.

A sizable proportion of Norwegian-farmed salmon is processed abroad. There are a number of reasons for the relatively low volume of domestic processing, involving distance to markets, trade barriers and market access for processed products, and cost levels in Norway. New technology to extend shelf life in addition to automation and higher efficiency of processing lines may help to establish a higher proportion of domestic processing of produced salmon.

Relevant research topics include:

- Measuring and monitoring production organisms and the environment inside and outside the facility, including machine vision and sensor technology for decision support in production and condition-based maintenance;
- Digitalisation of aquaculture companies' organisation, expertise and operations, including network technology for processing large amounts of data;
- Technology for efficient production of high-quality feed and technology to facilitate optimal feeding of production organisms in various production concepts;
- New and/or more efficient and sustainable production concepts for utilising different sites for different species and life stages;
- Technology for handling and utilising nutrient waste discharges, sludge and residual raw materials from fish farming as resources in other value chains;
- Technology for preventing and combatting salmon lice, etc.;
- Composition, development and effects of bacterial flora, including biofilm in aquaculture environments, and how to control them;
- Improved safety for humans, fish and environment, especially in relation to high-risk or critical operations;
- Development of specialised vessels and multi-use platforms for aquaculture;
- Energy optimisation and use of renewable energy solutions during production and operation of different technological components;
- New materials and methods to optimise production, forces, weight, operational practises/maintenance, costs and recycling solutions;

- Technology for enhanced welfare and production efficiency by influencing fish physiology and behaviour, including use of lighting, water current, etc., in production;
- Companies' internal logistics and logistics between partners and between the various stages in the aquaculture sector;
- Automation and higher efficiency of processing lines to ensure high quality and full utilisation of raw materials at every stage, including systems for fractionation and collection of residual raw materials;
- Methods and technologies for efficient slaughter of large numbers of fish, e.g. diseased fish, to safeguard welfare, the environment and profitability and prevent the spread of infection;
- Methods and technologies for enhancing traceability and extending shelf life of products, including sustainable packaging of satisfactory quality.

Environmental relevance

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. Technology for fully utilising raw materials and side streams in the processing stage will help to increase resource utilisation and reduce waste.

Cooperation and shared interfaces with other Research Council programmes

This research area 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; with the MARINFORSK and BIONÆR programmes with regard to technology for processing and packaging; and with the MILJØFORSK programmes as regards fish escapes.

Research area 5: Targeted initiatives

Objective: *The programme will fund both basic research and applied research activities for developing technology and know-how to ensure that Norwegian aquaculture includes production of* low trophic-level species*, is based on* sustainable feed ingredients *and produces* safe and healthy seafood*.*

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 lower in the food chain 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, as products for direct human consumption, and other industrial purposes. These are markets and processes that are currently underdeveloped.

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, mesopelagic fish, insects, algae or other low trophic-level marine 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.

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.

1. Production of marine species lower in the food chain (low trophic-level species)

Relevant research topics include:

- All challenges related to production and processing of new marine resources lower in the food chain.

2. Sustainable feed ingredients

Relevant research topics include:

- Alternative sources of protein, lipids and more that can be utilised industrially and do not compete with food for humans.

3. Safe and healthy seafood

Relevant research topics include:

- Safe feed and a clean environment that yields safe and healthy seafood.

Environmental relevance

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 better economic circumstances. This requires food production that must make less use of resources which are currently used for direct human consumption.

Production and use of species lower in the food chain reduces energy costs of food production and will contribute to circular resource utilisation and reduce the environmental impacts of aquaculture.

Cooperation and shared interfaces with other Research Council programmes

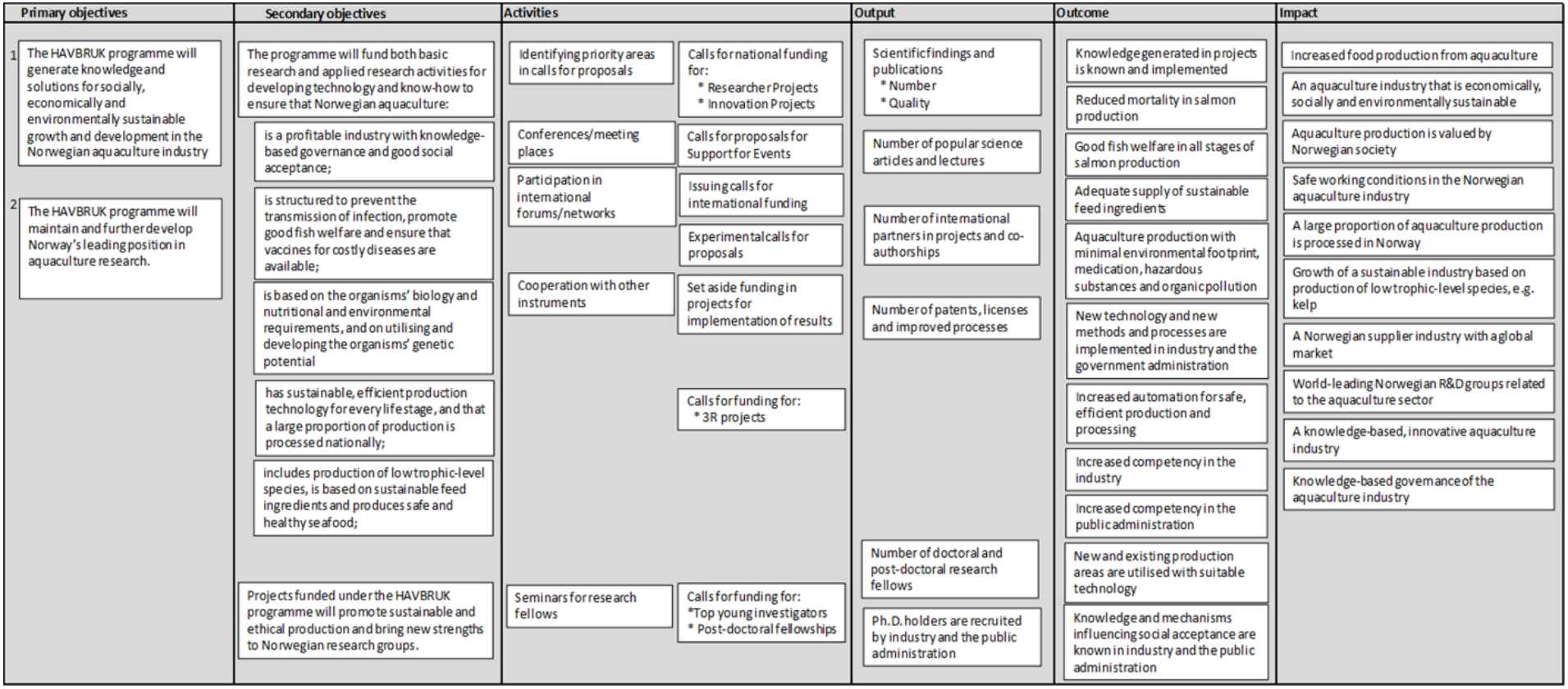
This research area shares an interface with the ENERGIX, BIOTEK2021, MARINFORSK and BIONÆR programmes regarding development and utilisation of marine biomass for various uses; with the BIONÆR programme with regard to land-based resources for fish feed; and with the BIONÆR programme and the Large-scale Programme on Health, Care and Welfare Services Research (HELSEVEL) regarding safe and healthy food.

Key documents

The work programme for the Large-scale Programme on Aquaculture Research (HAVBRUK) is based on the following key documents:

- "Value created from productive oceans in 2050", The Royal Norwegian Society of Sciences and Letters and the Norwegian Academy of Technological Sciences (2012).
- *Fast i fisken. Evaluering av Norges forskningsråds program HAVBRUK – en næring i vekst* ("An evaluation of the Research Council of Norway's programme Aquaculture – An Industry in Growth (HAVBRUK)", in Norwegian), Oxford Research (2013).
- The HAV21 national marine R&D strategy (2012).
- Meld. St. 7 (2014–2015) Long-term plan for research and higher education 2015–2024, white paper from the Ministry of Education and Research.
- "Positional analysis of selected countries in Fisheries & Aquaculture with the mapping of their collaboration with Norway, 2003-2012", Science-Metrix (2014, with updated figures from 2017).
- The Research Council's strategy "Research for Sustainable Societal and Industrial Development" (2017)

The HAVBRUK programme logic model



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Publisher:
© The Research Council of Norway
www.rcn.no/havbruk

May 2018
ISBN 978-82-12-03704-5 (pdf)

Design cover:
Melkeveien Designkontor AS
Photo cover: Geir Helge Solevaag
English translation: Darren McKellep/
Carol B. Eckmann