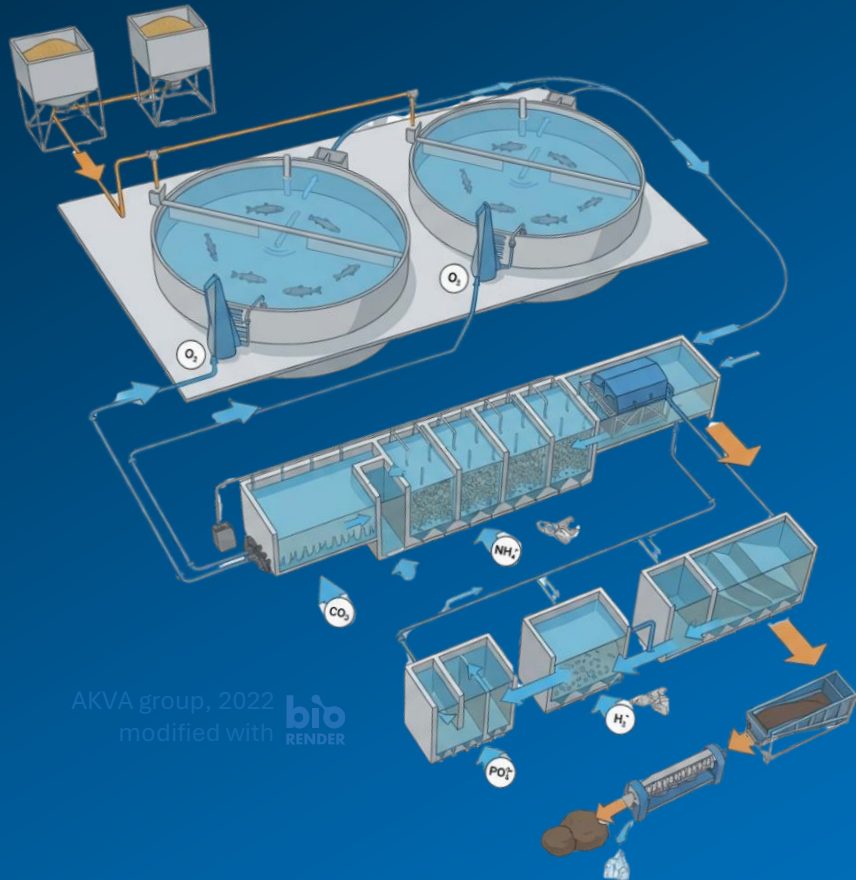




SINTEF

# Land-Based Aquaculture

Reflections on salmon smolt RAS success, market-size production challenges, and the potential of standardized and modular small-scale systems



AKVA group, 2022  
modified with **bio**  
RENDER



Illustration by AKVA Group

Roman Netzer • SINTEF Ocean, Norway  
AQUAXMGRID Initiative Symposium • Tokyo • March 17, 2026



SINTEF

ONE OF EUROPE'S LARGEST **INDEPENDENT**  
**RESEARCH ORGANISATIONS**

**4,0 bill NOK** (~ \$ 400M)  
turnover

**2200**  
employees

**7000**  
projects

**3200**  
customers

INTERNATIONAL TURNOVER

**652 mill NOK** (~ \$ 68M)

NATIONALITIES

**80**

PUBLICATIONS (INCL. DISSEMINATION)

**6200**

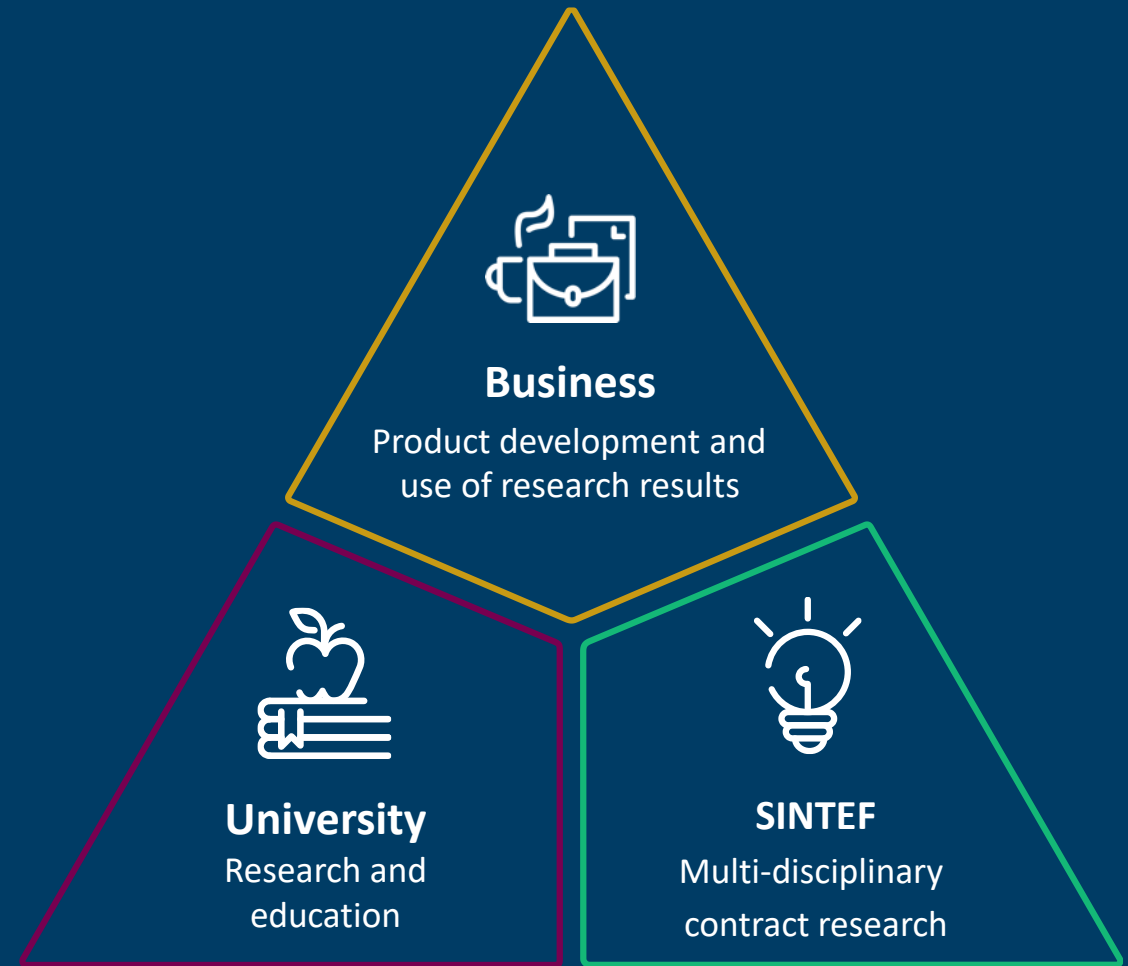
CUSTOMER SATISFACTION

**4,5 / 5**



SINTEF

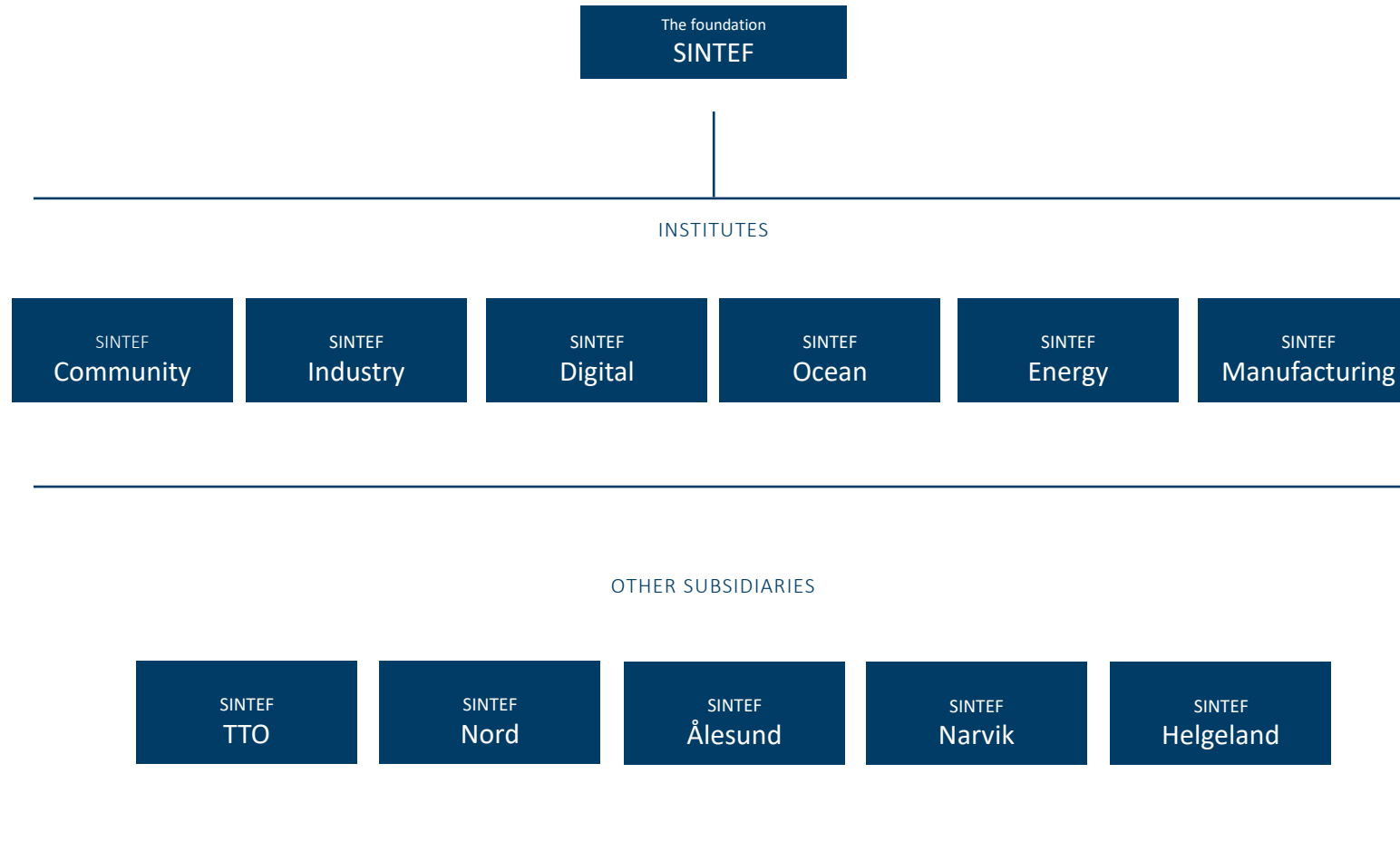
# Innovation through co-operation and expertise



> 90% funding from third parties



# Our organisation – a multidisciplinary science group



# SINTEF Ocean's purpose and core areas

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«Together, we develop ocean industries for the future»

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FOOD



ENERGY



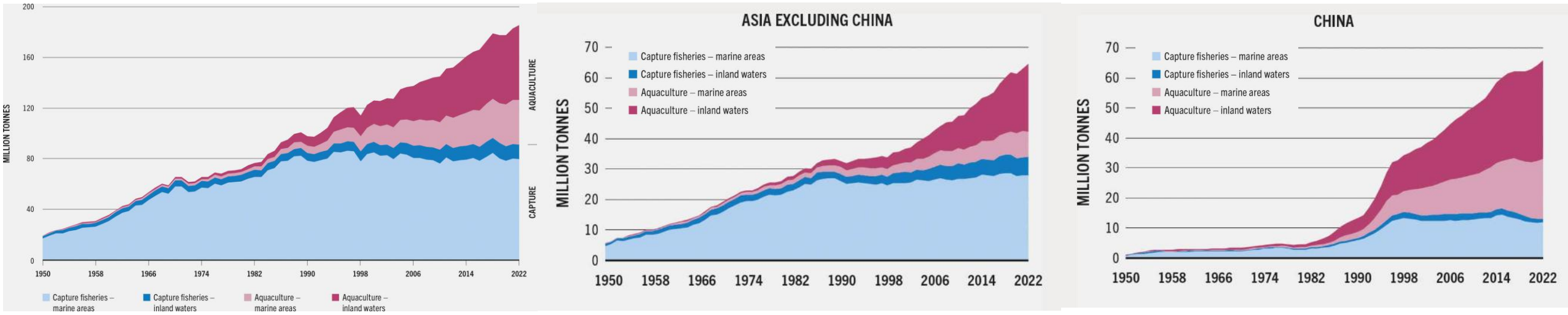
MARITIME



ENVIRONMENT

# Fisheries and aquaculture production

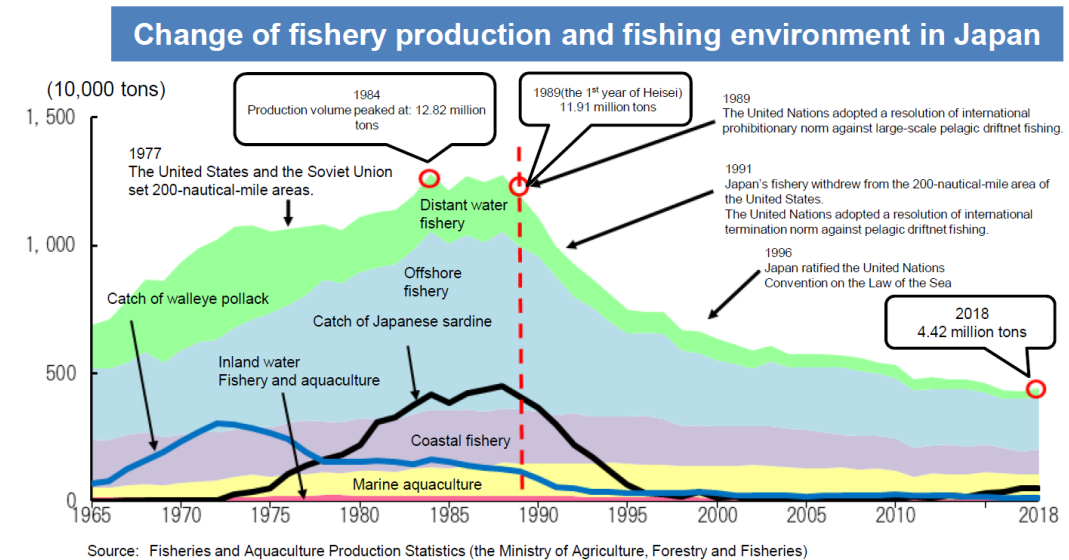
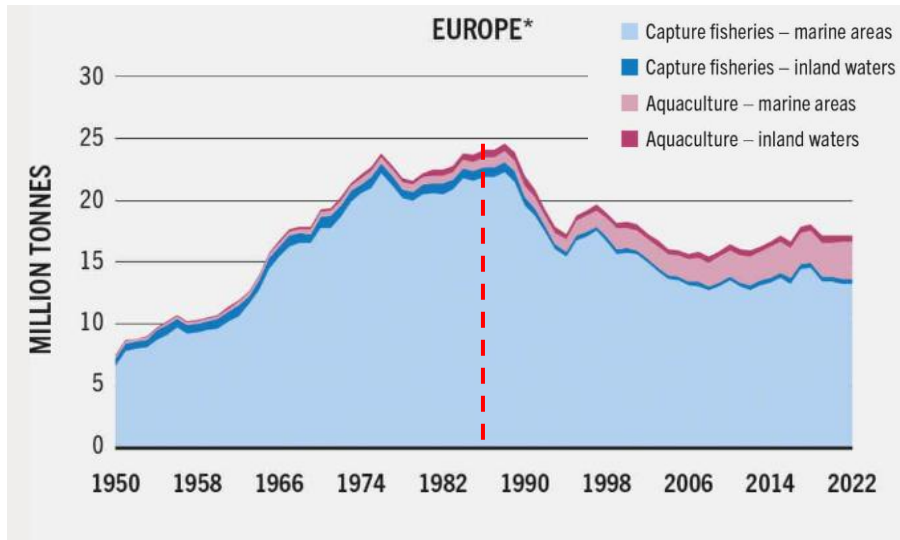
## Worldwide and Asia



- Worldwide ~ 50% of total seafood is produced in aquaculture
- Demand on high-quality seafood protein is growing
- Capture fisheries is stagnant
- Aquaculture is continuously growing worldwide and in most of Asia
- Massive growth of aquaculture production in China since the late 1980s

# Fisheries and aquaculture production

## Europe and Japan



- Significant decline in capture fisheries since the late 80s in Europe and Japan
- Aquaculture production in Japan has been stagnant for > 40 years; very slowly growing in Europe

### Reasons:

#### Japan

- Establishment of 200-nautical-mile Zones (EEZs)
- Collapse of major pelagic stocks
- Overfishing and weak resource management
- Coastal habitat degradation and climate change

#### Europe

- Overfishing
- Ineffective fisheries policy
- Stock rebuilding measures
- Climate change

# R&D on RAS - Recirculating Aquaculture Systems

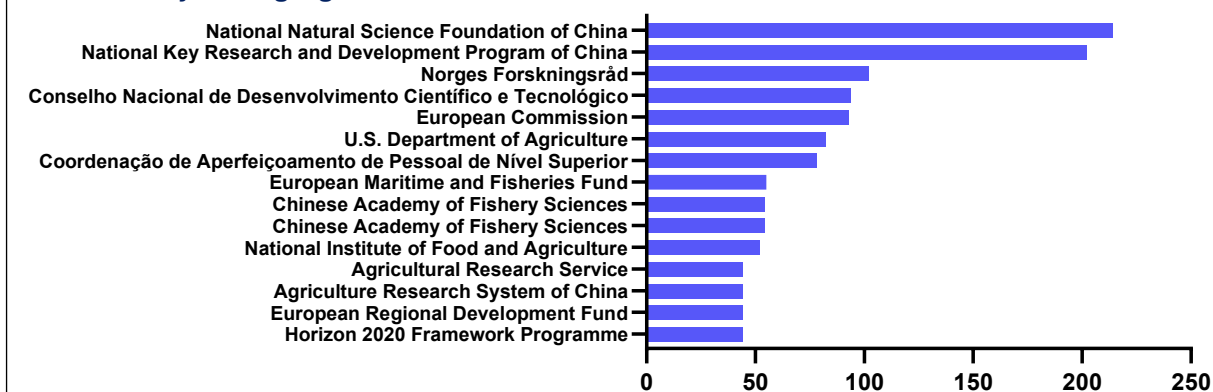
## Modern RAS research started in Japan and resulted in a viable business:

- Earliest scientific research on RAS was conducted in Japan in the 1950s focussing on biofilter design for carp production
- No commercial adoption due to high construction and operating costs and farmer inexperience
- 1960s–1980s, Germany and Denmark advanced RAS into more robust “factory” fish farming concepts and commercial applications

## RAS research situation:

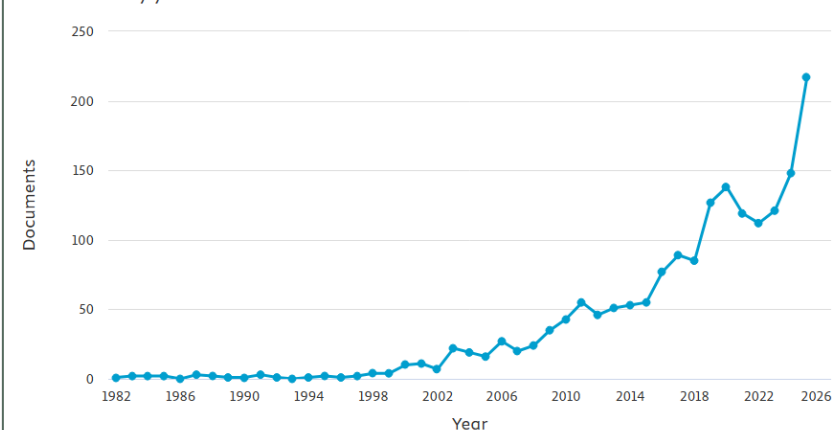
- Research on RAS has been growing massively since late 1990s worldwide
- China became dominating in RAS research since 2012
- China and US are dominating research on RAS today
- Direct correlation between R&D and market dominance

Documents by funding organization 2012 - 2026



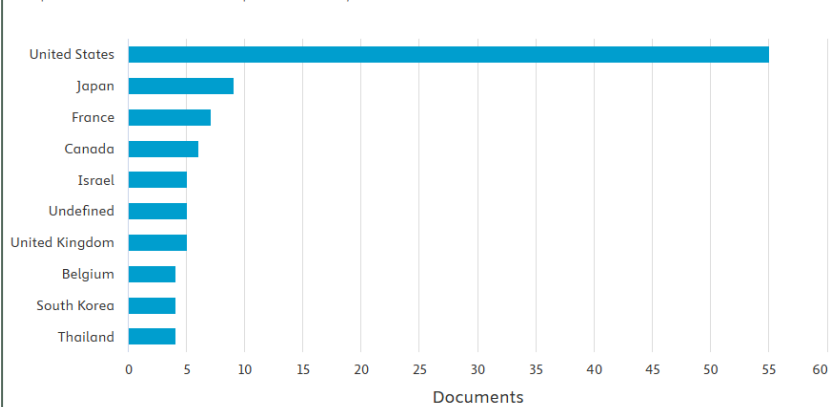
SCOPUS query : (KEY(recirculating aquaculture systems))

Documents by year



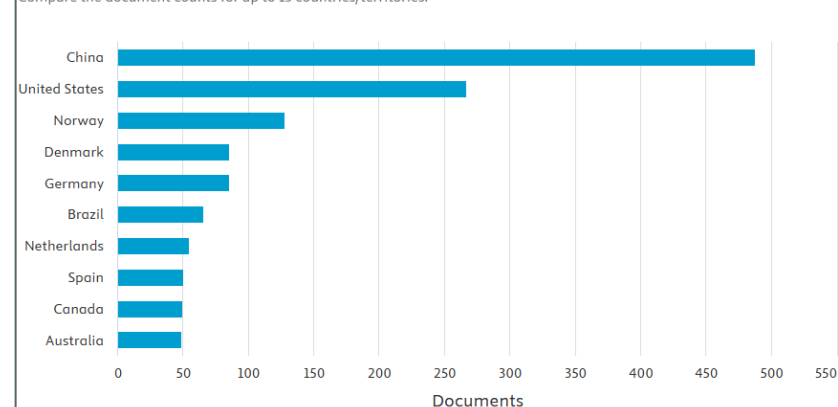
Documents by country or territory 1982 - 2005

Compare the document counts for up to 15 countries/territories.



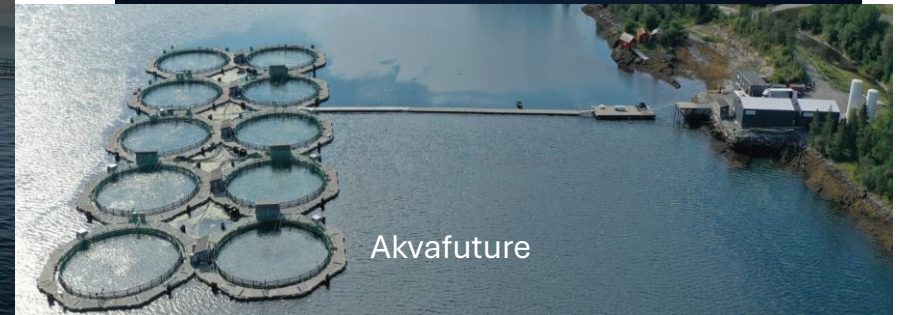
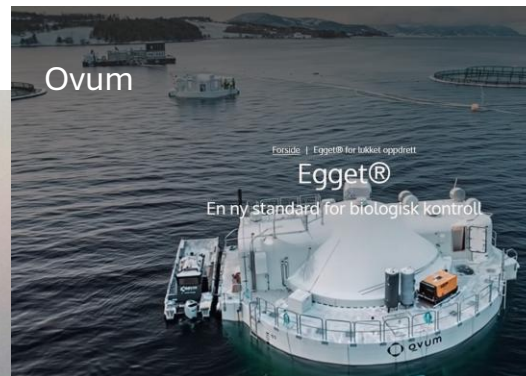
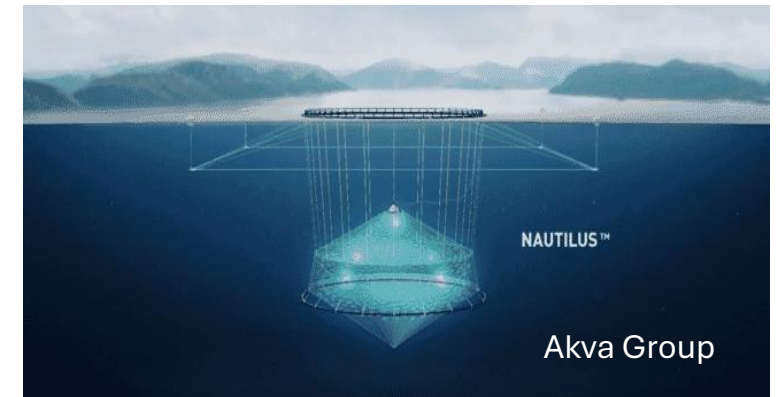
Documents by country or territory 2006 - 2026

Compare the document counts for up to 15 countries/territories.



# Norwegian salmon aquaculture

- Atlantic salmon farming on a commercial scale started 1970, with the first successful sea-cage production
- Today, Norway is the world's largest Atlantic salmon producer
- More than half of all farmed Atlantic salmon worldwide
- > 450 million farmed Atlantic salmon in net pens along the Norwegian coast
- Traditional ocean net pen systems dominate production
- Growing pressure: sea lice, disease, environmental concerns
- New production methods are currently under implementation
- Strong consolidation trend: from 365 to 65 companies within 30 years



<https://doi.org/10.1016/j.aqrep.2019.100216>

<https://thefishsite.com/articles/akva-steps-up-submersible-salmon-cage-technology>

<https://www.akvafuture.com/>

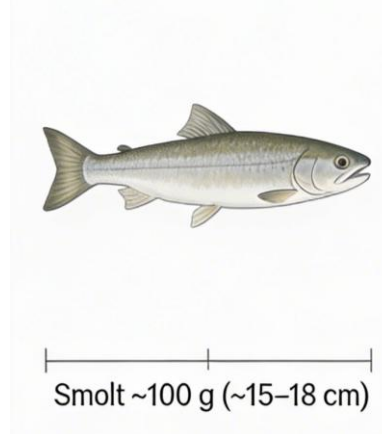
<https://www.ovum.no/>

<https://www.fishfarmingexpert.com/fish-farm-ocean-farm-1-offshore/now-we-get-down-to-work-says-salmar-chief/1309692>

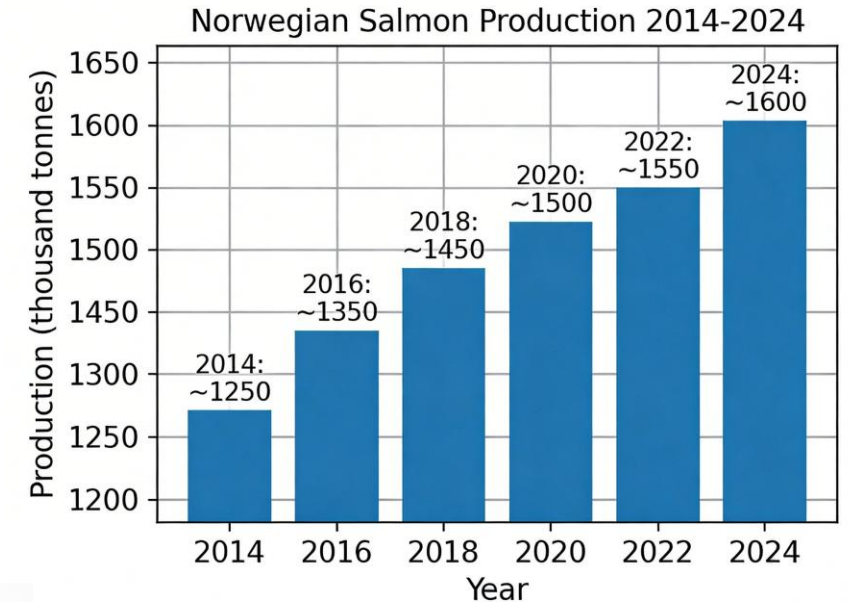
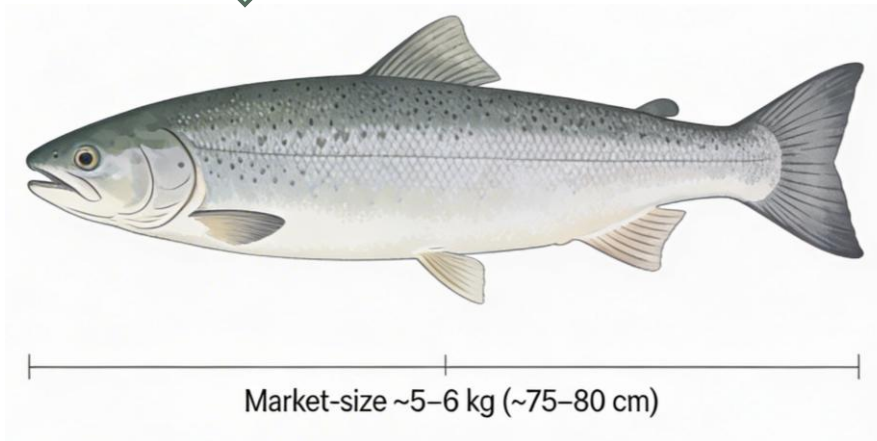
# Norwegian salmon aquaculture – Production method

Key to success of salmon production in Norway: 2-stage production process

## 1. Smolt production in land-based systems



## 2. Grow-out in net pens



- Norway dominates global salmon production with ~1.6M tonnes (2024)
- Steady growth trajectory: +28 % increase from 2014-2024

# RAS for smolt production: A success story?



<https://us.asc-aqua.org/2021/05/24/explained-what-is-ras-aquaculture/>

**YES!**

**But:** Even the most modern RAS facilities have problems!

- ~230 licensed hatcheries producing >400 Mio smolts annually
- In total ca. 350 commercial land-based aquaculture facilities in Norway
- Rapid conversion from flow-through to RAS technology (**estimated 150-250 RAS today**)
- Production scale: 2-6 Mio smolts per facility/year
- **Target smolt sizes increasing:** 100 g → 250 g → 1 kg
- Grieg Seafood just announced to test grow-out in post-smolt facility (4.5-5 kg, 1,500 t)

# Key success factors for smolt RAS

- **Limited time on land (10-18 months depending on target size)**  
→ Prevents the cascading problems seen in long-term RAS operations (decreasing water quality)
- **High-value product with guaranteed market demand (for years, there has been a shortage on salmon smolt)**  
→ Every salmon farmer needs smolts, demand is essentially guaranteed, high production security by long-term contracts
- **Proven water treatment technologies implemented at large scale**  
→ Biofilter technology, oxygenation, CO<sub>2</sub> stripping, particle removal, etc. is well established
- **Intensive production enables strong economics → R&D-supported technology development**

## SalMar Senja:

29 Mio smolt/y (120 g)

Images from UltraAqua



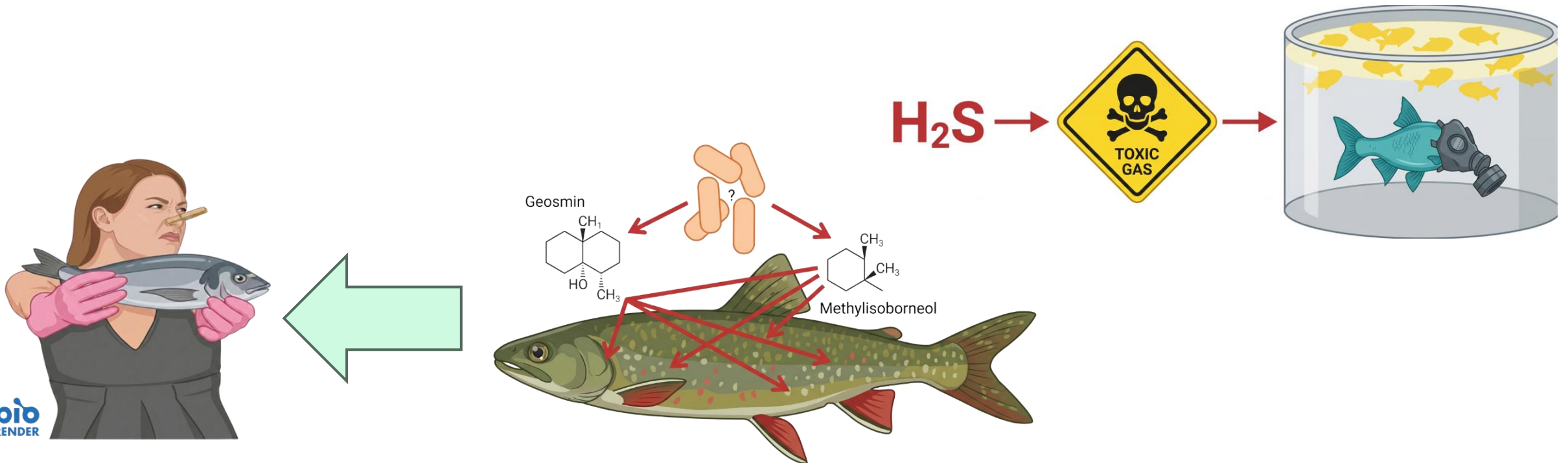
## First pre-built RAS modules



# Challenges in market-size salmon production in RAS

- Extended time on land: 20-30 months vs 10-18 months
- Exponentially higher biomass and organic loading
- Changing water chemistry and microbiota

- Declining water quality, declining growth rate
- Potentially higher salinity increases risks for  $H_2S$  production  $\rightarrow$  sudden mass mortality
- Off-flavour compounds  $\rightarrow$  reduced quality

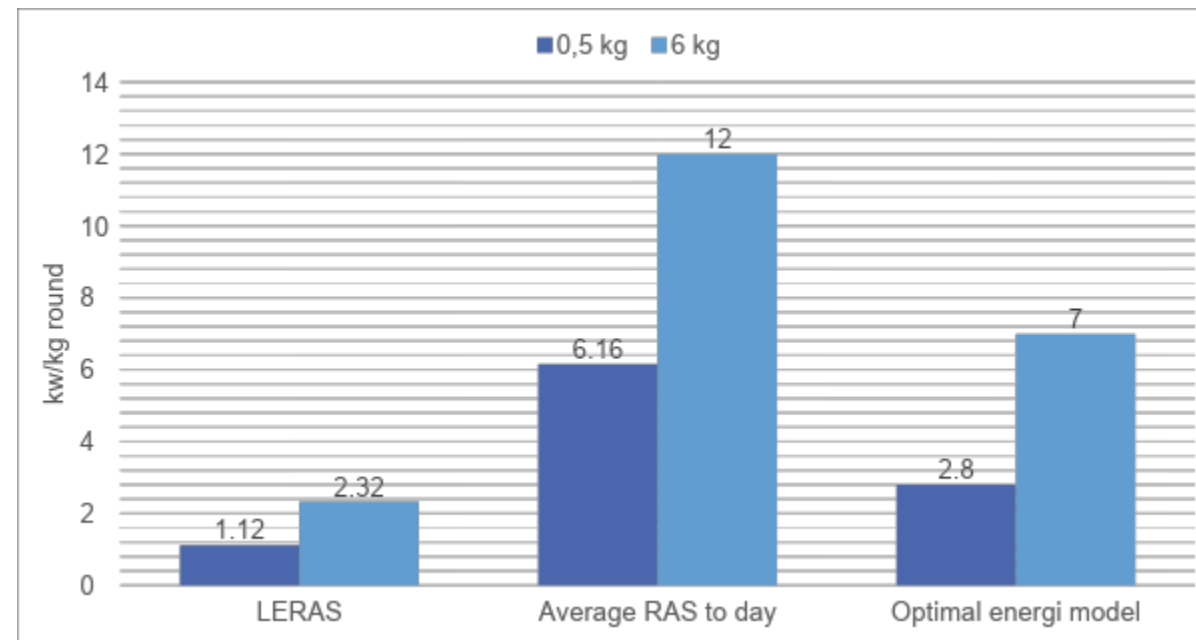


# Economic challenges for salmon RAS

- Massive investments costs for large RAS facilities + high operating costs + high operational risk
- Production costs: 2-3x higher than sea cage farming
- Few facilities demonstrate profitability
- Energy-efficient technologies can reduce production costs significantly
- Market-size fish production in RAS can, **BUT has not to be** as cheap as in sea-cage production.

## Potential for

- ➔ Higher premium quality
- ➔ Better fish welfare (e.g. no de-lousing required)
- ➔ More sustainable and local production



# The scale paradox

## Industry thinking

"Go big" - need 5,000+ tonnes for profitable production

## Reality

Most market-size RAS struggle at any scale. Technical challenges don't scale away.



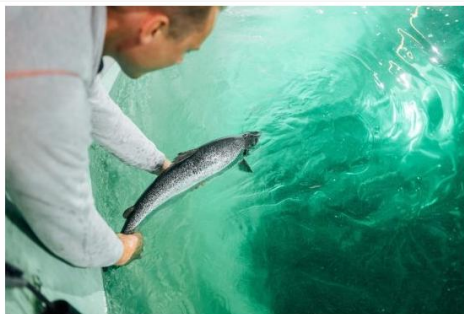
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News > Industry update Systems

### Atlantic Sapphire reports emergency harvest, growing mortality rates

October 18, 2022

By Nestor Arellano



(Image: Atlantic Sapphire)

Growing mortality rates at its Miami-based recirculating aquaculture system facility has dampened harvest expectations for Norwegian land-based aquaculture company Atlantic Sapphire.



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### Proximar Seafood loses 170,000 fish due to 'human error'

May 30, 2025

By RAStech staff

Proximar Seafood reported a fish mortality incident at its Oyama, Japan facility that has led to the loss of an estimated 170,000 fish.

The [company statement](#) outlines that the incident took place overnight where circulation pumps went offline and oxygen levels in two tanks fell below critical levels, leading to the loss of fish.

"In preparation for an upcoming fish transfer, an empty tank was being filled during the night. Due to malfunctioning automated valves, the operation was handled in manual mode. However, due to human error and breach of procedures, the level in the pump sump went below the minimum set point, leading the circulation pumps to stop. Following this, the oxygen level in two tanks fell below critical levels, leading to mortality," the statement read.



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### Nordic Aqua reports lower harvest volumes due to off-flavour

July 25, 2024

By RAStech staff



(Image from Nordic Aqua Partners)

Nordic Aqua, an Atlantic salmon RAS farmer, has announced that about 190 metric tonnes of head-on-gutted (HOG) fish are ready to be harvested after detecting an off-flavour compound in the fish.

# Salmon aquaculture in RAS

## Public plans, October 2019



- **Total planned capacity:** ~700,000 tonnes of market-size salmon in RAS
- **Geographic distribution:** Major investments across North America (317,000 mt), China (137,000 mt), Norway (165,000 mt), and emerging regions
- **The reality check:** By 2024, actual global RAS salmon production reached only 20,000-25,000 tonnes (<5% of 2019 projections)
- **Key lesson:** Massive gap between announced plans and operational reality highlights technical, economic, and biological challenges at scale

Source: Rabobank 2019

### 2025 status:

- Investor interest in RAS/land-based aquaculture has accelerated despite enormous operational and financial challenges!
- Significant increase of investments in land-based aquaculture: > \$ 2 billion, > 90% in Atlantic salmon projects  
Notable projects in Norway, Iceland, and Japan (Spheric Research, Land-based Aquaculture Report 2025).
- Industry forecasts project the global RAS equipment market to more than double to \$ 9 billion by 2031 (7.2 % CAGR), driven by water-use regulations and urban proximity advantages (The insight partners, 2025).

# Large-scale market-size salmon production on land

- Salmon Evolution – Norway - FTS - Seawater → currently 4,400 t/y; 36,000 t planned
- NOAP – China – RAS – Freshwater → currently 2,000 t/y Atlantic salmon; 20,000 t/y planned
- Proximar - Japan – Freshwater → currently 5,300 t/y Atlantic salmon
- Pure Salmon Japan – current design for 10,000 t/y Atlantic salmon

## .... Start small(er)...???

- NTT Green & Food – Japan → planning to produce 310 t/y trout & 260 t/y coho salmon in 2026

## Huge loan for Japanese RAS project

News 04 Jun 2024 by Vince McDonagh



The Japanese aquaculture company, Soul of Japan, has secured a huge 33 billion yen loan (£165m) to develop and build a RAS salmon facility in the country.

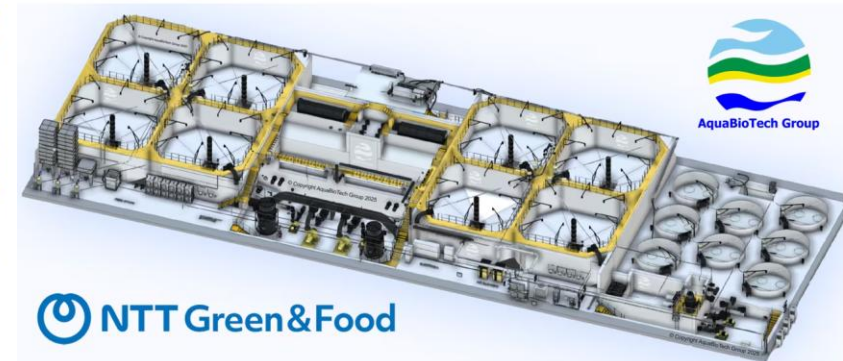


File photo of fish being processed at Nordic Aqua Partners' facility in Ningbo, China. The company is carrying out a private placement of shares to raise funds to compensate for lost income in Q3 after problems with geosmin. Photo: Nordic Aqua Partners

## Nordic Aqua Partners raises extra funds after 'off flavour' problems in RAS

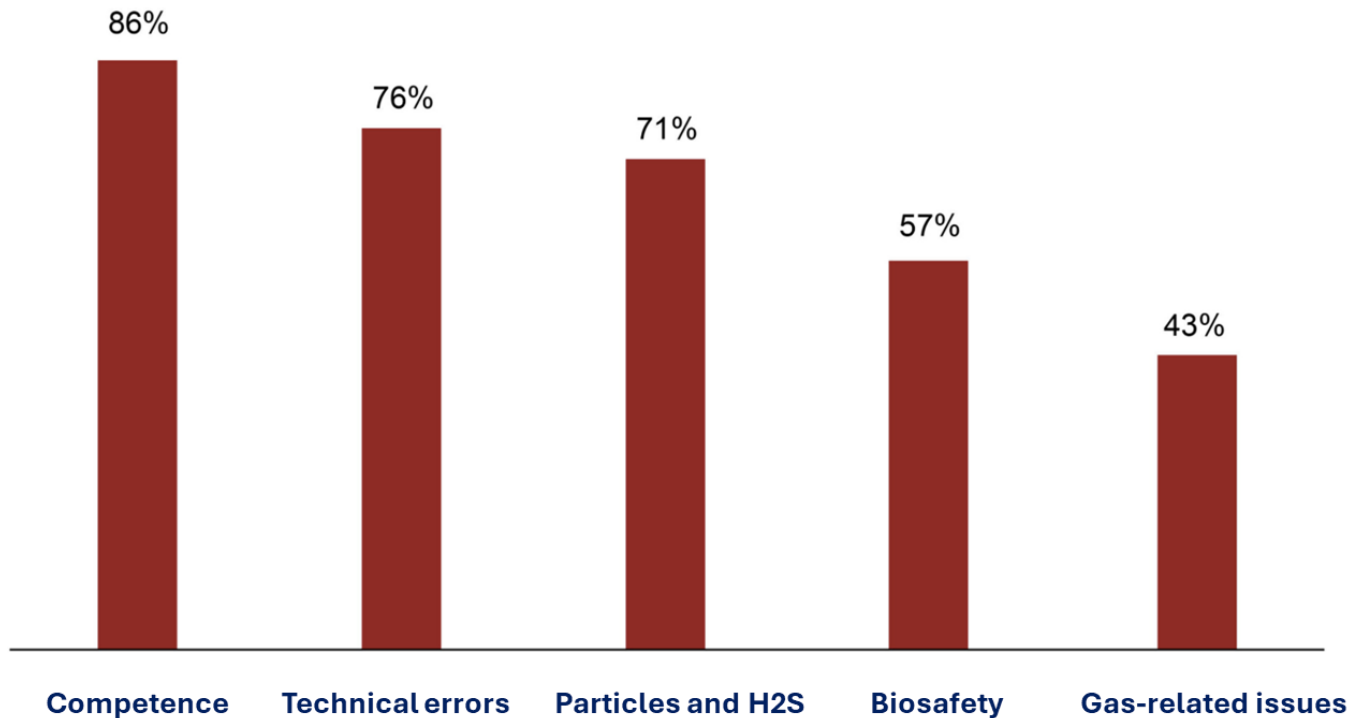
## Major RAS salmon and trout facility to break ground in Japan

NTT Green & Food (NTT G&F) is set to begin construction in early 2026 on a major Recirculating Aquaculture System (RAS) facility for Coho Salmon and Trout in Kesennuma City, Miyagi Prefecture, Japan.



 NTT Green&Food

# Major risks in land-based aquaculture



Atlantic Sapphire's RAS facility in Denmark. Photo: Atlantic Sapphire.

## Atlantic Sapphire blames human error for fish die-off

On-land salmon farmer Atlantic Sapphire has blamed human error for the loss of around 400 tonnes of fish at its recirculating aquaculture system (RAS) facility in Denmark.

Editors

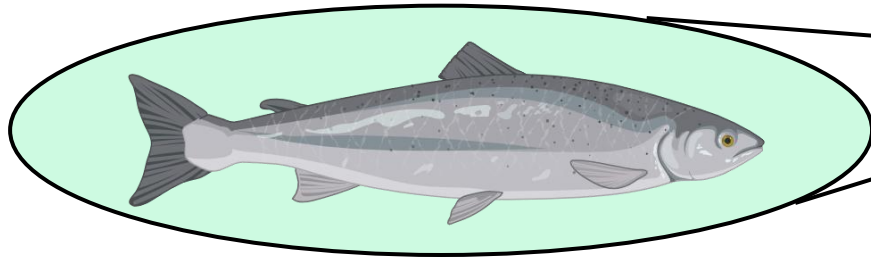
PUBLISHED 12 July 2021 - 09:35 MODIFIED 12 July 2021 - 10:06



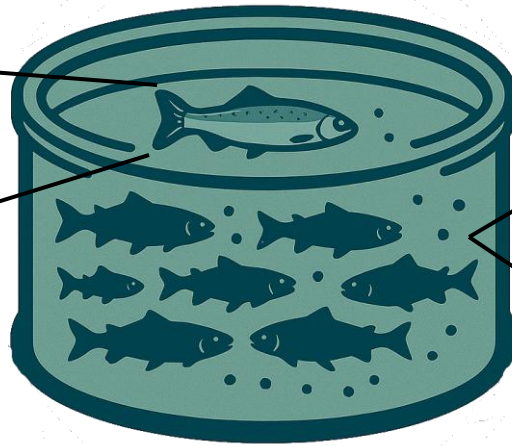
Based on a survey of 14 commercial salmon smolt RAS in Norway conducted by Morefish, human factor is pivotal.

# RAS contains more than just fish

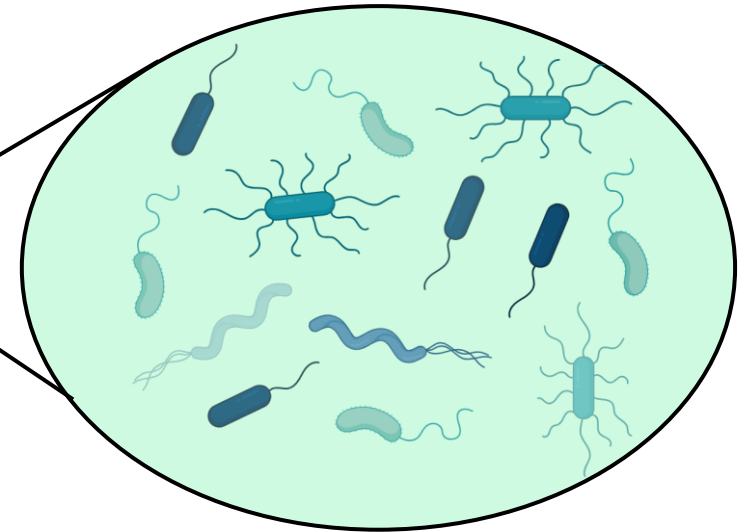
## Fish



- Fish welfare
- Product quality
- Productivity
- Sustainability



## Microorganisms



- Consumes up to 30-70% of the oxygen in a RAS
- Critical for water quality
- Important for system stability
- Microbial community structures are critical in RAS

# In the blind spot - Microbial communities

Knowledge and control of microbial communities is the key to successful RAS operation

## The good,



- Probiotics
- Nitrifying bacteria
- Denitrifying bacteria

## the bad



- Pathogens
- Virus

and

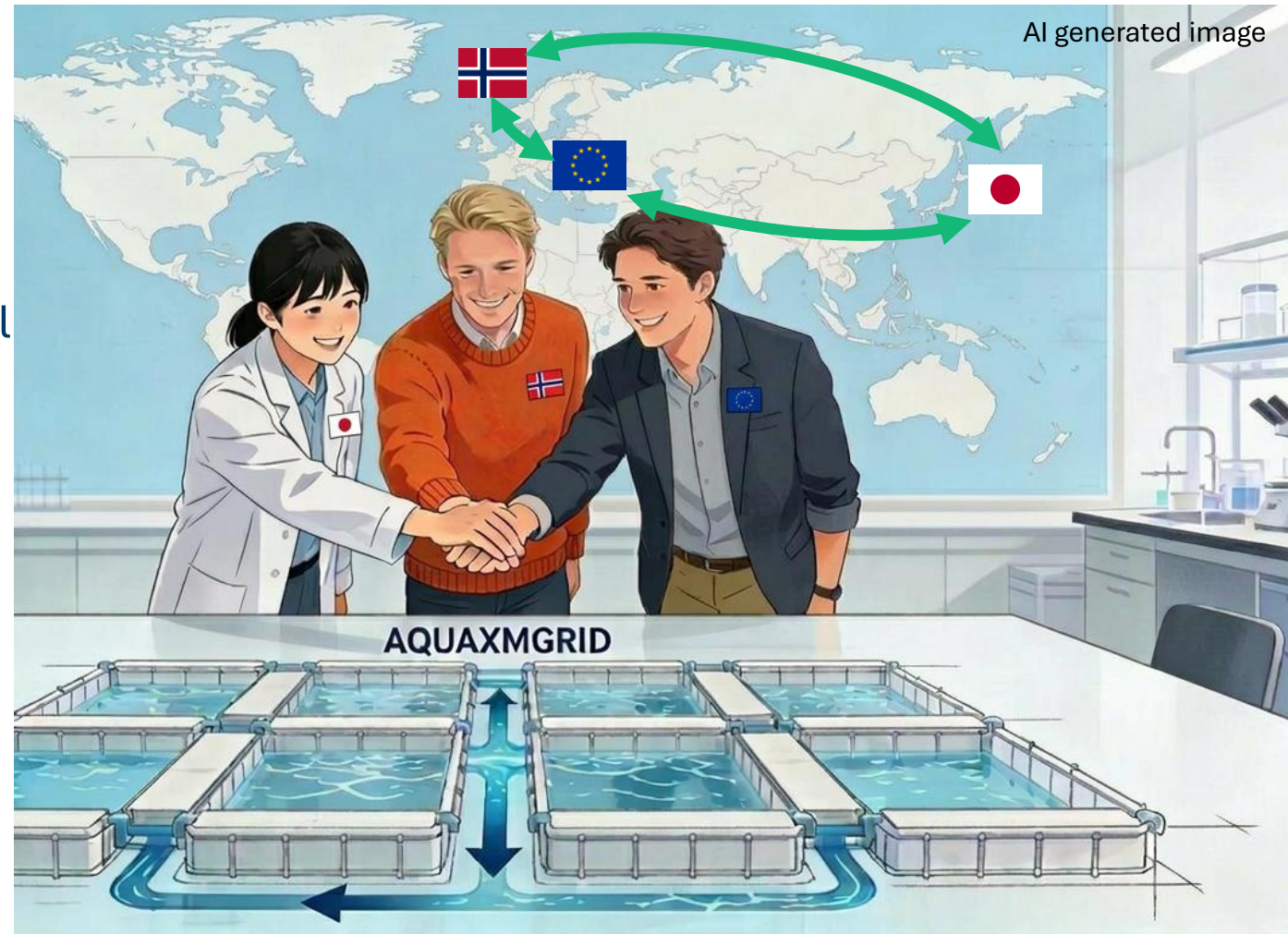
## the ugly?



- Off-flavour producing bacteria
- Sulfate reducing bacteria
- Opportunistic microbes
- Protists, algae,...

# AQUAXMGRID - Pathway to viable and sustainable land-based production

- Develop standardized modular platforms for rapid deployment of RAS
- Focus on species where RAS provides clear advantage
- Stimulate local production, **complementary** to mega-facility and long transportation model
- Integrate renewable energy and digital solutions from design stage
- Make it easier and less risky to start aquaculture business.



# Summary and conclusion

- Salmon smolt RAS success provides valuable lessons on technology and standardization
- Market-size salmon production in RAS faces persistent challenges
- RAS for market-size fish production remains an infant but rapidly emerging technology
- Alternative approach: standardized, modular, small-scale systems
- International collaboration is important to achieve global impact
- RAS has strong potential to enhance sustainable seafood production worldwide
- Public funding to support robust, R&D-driven collaborations is required to build a resilient industry



**Together, we have the brains and muscle to advance sustainable RAS innovation.**

# Thank You!

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In collaboration with University of the Ryukyus and AQUAXMGRID Initiative



琉球大学  
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