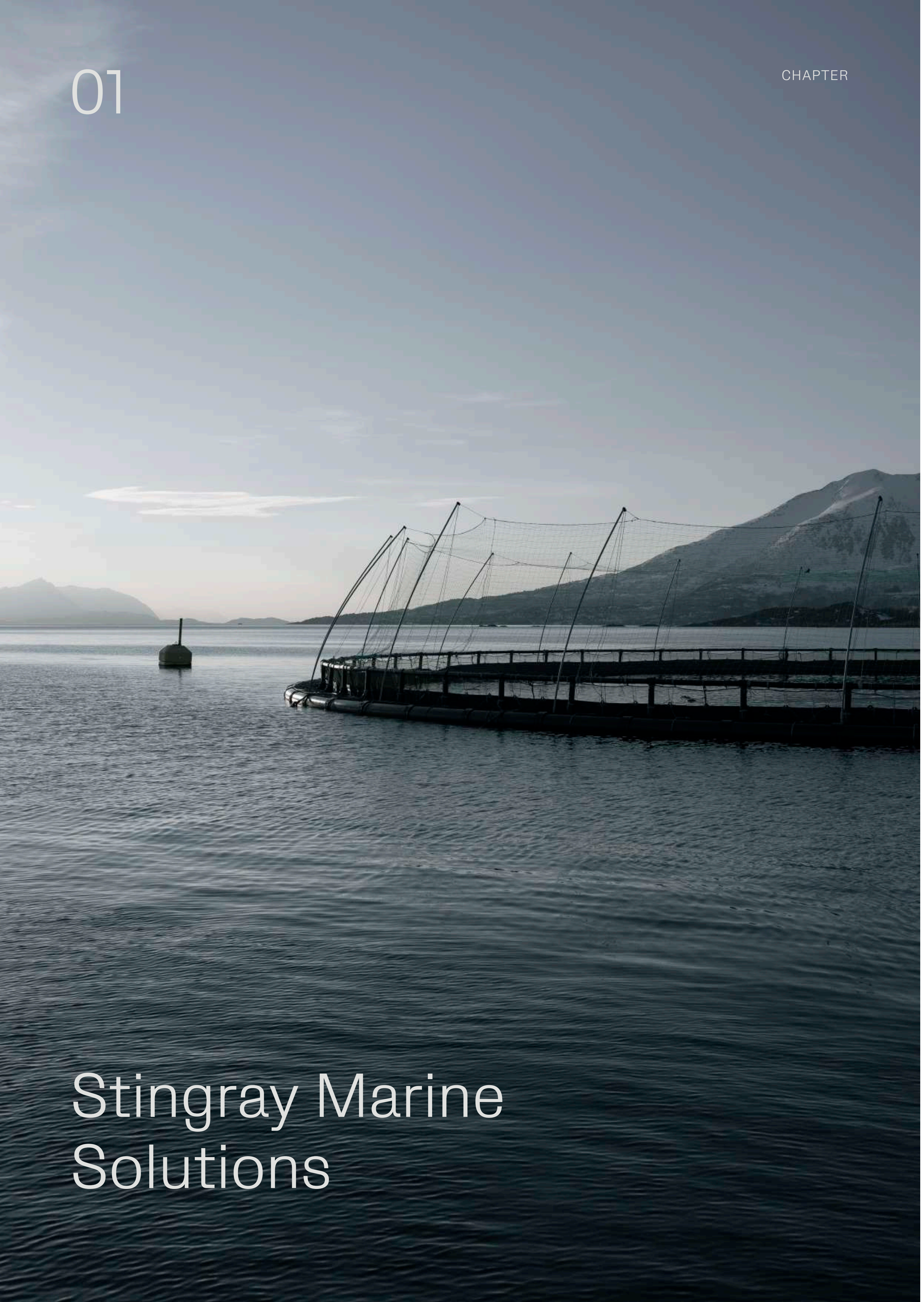
# Laser focus on Fish Health

Annual report 2023

Stingray






01.1

# Stingray Marine Solutions AS

Stingray Marine Solutions AS provides intelligent technology for sustainable and welfare-friendly salmonid aquaculture.

The Stingray system utilizes stereo-machine vision, artificial intelligence, and high-precision laser technology to gently and efficiently remove parasitic sea lice from farmed fish.

Modern data infrastructure and advanced information processing turn each Stingray node into a Fish Health Hub™ that provides valuable diagnostics in actionable reports to farmers.

This empowers our customers to optimize production by focusing on fish welfare and minimizing the need for handling of their animals.

01.2

# Organizational structure

Founded in 2012

Commercial since 2014

160 employees (*January 2024)

Offices in Oslo and Fauske

Factory in Oslo

Proud producers of Stingray nodes,
made in Norway

| | |
|---|---|
| Hardware | Production of node components and assembly of the finished product |
| Software | Development of bespoke software applications, detectors and continuous updates |
| Aqua | Customer support & advice, biological monitoring, research, and development |
| Operation | Node service, infrastructure, technical support and installation optimization |
| Control | Daily operation of the nodes, biological and technical customer support, and customer training |



01.3

# Our philosophy

### **T**ydelig

Clear organization, processes, and communication. Structured routines, optimized workflows, and updated applications.

### **Æ**rlig

Honest communication and action both internally and externally to build trust. Trust and customer satisfaction necessitate openness and integrity.

### **L**idenskapelig

Passionate pride in what we do, aiming to deliver the best possible product and services. We are passionate about our customers and fish health.

**Noun**
**tæl** *m (definite singular tælen, indefinite plural tæler, definite plural tælene)*

1. perseverance, drive, determination, doggedness, grit, sisu

01.4

# Our history

### 2014
Commercial launch

12 nodes produced

### 2015
Node tripling

... and an increase in laser pulses of 1300% in one year

### 2016
Lice kills

4.1 million salmon lice killed since commercial launch

### 2017
Continuous node increase

178 nodes produced since 2014

### 2018
Image-based lice counting

Release of image-based sea louse counting application

### 2019
Node #350

transported to the customer

### 2020
Fish passings

launched for better understanding of performance

### 2021
Stingray Aqua

The Aqua Vertical is established

### 2022
Post stamp

Issued in stamp collection booklet "Research, Innovation, Technology", Posten Norway 1. oct 2022. Printrun: 220.000

**And still going strong**

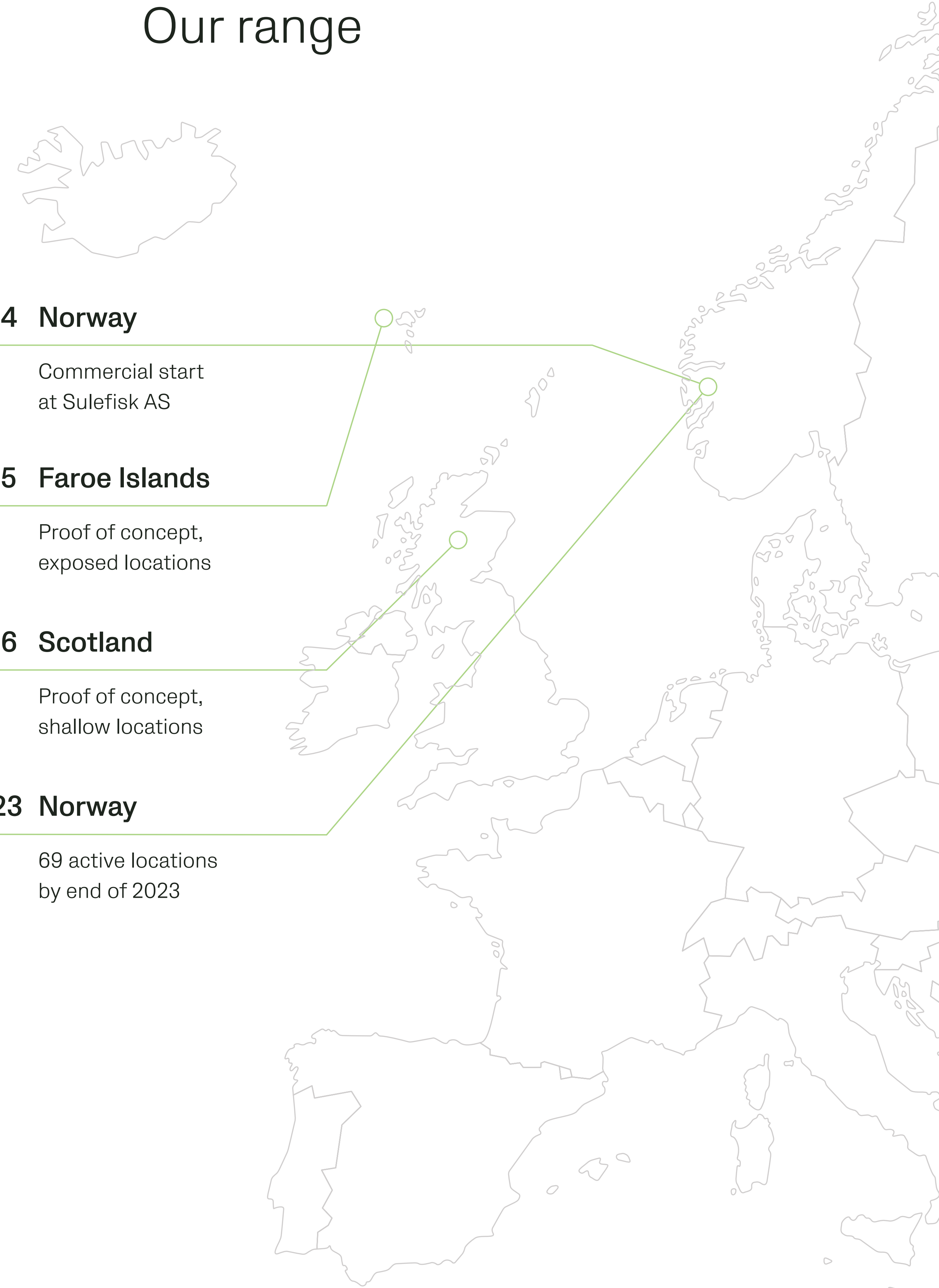
Nordlaks, August 2023
Milestone celebration

# Installation of Node 1000





# Our range



**2014 Norway**

Commercial start
at Sulefisk AS

**2015 Faroe Islands**

Proof of concept,
exposed locations

**2016 Scotland**

Proof of concept,
shallow locations

**2023 Norway**

69 active locations
by end of 2023

01.6

# State of the industry 2023

Stingray Aqua was officially launched in 2021 as the fourth delivering vertical of Stingray Marine Solutions AS. The vertical has grown to a total of 24 employees, as well as an additional 13 employees in the affiliated Positioning team, by the beginning of 2024.

Stingray had a market share of 11% of all Norwegian aquaculture salmonid locations in 2023 and expect to increase this to 20% by the end of 2024. The amount of nodes-in-the-water puts Stingray Aqua in a unique position to provide an overview of delousing effects and results along the coast of Norway.

The increase in Stingray's market share led to better louse control, but also a decreasing number of cleaner fish. Whether this decrease is a natural market process or a direct effect of our technology is ultimately irrelevant for our goal to improve fish welfare by minimizing the number of cleaner fish used by the industry. In Norway, the use of lumpfish has fallen by 63% since 2019 and major lumpfish producers have either been shut down or assigned to growing different aquaculture species, such as cod. Lumpfish and all wrasse species have recently been recognized as being sentient - as part of the Animal Welfare (Sentience) Act 2022, helping to protect these fish using stricter animal welfare regulations.

Economically, a weak Norwegian krone has facilitated record export-based profits for salmon farmers. However, the announcement of a "grunnrenteskatt", a resource rent tax, has caused major concern within the industry. Echoing the farmers, it is unlikely that a simple flat resource rent tax can account for the complexity of a vertically integrated industry such as salmon farming.

This new tax does not provide direct incentives for solving fish health shortcomings in the industry. The fish-welfare debate keeps recurring and repeating the same patterns each time Norwegian Veterinary Institute publishes the annual Fish Health Report. A publication by Menon Economics and Nofima on behalf of the Norwegian Animal Protection Alliance (Dyrevernalliansen) advocated to include fish mortalities as an indicator for fish welfare in the Traffic Light System, which in turn, is being questioned in its effectiveness to protect the animals.

The overall Norwegian salmon mortality rate increased significantly with a record 62.7 million farmed salmon dying during the sea phase. This figure represents an increase of six million deaths compared to 2022, equating to almost 17% of the total number of releases in Norway that year. Both the absolute numbers and the percentage of mortality are at their highest levels ever recorded.

Standard Norge started to develop a national standard on non-invasive lice counting, "håndteringsfri lusetelling", in the absence of a corresponding regulation. Stingray actively supports the development of the standard by providing AI and steering committee experts, which gives us a unique opportunity to influence decision making according to our high animal welfare and ethical goals. Once delivered, this standard will help towards implementing an updated legal framework for lice counting and sea louse control.

Environmentally, 2023 was an interesting year for Norwegian Aquaculture. Due to the onset of El Niño in July and record high temperatures during the summer, disproportionate lice pressure had been predicted. However, for Stingray customers, but also the whole of the industry to a lesser extent, extreme sea louse levels were avoided during autumn.

Major outbreaks of string jellyfish (*Apolemia uvaria*) were observed along the Norwegian coast. It was estimated that they caused 15% of all fish mortalities in November, and 19% in December. Whether this is a side effect of climate change, El Niño or other unrelated environmental effects is unclear at this stage. The Institute of Marine Research In Norway recorded high levels of jellyfish in 1997, 2001, 2021 and 2022. However in 2023, these jellyfish proved to be exceptionally abundant and lethal to farmed salmonids. Stingray Aqua has done its very best to monitor the level of jellyfish via our camera systems and evaluate/communicate the inflicted damage, by tracking and analyzing wounds on the fish. In addition, it is unclear how much damage caused by conventional delousings has been mistakenly attributed to jellyfish sores, inflating the overall impact assessment.

*Caligus elongatus* and *spp.* were particularly abundant in Northern Norway. This is not a new phenomenon and precedes our focus on this parasite species in Stingray. Caligus are not regulated by law and there are no official count numbers. Stingray is currently working on an improved sea louse detector including Caligus in order to obtain a proper overview over this lesser parasite. In the absence of scientific literature on this topic, it is unsure whether the abundance of Caligus is due to environmental changes, a decrease in delousing procedures due to the effectiveness of the Stingray system in killing *Lepeophtheirus salmonis*, or indeed a more accurate observation of a "normal" situation due to better detector and analytics procedures in Stingray.

Uncontrolled outbreaks of lice in Iceland with massive associated fish mortality have been an embarrassment for Norwegian-backed companies, which have not been able to conduct effective delousing and were overwhelmed by unprecedented sea louse levels. The events caused anti-salmon farming protests in Iceland and negative press in Norway. As a direct result, Stingray has decided to help by deploying its technology in Iceland by Q2 2024.

In this report, we have collected the combined results, developments in the field, and projects carried out by Stingray Aqua in order to provide a comprehensive, transparent, and scientific summary of our work in 2023, hopefully guiding further reflections on how to change this industry for the better in 2024.

All of us in Aqua hope this year's summary will provide the necessary insights into the success story that has been Stingray for many years and the very real positive impact we have on fish health for the over 60 million animals in our care.

BENEDIKT FRENZL
Aqua Manager

01.7

# Stingray dictionary

Table 1: A list of Stingray-related terms with definitions and abbreviations (if applicable).

| ABBREVIATION | TERM | DEFINITION |
|---|---|---|
| | Alternative treatments | A sea louse treatment which is not continuous. Alternative treatments can be medical, mechanical or chemical and typically involve handling of the fish. Cleaner fish, lice skirts and Stingray deployment are not considered an alternative treatment in this context. |
| | Analysis context | Determines the criteria, data points, and objectives that are relevant for the analysis; specific aspects of the subject matter the analysis will concentrate on. |
| AI | Artificial intelligence | The capability of a machine or computer program to perform tasks that typically require human intelligence. |
| | Biometrics | Variouas measurements to quantify and analyze various biological characteristics, traits, or parameters of farmed fish. In this document mainly referring to weight, biomass and growth data in fish. |
| BU | Buoy | A flotation device that provides buoyancy to a node and positions the laser unit in the cage. Also referred to as the buoy unit. The top part of the Stingray node and integral for the positioning process. |
| | Crowding | The process of gathering fish together, typically at the surface water layer and associated with delousing. |
| | Delousing | Removal of lice. The process of eliminating or reducing infestations of parasitic copepods known as salmon and sea lice from farmed fish. |
| | Detector | The process of designing, creating, and refining devices or systems used to detect and measure specific signals, substances, or phenomena in various applications. |
| | Diagnostics | The process of identifying, detecting, and analyzing diseases, pathogens, parasites, or other health-related issues affecting farmed fish populations. |
| | Fish health | The overall well-being and condition of fish, including their physical, physiological, and behavioral status. |
| | Fish sequence | Sets of 20-28 consecutive fish images that are analyzed to explore different aspects of fish health and behavior, depending on the selected analysis context. Each fish sequence represents one physical fish. |
| | Full node coverage | Full coverage or full node coverage is the recommended Stingray deployment strategy. It requires that each pen stocked with fish at a given location has a minimum of two nodes installed for the complete production cycle. |
| | Handling | The process of physically interacting with fish for various purposes, such as sorting, grading, transferring, or transporting them within or between aquatic facilities. Handling is typically very stressful for the animals. |
| | Louse package | A data package includes a sea louse detection report, an animation of the laser pulse trajectory, four images tracking the laser path, and a video showcasing each laser pulse. |
| NC | Node/Pen cabinet | The pen cabinet provides internet and electricity to the Stingray node. It also facilitates communication with the data cloud. Also referred to as node cabinet. The pen cabinet is mounted to the handrail/net fixtures. |



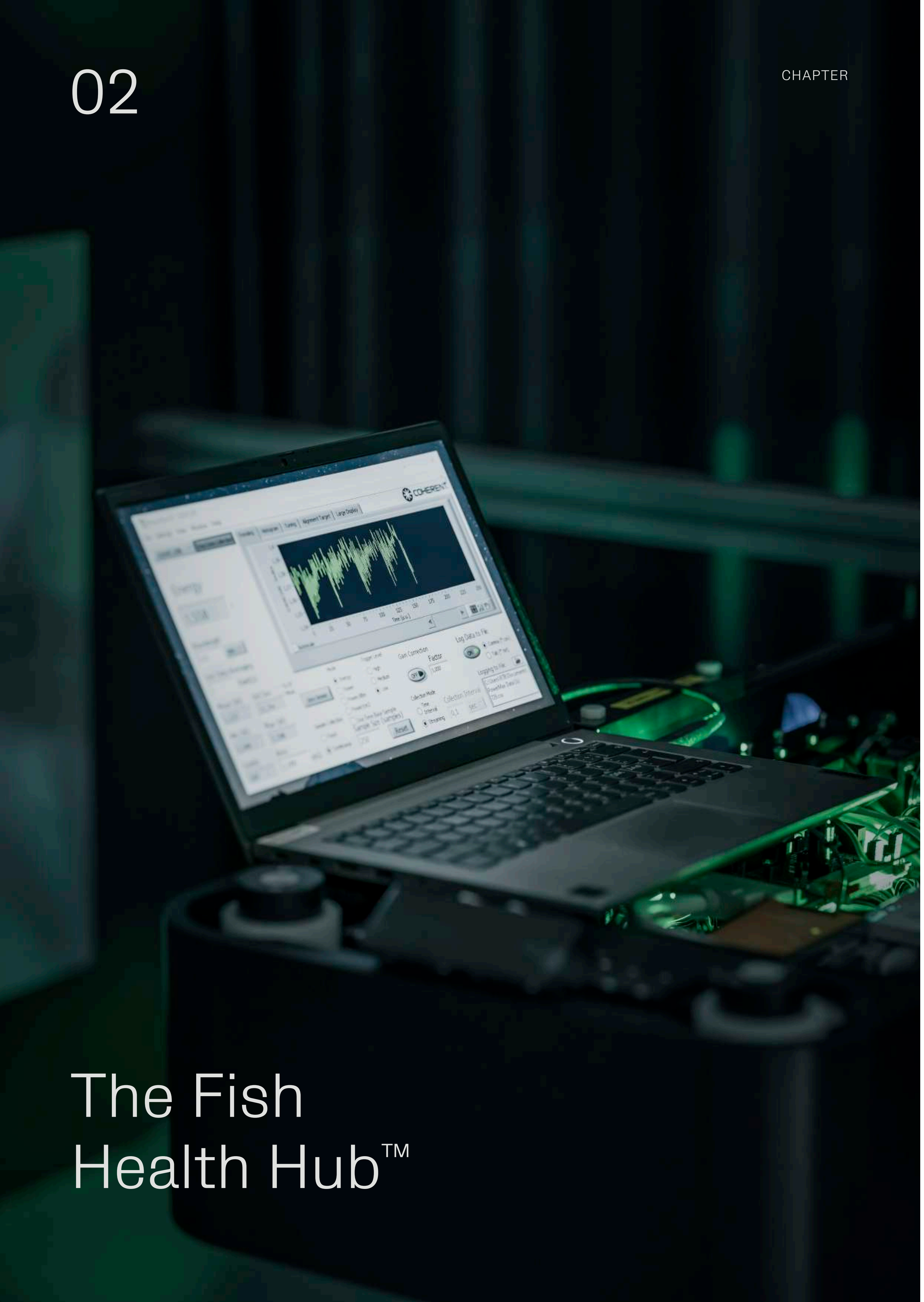
Table 1 continued: A list of Stingray-related terms with definitions and abbreviations (if applicable).

| ABBREVIATION | TERM | DEFINITION |
|---|---|---|
| | Passings | The number of fish that passes in front of the node's cameras. |
| | Positioning | Placing the Stingray node correctly in the pen to ensure maximum fish passings. |
| PA | Production area | 13 distinct aquaculture production areas along the Norwegian coast. Production areas are used to define production biomass allowance and monitor the health of wild salmon populations. |
| | Pulses | The number of laser pulses emitted from the node towards sea lice. |
| | Resistance | Resistance describes the build up of tolerance towards antiparasitic medication in sea lice. Resistance has been associated with excessive treatment frequency, treatment intensity and farm/fish density. |
| | Salmon lice | A group of parasites that infest salmonid fish. Sea lice attach themselves to the skin of fish, grazing on the animal and causing irritation, tissue damage, and potential mortality, especially in large infestation situations. Sea lice are also a major cause for secondary infections at active feeding sites. In this document sea lice mainly refer to *Lepeophtheirus salmonis* and *Caligus elongatus/curtus*. |
| | Sexual maturation | The physiological process by which farmed fish reach sexual maturity and become capable of reproduction. During sexual maturation, fish undergo various changes in their physiology, reproductive organs, hormonal profiles, and behavior to prepare for spawning and reproduction. |
| Node | Stingray nodes | Devices used to shoot and remove salmon lice using lasers. A complete Stingray node consists of one SU and one BU connected together with an SU cable. |
| Pilots | Stingray pilots | Stingray pilots and customer pilots are Academy-educated staff responsible for Positioning of the nodes. |
| SU cable | SU cable | Connects the BU and SU and is used for vertical positioning of the node. |
| SU | Submerged Unit | Also referred to as the laser unit. The submerged part of the node containing LED lights, sensors, cameras, and lasers in the Stingray system. |
| BU cable | Surface cable | Also referred to as BU-cable. Connects the node with the node cabinet and is used for horizontal positioning of the node. |
| | Treatment methods | Treatment methods are grouped into invasive and non-invasive treatments. Invasive treatments require handling of the fish and include bath treatments and mechanical treatments. Bath treatments include freshwater, antiseptic and pharmaceutical treatments. Mechanical treatments include flushing and brushing and other external removal methods. Non-invasive treatments include in-feed medication and passive methods such as the use of cleaner fish, physical sea louse barrier skirts or Stingray laser delousing. |
| | Welfare parameters | Specific indicators or metrics used to assess the overall well-being, health, and quality of life of farmed fish. Examples are water quality, stocking density, behavior, health status, feed quality, mortality, handling and transportation, and environmental enrichment. |

02

CHAPTER

# The Fish Health Hub™





02.1

## The Stingray System

Stingray Marine Solutions AS has developed a delousing and fish monitoring system called The Fish Health Hub™. The Fish Health Hub™ comprises one robust hardware platform and all bespoke software applications, as well as a team of experts interpreting and disseminating results generated by the system. The hub is best known for its optical system and high-powered laser beam, exposing sea lice to a lethal dose of energy without interfering with the fish itself, a method referred to as optical delousing.

The system has been designed to directly complement and/or challenge existing delousing methods in its effectiveness and fish welfare aspects. Existing treatment methods for salmon lice, whether medicinal, mechanical, or medication-free, largely require handling through pumping, crowding, and moving fish between pens, as well as irregular use of various chemicals [1]. Handling procedures cause high stress levels and direct damage to the animals [2]. In addition, secondary effects of fish handling can contribute to infections, reduced fish health, and notably make the fish less resistant to salmon lice and recontamination [3].

Sea louse control through Stingray has been proven to be a gentle, non-invasive, medication-free alternative to existing methods. The system has been in use since 2014 at ~200 sites at over 40 aquaculture companies in Norway and internationally. Cumulative operational uptime now corresponds to more than 1,800 years of continuous delousing.

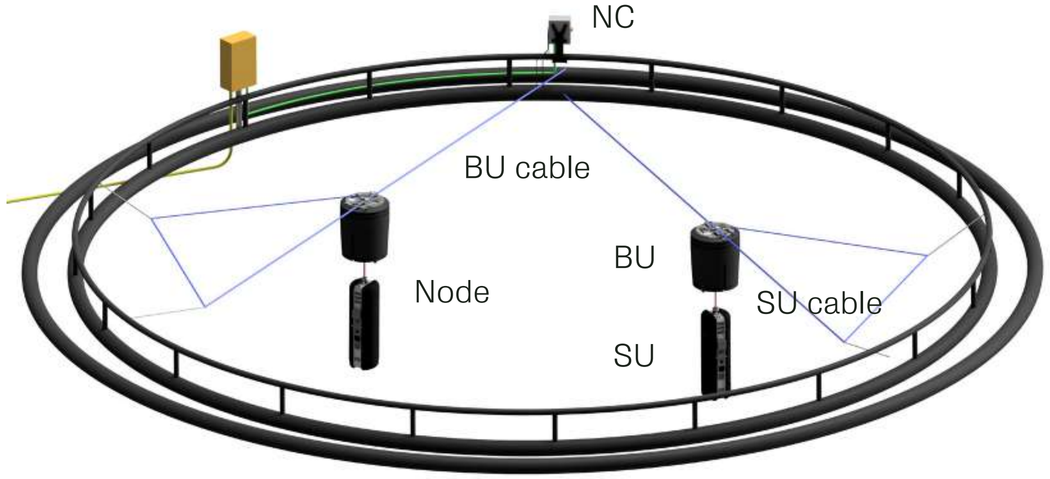
In addition to delousing, the system offers an array of AI-supported fish- and welfare monitoring-systems, including sea louse counting tools, wound and fish maturation detectors as well as biomass estimations.

Stingray provides all customers with access to a customer portal with analysis, data interpretation and visualization and documentation features. Resulting continuous surveillance gives Stingray unique insight into the overall health status of the animals and allows for passive monitoring of the animals in their undisturbed farming environment.

The hardware platform consists of a buoy (BU) and a submerged unit (SU) that make up the Stingray node, a surface cable, fixtures and a pen cabinet (NC)(figure 1). The buoy provides buoyancy to the node and is used for positioning the laser unit in the fish pen. The submerged unit includes LED lights, sensors, thrusters, cameras, and the laser used to pulse/shoot sea lice. The pen cabinet provides required electricity and internet to the system.

Typically two-four nodes per fish pen are installed alongside fish stocking of a new production cycle to ensure appropriate levels of delousing and continuous surveillance of the fish stock. The actual amount of nodes per pen required is dependent on various parameters such as sea louse infection pressure, geography and customer expectations.

Figure 1: Model of how a fish pen can look with the Stingray system installed.




1. Overton, K., Dempster, T., Oppedal, F., Kristiansen, T. S., Gismervik, K., & Stien, L. H. (2019). Salmon lice treatments and salmon mortality in Norwegian aquaculture: a review. Reviews in Aquaculture, 11(4), 1398-1417.
2. Sommerset I., Wiik-Nielsen J., Oliveira V.H.S, Moldal T., Bornø G., Haukaas A. and Brun E. Norwegian Fish Health Report 2022, Norwegian Veterinary Institute Report, series #5a/2023, published by the Norwegian Veterinary Institute in 2023
3. Delfosse, C., Pageat, P., Lafont Lecuelle, C., Asproni, P., Chabaud, C., Cozzi, A., & Bienboire Frosini, C. (2021). Effect of handling and crowding on the susceptibility of Atlantic salmon (*Salmo salar* L.) to *Lepeophtheirus salmonis* (Krøyer) copepodids. Journal of Fish Diseases, 44(3), 327-336.



## One Hardware
## Multiple Applications

STINGRAY LICE CONTROL

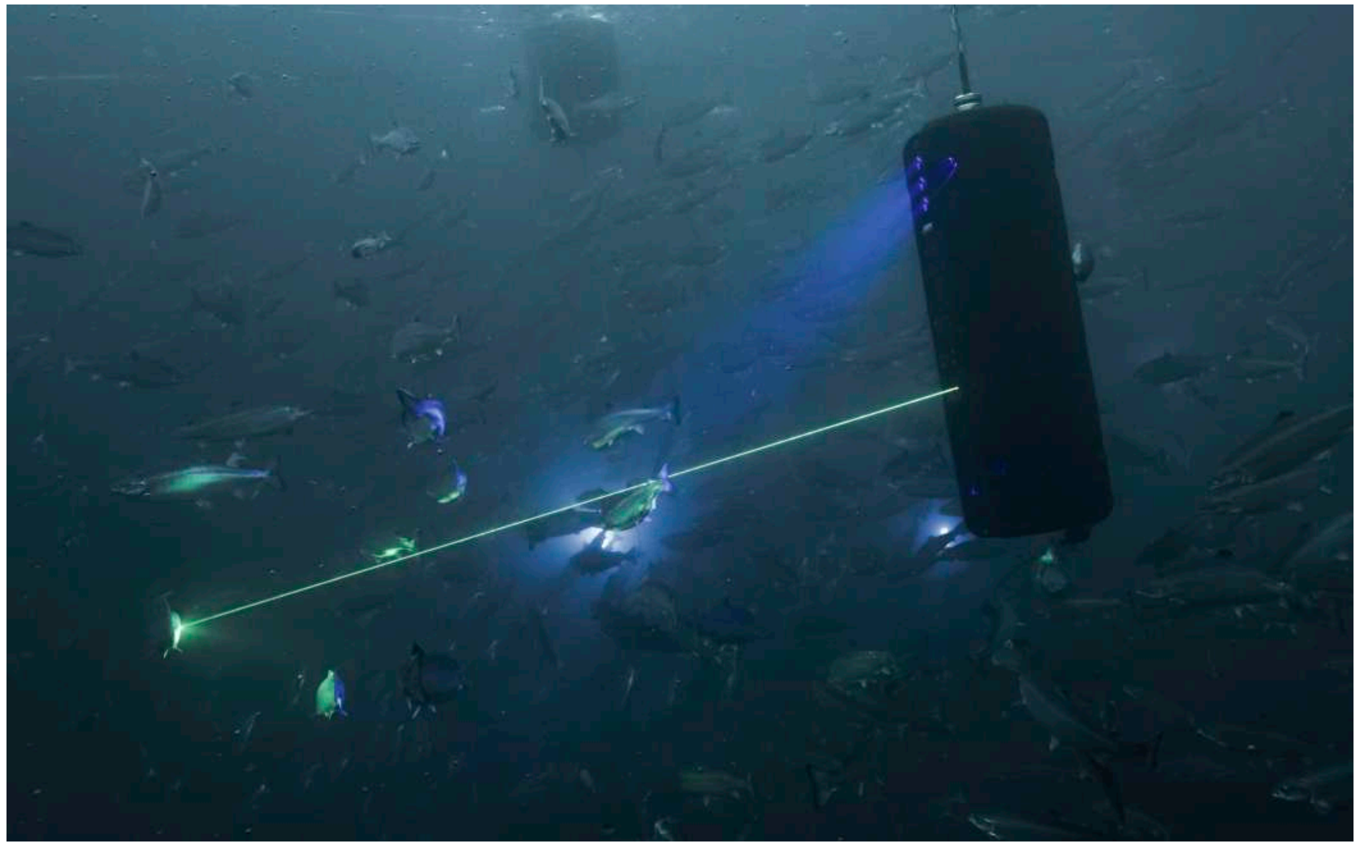
**Optical delousing**
Salmon (2014)
Trout (2017)

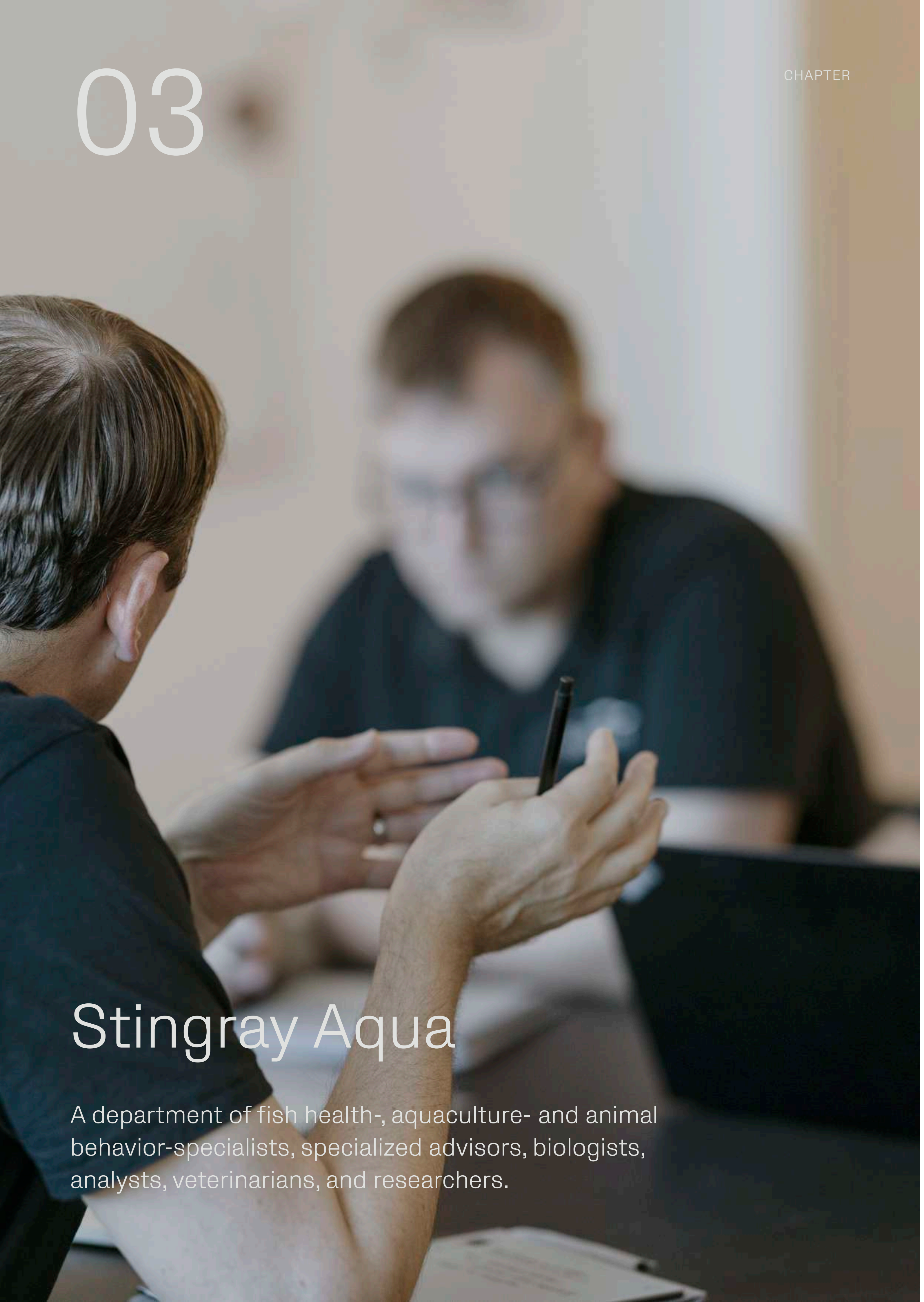
**Lice counting**
Weekly (2018)
Daily (2019)

**Diagnostics**
Wounds (2019)
Sexual Maturation (2019)

**Biometrics**
Weight
Calculation (2019)

STINGRAY PRODUCTION CONTROL





03

CHAPTER

# Stingray Aqua

A department of fish health-, aquaculture- and animal behavior-specialists, specialized advisors, biologists, analysts, veterinarians, and researchers.



03.1

## Our team

### Analytics

The Analytics team is responsible for image-based analysis, data interpretation and detector maintenance & development.

### Fish Health

The Fish Health team provides fish health advice, result structuring & dissemination as well as communication with external fish health staff.

### Advisory

The Advisory team provides several areas of expertise, collaborating with internal and external organizations and stakeholders.

### Research

The Research team leads and quality assures research projects, providing scientific feedback on biological and technical issues and results.

03.2

# Our strenghts

## Optical delousing

Machine vision and artificial intelligence enable optical delousing

## No handling

Both delousing and counting of lice becomes a non-invasive operation

## Control

Improve fish welfare, production control, and economic results for customers



03.3

# Applicable social, political, economic & environmental issues

Environmental, political, and economic factors frequently determine the necessity for research projects within Stingray's Research Team.

## Cleaner fish decline

The use and deployment of cleaner fish is continuously declining as the government tightens welfare regulations regarding their utilization.

Fiskeridir.no/Akvakulturstatistikk/Rensefisk, last accessed [24.04.2024]

## Atlantic salmon returnee decline

The number of returning wild Atlantic salmon continues to decrease. This is attributed to existing farming operations and associated disease- and escapee problems.

Vitenskapsradet.no/Status-of-wild-atlantic-salmon-in-Norway-2023, last accessed [24.04.2024]

## Pink salmon returnee increase

The population of Pink salmon returns continues to rise. Their rapid proliferation has led to AI efforts to sort Pink from Atlantic salmon entering rivers in Northern Norway.

Miljodirektoratet.no/pukkellaksuttak, last accessed [24.04.2024]

## Natural resource rent tax

The Norwegian government has introduced a resource rent tax targeting sea-phase revenues in salmonid aquaculture. Impacts on the industry and its suppliers remain controversial.

## NYTEK23

A new standard for aquaculture sites mandates that farmers and Stingray comply with updated requirements.

## Non-invasive counting standard

A standardization committee established by Standard Norge is working to develop unified requirements for all image-based counting methods.

## *Apolemia uvaria* jellyfish invasion

The jellyfish invasion is estimated to have caused 15% of all fish mortalities in November and 19% in December 2023.

## Sea lice outbreaks in Iceland

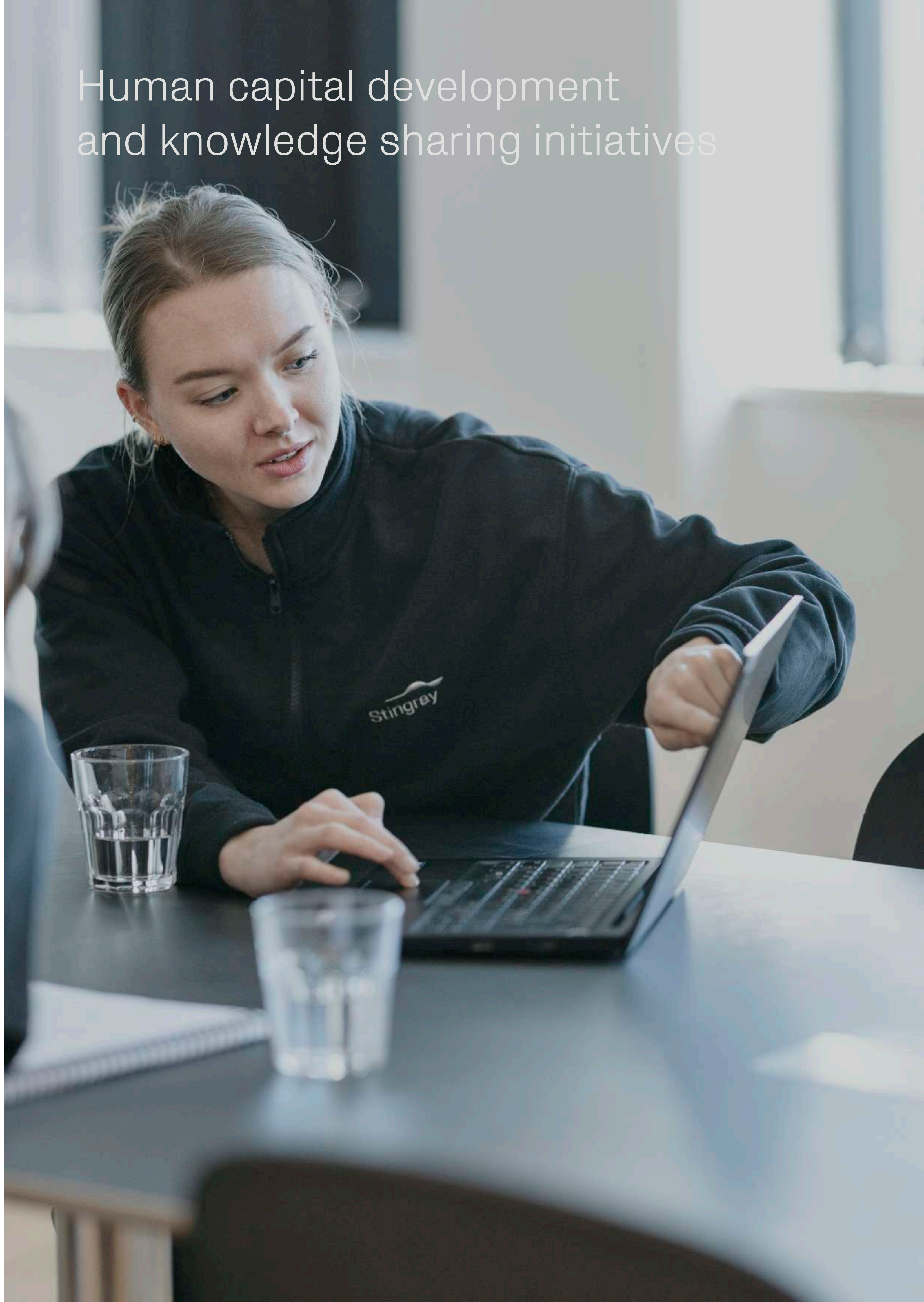
Sea lice outbreaks have resulted in significant mortality rates and subsequently sparked anti-salmon farming protests and negative press coverage.

## Caligus abundance in the North

Since Caligus are not regulated by law, there are no official numbers available. Consequently, it remains unclear whether this species requires additional attention.



# Human capital development and knowledge sharing initiatives



03.4

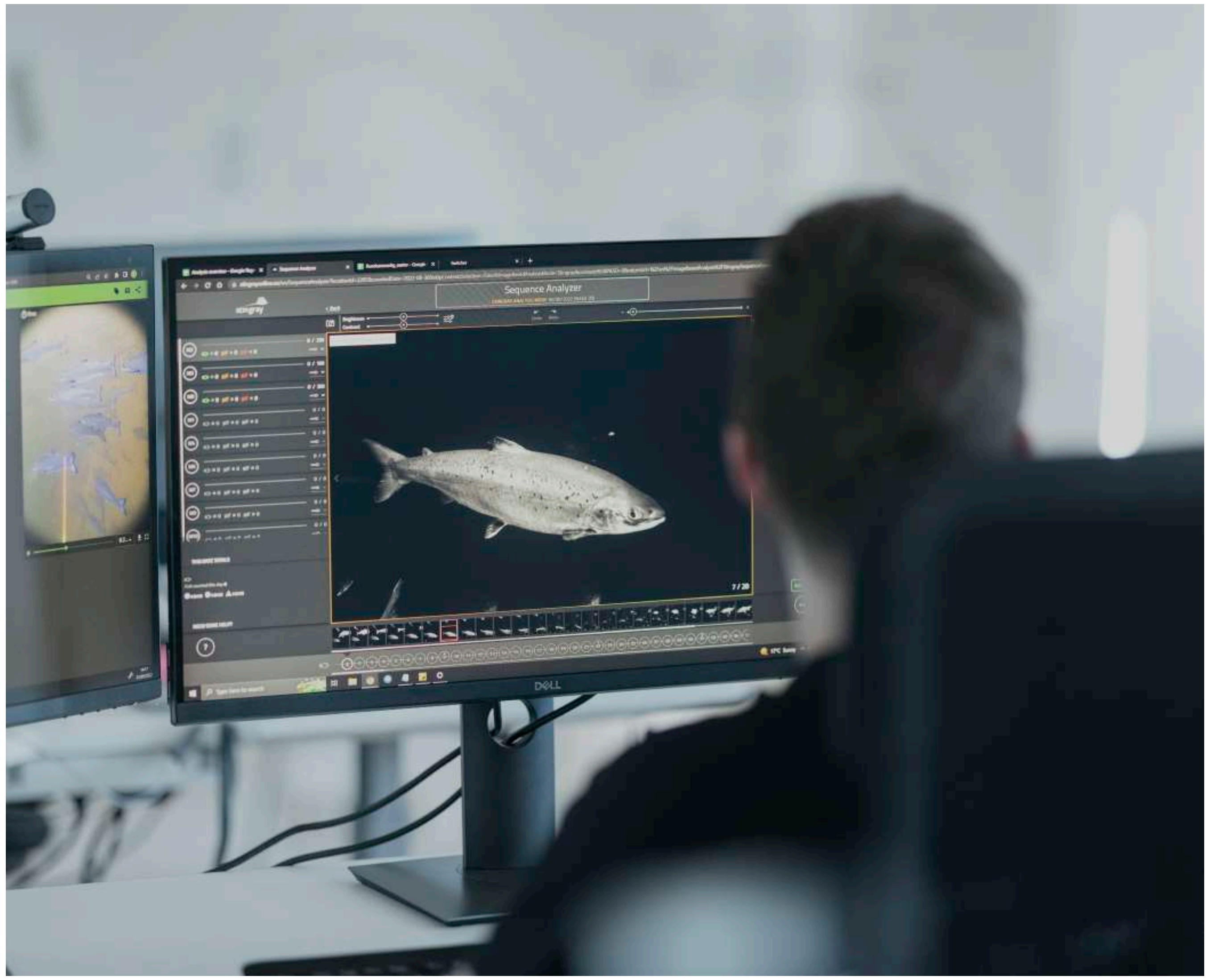
# Internship year of 2023

## Fisheries- and Aquaculture science

Two students from the Arctic University of Norway in Tromsø (UiT) interned over a three-week period, alternating between the Analysis team and the Positioning team. This allowed them to gain insights into various aspects of Stingray as a whole and the Aqua department in particular.

## Veterinary medicine

A student from the Norwegian University of Life Sciences (NMBU) spent a week shadowing a veterinarian at the Aqua department in Stingray. Daily tasks and project work provided the student with insight into the (a)typical veterinary work tasks in the company.



03.5

# Stingray Annual User Forum

For 10 years, Stingray has organized an annual forum for its users, which has taken place at the headquarters in Oslo. This forum attracts fish farmers from the whole of Norway, who participate to gain professional and social enrichment. Our aim is to build mutual trust which will benefit daily operations and long term customer satisfaction. The forum makes it possible to communicate complex work tasks, such as service, repairs, and the development of both hardware and software, emphasizing our focus on building transparent business relations.

To strengthen our commitment towards this goal, Stingray invites all its users to Oslo once a year. The day includes professional content from Stingray, and provides fish farmers with the opportunity to exchange experiences among themselves through cross-company networking. The professional program is led by various key personnel from each department. At the Stingray User Forum 2023, 15 presentations in addition to a keynote by Stingray's CEO were held.

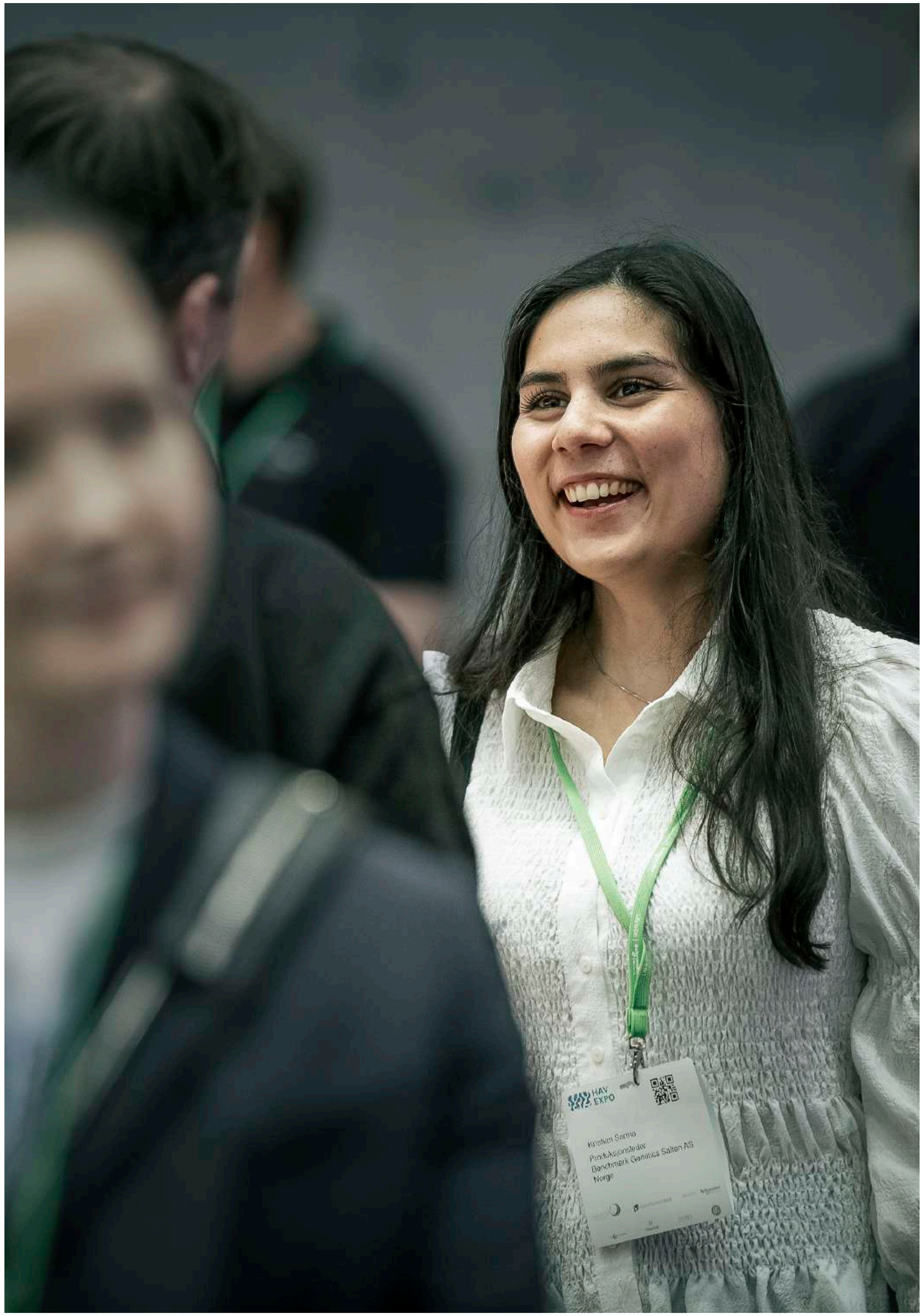
The presentations covered topics such as sea lice counting, positioning routines, operational results, and added value for customers. Each year, Stingray staff are rotated based on qualifications and knowledge. While the overall theme of the presentations remains relatively constant, the content is adapted in line with the development of new technology and industry events.

In total, 120 people were involved in organizing the Stingray User Forum 2023, with 81 visiting customers from 24 different fish farming companies.

03.6

# Stingray presence 2023

| | |
|---|---|
| 12th-13th of Jan | Annual Meet Aquaculture North |
| 17th-18th of Jan | LfL Further Education Conference for Fish Farming and Fish Breeding |
| 8th of Feb | Engesund Visitor Center, analysis workshop |
| 15th-16th of Feb | Håp i Havet (Sponsor) |
| 7th of Mar | Salmon City (Sponsor) |
| 18th of Apr | Youngfish East evening event |
| 25th-27th of Apr | Seafood Expo Global |
| 14th of Sep | Business day for the Student Association for Fish Health and Aquaculture (Main sponsor) |
| 6th of Oct | Oktoberfest in Fauske (Sponsor) |
| 18th of Oct | Havets døgn (Superior sponsor) |
| 10th of Nov | Lerøy Aurora Fish Feed gathering |
| | +++ |






04.1

## Sustainability in Stingray

At its core, our system utilizes a laser to target and eliminate sea lice from farmed salmonids in sea cages. This process relies on dedicated detectors that are based on machine vision and artificial intelligence. Simultaneously, conventional logging of environmental and operational data by integrated sensors provides a wealth of supportive data.

From a manufacturing standpoint, each Stingray node has a four to six year life cycle with a material integrity guarantee and a contractually enforced recycling and depositing scheme. Automatization and robotization is increasingly incorporated during manufacture and assembly.

In addition, Stingray minimizes its environmental footprint by prioritizing pollution-free operations and recirculation of several major parts. By implementing and supporting infrastructure developments required for our real-time data processing and collection, we incentivize local investments and upgrades in coastal areas where most of our customers are located.

We support the 2019 UN Global Sustainable Development Report's recognition of animal welfare as a missing component, as part of our strong emphasis on animal welfare. Our system has been designed with fish health in mind and serves as a monitoring tool for welfare-related parameters. As a company, we care about increased productivity, production control, predictability, and quality assurance, while also fulfilling our ethical obligations towards improving animal welfare and reducing fish mortality rates by minimizing the need for mechanical delousing and unnecessary handling of the animals. We aim to develop automated warning systems for disease outbreaks, aberrant behavior, and stress in farmed fish. Our specialized advisor teams monitor fish health and welfare, and provide veterinary follow-ups and consultation to our customers.

Through the fusion of AI, machine vision, and human expertise, Stingray ensures traceability and accountability of our operations, thus contributing to a sustainable future for aquaculture.

Source: United Nations' 17 Sustainable Development Goals


04.2

# Five freedoms of animal welfare

## Freedom from....

### Hunger & thirst

- Fresh water
- Suitable diet to stay healthy and energetic

### Discomfort

- Safe and healthy environment
- Protection
- Comfortable resting area

### Pain, injury & disease

- Vaccination to prevent disease & illness
- Treatment & medication
- Monitoring

### To express normal behavior

- Moving freely
- Sufficient space

### Fear & distress

- Prevent mental suffering
- Prevent overcrowding
- Safe space

04.3

# The Stingray way; Expanding the five freedoms

The concept of the Five Freedoms was first outlined in 1965 [1]. It was considered a response to the observed animal cruelty in the chicken battery cages that were common at the time. Brambell's Five Freedoms have since been accepted as a conclusive framework and starting point for animal welfare awareness. The Five Freedoms concept was the first and easiest to implement of all animal welfare frameworks. Unsurprisingly, it has not stood up to the test of time without criticism, and it can only be considered as a baseline in 2023.

Four of the five freedoms are defined as "absence of" arguments, suggesting that the absence of negative factors automatically leads to improved welfare. The fifth freedom, which is to express normal behavior, has to be seen critically for all farmed animals, since natural behavior expression will, by default, be suppressed in all farming operations. The framework is also highly biased towards thinking how animals should be treated, thus reflecting an ethical, rather than a strictly scientific approach to the problem.

This is best summarized in an article by Mellor [2], who emphasizes the importance of recognizing both negative and positive experiences in animals' lives and argues for a model that aims for animals to have "lives worth living". This involves minimizing negative experiences, while simultaneously facilitating positive experiences through improved environments and welfare practices.

In the light of an improved understanding of animal welfare, common (mis)practices in the aquaculture sector, and recent technological advances, we have decided to expand the concept of the Five Freedoms with the newer framework of Five freedoms, Five domains, and Three orientations:
The Five domains model (table 2) does not define good or bad welfare. It provides a method to assess animal welfare by scoring positive and negative impacts. The Three orientations (figure 2) are biological function, affective state, and natural living. Biological function describes physical and physiological parameters by assessing biological performance or the lack thereof. Affective state is a scientific term for assessing the animals' motivations, preferences, and behaviors. The natural living orientation, focusing on positive environmental experiences outside of human restrictions, can be considered irrelevant for salmonid aquaculture, but must be considered in relation to wild cleaner fish use for delousing.

In addition, we believe that the direct impacts of bad welfare, mainly attributed to suboptimal production procedures or handling requirements, should be detected and graded continuously. Stingray's wound detector has been based loosely on the guidelines outlined in the "FishWell" document [3] and all Stingray development aims at incorporating the available scientific evidence that is useful for monitoring, interpretation, and dissemination of welfare indicators for fish under our care.

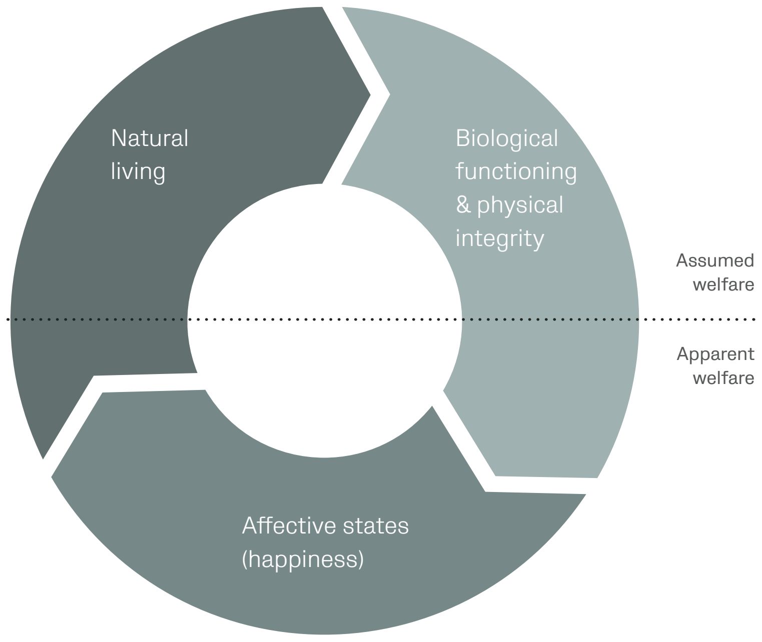



Figure 2: The three orientations of welfare [1].
Table 2: The five domains of welfare [2,3].

## Animal welfare for Stingray is achieved by

- No damage
- No handling
- No starving periods
- No pharmaceuticals/chemicals
- Traceability
- 24/7 surveillance
- Automated/manual warning for disease/behavior/stress
- Reduced secondary infections/mortality
- Fish health & specialized advisor teams
- Fusion of AI, machine vision & human expertise

PHYSICAL/FUNCTIONAL DOMAINS

| Survival-Related Factors | | | | | | Situation-Related Factors | |
|---|---|---|---|---|---|---|---|
| 1 Nutrition | | 2 Environment | | 3 Health | | 4 Behavior | |
| **Restrictions**<br>Restricted water & food, poor food quality | **Opportunity**<br>Enough water & food, balanced & varied diet | **Restrictions**<br>Uncomfortable or unpleasant physical features of environment | **Opportunity**<br>Physical environment comfortable & pleasant | **Restrictions**<br>Disease, injury and/or functional impairment | **Opportunity**<br>Healthy, fit and/or uninjured | **Restrictions**<br>Behavioral expression restricted | **Opportunity**<br>Able to express rewarding behaviors |

AFFECTIVE EXPERIENCE DOMAIN

| 5 Mental State | | | | | |
|---|---|---|---|---|---|
| Negative Experiences | | | Positive Experiences | | |
| Thirst<br>Hunger<br>Malnutrition<br>Malaise<br>Chilling or overheating<br>Hearing discomfort | Breathlessness<br>Pain<br>Debility<br>Weakness<br>Nausea<br>Sickness<br>Dizziness | Anger,<br>Frustration<br>Boredom<br>Helplessness<br>Loneliness<br>Depression<br>Anxiety<br>Fearfulness<br>Panic and exhaustion | Drinking pleasures<br>Taste pleasures<br>Chewing pleasures<br>Satiety<br>Physical comforts | Vigor of good health and fitness<br>Reward<br>Goal-directed<br>Engagement | Calmness<br>In control<br>Affectionate<br>Sociability<br>Maternally rewarded<br>Excited playfulness<br>Sexually gratified |

WELFARE STATUS

1. Webb, L. E., Veenhoven, R., Harfeld, J. L., & Jensen, M. B. (2019). What is animal happiness?. Annals of the New York Academy of Sciences, 1438(1), 62-76.
2. Mellor, D.J.; Beausoleil, N.J. Extending the 'Five Domains' model for animal welfare assessment to incorporate positive welfare states. Anim. Welfare 2015, 24, 241–253. &
3. Mellor, D. J. (2016). Updating animal welfare thinking: Moving beyond the "Five Freedoms" towards "a Life Worth Living". Animals, 6(3), 21.

04.4

# “Cleaner” fish

The use of cleaner fish to provide biological sea louse control was first described in the 1990s and widely implemented in aquaculture since the early 2010's, mainly in Norway and Scotland.

In 2019, a peak number of more than 60 million cleaner fish were used in the Norwegian salmon industry [1,2]. The most common species were farmed lumpfish (*Cyclopterus lumpus*) and various wild caught wrasse, mainly Goldsinny wrasse (*Ctenolabrus rupestris*), Ballan wrasse (*Labrus bergylta*) and Corkwing wrasse (*Symphodus melops*), but also less popular species such as Cuckoo wrasse (*Labrus mixtus*) and Rock cook (*Centrolabrus exoletus*). The full-scale farming of Ballan wrasse proved to be challenging while the farming of lumpfish was quickly successful.

The effectiveness of these “cleaners”, while anecdotally reported, was difficult to prove, while animal welfare problems, fueled by poor survivability, were obvious [3,4].

During the last three years, the pressure to improve welfare and survivability has outweighed the need to reduce lice levels to a degree. The public has become more concerned about cleaner fish mortality, resulting in tightened regulations for the use of cleaner fish by the authorities.

In 2023, a hearing note was published that criticized the “free” use of cleaner fish in salmon aquaculture, the unwillingness of the authorities to act, as well as the increased concern for a lack of welfare and high mortalities.

As a result, numbers declined from peak 60 million fish in 2019 to 33 million in 2022, a reduction of nearly 50% in only four years time. Most of this reduction is due the reduced use of farmed lumpfish and stricter regulations for the use of wild caught wrasse [4].

In the industry, however, the perceived “need” for cleaner fish remains, as the salmon louse persists as a problem. The complete ruling out of cleaner fish use without available suitable alternatives, such as the Stingray system, could lead to an increase in reactive, mechanical, or medical treatments and all associated welfare challenges. In Stingray Aqua, we actively try to combat the hesitation towards adopting new delousing technologies and facilitate the shift away from a biological solution towards a technological one.


1. Fiskeridir.no/Cleanerfish-Lumpfish-and-Wrasse [26.04.2024]
2. Sommerset, I. W.-N., Jannicke; Moldal, Torfinn; Silva de Oliveira, Victor Henrique; Bornø, Geir; Haukaas, Asle; Brun, Edgar (2023). Fiskehelserapporten 2022. Bergen, Veterinærinstituttet S17, Tabel 2.1
3. Barrett, L. T., Overton, K., Stien, L. H., Oppedal, F., & Dempster, T. (2020). Effect of cleaner fish on sea lice in Norwegian salmon aquaculture: a national scale data analysis. International Journal for Parasitology , 50 (10), 787-796.
4. Sommerset, I. W.-N., Jannicke; Moldal, Torfinn; Silva de Oliveira, Victor Henrique, Svendsen, Julie Christine; Haukaas, Asle; Brun, Edgar. (2024). Fiskehelserapporten 2023 S96-97.




04.5

# Sentience & intelligence

“Lumpfish have unique personalities, with evidence showing that individuals can differ in their delousing ability [...] and food preference [...].

In addition, members of the wrasse (Labridae) family have been reported to display tool use [....]. For example, using a rock to crush a cockleshell and using anvils to smash food into smaller pieces. There is also evidence that some species can recognize themselves in a mirror, suggesting the fish might be self aware - or at least more aware than previously thought [...].

Wrasse and lumpfish have recently been recognized as sentient beings as part of the Animal Welfare (Sentience) Act. “

Austry, D. A. (2022). Cleaner fish - the millions of hidden casualties of the salmon industry. Conservative Animal Welfare Foundation

04.6

# Aquaculture regulation revolution: Stingray's participation in standardization and innovation

Our advancements in technology, particularly concerning weekly lice counting in fish pens, have led to a increased demand for dispensations from mandatory manual lice counting in favor of non-invasive lice counting, also referred to as image-based lice counting. This prompted the Norwegian Ministry of Trade, Industry and Fisheries to urge the Norwegian Food Safety Authority (Mattilsynet) to support the development and adoption of enabling technology while ensuring that regulations remain supportive of innovation. Since initial attempts to convene competing technology suppliers proved unsuccessful, especially due to data sharing concerns, a committee was formed by Standard Norge in collaboration with the Norwegian Food Safety Authority to establish a national standard for non-invasive counting. This standardization initiative aims to eliminate the need for dispensations by providing a unified framework for all non-invasive lice counting systems, ultimately modernizing outdated fish health regulations.

Stingray is actively participating as committee lead and have been instrumental in shaping discussions and introducing key concepts, such as updated terminology and definitions for sample size, representative sampling, equipment mobility, and acceptable error margins.

Our customers have increasingly obtained dispensations from the legal obligation to count lice manually, and instead adopted Stingray's non-invasive lice-counting solution since 2021. This indicates a growing acceptance of our technology within the industry (figure 3) and aligns with higher welfare standards by minimizing routine handling during counting procedures.

354 locations have been granted dispensation by the Norwegian Food Safety Authority to conduct lice counting using image-based methods facilitated by Stingray technology.

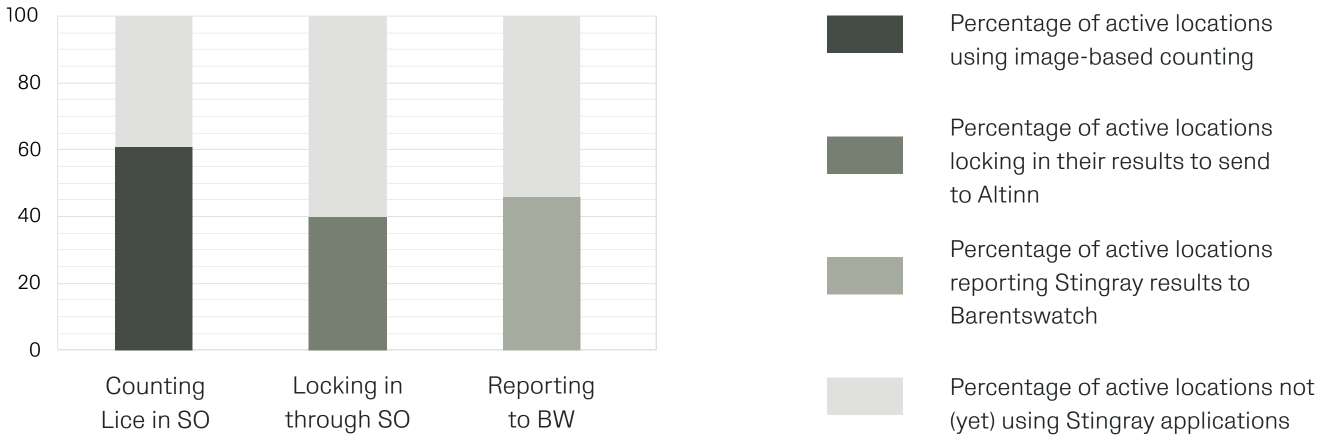
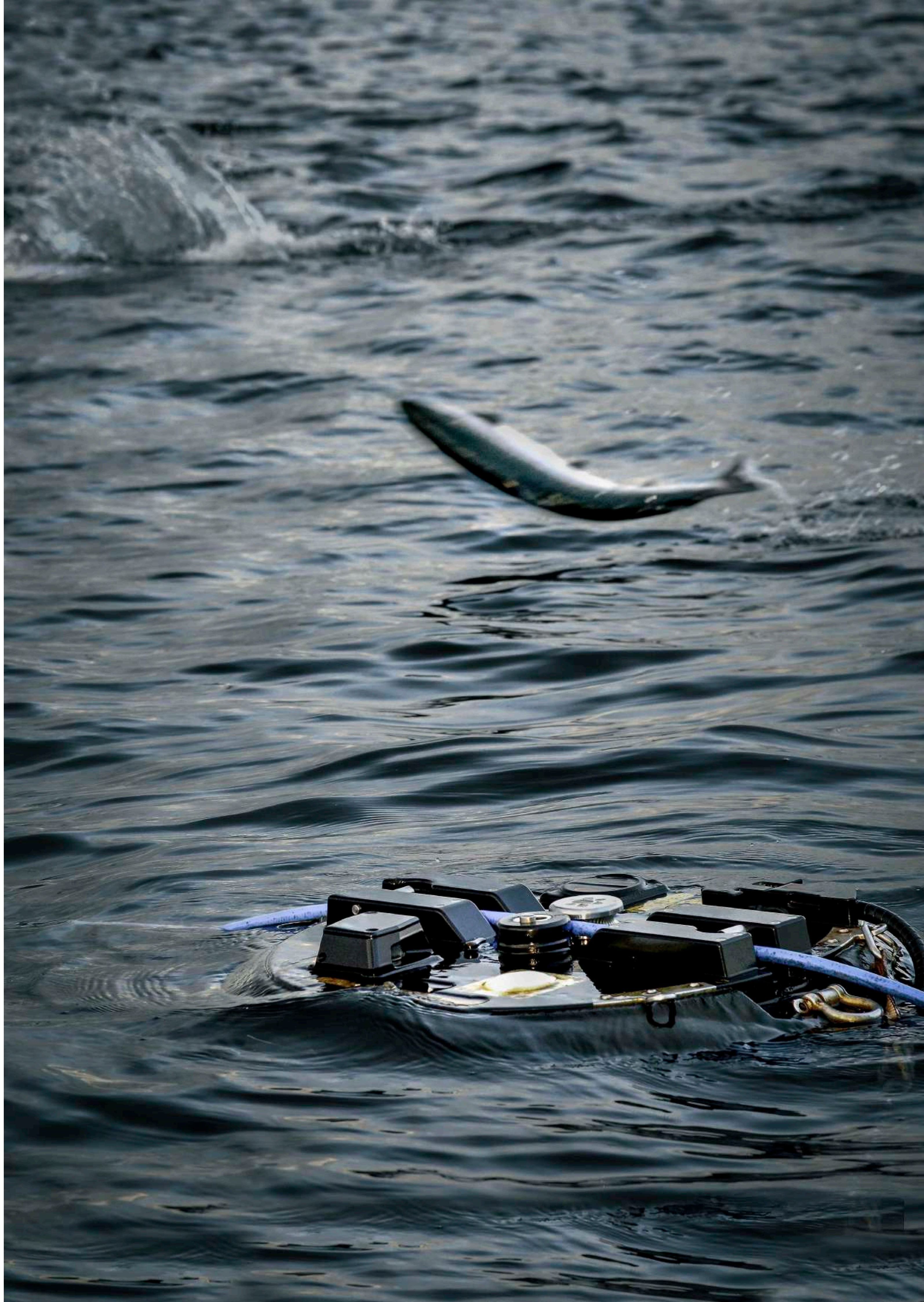
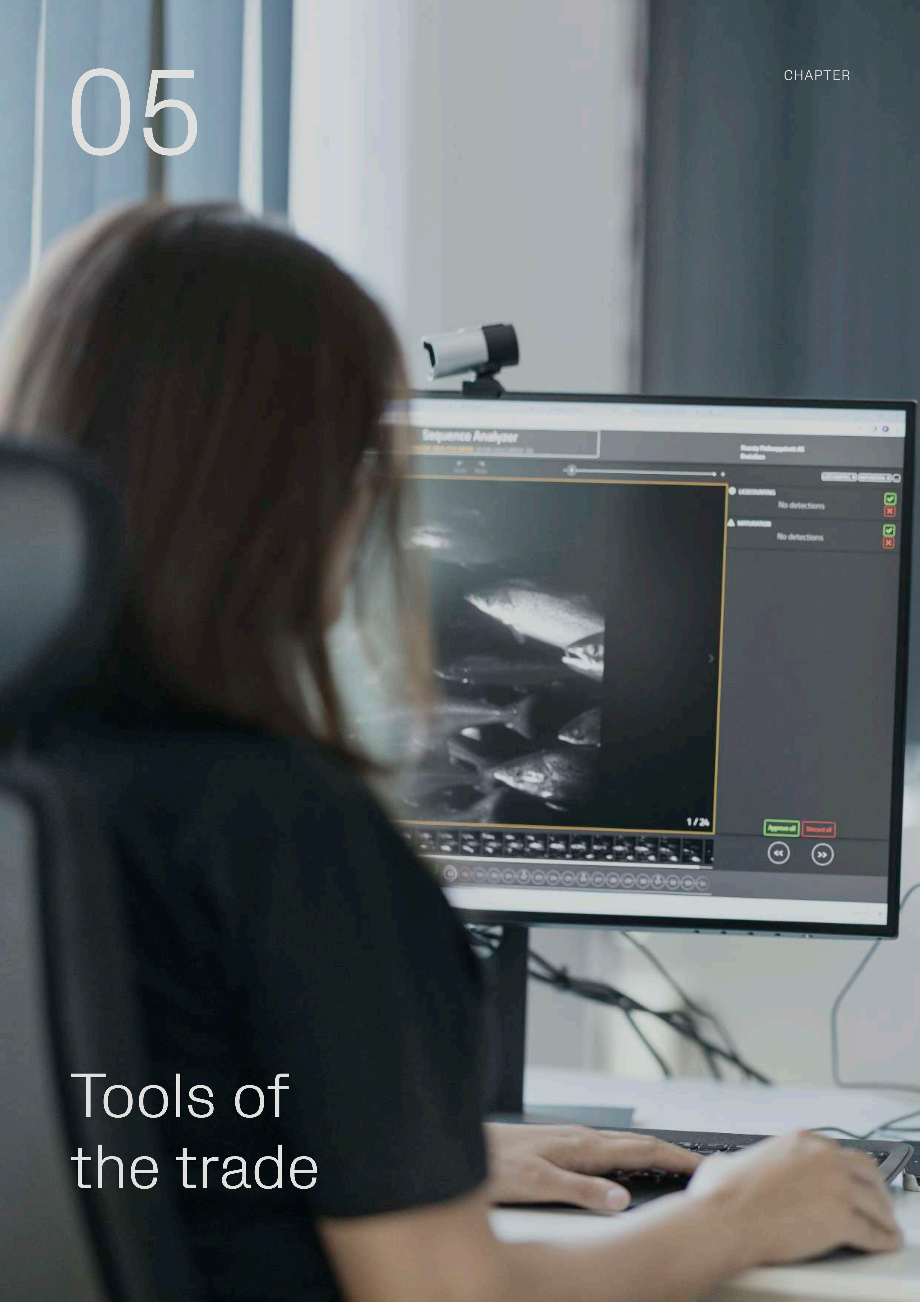



Figure 3: The percentage of active Stingray locations using image-based counting, locking in their results to Altinn, and reporting Stingray results to Barentswatch. Light gray represent active locations not yet implementing Stingray applications.



05

CHAPTER




# Tools of the trade



05.1

## The right tools for the job

Stingray uses a variety of AI systems, bespoke applications and third party programs to our customers with all the necessary results, effects and feedback required.

### Collaboration

Collaboration between the in-house Software team and Aqua team fosters professional cooperation and facilitates successful project outcomes.

### Aim

Aim to develop new features and systems and increase the performance and capabilities of existing ones through innovations and iterative improvements.

### Statistics

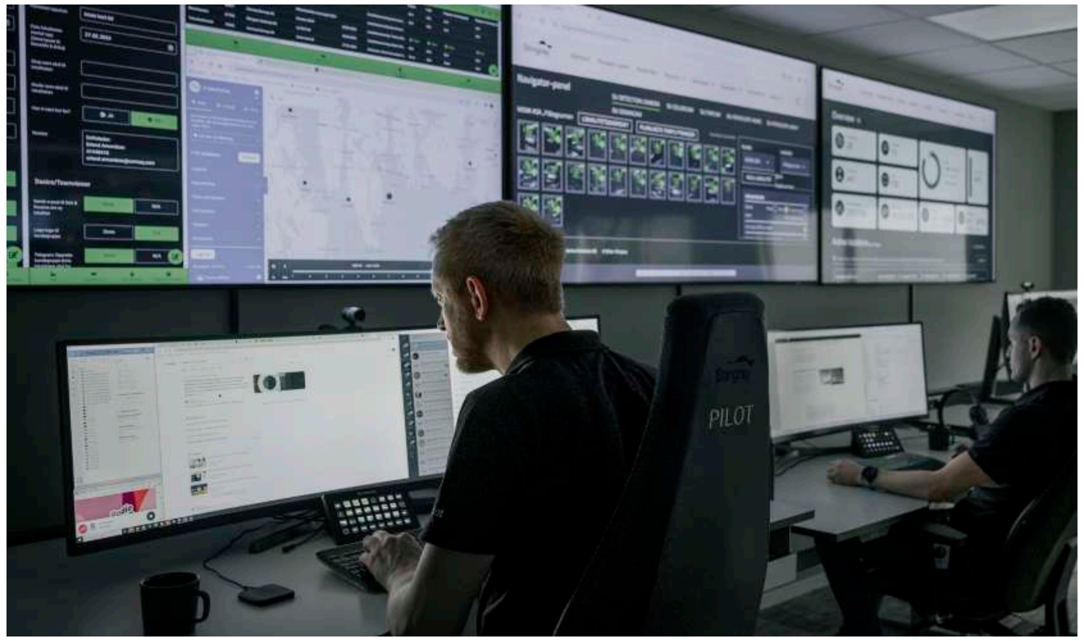
Improved quality and reliability of results through scientific statistical evaluation and validation.

### Efficiency

Concerted effort to minimize routine work through automation and standardized work procedures.

05.2

# Artificial Intelligence




## Sexual maturation

A classifier that determines if salmon are fully sexually mature or not. This is an important parameter to assess product quality prior to harvest.

## Biometrics

Biometrical weight detector providing daily biomass, weight distribution, and growth estimates. This data is commonly used for production planning.

## Louse kill detector

A machine vision system that detects lice in real-time, triangulates the position of the parasite on the moving fish and supplies target data for the laser.

## Wound score

The wound detector identifies and scores wounds on the body of the fish. This metric is used to assess overall health status and can help with disease diagnostics.

## Lice counting

A computer vision system to classify sea lice in image sequences of salmon and trout. This detector is actively used for both image based and fully automated lice counting by both Stingray and customers.

05.3

# Detector development in 2023

### LiceAut

Automatic lice counting using images

According to Norwegian regulations, farmers are obliged to manually perform weekly lice counts and report the results to the government. If the amount of adult female lice exceeds a threshold value of 0.5 per fish (0.2 during outmigration of wild salmon smolts), delousing operations are mandated to protect both wild and farmed salmonids from further infestation. Since 2021, dispensations from this regulation can be granted by the Norwegian authorities in favor of image-based counting methods.

Our machine vision system can classify and count lice automatically in a sequence of images of a salmon or a trout.

The machine vision system has been developed using deep learning and convolutional neural networks. The first detector was put in production in 2018, and was developed to identify and count adult female lice. We have since, in several iterations, retrained and updated the LiceAut detector to recognize adult female and mobile salmon lice, and adult female caligus.

The latest detector, released end of 2023, is currently four times more accurate in detecting and counting adult female salmon lice compared to older versions.

### Wound score

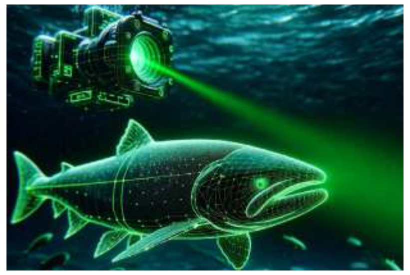
Automatic wound counting and scoring using images

Wounds are a major animal welfare concern and lead to huge economic losses due to mortalities and downgrading of affected fish at harvest. Winter ulcers are caused by the bacterium *Moritella viscosa* and are particularly prevalent when water temperatures are low. Wounds and secondary ulceration can be caused by mechanical damage following e.g. jellyfish blooms or handling procedures.

A new version of our wound detector was released in December 2023. This detector has a 96% agreement rate when compared with a trained human analyst, which effectively makes manual wound analysis redundant.

Stingray is now able to provide an accurate overview over the health status and the severity of observed wounds. The severity is estimated by comparing the wound size to other body size dependent features of the fish as well as overall wound abundance.

Stingrayonline.no still provides the option to manually check the images used by the fully automated detector. These images are typically used by the Fish Health team to interpret wounds according to cause and healing status and provide consultation to our customers.



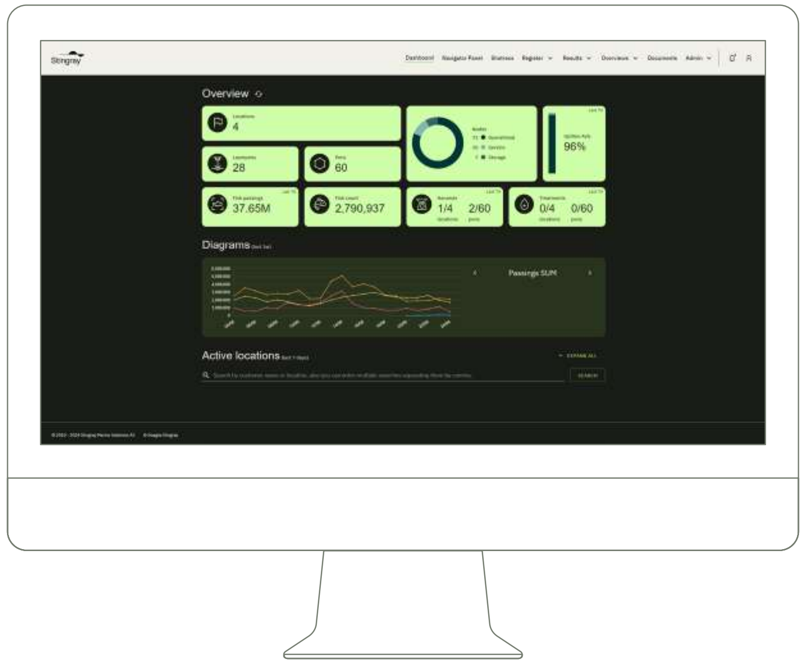
05.4

# Stingray Online

Stingray Online, Stingray's customer portal includes data registration and calendar overview pages, as well as graphical result and data mining possibilities. Stingray Online grants access to non-invasive/image-based counting via the Sequence Analyzer and the node positioning tool called Navigator. The portal requires continuous updates to align with the evolving needs of the industry and implementation of new features/results. Significant in-house resources are required to maintain this portal, including primary users, customer contacts, analysts, communication specialists, researchers, translators, design experts and software engineers.

v13.0

The most extensive update since launch 8 years ago



The process of developing and launching Stingray Online version 13.0 spanned a total of 262 calendar days, from the initial stages of development to the final release.



05.5

# Stingray Academy

Stingray Academy is an internal and external online learning platform designed to introduce various Stingray systems to customers, employees, and third-party users. It provides essential information on health and safety, system use, product warranty and relevant background. The platform is updated frequently to ensure that all Stingray users have adequate information to operate the equipment safely.

Stingray Academy provides the necessary teaching platform for training Stingray customer pilots. Customer pilots are customer users who can operate the nodes without supervision by Stingray staff (figure 4).

841

registered users

275

new users with "Basics" course diploma in 2023

430

users with "Basic" course diploma

261

users with "Pilot" course diploma

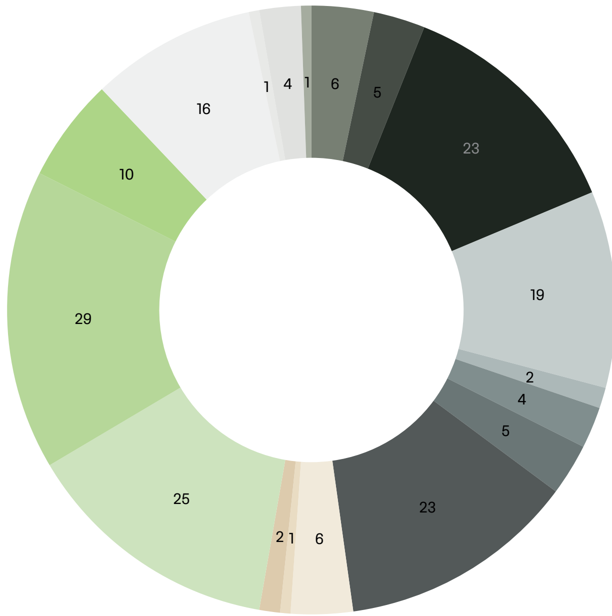
410

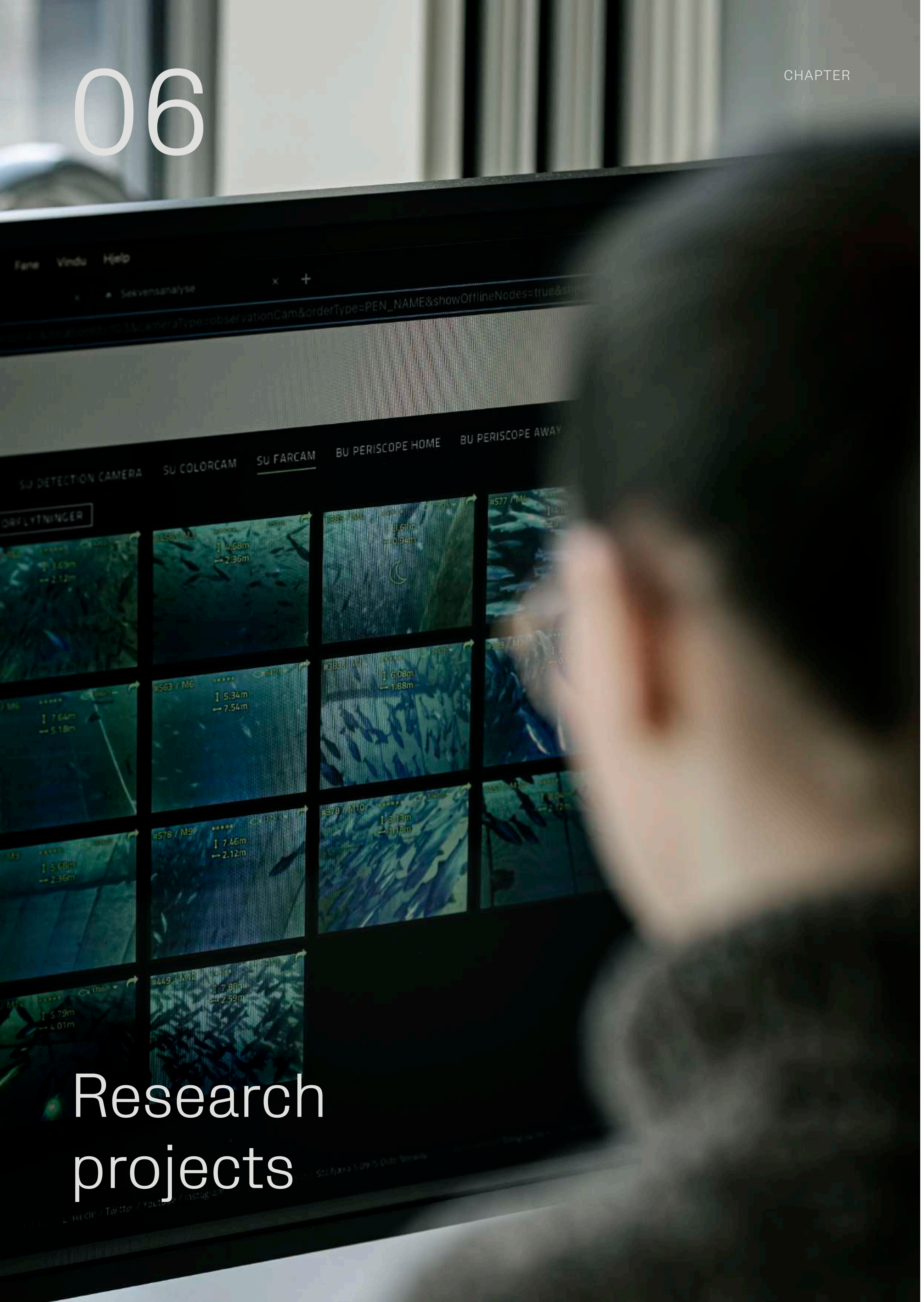
users completed Stingray Online course

114

users completed Fish Health course

Figure 4: Number of certified customer pilots/customer as of December 2023.






CHAPTER

06

# Research projects



06.1

## Biometrics

Stingray's weight detector is in production in its current version since February 2023. It delivers fish weight distribution- and biomass estimates with either weekly or daily granularity at pen- and cohort level (figure 7). This detector relies on stereo vision-based estimates from individual fish and was refined several times based on customer feedback.

With the introduction of a harvest loss estimate, provided by the user, the system can display harvest weight and weight class distribution estimates, calculated from live weight measurements.

On average, Stingray estimates deviate less than ±5% from manual customer estimates for all weight classes. When compared with harvest data, Stingray estimates provide on average a more accurate picture than manual estimates ahead of harvest (figure 6).

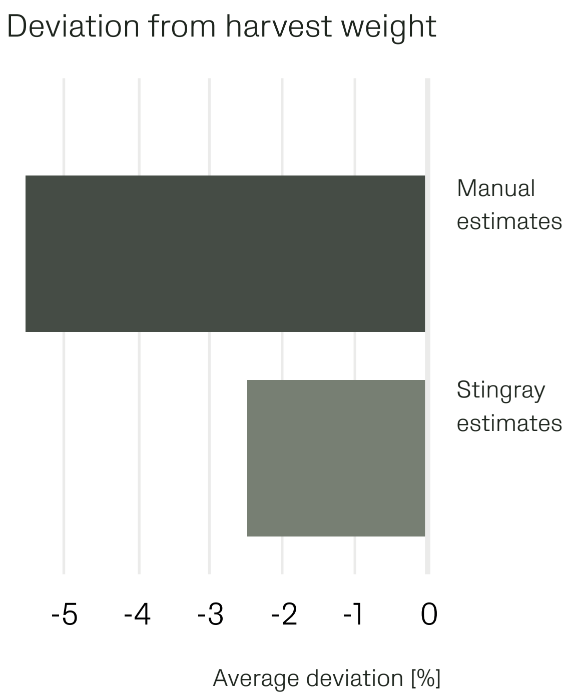



Figure 6: Average percent deviation from harvest weight for manual customer estimates and detector-based Stingray estimates.

| 918 | 3587 g | ± 35 g |
| --- | --- | --- |
| fish sequences processed | average weight | standard error of mean |

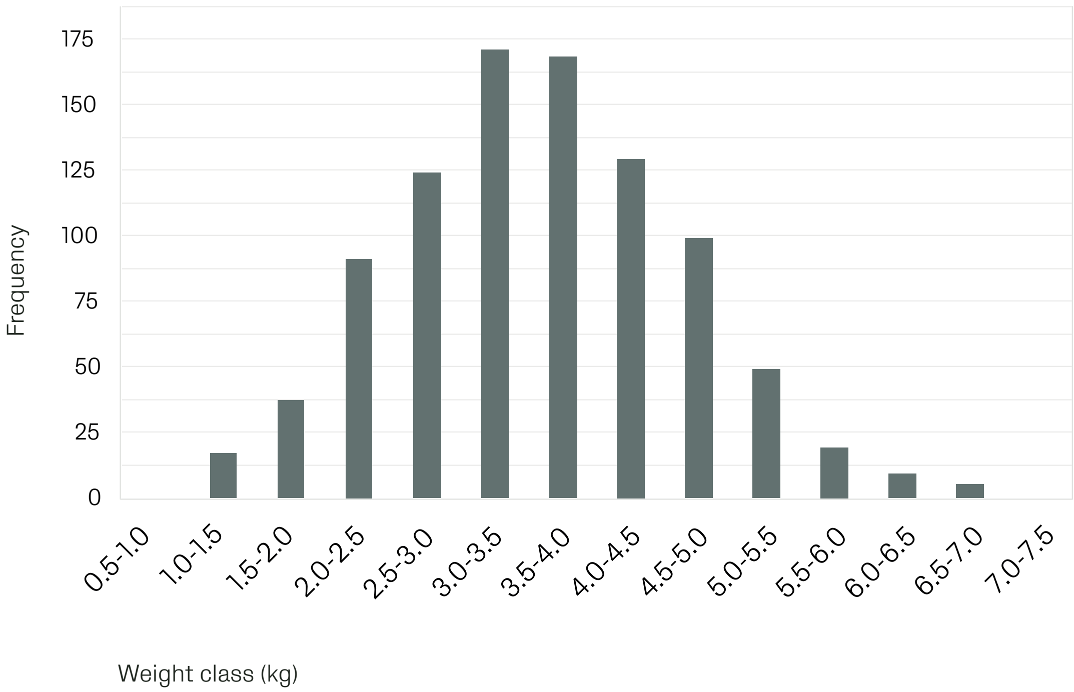



Figure 7: Automated estimates for average weight, and weight distribution.

# Attachment preferences of sea lice

The distribution of sea lice on salmonids in sea cages does not occur at random [1]. Where lice attach on a fish depends on life-cycle and abundance of the parasite, the prevalent hydrodynamics, as well as on the anatomy and physiology of the host.

When validating image-based lice counts, a recurring question concerns the significance of sea lice that are invisible on the rear-facing side of the fish in a 2D image. In Stingray, we have the unique opportunity to map lice distributions on large numbers of undisturbed fish during the entire marine phase of the production cycle based on lice detections that are confirmed by human analysts.

The resulting heat map (figure 8, upper) forms the basis for the assignment of 15 areas (figure 8, lower) that provide a more fine-grained picture of lice attachment preferences. It demonstrates that settlement of adult female and mobile lice under commercial conditions is mostly restricted to a few areas behind the adipose and anal fins, along the dorsal midline, and on the operculum of the fish (figure 9).

Since image-based counts in Stingray are conducted on image sequences of a moving fish, rather than individual images, the total visible surface area on a fish is larger than 50%. Combined with our new knowledge about actual attachment sites, this suggests that a substantial proportion of lice will be visible from either side of the fish.

These results have implications for our involvement with the Standard Norge committee SN/K 613 on "Non-invasive lice counting", because they concern the comparability of lice counts obtained by different methods.

A Master's project at the University of Bergen, which was conducted in association with Stingray, revealed no indication that image-based counts were underreporting lice numbers when compared to manual counting.

Different counting methods are subject to various biases that influence counting results [2], and the statistical confidence in reported lice numbers is relatively low due to small sample sizes and the non-normal distribution of lice between fish [3]. Our current results suggest that the inadequacies in manual lice counts outweigh those of image-based counting both statistically and in practice.

Adult female
Sample size 224 002

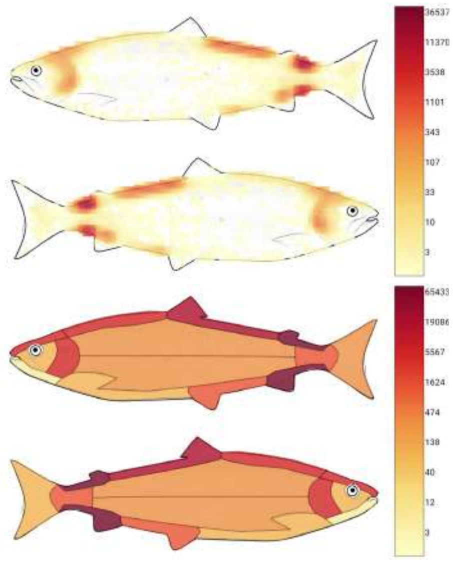


Figure 8: Adult female salmon lice (*Lepeophtheirus salmonis*) on farmed Atlantic salmon (*Salmo salar*). Upper: Heat map of detector-based louse positions confirmed by human analysts. Lower: Settlement intensity within outlined fish segments. Sample size: 224 002 individual fish.

1. Bui, S., Oppedal, F., Nola, V., & Barrett, L. T. (2020). Where art thou louse? A snapshot of attachment location preferences in salmon lice on Atlantic salmon hosts in sea cages. Journal of fish diseases, 43(6), 697-706.
2. Thorvaldsen, T., Frank, K., & Sunde, L. M. (2019). Practices to obtain lice counts at Norwegian salmon farms: status and possible implications for representativity. Aquaculture Environment Interactions, 11, 393-404.
3. Helgesen, K. O., & Kristoffersen, A. B. (2018). Telling av lakselus–Hvordan forstå og håndtere usikkerheten i telleresultatene. Counting of salmon lice–how to understand and handle uncertainties in counting results). Report, 22-2018.

## Lice distribution on salmon and trout

All types of lice

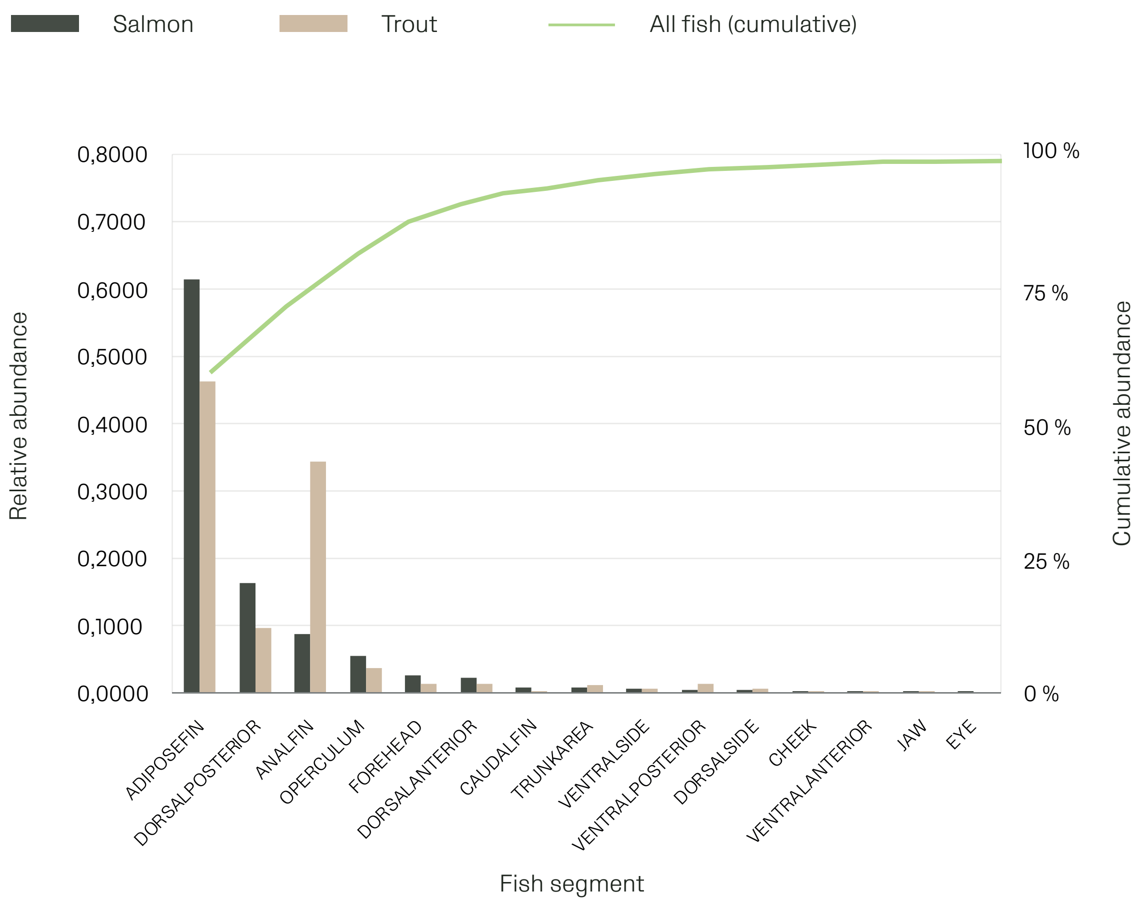



Figure 9: Relative distribution of sea lice (adult females, mobiles, and Caligus) on farmed Atlantic salmon (dark gray bar), rainbow trout (beige) and all fish (green line) by fish segment.

06.3

# Fallacy of a correction factor in automated computer vision-based lice counting

Andersen, Marlin Firveld. MSc thesis. The University of Bergen, 2023.

**Master thesis**
This thesis emerged from a collaboration between the University of Bergen (UiB) and Stingray. The goal was to find a correction factor compensating for the lee side of fish, away-facing from the cameras. To achieve this, manual lice counts performed by farmers were considered as the “true” lice abundance at a given fish farm location. Image-based counts and other pertinent variables were then utilized to model these manual counts. Initially, the assumption was that a correction factor would need to adjust image-based or automated counts upwards, accounting for potential lice on the unobserved side of the fish. However, the findings of this thesis revealed the exact opposite. Manual counts consistently tended to yield lower results than image-based counts, necessitating a correction factor to downwardly adjust the latter to achieve parity.

We can see from table 3 that for all locations analyzed in this assignment, simple linear models with manual counts as target variables and image-based counts as explanatory variables have coefficient estimates for the slopes lower than 1. The $R^2$ values show that image-based counts struggle to explain the variance present in the manual counts. Location 2 (as shown in table 3) was the location where image-based counts explained the greatest amount of variance in the manual counts.

**Relevance for Stingray**
Stingray has been actively researching correction factors for an extended period. Initially, the Norwegian Food Safety Authority mandated a correction factor for automated or image-based lice counting as a prerequisite for companies seeking commercial use of such technology. While this requirement has since been relaxed, the underlying issue remains pertinent. The goal is to refine automated lice counts, if necessary, to obtain a more accurate estimation of actual sea lice counts within a pen.

Table 3: Summary statistics of the linmodImFem model, with manual counts as dependent variable and image-based counts as independent variable. Locations are denoted under Location by their respective numbers, coefficients are the names of the coefficients, whereas the values under estimate are the coefficient estimates for the intercept and image-based count variables. The std.error stand for standard error. The t-value is a statistic that measures the number of standard errors that the estimate is away from zero. The p-value can aid in determining if a coefficient is statistically significant or not.

| Location | Coefficients | Estimate | Std. error | t.value | p.value | $R^2$ |
|---|---|---|---|---|---|---|
| 1 | intercept | 0.0291 | 0.0383 | 0.0383 | 0.448 | 0.396 |
| 2 | intercept | 0.0153 | 0.0317 | 0.0317 | 0.631 | 0.798 |
| 4 | intercept | 0.0533 | 0.0366 | 0.0366 | 0.147 | 0.549 |
| 6 | intercept | 0.0768 | 0.0552 | 0.0552 | 0.166 | 0.366 |
| 1 | imageFem | 0.974 | 0.144 | 0.144 | < 0.0001 | 0.396 |
| 2 | imageFem | 0.888 | 0.114 | 0.114 | < 0.0001 | 0.798 |
| 4 | imageFem | 0.515 | 0.124 | 0.124 | < 0.0001 | 0.549 |
| 6 | imageFem | 0.982 | 0.171 | 0.171 | < 0.0001 | 0.366 |





**Implications**
Although this project did not yield a definitive correction factor, it provided valuable insights into the challenges of lice counting. Estimating the mean of a large population with a heavily skewed distribution poses significant challenges. Compared to symmetric distributions like a normal distribution, much larger sample sizes are required to achieve accurate estimates. Additionally, the inherent uncertainty in population parameters within a pen or fish farm location exacerbates the complexity of the problem.

Figure 10 demonstrates that increasing the sample size from twenty to 120 samples substantially reduces the margins of error, making a case for fully automated lice counts. Confidence intervals, derived from a theoretical distribution of lice among fish through simulation studies, highlight the importance of sample size in reducing uncertainty.

Using manual counts as the “truth” is not ideal for deriving a correction factor. As soon as fully automated lice counts are available, methods from this thesis can guide the determination of sample sizes for accurate estimates. Alternative approaches will be necessary to establish a correction factor when automated counting becomes feasible.

The final model in the thesis is represented as:

*Manual counts*$_{ij}$ = *-0.00684 + 0.548*image-based*$_{ij}$ + *0.228*normPulses*$_{ij}$ + $b_{0i}$ + $\varepsilon_{ij}$, where $\varepsilon_{ij}$ is assumed to be normally distributed with mean 0 and variance $\sigma^2$ that is a power function of the normalized pulses and follows an AR(1) correlation structure.

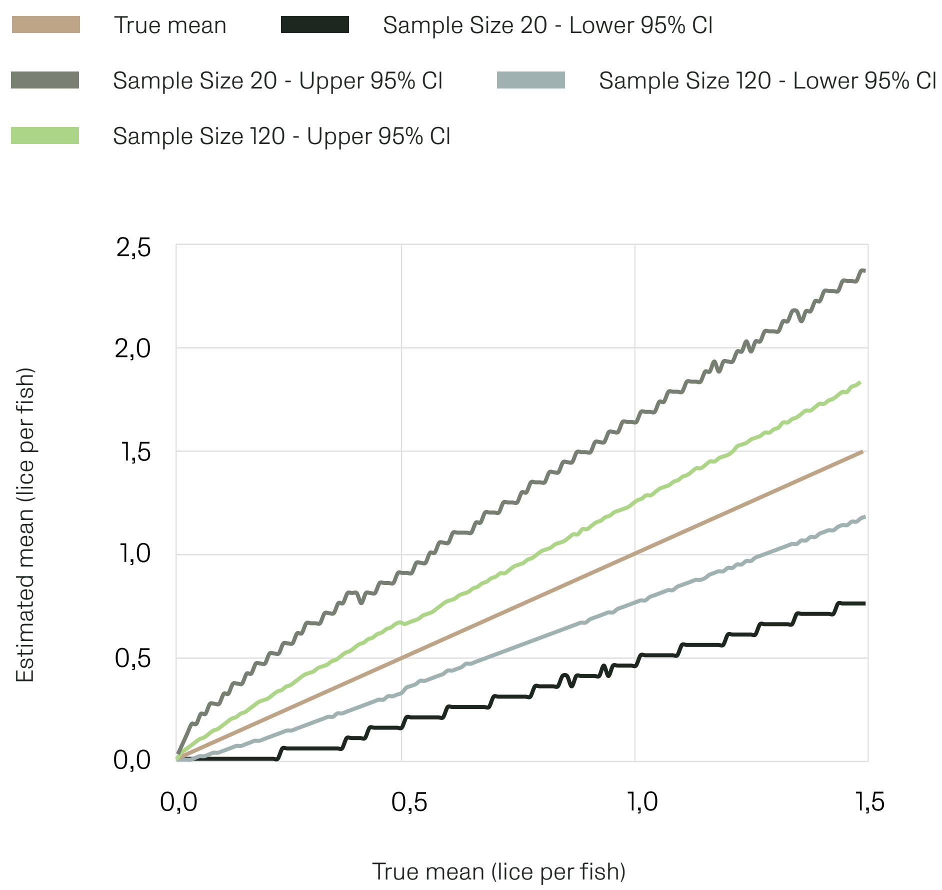



Figure 10: 95% confidence intervals around different population means when the sample sizes are twenty and 120 fish, with replacement. The upper darker red line is the upper bounds of the interval, whereas the lower lighter line is the lower bounds of the intervals based on twenty samples. Equivalently, the lower blue line is the lower bounds and the upper blue line is the upper bounds of the intervals based on 120 samples. The black line in the middle is the population means (True mean in the figure). The x-axis shows the population means and the y-axis shows the estimated mean lice per fish. The intervals have been calculated for theoretical population means ranging from zero to 1.5, with 0.01 step increments.

CHAPTER 07

# Biological results



07.1

## Successful deployment

An investment in Stingray's laser technology necessitates thorough preparation and a commitment to success. The system requires stable energy to function, a crane boat for deployment and a cleaning routine in place. Stingray assumes responsibility for node installation and provides all necessary training through Stingray Academy. The system will collect data and visualize results from day one, available for analysis and interpretation in the online customer portal.

Stingray recommends full coverage with nodes from stocking and throughout the complete production cycle. In addition, areas with high location density, high lice pressure, and/or areas without pro-active treatment plans will require additional nodes/pen. Stingray typically recommends three to four nodes/pen in critical areas.

Stingray will always provide all services, irrespective if customers hire their own staff or rely on Stingray personnel alone. However, even though not strictly required, we recommend the implementation of specific customer staff roles, such as a dedicated staff member responsible for Stingray systems and trained Stingray customer pilots. Operational and biological success has been linked to good communication and professional collaboration between customer and supplier.

Achievable results can vary due to a number of factors. In general, Stingray expects a reduction in overall louse numbers and a possible reduction in alternative treatment interventions.

| General factors affecting delousing |
|---|
| Geography |
| Species farmed |
| Feeding strategy |
| Water temperature |
| Fish stock/biomass |
| Treatment strategies |
| Fallowing and stocking strategies |
| Hydrodynamics/water exchange rates |
| Sea water chemistry/freshwater run-off |
| Farm density/proximity to neighboring farms |
| Deployment strategy and prevalent louse levels |

| Human factors |
|---|
| Training of staff |
| Response times |
| Commitment to success |
| Availability of equipment |
| Implementation of routines |
| Fish passings achieved by pilots |
| Customer expectation and success definition |

| Biological factors |
|---|
| Behavior |
| Health status of farmed fish |
| Overall sea louse population |

While it is difficult to predict actual louse numbers at any given pen, location or production area with certainty, Stingray's databases can provide an aggregated overview for different generational production cycles for all Stingray customers. Sea louse abundance/infection tends to follow a typical seasonal pattern. Autumn is generally considered to be the most challenging season due to high louse reproductive rates at warmer water temperatures.

Figure 11 and 12 show a spring and autumn stocking, respectively. A clear difference in first year-at-sea fish is seen comparing spring and autumn fish, with spring fish being exposed to higher louse infection pressures during their first autumn at sea. The figures clearly demonstrate reduced louse numbers for Stingray-covered production cycles, particularly during the colder seasons.

### Adult lice per week, Spring 2022

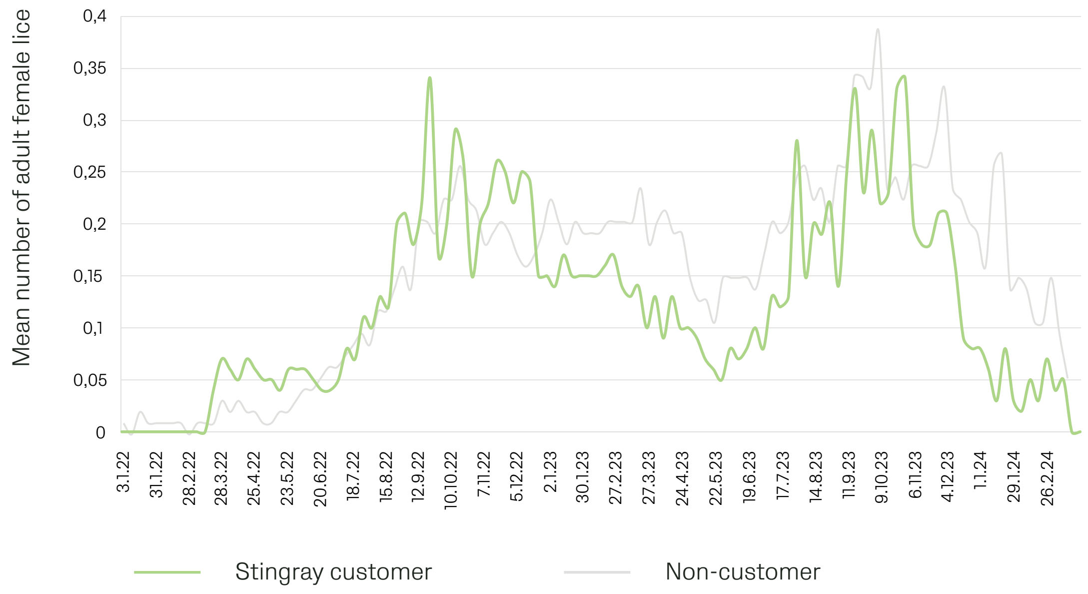



Figure 11: Mean number of adult female salmon lice for Spring 2022 stocking cycles for Stingray-users (green) and non-Stingray locations (gray). Weekly means are calculated using publicly available data for all locations, Spring 2022-generation.

### Adult lice per week, Autumn 2022

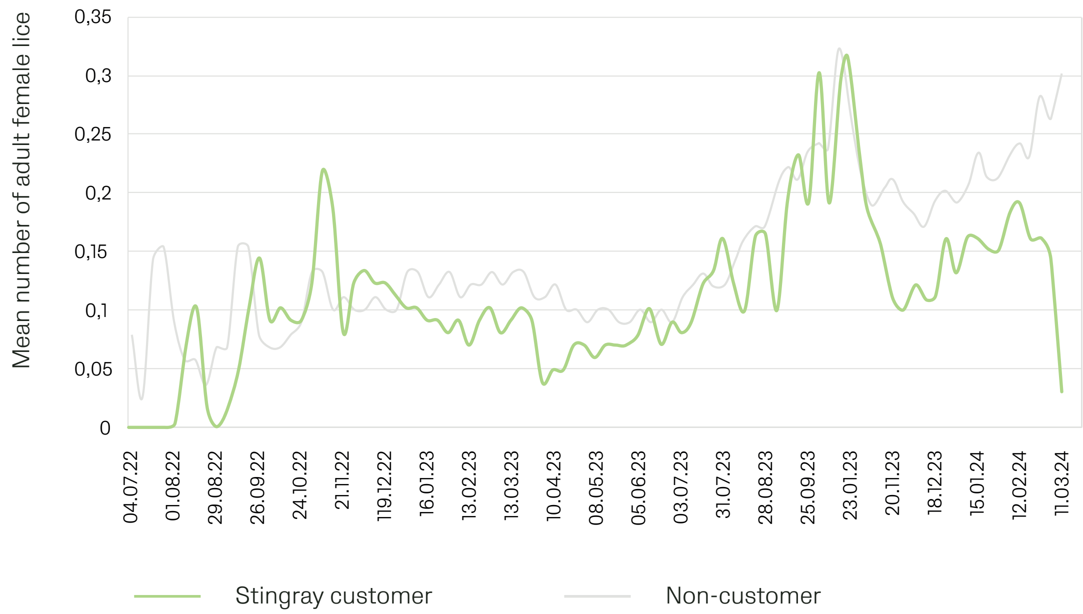
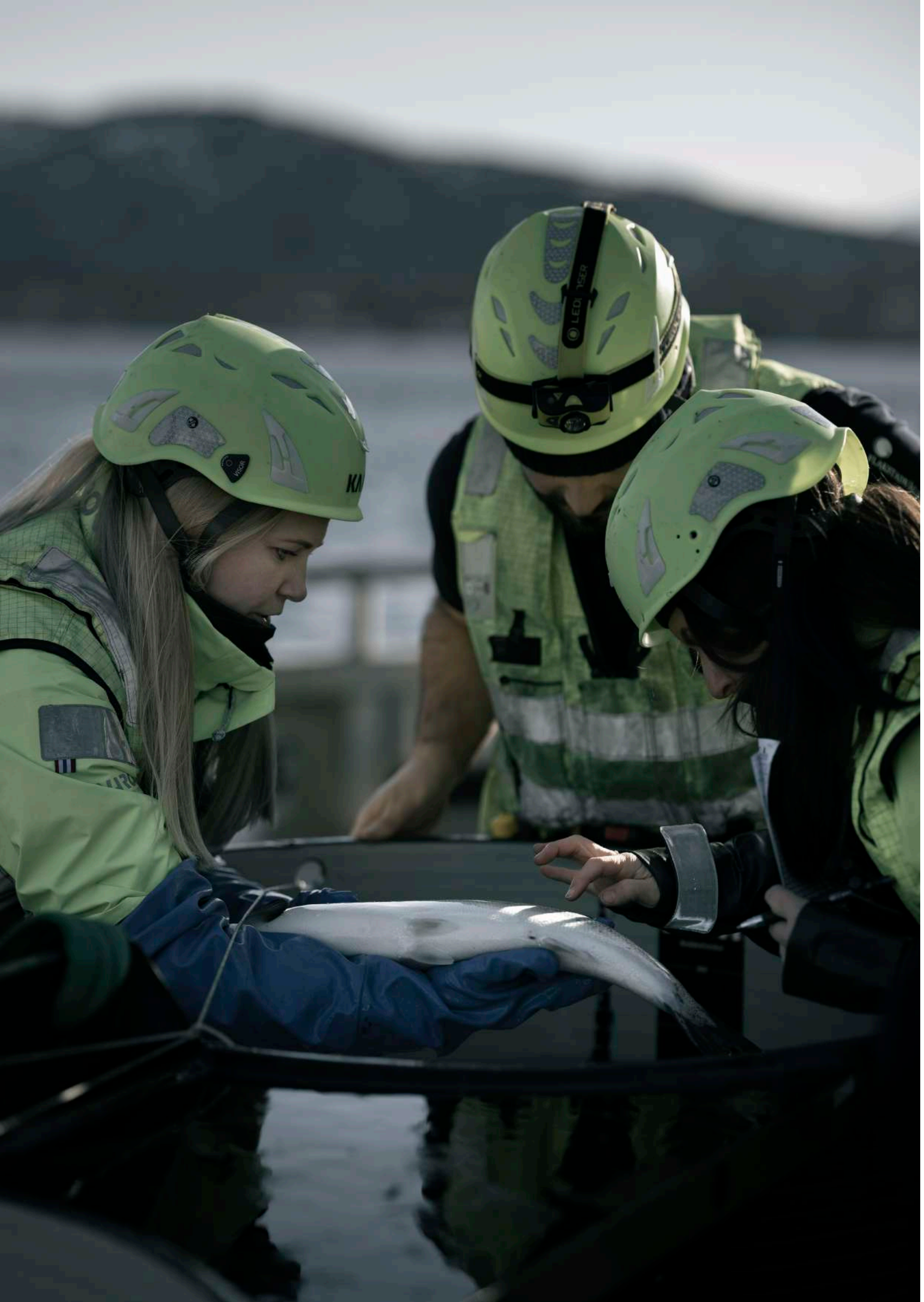



Figure 12: Mean number of adult female salmon lice for Autumn 2022 stocking cycles for Stingray (green) and non-Stingray locations (gray). Weekly means are calculated using publicly available data for all locations, Autumn 2022-generation.



07.2

# Production areas in Norway

In 2017, the Norwegian coastline was divided into 13 production areas (PAs), which form the basis for the regulation of biomass capacity for salmon and trout farming by the so-called traffic light system. Every second year, the Ministry of Trade, Industry, and Fisheries updates the growth opportunities of the industry derived from model-based assumptions of the mortality rates of wild salmon smolts attributed to salmon lice that originate from aquaculture sites within the respective production area. The color code of the traffic light system has the following implications:

Green = can achieve a 6% increase in production. In this category, it is assumed that less than 10% of wild salmon smolts may die as a result of salmon lice.

Yellow = no change in production. In this category, it is assumed that 10–30% of wild salmon smolt may die as a result of salmon lice.

Red = must undergo a 6% reduction in production. In this category, it is assumed that over 30% of wild salmon smolt may die as a result of salmon lice. Fish farmers falling into this category can apply for exemption from the reduction if they can demonstrate low lice numbers, and active measures to control louse levels. This has been achieved by several Stingray customers through the use of our system.

Figure 13: Production areas in Norway, spanning 20-30 nautical miles off of the coast line. The map depicts the traffic light as of December 2023. The green pins indicate active locations with Stingray systems deployed in January 2024. The color of each production area represents the change in biomass capacity regulated by the traffic light system.

The 13 production areas are as follows (figure 13):

Area 1: Swedish border to Jæren
Area 2: Ryfylke
Area 3: Karmøy to Sotra
Area 4: North Hordaland to Stadt
Area 5: Stadt to Hustadvika
Area 6: Nordmøre and Sør-Trøndelag
Area 7: Nord-Trøndelag including Bindal
Area 8: Helgeland to Bodø
Area 9: Vestfjorden and Vesterålen
Area 10: Andøya to Senja
Area 11: Kvaløya to Loppa
Area 12: West Finnmark
Area 13: East Finnmark

# Aquaculture industry lice trends

In Norway, significant changes in sea louse abundance and infection pressure have been observed in the last few years, particularly during the summer of 2023. A reduction in lice pressure compared to the preceding four years (figure 14, 15) has been reported.

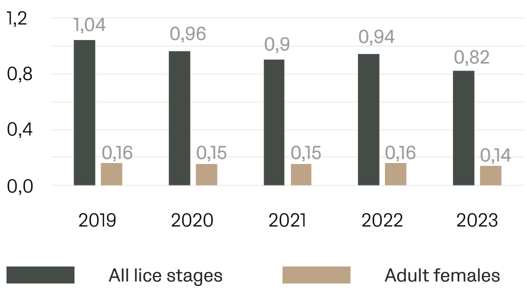



Figure 14: Lice pressure in Norway for Q2 the past five years. Mean values for adult females are indicated in beige, while the mean for all lice stages are indicated in dark green.

In 2023, the average of 0.14 adult female lice per fish, was slightly lower than the 0.15 recorded in 2021. Similarly, when considering all stages of lice, the numbers showed improvement, with 0.82 in 2023 compared to 0.9 in 2021. These figures suggest a gradual but potentially positive trend in managing the overall louse population.

Mean number of adult females per fish

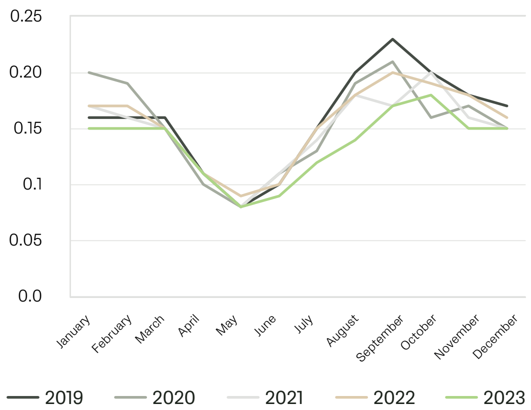



Figure 15: Average amount of adult female lice/fish throughout the year, the past five years.

One particularly encouraging development is a reduction in the number of lice threshold violations in 2023 compared to previous years. This reduction is most evident in PA10, which experienced nearly a 70% decrease in weeks exceeding the lice threshold. Additionally, other regions in the north, along with PA4 and PA5, also witnessed significant decreases in lice threshold breaches. These trends indicate progress in controlling lice infestations across various production areas.

As no clear definition for what constitutes a treatment has been established, available public data, such as from Barentswatch, provides only a rough approximation for treatment frequency. This is further complicated by treatment strategy, single pen vs. whole location treatments, short vs. long term treatments and the different treatment methods employed (figure 16). To account for the unique characteristics of each production area and method, we therefore calculate the percentage of active locations undergoing treatment, in order to judge treatment frequency trends in the industry, referred to as treatment weeks in this document (figure 17). This also provides us with a weighted average for treatment interventions irrespective of production cycle length or time period analyzed.

Distribution of treatment methods

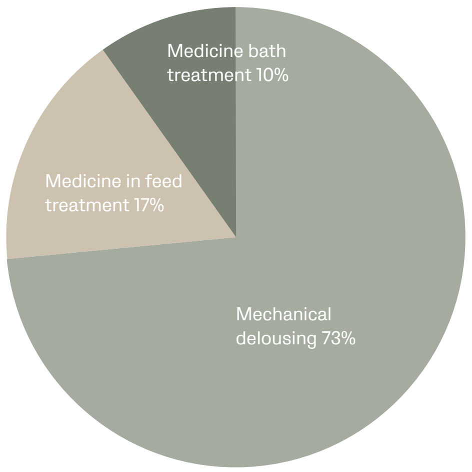


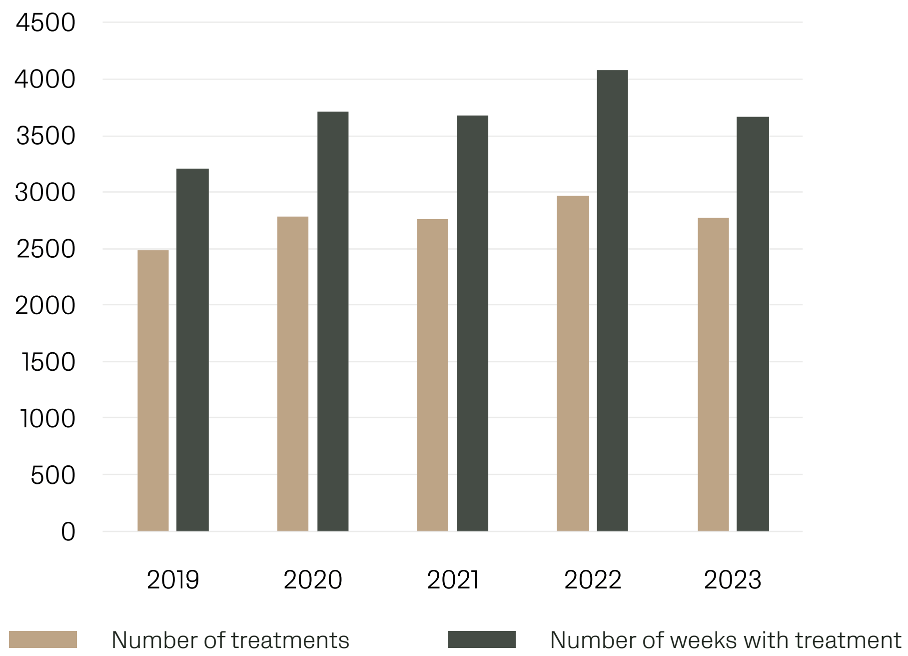

Figure 16: Distribution of treatment methods used in 2023 across all fish farmers in Norway.



Results from 2023, show PA5 having the most significant increase in treatment frequency, while PA10 experienced the highest decrease (figure 18, 19). This is a deviation from historical trends and underscores the dynamic nature of lice management strategies and the need for adaptive approaches.

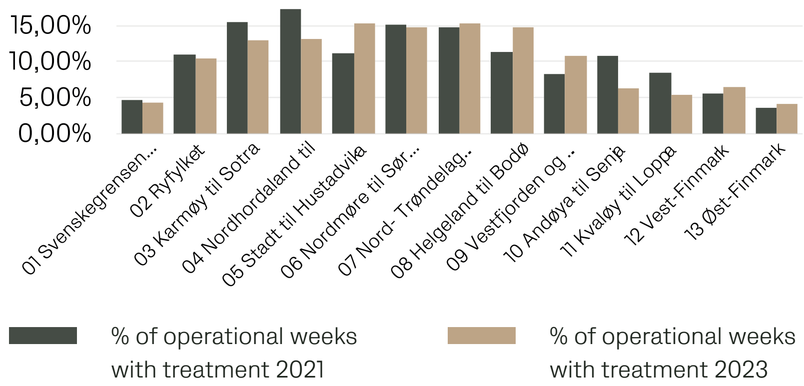
Number of treatments vs. number of weeks with treatments

Figure 17: Number of treatments vs. the number of weeks with treatments from 2019 to 2023.



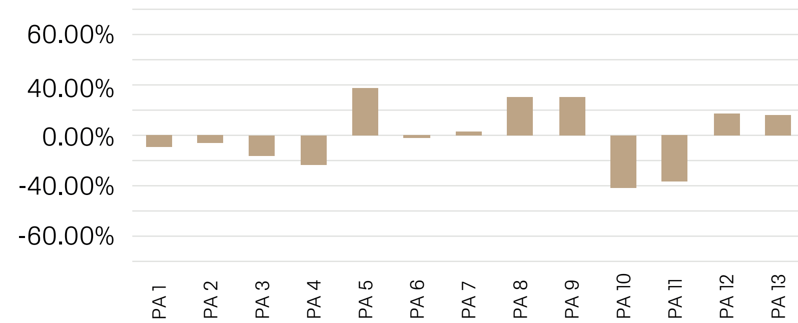

Percentage of operational weeks with treatment

Figure 18: Percentage of operational weeks with treatments per production area in 2021 compared to 2023.




Percentage difference from 2021

Figure 19: Percentage difference between treatments in 2023 vs. treatments in 2021 per production area.




07.4

# Stingray leads industry transformation

Proportion of Stingray sites per week

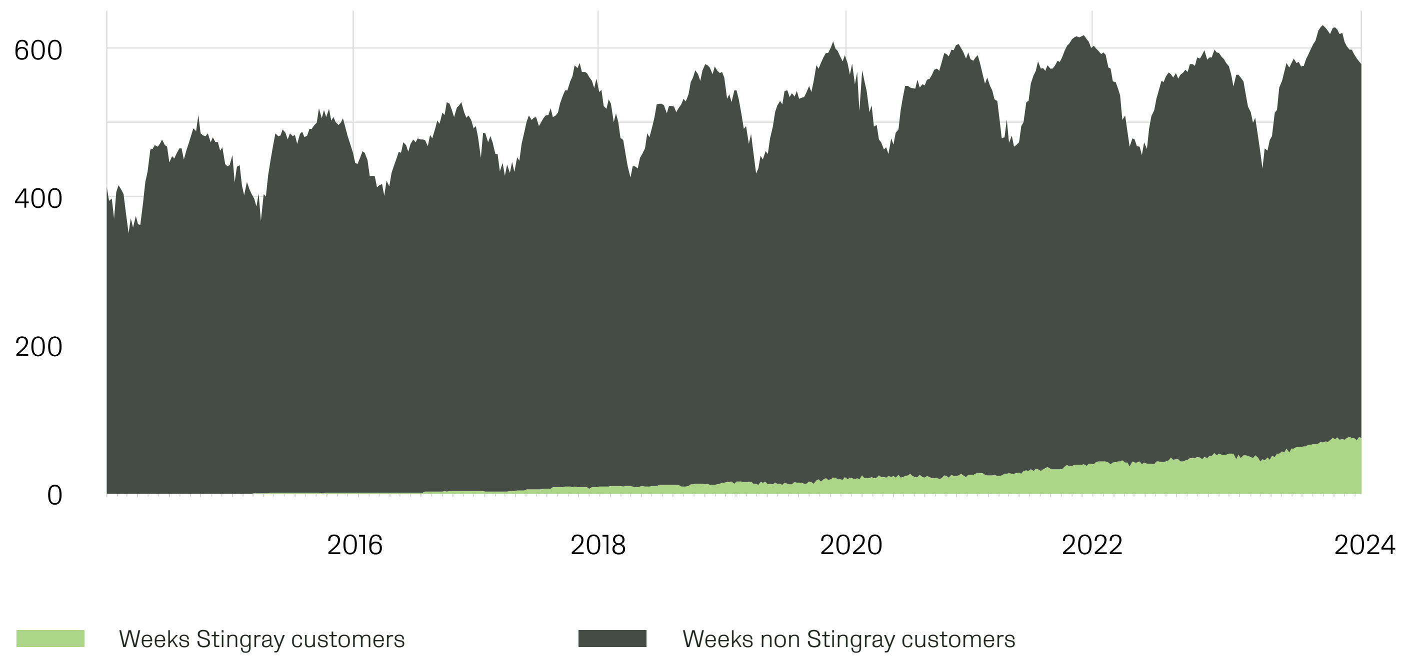



Figure 20: Weekly Stingray market share from 2014 until 2024. Stingray customers (green) and non-customers (gray). The recorded decrease in active locations during winter months does not indicate a reduction in the overall number of locations in Norway, but a result of counting/reporting lice every 14 days during cold sea conditions.

Throughout the course of 2023, the market share of Stingray nodes has witnessed a remarkable boost, nearly doubling in number, and achieving an impressive coverage of 11% of all locations across Norway by the end of December. Overall, Stingray nodes were operational in 8.5% of all location weeks throughout 2023 (figure 20).

The recorded registration drop in active locations during the winter months underscores the necessity of adapting novel, automated monitoring strategies independent of seasonal variations and environmental factors, ensuring continuous, comprehensive and accurate data collection.

Adult female lice per fish vs. market share % Stingray


Figure 21: Average number of adult female lice in 2023 per production area for Stingray customers (green) and other locations (dark gray), ranged by Stingray market share in percent (beige line) within each production area.

A closer examination of Stingray's market share reveals a varied distribution of nodes across different regions, with a significant concentration in PA10. As Stingray's market share increases within specific production areas, the disparity in lice levels between Stingray customers and other salmon producers widens (figure 21). Figure 22, illustrating the average number of adult female lice per fish for the year 2023, reveals the full impact of laser delousing. This can be attributed to two complementary results: Stingray's technology contributes to maintaining lower overall lice pressure within the region and/or our customers achieve superior lice management results owing to the advanced capabilities of Stingray's monitoring system.

Difference in number of lice per fish

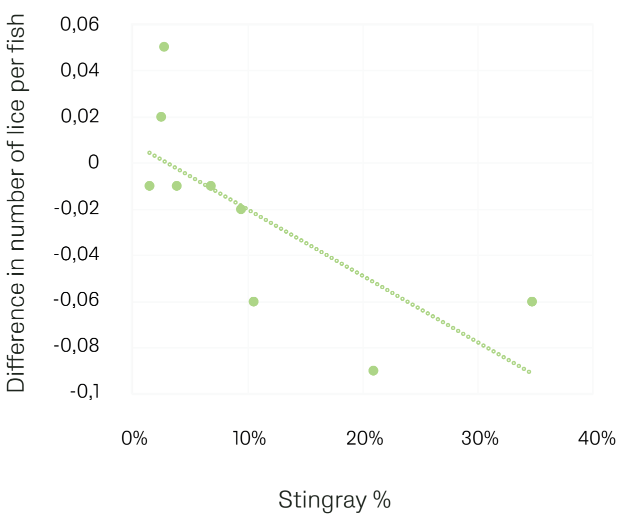



Figure 22: Difference in the number of lice per fish between Stingray customers and all other locations for all production areas in which Stingray operated in 2023, depending on Stingray market share in percent of these production areas.

Similarly, the data analysis indicates a lower frequency of treatment weeks among Stingray customers compared to other companies within the same PAs (figure 23). This suggests that Stingray's technology plays a significant role in reducing the need for treatments, as our customers demonstrate a decreased requirement for interventions to manage sea louse levels effectively.

The analysis highlights a similar trend concerning the number of treatments, with increased discrepancies between Stingray customers and other companies in the same PAs as Stingray's market share expands (figure 24). This demonstrates that Stingray's innovative delousing and monitoring solutions contribute to minimizing the necessity for treatments among our customers.

% of operational weeks with treatments

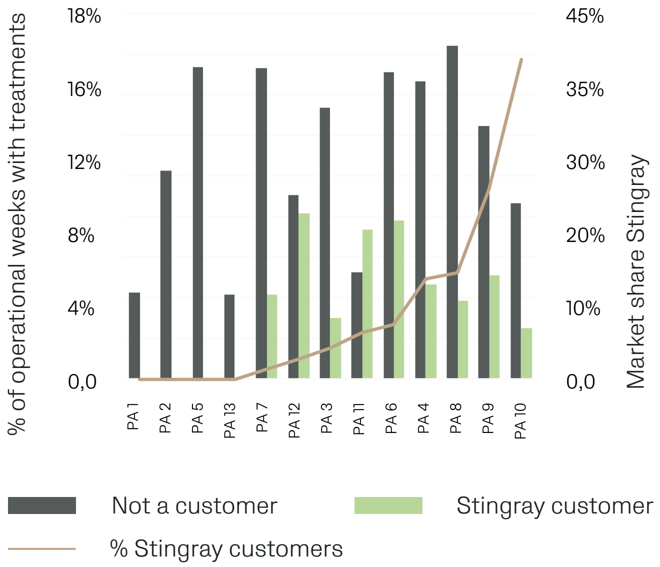



Figure 23: Percent of operational weeks with treatments in 2023 per production area for Stingray customers (green) and other locations (dark gray), ranged by Stingray market share in percent (beige line) within each production area.

Difference in % treatment weeks

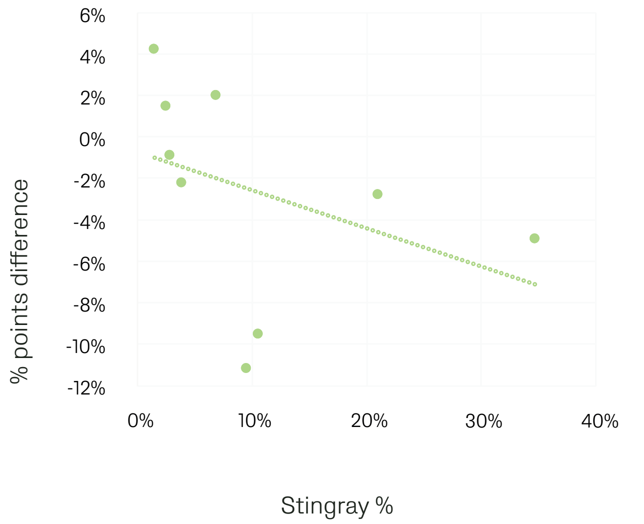



Figure 24: Percent difference in the amount of operational weeks during which fish were treated at Stingray customers and all other locations for all production areas in which Stingray operated in 2023, depending on Stingray market share in percent of these production areas.

07.5

# Comparative analysis of production areas with and without Stingray technology

The following section utilizes Stingray- and publicly available data to compare various production areas with and without Stingray deployment since 2016. Four different PAs were selected for comparison due to their high coverage of laser usage. Despite the good coverage with Stingray technology, non-laser locations are still available for comparison of the effects. The selected PAs are:

## PA 4

North Hordaland to Stadt

## PA 8

Helgeland to Bodø

## PA 9

Vestfjorden and Vesterålen

## PA 10

Andøya to Senja



07.6

# Production area summary | PA 4

- Reduced treatment interventions and some completely treatment-free production cycles (figure 25, 26)
- Existing customers purchase additional Stingray systems and expand coverage (figure 27)
- Improved harvest planning through the use of Stingray's sexual maturation detector
- Higher harvest weights achieved than during previous production cycles
- Below PA-average amounts of adult female lice per fish (figure 26)
- Reduction/phasing out of cleaner fish use at some locations
- High demand for Stingray-trained customer pilots

Proportion of production weeks

Proportion of treatment weeks

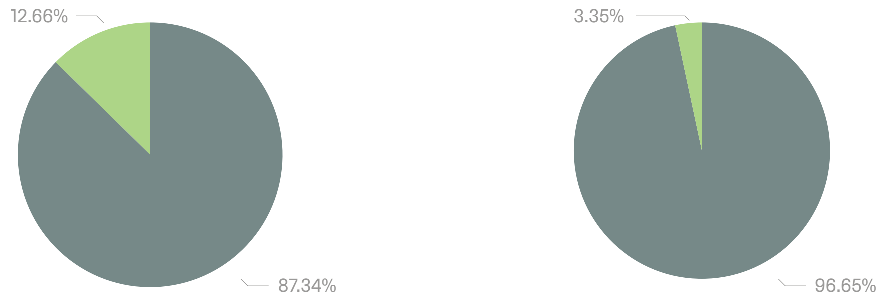
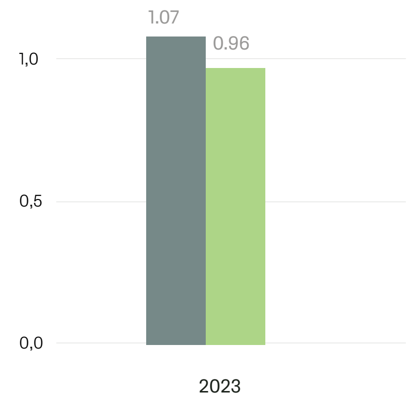



Figure 25: Proportion of production weeks (left) for Stingray customers (green) and non-customers (gray). Proportion of treatment weeks (right) for Stingray customers (green) and non-customers (gray). Data from Barentswatch on location level at the different customers.

Avg lice per fish per year




Stingray

Non Stingray

Figure 26: Average amount of lice per fish in 2023 for Stingray customers (green) and non-customers (gray) in PA 4.

Stingray market share PA4

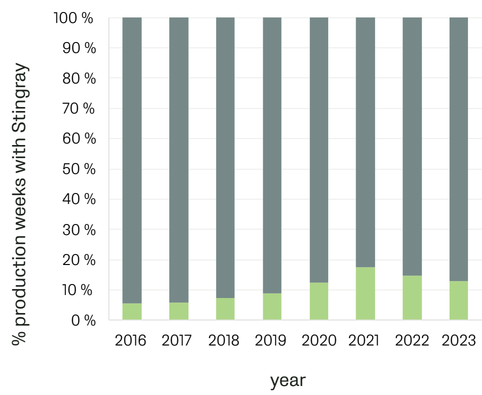


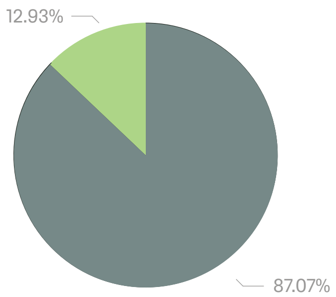

Figure 27: Stingray market share increase in production area 4 from 2016 to 2023.

07.7

# Production area summary | PA 8

| |
|---|
| Customers use Stingray technology as a selling point for their marketing strategies |
| Reduced/avoided treatment interventions during production cycles (figure 28) |
| 60% reduction in delousing compared to the previous generation |
| Below average amounts of adult female lice per fish (figure 29) |
| Phasing out of cleaner fish entirely, replaced by Stingray technology (figure 30) |

Proportion of production weeks




Proportion of treatment weeks

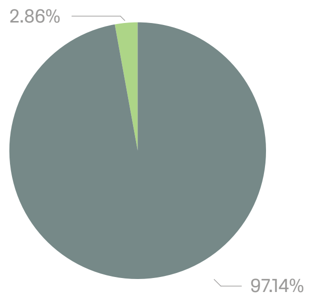
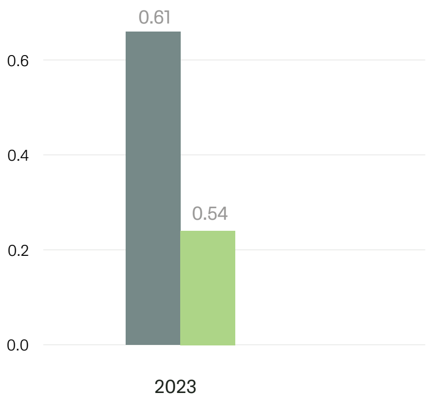
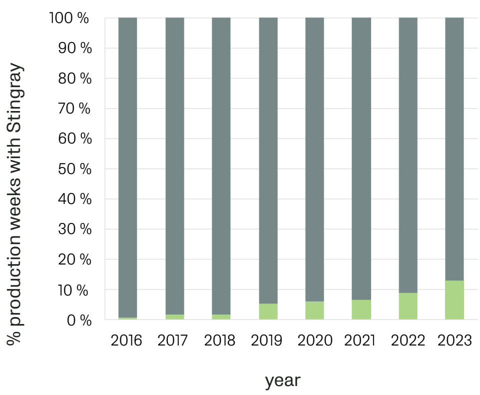



Figure 28: Proportion of production weeks (left) for Stingray customers (green) and non-customers (gray). Proportion of treatment weeks (right) for Stingray customers (green) and non-customers (gray).

Avg lice per fish per year




Stingray market share PA8




Stingray

Non Stingray

Figure 29: Average amount of lice per fish in 2023 for Stingray customers (green) and non-customers (gray) in PA 8.

Figure 30: Stingray market share increase in production area 8 from 2016 to 2023.

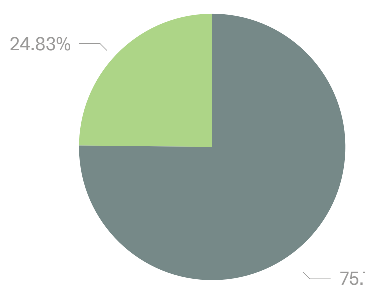


07.8

# Production area summary | PA 9

| |
|---|
| Avoided spring delousing |
| Reduced/avoided treatment interventions during production cycles (figure 31) |
| Below average amounts of adult female lice per fish (figure 32) |
| Reduction/phasing out of cleaner fish use as Stingray market share increases (figure 33) |
| Higher harvest weights than comparable previous production cycle |
| Extended duration between stocking and need for first reactive treatment |

Proportion of production weeks




Proportion of treatment weeks

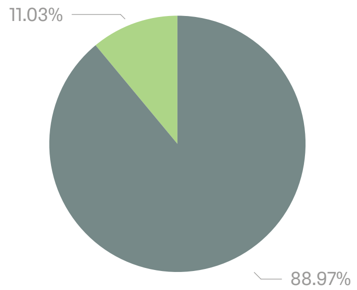
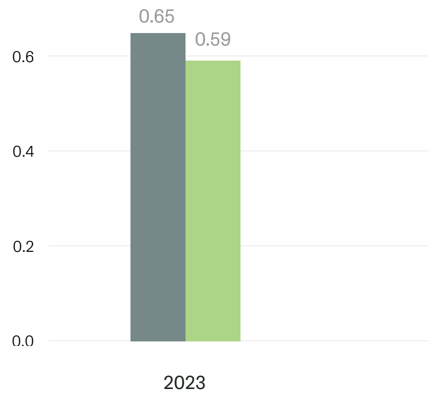
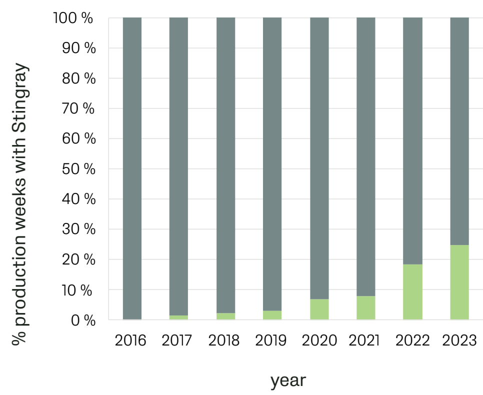



Figure 31: Proportion of production weeks (left) for Stingray customers (green) and non-customers (gray). Proportion of treatment weeks (right) for Stingray customers (green) and non-customers (gray).

Avg lice per fish per year




Stingray market share PA9




Stingray

Non Stingray

Figure 32: Average amount of lice per fish in 2023 for Stingray customers (green) and non-customers (gray) in PA 9.

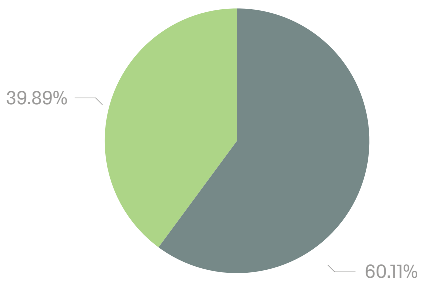
Figure 33: Stingray market share increase in production area 9 from 2016 to 2023.

07.9

# Production area summary | PA 10

| |
|---|
| Reduced treatment interventions and some completely treatment free production cycles (figure 34) |
| Below average amounts of adult female lice per fish (figure 35) |
| 1/3 of locations with Stingray coverage (figure 36) |
| All customers employ their own pilots |
| Avoided spring delousing |

Proportion of production weeks




Proportion of treatment weeks

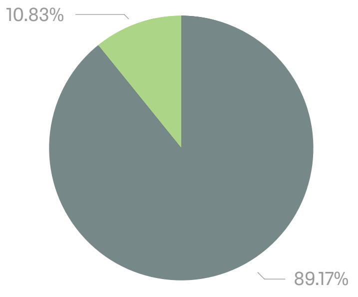



Figure 34: Proportion of production weeks (left) for Stingray customers (green) and non-customers (gray). Proportion of treatment weeks (right) for Stingray customers (green) and non-customers (gray).

Avg lice per fish per year

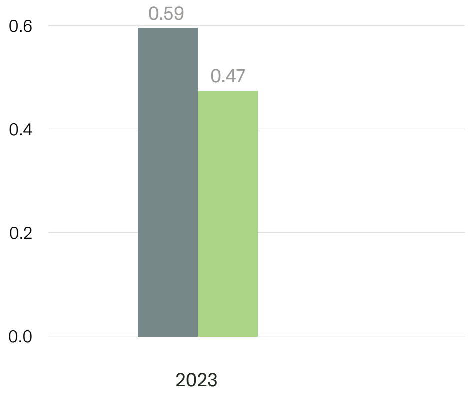



Figure 35: Average amount of lice per fish in 2023 for Stingray customers (green) and non-customers (gray) in PA 10.

Stingray market share PA10

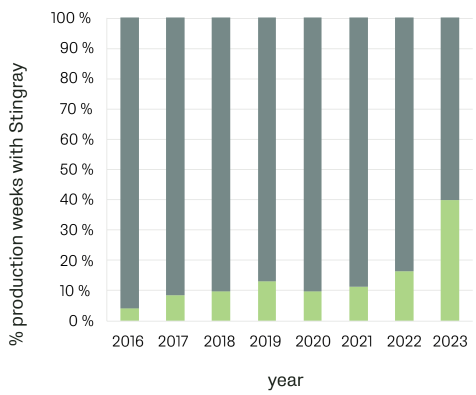
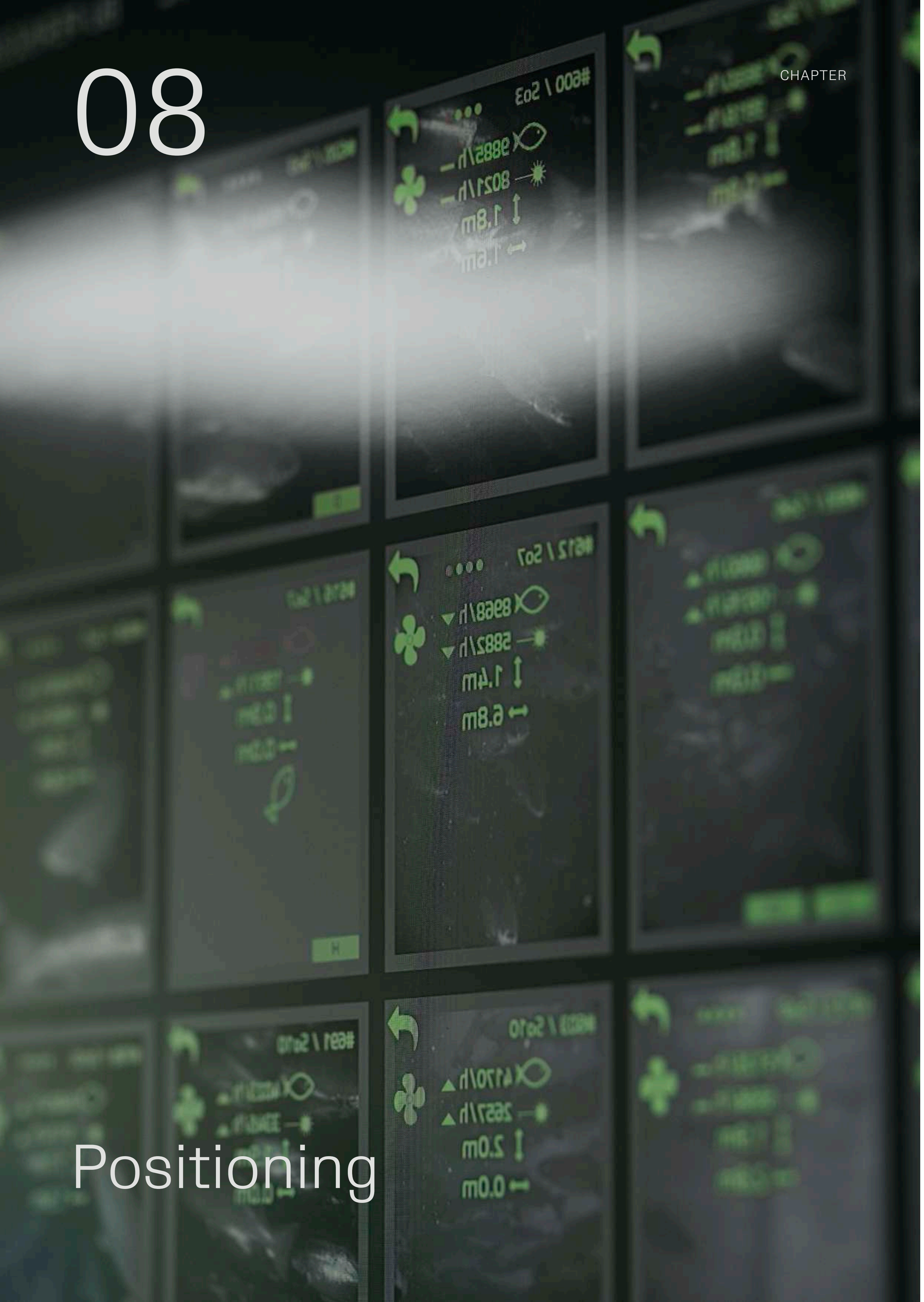


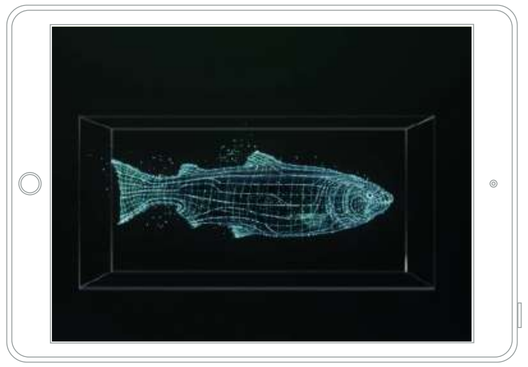

Figure 36: Stingray market share increase in production area 10 from 2016 to 2023.

Stingray

Non Stingray



# 08 CHAPTER Positioning



The Stingray Positioning team consists of Stingray pilots with expertise in salmonid aquaculture, marine biology, behavioral ecology, and production routines.

Through continuous monitoring of all systems along the coast, the Positioning team maintains regular contact with our customers to ensure they get the best out of the equipment;

**All day, every day.**

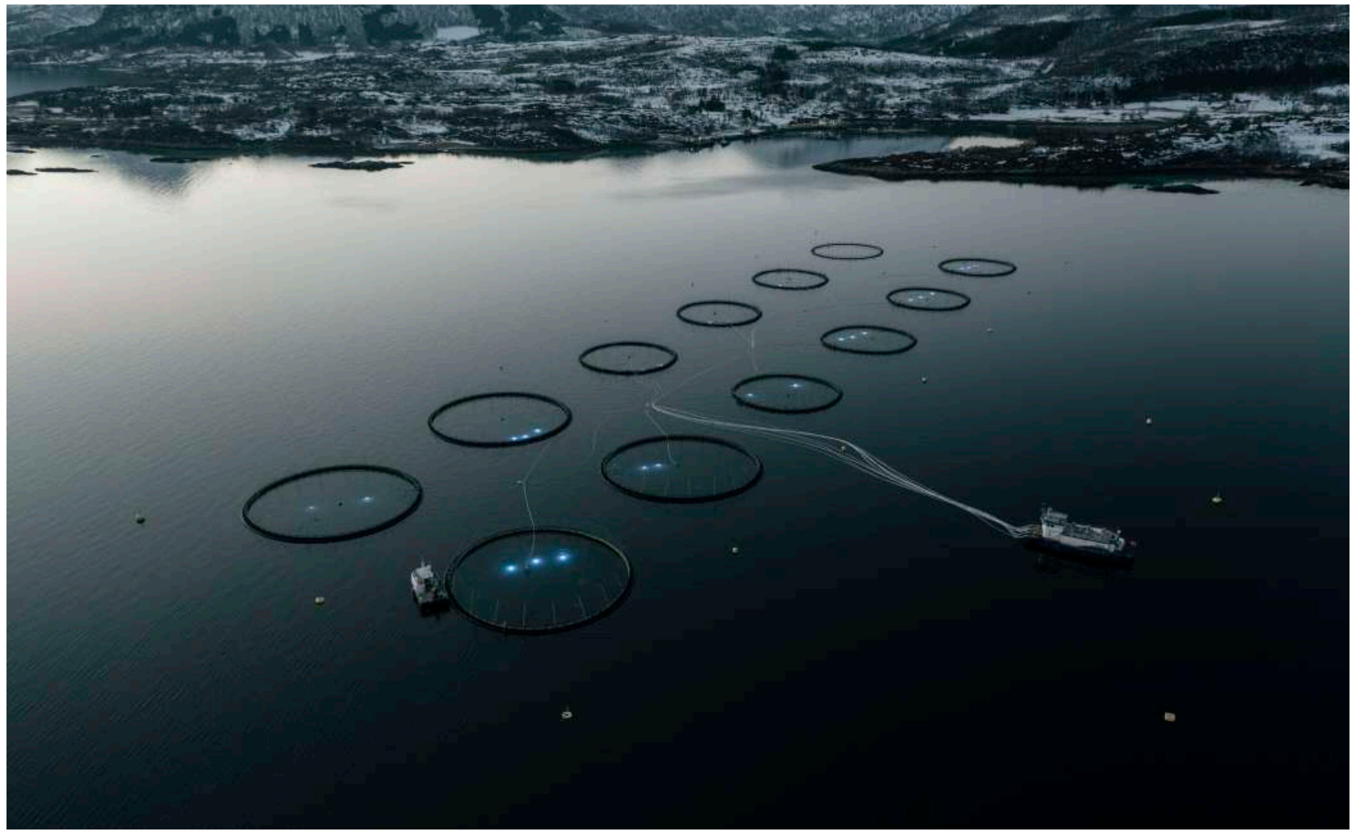
08.1

# Positioning through 2023

1045 active laser nodes are installed at

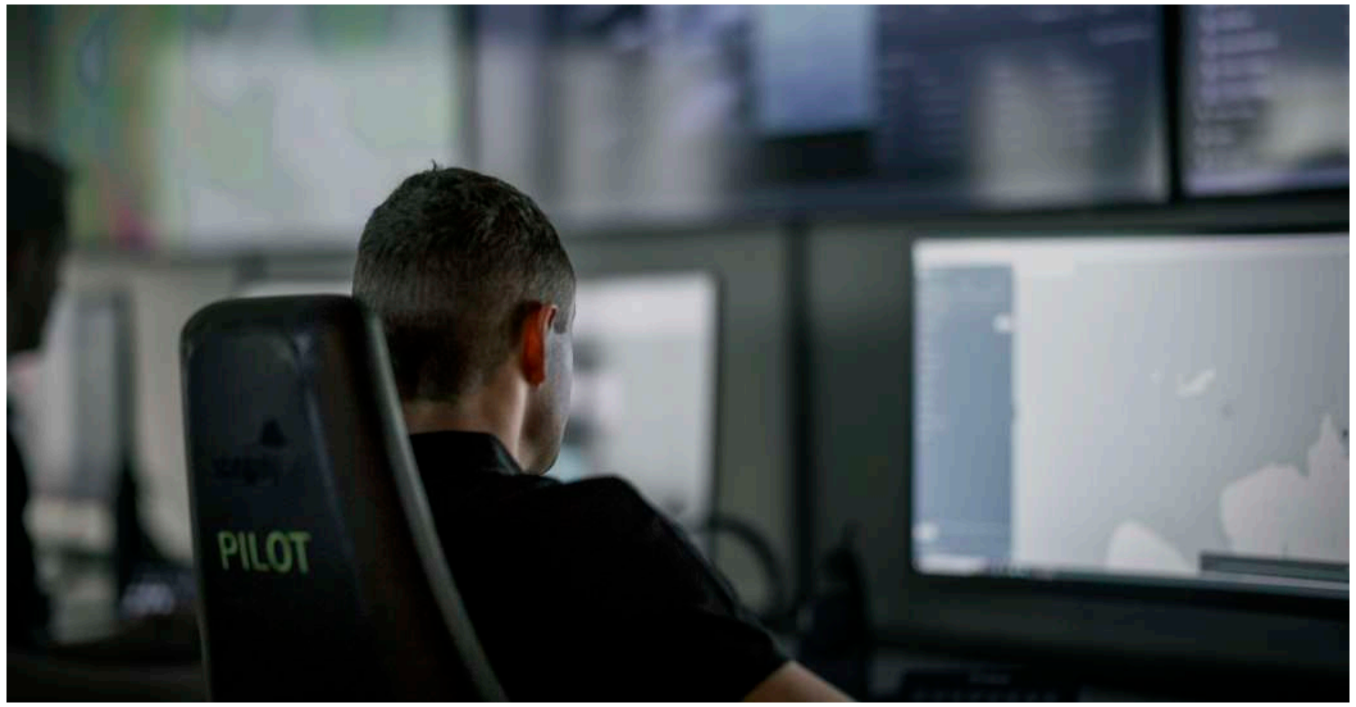
108 locations that are owned by

28 salmon and trout farming companies



08.2

# Positioning news in 2023




### Autopilot

Mapping of the pen, automatically adjusting node position to areas with higher fish density.

### Net detector

Identification and alert for nodes that have the visual field restricted to the net of the pen.

### Storm detector

Unbiased decision making to safely operate nodes during storms and severe weather conditions.

# 13 780 000 000

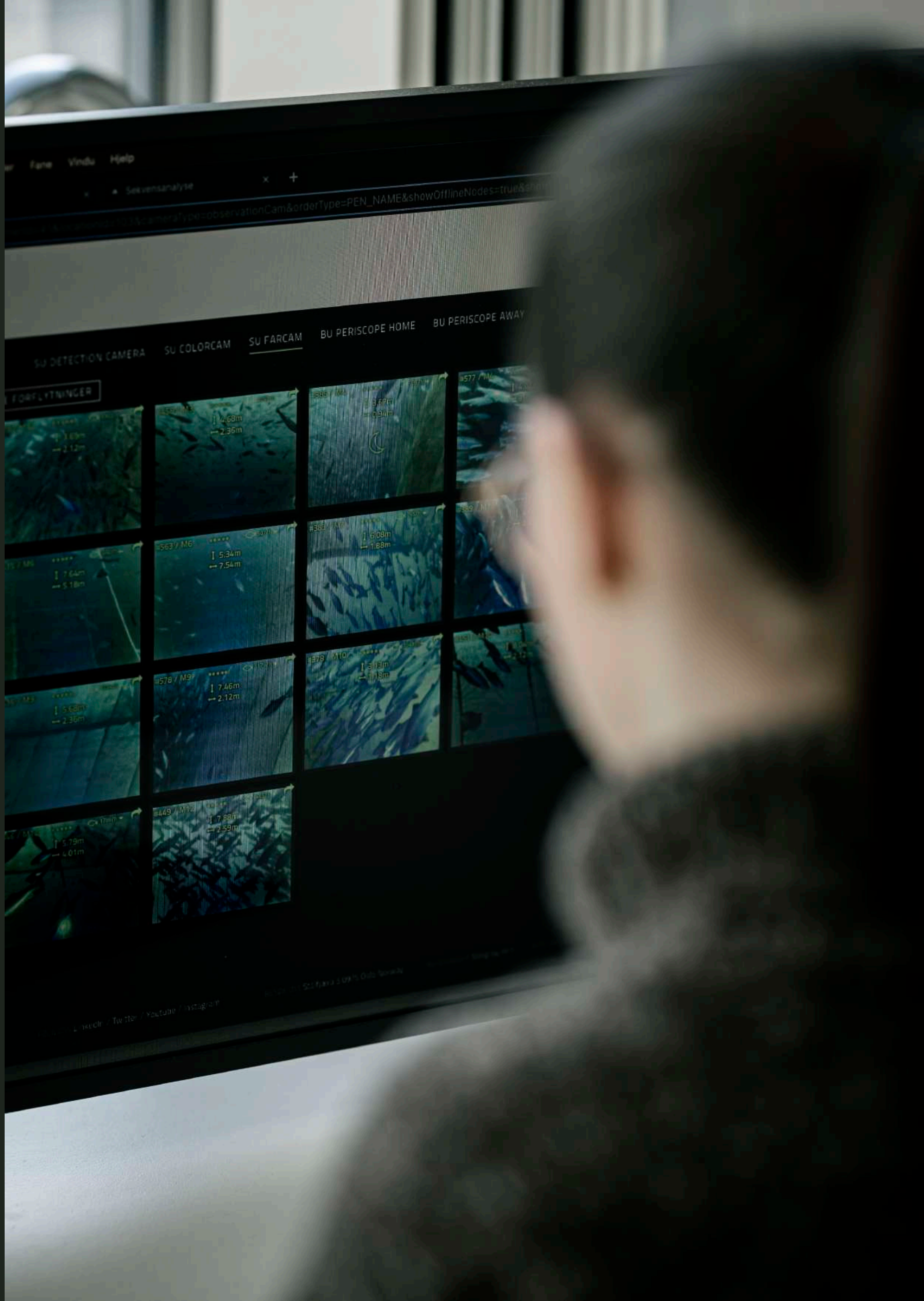
registered fish passings in 2023

# 11 110 000 000

registered laser pulses in 2023

# 60 000 000

salmon and trout continuously monitored, deloused, and under daily Stingray care in 2023



01.1

# Stingray Aqua department testimonials

*"In 2023 we saw a decrease in the use of so-called cleaner fish in favor to an increase in use of our Fish Health Hub™. This year I expect an even bigger step away from the use of the biological "cleaners" and looking forward to being a strong contributor to the company's further growth!"*

**SEBASTIAAN C. A. LEMMENS**
Advisory Team

*"In 2023, we observed further decrease in fish handling, highlighting the importance of optimizing preventive measures. Looking forward to further improvements in welfare in 2024."*

**NIVES VOJVODIC**
Fish Health Team

*"Our unmatched image analysis expertise allowed 2023 to be our best year to date in terms of new detectors and features.*

*Spoiler alert: For any louse out there in a Stingray covered pen, 2024 is shaping up to be a nightmare."*

**BENJAMIN SØRENSEN**
Analysis Team

*"With expanding coverage along the Norwegian coast and continuously improving detectors, we are now able to gather scientific insights and provide fact-based solutions at a scale few were able to imagine just a few years ago."*

**MARTIN WORM**
Research Team

"The decision to expand the use of our lasers, driven by positive results in fish health, is a testament to the potential of our technology for further growth and development in the industry."

JOHN ARNE BREIVIK
CEO of Stingray Marine Solutions AS

**The Fish Health Hub™**
Stingray Marine Solutions AS
stingray.no