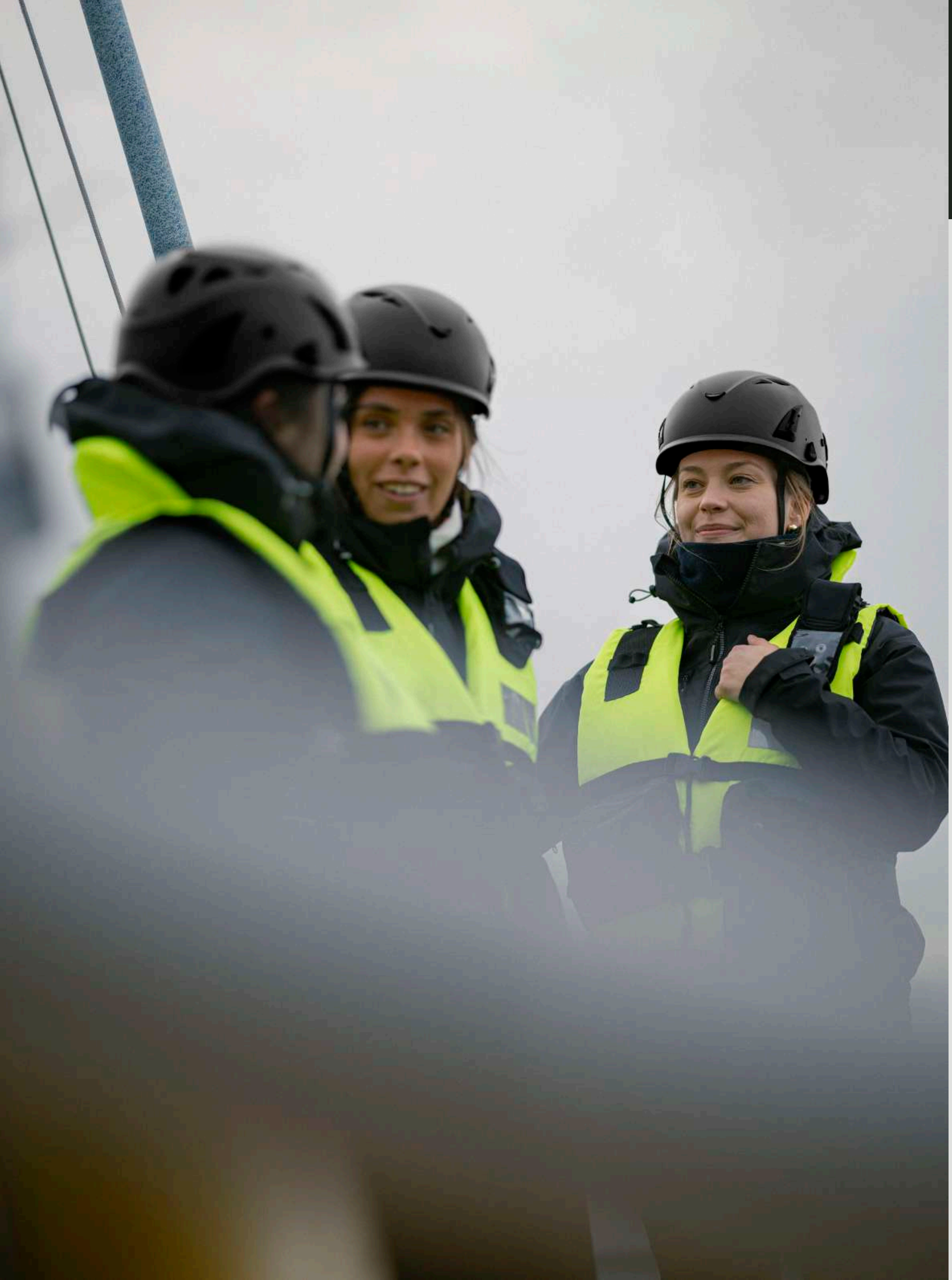
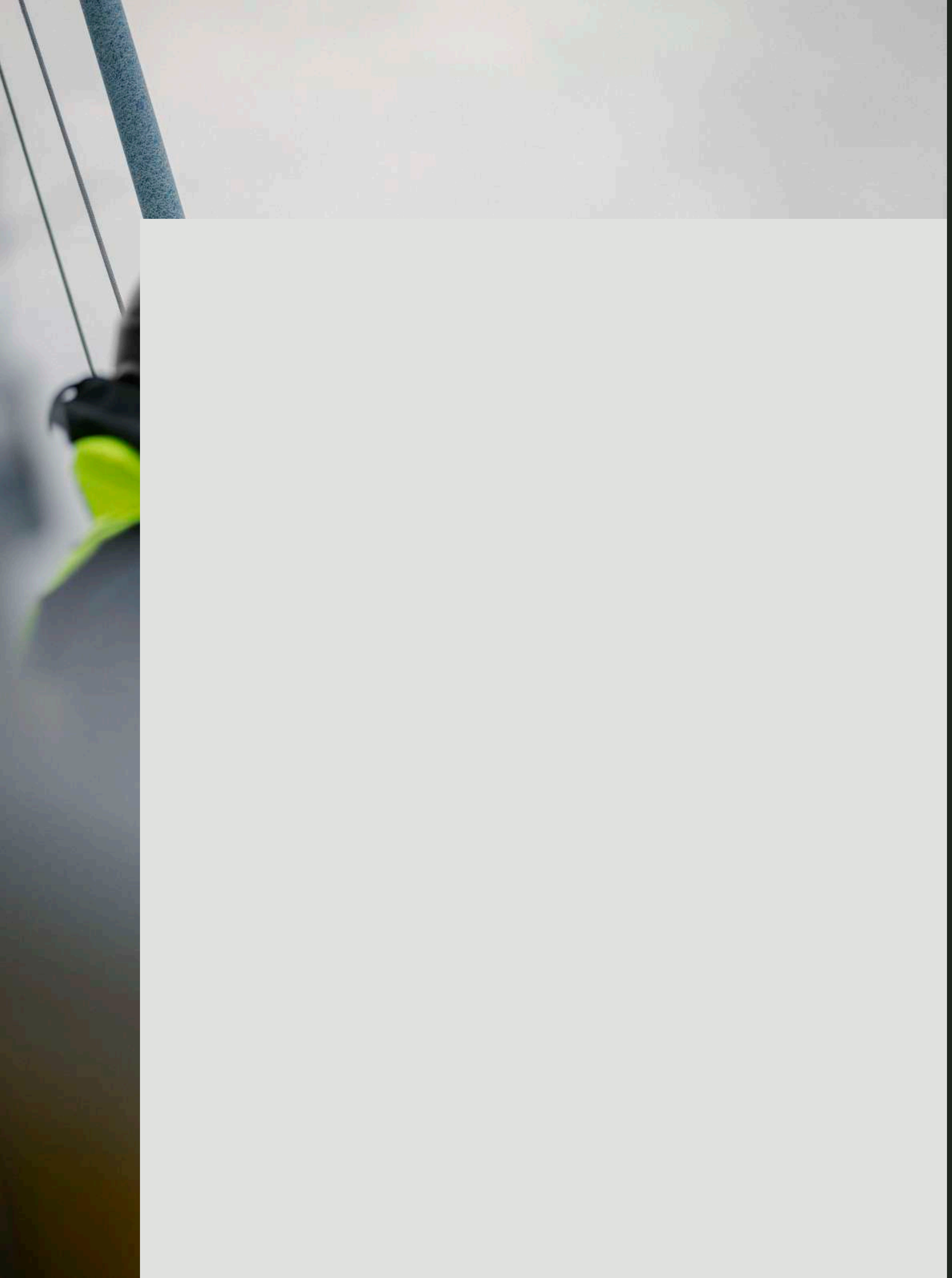
Laser focus on Fish Health

Stingray



1.0

Stingray & the Industry



Stingray Marine Solutions AS is a pioneer in sustainable, welfare-friendly technology for salmonid aquaculture. The company's patented sea louse control solution, Optical Delousing, offers customers a non-invasive, fish welfare-friendly, and technologically advanced approach to solving the sea louse problem. Modern camera and detection technology combined with advanced robotics, enables around-the-clock monitoring and fish surveillance. Highly skilled and specialized teams of employees, adhering to scientific, standardized, and certified processes, have established Stingray as the market leader in high-tech and artificial intelligence (AI) applications within salmonid aquaculture.

1.1

Stingray Marine Solutions

Stingray was founded in 2012 and has been commercial since 2014. Stingray provides intelligent technology designed to promote and enable sustainable and welfare-friendly practices in the aquaculture industry. The company employs close to 200 people, with offices and service centers in Oslo and Fauske, along with a production facility in Oslo.

Stingray is organized into five specialized departments, each contributing to high-quality support and innovation:

Stingray organizational structure

1800
years of continuous delousing

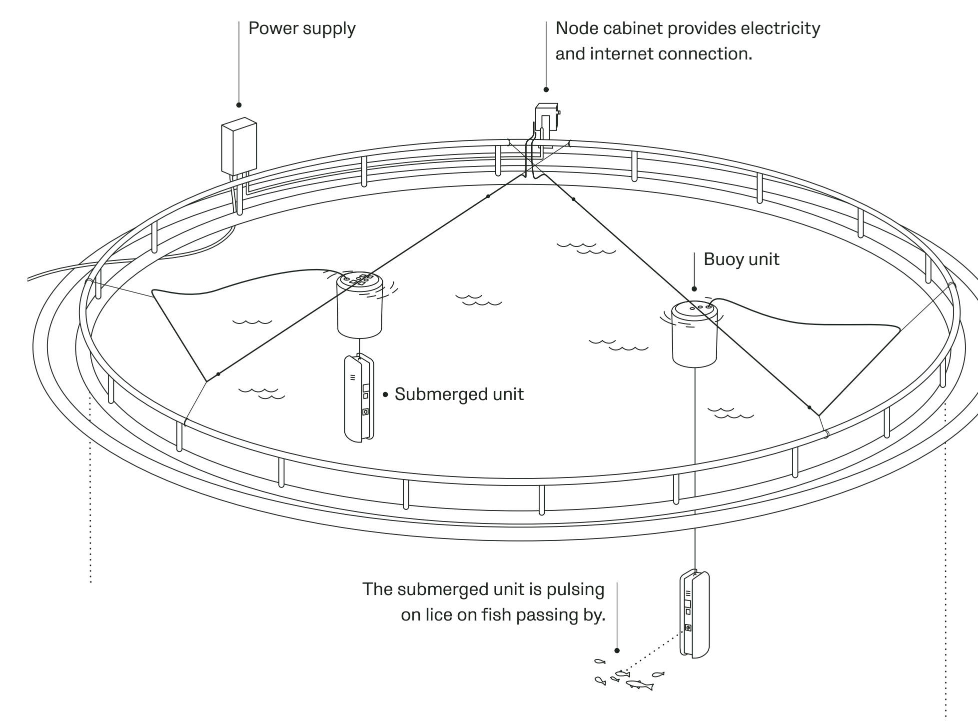
40
aquaculture companies

Stingray has developed a delousing and fish monitoring system called the Fish Health Hub™, which integrates robust hardware, bespoke software applications, and a resolute team of experts who interpret and disseminate data generated by the system. The Stingray system, proudly produced in Norway, is best known for its high-powered optical system and laser technology. The system administers a lethal dose of energy to sea lice, *Lepeophtheirus salmonis* (Krøyer, 1837) and *Caligus elongatus* von Normann, 1832 - without affecting the fish, *Salmo salar* (Linnaeus, 1758) and *Oncorhynchus mykiss* (Walbaum, 1792). Stingray systems are well established and proven by a cumulative operational uptime, the percentage of time when the systems are active, exceeding 1,800 years of continuous delousing across 40 aquaculture companies, as of 2024.

Traditional sea lice treatments rely on medicinal or mechanical interventions that involve fish handling, crowding, and transfer of fish between production units/fish pens. Stingray's solution circumvents the welfare concerns and efficacy challenges associated with these methods.

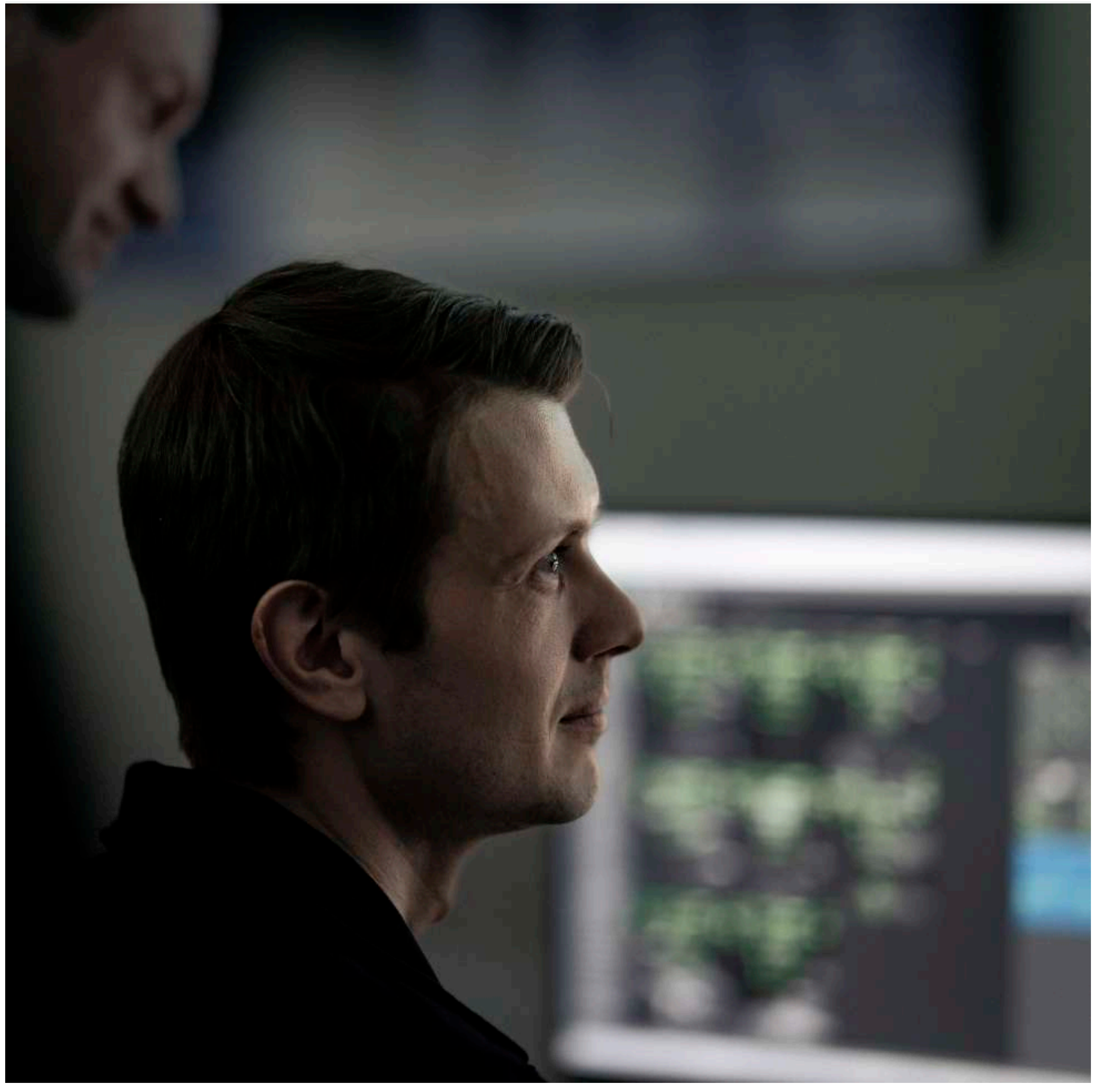
The Stingray system additionally operates as a comprehensive monitoring and diagnostic system, allowing for real-time artificial intelligence (AI)-supported fish and welfare monitoring, including sea louse counting, wound detection, fish maturation assessment, and biomass estimation. Each Stingray laser node, the core of this system, is composed of a buoy (BU) and submerged unit (SU) with LED lights, sensors, thrusters, cameras, and the laser, all of which are powered and connected via a pen cabinet (NC, or node cabinet), using standard electrical supply. This robust hardware platform, along with sophisticated software, facilitates passive fish monitoring capabilities and provides farmers with continuous insight into fish health in an undisturbed farming environment.

Stingray's Fish Health Hub™



Typically, two to four laser nodes per pen are installed at the start of a new production cycle to ensure appropriate levels of delousing and continuous surveillance. The exact number of laser nodes is tailored to factors such as sea louse infection pressure, geographic considerations, and customer requirements. Upon purchasing, customers receive access to Stingray's customer portal, Stingray Online, which offers comprehensive data interpretation, analysis, visualization, and documentation features. These tools empower fish farmers to make data-driven decisions to enhance fish welfare and optimize production.

Through the laser node and accompanying system, Stingray offers aquaculture companies a powerful tool that optimizes fish health, reduces the need for handling, and supports the industry's goals towards sustainable, welfare-centered farming practices.



1.2

Quality assurance in Stingray

At Stingray, quality assurance is a cornerstone of our work. Our dedication to quality in production, service, and daily operations consistently meet and exceed industry-wide expectations. Stingray has developed a comprehensive framework supported by specialized departments and advanced technologies to ensure quality at every level of the organization.

The company's different departments each comprise of smaller teams specialized in their field.

Close collaboration with customers allows Stingray to prioritize fish welfare and environmental health throughout the entire production system. By aligning every step of the process with best practices, sustainable outcomes that support healthy aquatic ecosystems are ensured. This effort is complemented by a focus on data-driven, factual decision-making. By identifying performance metrics and potential stressors, Stingray implements targeted management strategies to address potential challenges, continuously and proactively. Stingray dedicates itself to advancing the quality assurance processes through ongoing innovation. Documenting breakthroughs and sharing knowledge, in-house and externally, enables Stingray to remain at the forefront of aquaculture technology and fish health research. Advisory work encompasses communication with government authorities to ensure compliance with regulations, fostering transparency and collaboration with stakeholders, and providing official rebuttals and statements when necessary. This work includes conducting risk assessments to identify and address potential challenges and implementing standard operating procedures to ensure consistency and excellence. Technical analysis (Figure 1) is the routine evaluation of all active laser nodes.

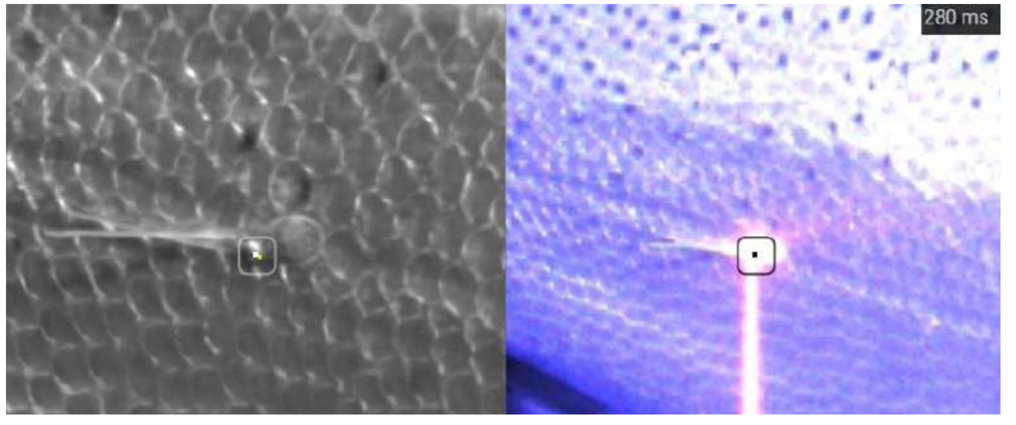


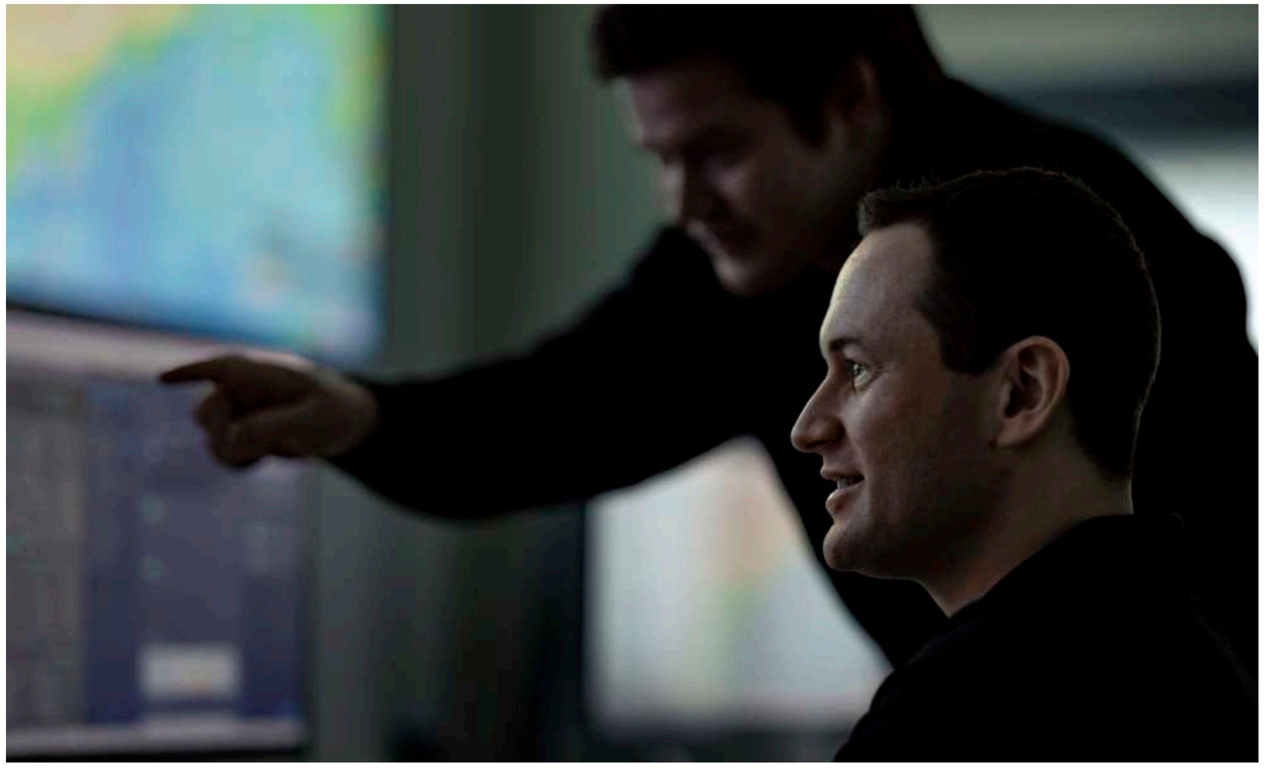
FIGURE 1.
Laser pulse analysis, comparing detection camera and color camera images.

This quality assurance analysis focuses on identifying anomalies or malfunctions, which are reported to the Operations department for appropriate actions such as rebooting, calibration, or scheduling additional maintenance.

Rigorous quality checks are conducted on smaller teams in all five departments, which enables control and quality in planning, production, everyday operation of laser nodes, and the interpretation of data continuously being delivered from the laser nodes.

ASC certification: Responsible seafood farming
The Aquaculture Stewardship Council ensures that aquaculture practices are environmentally sustainable and socially responsible. Founded in 2010, ASC certifications set stringent standards, addressing aspects such as water quality, wildlife protection, and fair treatment of workers and demonstrates a commitment to fostering positive relationships with local communities while maintaining ecological balance. Products carrying the ASC label signal to consumers that seafood is farmed responsibly, benefiting both people and the planet.

GLOBALG.A.P.: Ensuring global standards
GLOBALG.A.P. is a globally recognized certification system that underlines safe and sustainable practices across agriculture and aquaculture. It focuses on minimizing environmental impact, adhering to food safety requirements, and prioritizing worker welfare. Certification opens doors to international markets, highlighting producers' dedication to responsibly sourced products and compliance with rigorous standards.



1.3

State of the Industry 2024

A year dedicated to Control – Precision, Progress, and Purpose

This year marked an extraordinary milestone for Stingray - our 10th anniversary. Over the past decade, the company has transformed from a small engineering company with a bold idea into a leader of aquaculture innovation, driving advancements in fish health and the commercial implementation of AI into the aquaculture industry.

63
new employees joining Stingray in 2024 alone

2024 also became a year of remarkable growth and new opportunities. Our team has expanded significantly, with 63 new employees joining in 2024 alone, bringing our total workforce to 194 by year's end. This growth reflects our commitment to supporting an ever-increasing customer base and providing the industry with exceptional talent and expertise. Alongside this, our Stingray campus has grown, with new service centers opening in Oslo and Iceland, as well as the launch of our new factory in Oslo in February, further boosting much needed production capacity.

Stingray launched a new Control Vertical this year, enhancing operational precision and strengthening our technological offerings. The new vertical works in close collaboration with customers and Stingray pilots to maximize the benefits achieved through our technology.

Our first-ever ESG report underscores our dedication to sustainability, while the honor of being named "Innovator of the Year" by Element Logic ASA highlights that we have not lost our entrepreneurial and engineering spirit.

This positive development culminated in us welcoming Novo Holdings as a major shareholder, marking a new chapter in our journey of innovation and industry leadership for better fish health.

Stingray's commitments to innovation and sustainability are further reflected in our collaborative efforts with customers, prioritizing fish welfare and advancing technological solutions that align with key industry standards and government initiatives. Together with our customers we have placed a strong emphasis on fish welfare, sustainability, and technological innovation. This aligns, on purpose, with goals described by the 2023 Fish Health Report published by the Norwegian Veterinary Institute, and both the Animal Welfare Report and the Environmental Flexibility Proposal by the Norwegian government. All reports highlight the importance of, and the focus on sustainability and animal welfare and encourage efforts to improve fish welfare through disease prevention, stress reduction, and providing optimal living conditions. Cleaner fish, however, even though challenged due to welfare concerns, have been described as critical in managing sea lice - a notion that Stingray strongly disagrees with due to the ethical implications, as described in our chapter on cleaner fish use.

Additional incentives aimed at sustainability, such as the existing traffic light system and Norway's green production zones, can be seen as an incentive provided by the governments sustainability goals. However, despite being well meant, the governmental propositions pose real-life challenges. With potential delays in political decisions, the aquaculture industry faces uncertainty as it prepares for and actively implements these changes.

Stingray, in our role as market leader for non-invasive louse control, is suited to help our customers to a fantastic 2025, take on new legislature and tackle existing and emerging fish health challenges.

Iceland

2024 was a year of rebuilding and renewal for the fish farming industry in Iceland. The challenges of 2023, particularly the unprecedented sea louse outbreaks, underscored the need for enhanced management and collaboration across the industry. Stingray has taken a proactive role, working to restore trust and support sustainability through advanced sea louse management solutions. Alongside industrywide measures, such as increased well boat capacity, improved access to medical treatments, and coordinated lice strategies, Stingray is playing its role for a profitable Icelandic farming industry.

A critical focus for the Icelandic public has been, and still is, preventing sexual maturation within farms; a vital measure to safeguard Iceland's wild salmon populations from genetic crossbreeding with escaped fish. Stingray's maturation detection technology plays a key role in this effort, ensuring a balance between farming operations and environmental stewardship.

Norway

In Norway, significant changes in sea louse abundance and infestation pressure were observed in 2024. The aquaculture industry in Northern Norway encountered severe environmental challenges, driven by average sea temperatures rising 3°C above the seasonal norm. This surge in sea temperatures catalyzed a dramatic increase in lice development, with severe repercussions for both fish welfare and farm operations. Existing well boat capacity in Northern Norway proved insufficient to handle the unexpected and rapid escalation in lice numbers. As seen from our own results, the intense lice pressure led to a greater proportion of lice limit violations compared to previous years, in addition to an increased number of treatment weeks. This, in turn, pressured the aquaculture industry to prematurely harvest large volumes of fish.

While high lice numbers were also observed in Trøndelag and further south, the lice pressure remained within normal range, which is naturally higher in these regions.

Rising lice numbers also had an impact on the wild fish population. Anadromous sea trout (*Salmo trutta* Linnaeus, 1758) and Arctic charr (*Salvelinus alpinus* (Linnaeus, 1758)) were subjected to increased larval infestations. Trout and charr were more affected than migrating wild salmon in Northern Norway, as they spend proportionally more time inside the fjords with higher infection pressure.

The beginning of 2024 was also marked by challenging environmental conditions. In addition to the presence of the string jellyfish, severe weather further reduced the skin health of farmed fish. Winter ulcers continue to be a growing burden, with several producers forced to sell their fish at reduced prices for processing due to diminished quality. Unfortunately, we can assume that early 2025 may be equally challenging, especially in the Northern part of Norway. Increased treatment frequency may have left fish in poor condition heading into winter, significantly heightening the risk of wound development.

As in previous years, 2024 has seen alarmingly high mortality rates, with a national average of 18%. Three key health challenges stood out in 2023: injuries from delousing operations, gill diseases, and winter ulcers. There is little indication that this trend has shifted significantly in 2024. However, mortality rates vary greatly between locations, regions, and production areas, with some farmers achieving uplifting results.

We have dedicated ourselves to reducing mortality since our commercial launch 10 years ago and will continue this focus in 2025 and beyond. The persistent challenges posed by infectious diseases and high mortality rates underscore the urgent need for improved fish monitoring within the industry. To gain a clearer understanding of trends and challenges, it is essential to implement systematic and standardized methods for measuring fish health. Innovative technology, such as our own, is playing a pivotal role in this transformation. Advanced monitoring systems, combined with AI and machine learning, can continuously collect and analyze large volumes of data. This enables early detection of abnormalities and predicts potential health issues before they escalate. By gaining deeper insights into fish health and environmental conditions, farmers can make more informed decisions that enhance both economic efficiency and animal welfare.

A notable and positive trend for 2024 is the declining use of cleaner fish, with several companies phasing out their use entirely. The use of cleaner fish continues to raise critical questions regarding the treatment of animals in commercial production. Achieving sustainable aquaculture demands lice control solutions that preserve the welfare of all species while maintaining the quality of farmed salmon. The transition away from cleaner fish represents not only a technological and operational shift but also an ethical imperative to support responsible growth of the industry.

Good health and welfare of farmed fish should be fundamental requirements for growth. Preventative disease management,

In 2025, Stingray commits to being a leader in setting a new standard for significantly reducing fish mortality during the sea phase (towards and below 5%) and improving precision in the production phase, enabling more fish farmers to grow sustainably.

JOHN ARNE BREIVIK
11th January 2025

The very real positive impact on the health and welfare of the over

80 million

animals in Stingray care

along with proactive and effective lice control measures, is a fundamental practice for achieving this. Implementing the best available technology reduces the need for handling and treatment, while also protecting the surrounding environment, including wild fish populations. This approach results in healthier fish, greater transparency of their health status, and a more economically and environmentally sustainable aquaculture industry.

In this report, we have collected the combined results, developments and relevant projects to provide a comprehensive, transparent, and scientific summary of our work in 2024, hopefully guiding further reflections on how to change this industry for the better in 2025.

We in Stingray hope that this report will provide vital insights into the success story that has been Stingray for many years and the very real positive impact we have on the health and welfare of the over 80 million animals in our care.

DR. BENEDIKT FRENZL
Aqua Manager

HELENE BENTZEN
Veterinarian

1.3

Production areas in Norway

The 2017 implementation of production areas (PA) introduced a new system for regulating biomass capacity for Norwegian trout and salmon producers. The coastline was divided into 13 areas (Figure 2) and color-coded. The Norwegian Ministry of Trade, Industry, and Fisheries updates the color assigned to the various production areas biennially, according to survival rates of wild salmon smolts [1]. The system is referred to as a traffic light system.

Green = Can increase production by up to 6% [2]. In this category, it is assumed that less than 10% of wild salmon smolts die as a result of salmon lice [3].
Yellow = No change in production [2]. In this category, it is assumed that 10–30% of wild salmon smolts die as a result of salmon lice [3]. Two areas, PA6 and PA8, were changed from green to yellow in 2024.

Red = Must reduce production by 6% [2]. In this category, it is assumed that more than 30% of wild salmon smolts die as a result of salmon lice [3]. Fish farmers falling into this category can apply for exemption from the reduction if they can demonstrate low lice numbers, and take active measures to control louse levels [4], such as the use of the Stingray system.

The 13 production areas are as follows:

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

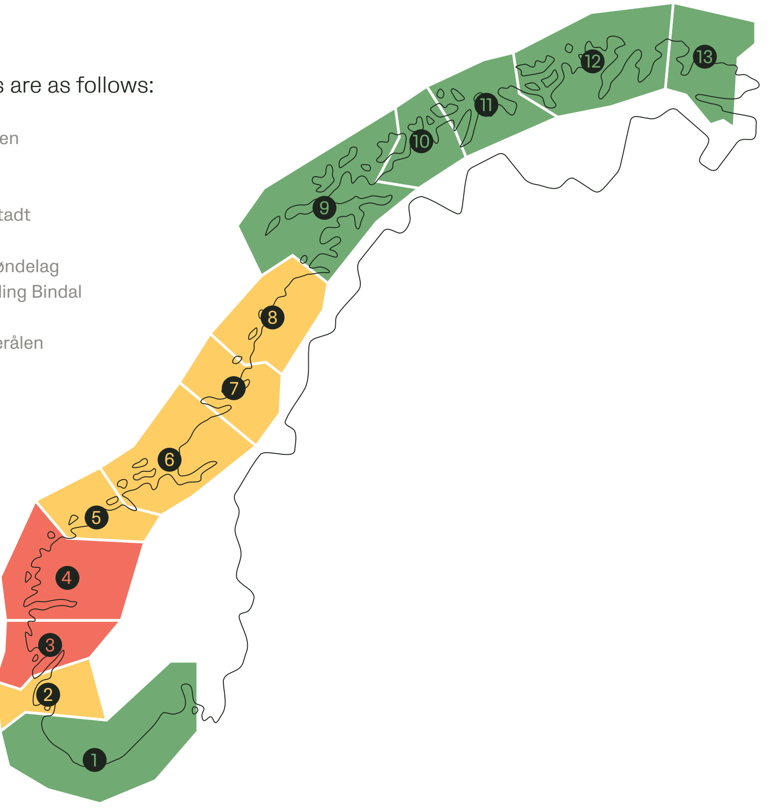
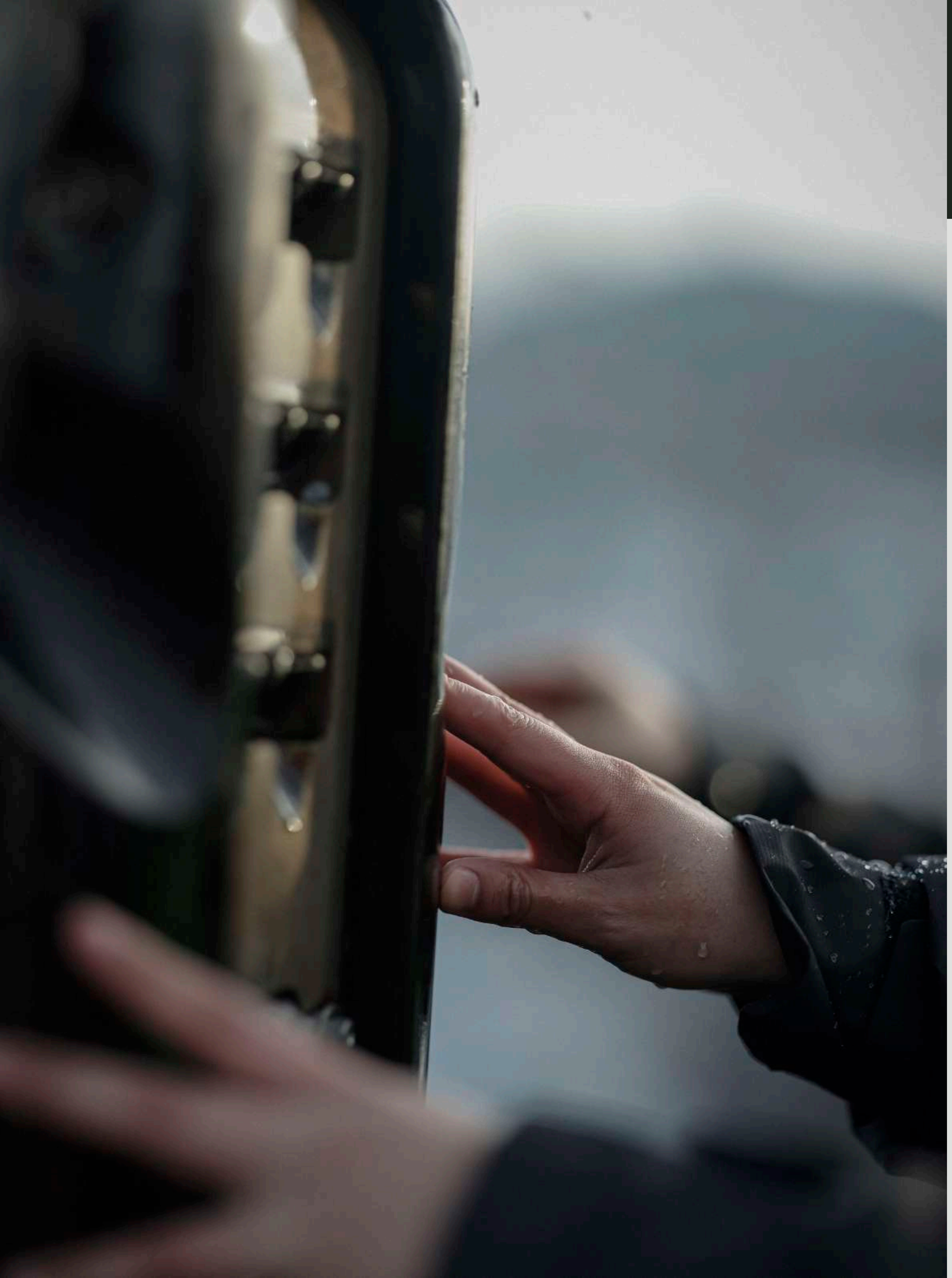
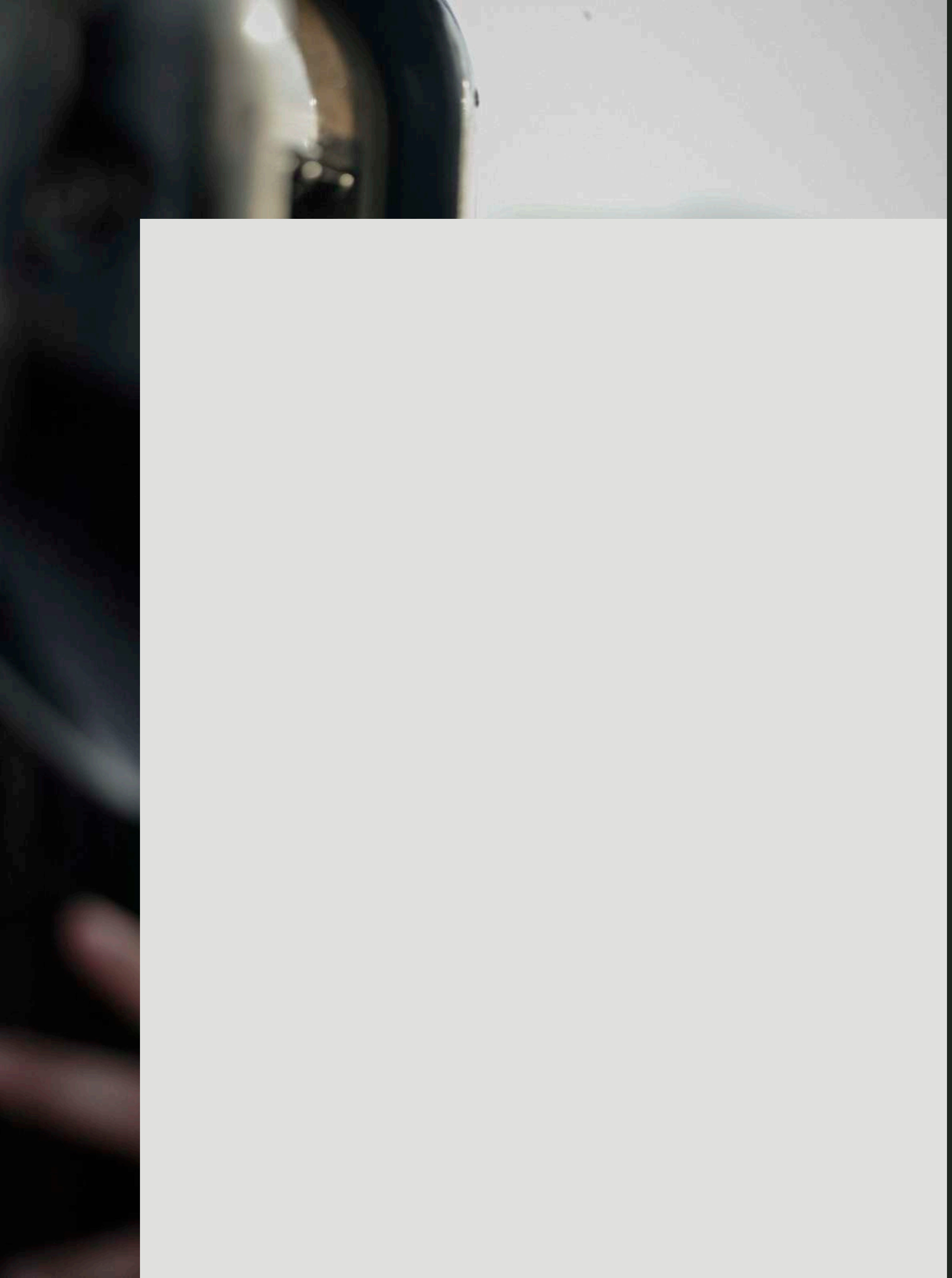


FIGURE 2.
Production areas and assigned traffic light colors 2024.



2.0

Sea Lice & Mitigation



Sea lice have been one of the most persistent and prevalent fish health issues since the beginning of salmonid aquaculture. Since its inception, the aquaculture industry has explored various innovative methods to prevent or treat sea lice infestations. Advances in technology have enabled fish farmers to develop significantly improved monitoring and control systems, as well as a deeper understanding of the parasites. Stingray is at the forefront of providing a continuous, non-invasive, and, above all, fish welfare-friendly solution to this critical challenge to fish health.

2.1

Sea lice development

Sea lice are parasitic copepods from the family Caligidae. This family includes over four hundred species of ectoparasites that attach to external surfaces of marine and brackish-water fish [5]. There are currently two types of sea lice that are potential threats for farmed salmonids in Norway and Iceland [6, 7], salmon lice, *L. salmonis*, and Caligus, *C. elongatus*. Salmon lice have evolved to be highly host-specific, attaching only to salmonid fish. In contrast, Caligus have a broader host range, capable of infesting multiple fish species such as cod and lumpfish [6, 8].

Ectoparasites, such as sea lice, live on the surface of the host and feed on mucus, skin, and blood. Because of their dependency on their host for survival, the host-parasite relationship is a delicate balance for both species to survive and reproduce. Sea lice infestation is linked to reduced fish growth, behavioral and neurochemical alterations, increased stress, skin and mucus damage, wound development, and mortality in severe cases [9-11]. When the lice burden is too high, extended grazing damage and wound development, down to the muscle layer, can be seen, particularly in the head region of the fish. Grazing damage is dependent on louse abundance, but also on host size, with smaller fish suffering proportionally at lower lice burdens compared to larger fish [12].

In modern aquaculture, a far greater threat to fish welfare than sea lice itself is the removal of lice with mechanical delousing methods [6, 13]. These methods were developed in response to resistance towards louse medications, but they have been shown to be a leading cause of mortality [6, 14].

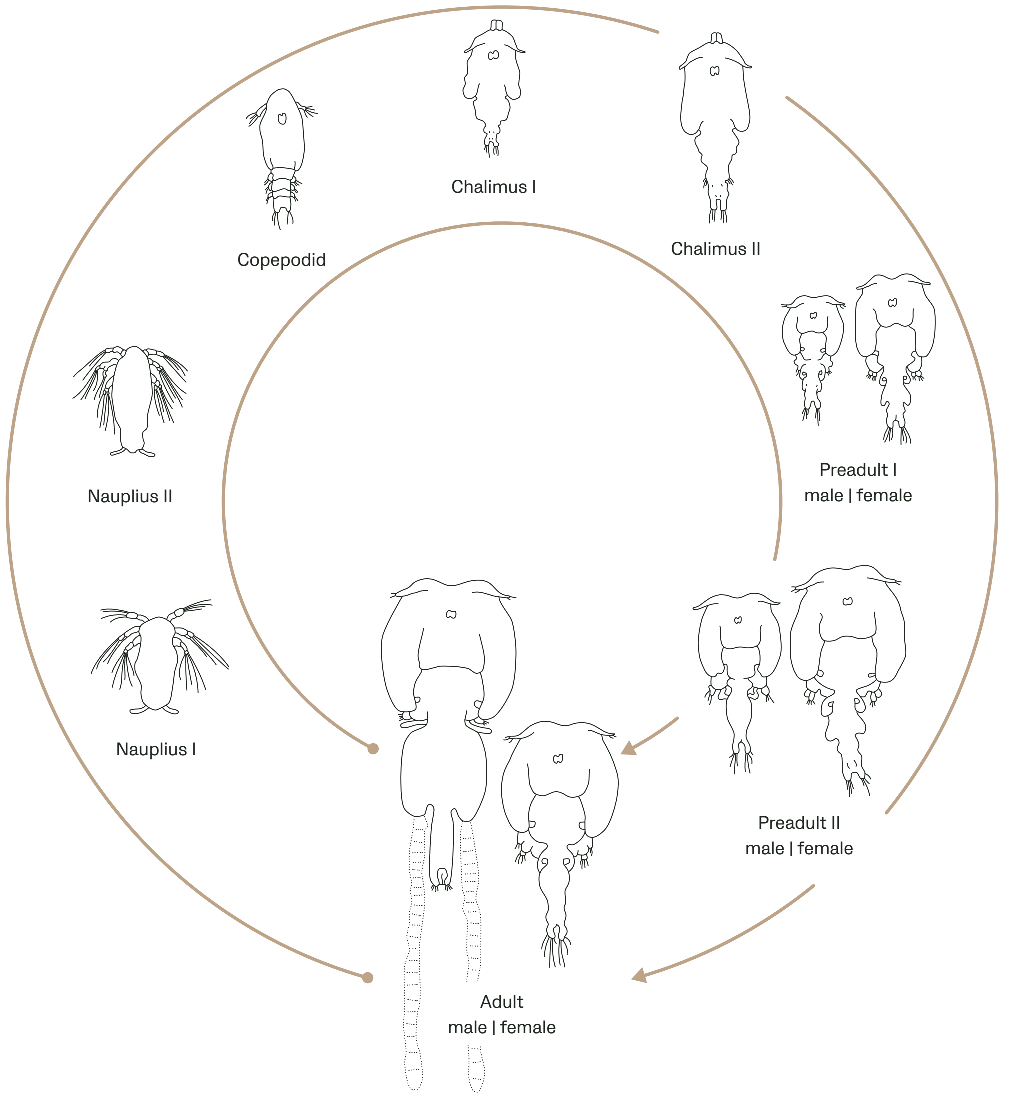
The development and widespread use of mechanical delousing methods, despite their significant impact on fish welfare, have been largely driven by the need to comply with Norway's stringent regulatory limits on salmon lice. Norway's national regulations impose strict limits to a maximum of 0.5 adult female salmon lice per fish, driving the increased need for delousing measures [15].

The intensification of aquaculture has further compounded the need for delousing measures to meet regulatory limits, as the crowded conditions create ideal environments for parasites to thrive and proliferate. High abundance of hosts in smaller areas makes perfect conditions for parasites to build up large populations in a brief period of time [16]. The Norwegian aquaculture industry stocks nearly half a billion salmonids in the sea annually, more than five times the number compared to in the 1990s [17].

Lepeophtheirus salmonis life cycle

The life cycle of salmon lice begins with nauplius larvae hatching from the egg strings. The nauplius larvae go through two planktonic stages before molting into the infective copepodid stage. Copepodids actively seek a salmonid host and attach to the skin or gills. The lice go through two fixed chalimus stages before molting into the mobile preadult and reproducing adult stages (Figure 3) [18].

FIGURE 3.
Life cycle of the salmon louse, *L. salmonis.*



Caligus elongatus life cycle

Caligus have four chalimus stages before molting into adults (Figure 4). They do not have any pre-adult stages like the salmon louse [18].

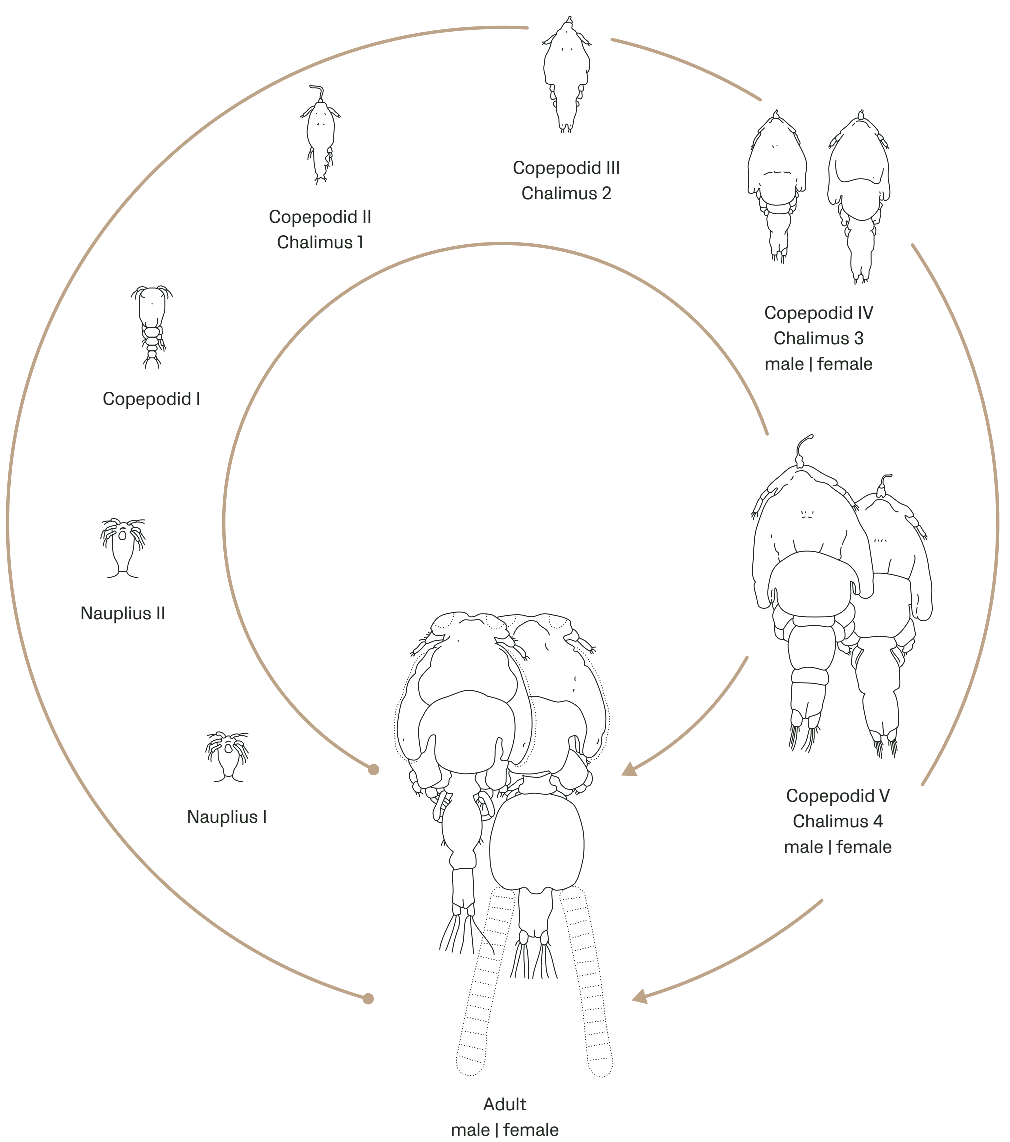


FIGURE 4.
Life cycle of *C. elongatus*, Illustration modified from Piasecki, Venmathi Maran [19]. Original work from Piasecki [20].

Temperature effect on development of salmon lice

Salmon lice are ectothermic - they do not produce internal heat, and their body temperature is dependent on water temperature [21]. Temperature is therefore a primary factor influencing the development rate of salmon lice. Higher water temperatures accelerate the progression through their life stages, increasing egg production, infestation, and survival rate [21-24]. Table 1 and Figure 5 summarize developmental rates at different temperatures.

TABLE 1.
Salmon louse development rates (weeks) at varying sea temperatures [22].

	3 °C	5 °C	10 °C	15 °C	18 °C
Preadult 1	12	7	3	2	1
Preadult 2	16	9	4	2	2
Adult	21	12	5	3	2

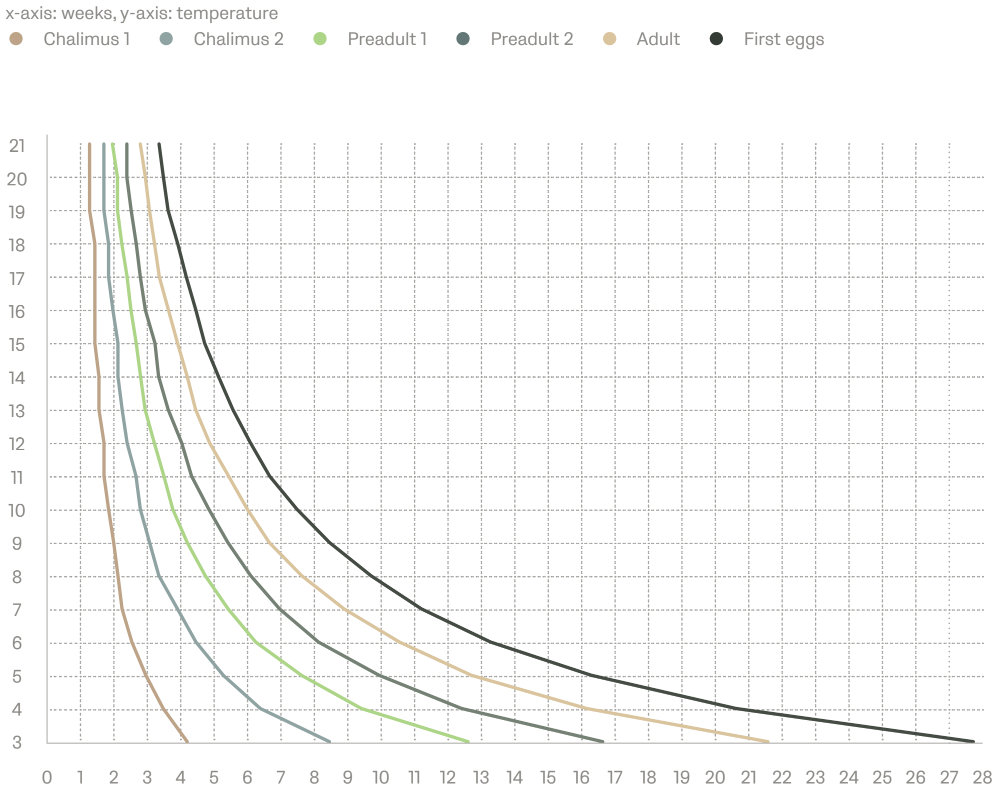


FIGURE 5.
Salmon louse development rates (weeks) vs. sea temperatures (°C) [22].

2.2

Mitigating the lice problem

The problem of sea lice is complex, but the industry is rising to the challenge with a range of solutions that combine mechanical improvements, biological control, and innovative technologies like laser systems (Table 2). The salmonid farming industry is exploring and implementing a range of solutions designed to reduce the reliance on pharmaceutical and mechanical treatment methods and improve fish welfare (Figure 6). By continuing to invest in these diverse approaches, the aquaculture industry can reduce the impact of lice on fish welfare and farm productivity, while also minimizing the environmental footprint of salmonid farming.

TABLE 2.
Commonly used delousing methods in salmonid aquaculture.

METHOD	DESCRIPTION	BENEFITS	CHALLENGES
Mechanical Delousing	Use water jets or brushes to physically remove lice. Thermal or freshwater treatment.	Effective under certain conditions.	Labor-intensive compared to automated solutions.
Medicinal Treatments	Use of chemicals or drugs to kill lice on fish. Often used as a direct response to heavy lice infestations.	Quick and effective in killing lice.	Risk of resistance development; environmental impact.
Cleaner Fish	Deploying species like lumpfish or wrasse to eat lice off salmon in the pens.	Natural solution: no chemicals involved.	Welfare concerns cleaner fish; variable effectiveness.
Laser Technology	Highly precise system targets and eliminates lice without harming fish. Operates in real-time, scanning and neutralizing lice as fish swim by.	Chemical-free, continuous lice control; reduces stress on fish; sustainable and efficient.	High tech solution requiring trained staff.
Shielding Nets	Nets with lice skirts or deep-water oxygen circulation systems to reduce lice exposure by preventing lice from entering pens.	Reduces exposure to lice-infested surface waters; improves fish welfare with high oxygen levels.	Potentially higher operational costs and complexity.
Submerged Farming	Keeping salmon deeper in the water column where lice larvae are less abundant, using snorkel nets or fully submerged farming setups.	Reduces lice infestations and protects fish from hazards like jellyfish.	Requires additional infrastructure and may limit natural behavior.
In-Feed Solutions	Feeding fish with medicated feed or additives designed to repel or kill lice.	Easy to administer; avoids physical handling.	Effectiveness can vary; risk of resistance.
Genetics	Research on breeding lice-resistant salmon through gene editing or selective breeding programs.	Long-term potential solution; reduces reliance on external lice controls.	Still experimental and requires significant research.
Vaccines	Developing vaccines to make salmon immune to lice infestations.	Preventative solution; reduces reliance on reactive treatments.	Still experimental and requires significant research.

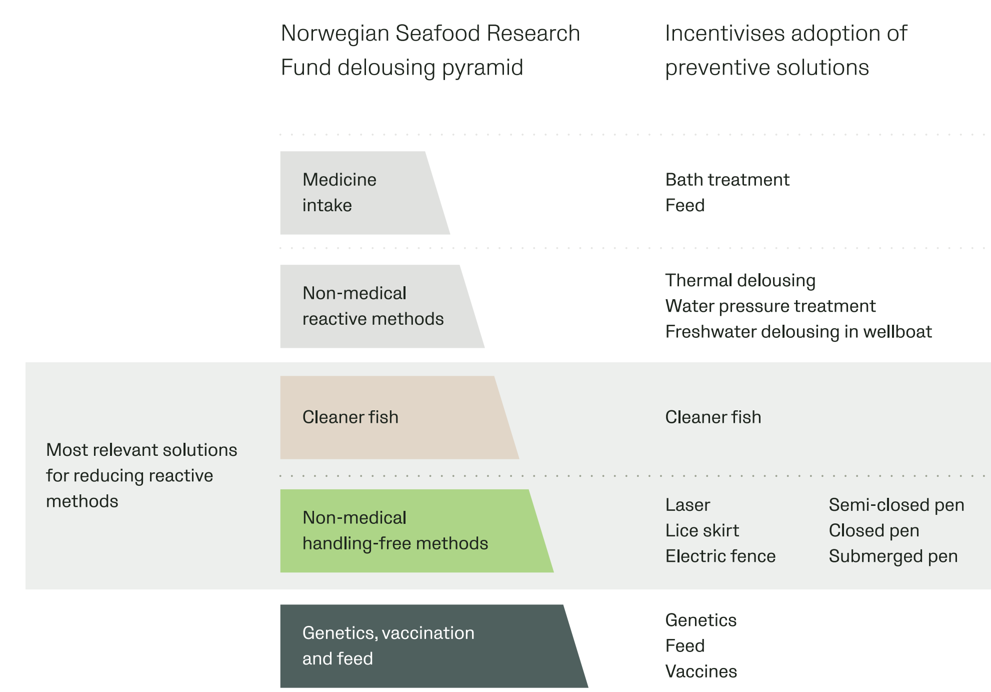
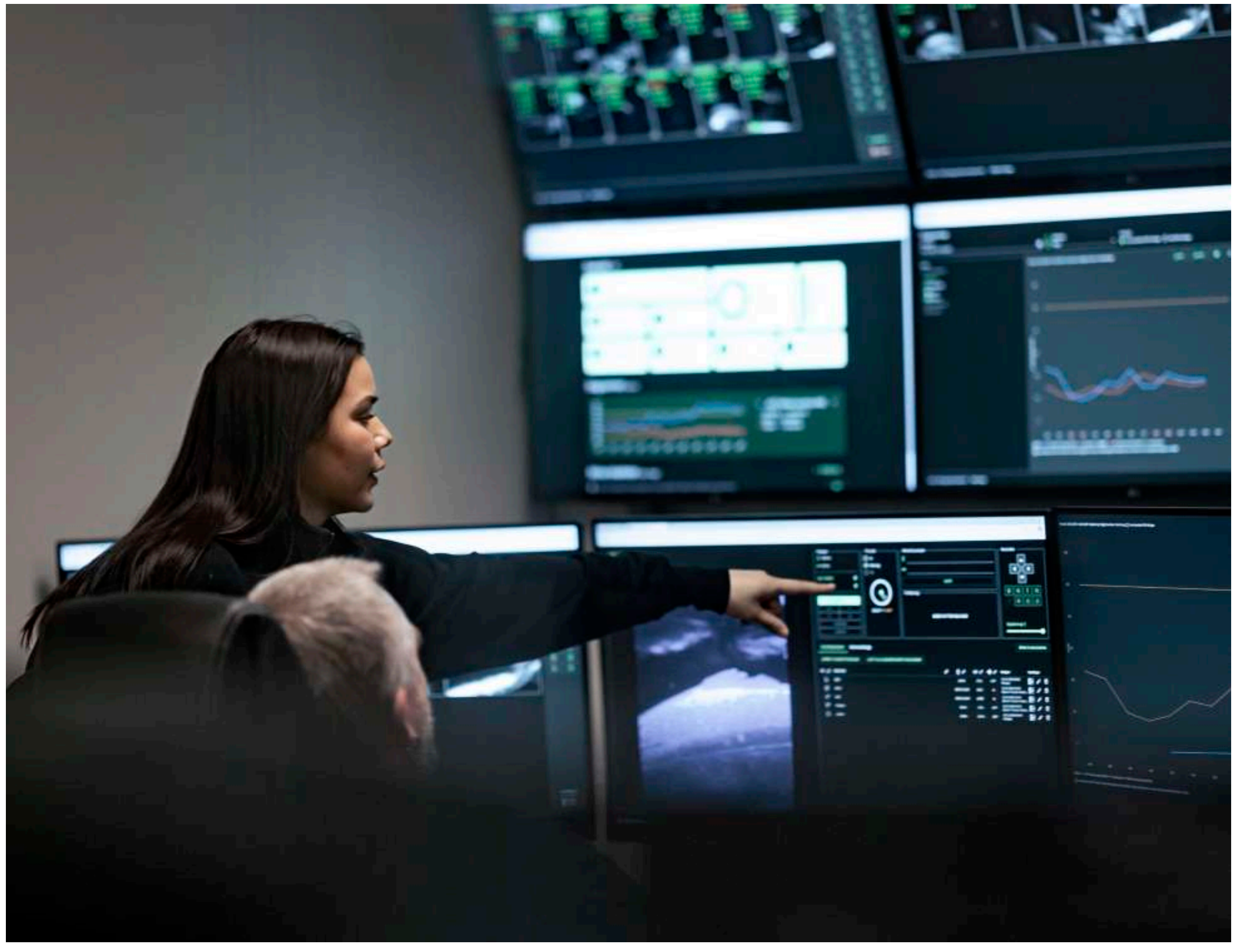


FIGURE 6.
Suggested hierarchy of delousing practices in salmonid aquaculture (FHF Industry Report 2016).

2.3

Stingray laser strategy

Achieving success with optical delousing for lice management starts with a well-planned laser strategy, ensuring enough laser nodes are deployed at the optimal time. Key considerations include expected lice pressure at the location or region, number of fish and density, past experiences, available resources for positioning and desired outcomes. In 2024, there was a stronger focus on fine-tuning strategies and sharing experiences. This resulted in improved baseline coverage with relocation of extra systems as needed, positioning priorities and increased use of automatic lice trend data to guide decision-making.

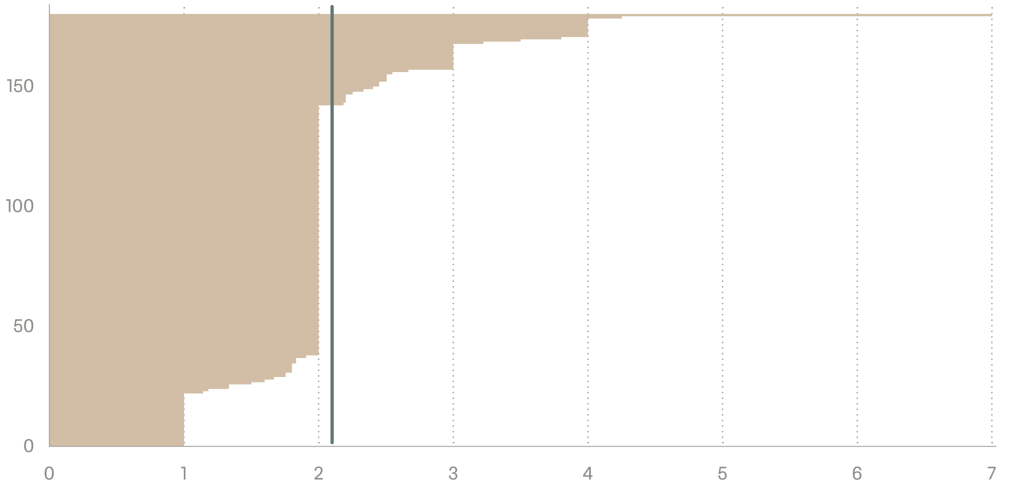


Number of laser nodes per pen

The recommended and most applied laser-coverage is two laser nodes per pen (Figure 7), increasing to three or four in situations with high lice pressure. Three to four laser nodes per pen is the baseline coverage for broodstock fish due to long production time, larger surface area for sea lice attachment and higher priority for zero handling. Five to eight laser nodes per pen have been sporadically used in traditional open pen-nets, when it was vital to avoid treatments.

FIGURE 7. Number of laser nodes per pen per location in 2024.

x-axis: number of laser nodes per pen, y-axis: locations
● Average number of nodes per location



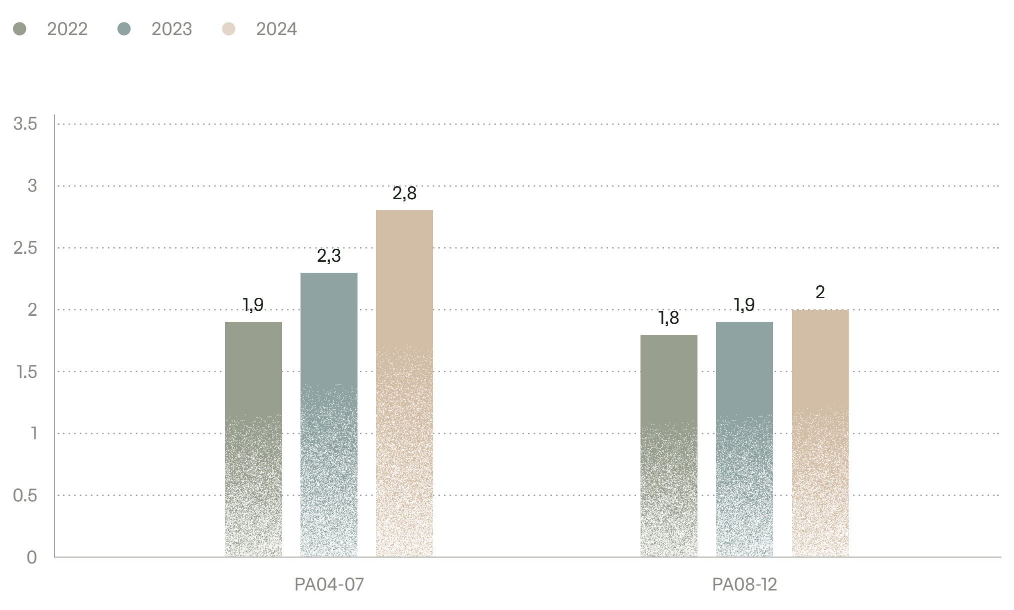
The number and density of fish, as well as pen size and type, are important parameters when planning the number of laser nodes per pen. Currently, Stingray does not provide a recommended number of fish or density per laser node. Historically, fish stock information has been recorded in Stingray Online at varying intervals—weekly, monthly, or even less frequently—leading to inconsistencies in the data, which makes it unsuitable for calculating or determining official recommendations. For now, the number of laser nodes per pen is mostly influenced by desired outcomes, infection pressure, and laser node availability. These factors, along with fish passings, vary greatly between locations and are believed to have a bigger impact on results than the number of fish per laser node.

Extended periods of cold temperatures and low infection pressure during winter (commonly observed in PA11-13 and the Westfjords of Iceland) may justify reducing the number of laser nodes down to one per pen in favor of controlling lice in other pens with higher lice levels.

A general rule of thumb is that deploying more laser nodes allows for a higher number of pulses targeting more lice within a shorter timeframe. However, using more than four laser nodes per pen may in some cases introduce positioning challenges, limiting the pen area covered by each laser node. Pen size, net type, other equipment placed in the pen, distribution of fish, weather conditions and sea lice level predictions will be crucial factors to consider when considering relocating laser nodes.

Figure 8 shows that locations in PA4 and PA6 have a deployment baseline of more than two laser nodes per pen, whereas PA8-12 maintain two laser nodes per pen. This reflects the regional differences in lice pressure across the country, with PA4 and PA6 requiring a customized laser strategy to address higher infection levels. The upward trend in number of nodes deployed for both groups, reflects the increased number of laser nodes that are available to prioritize full coverage and targeted delousing for exposed locations and pens.

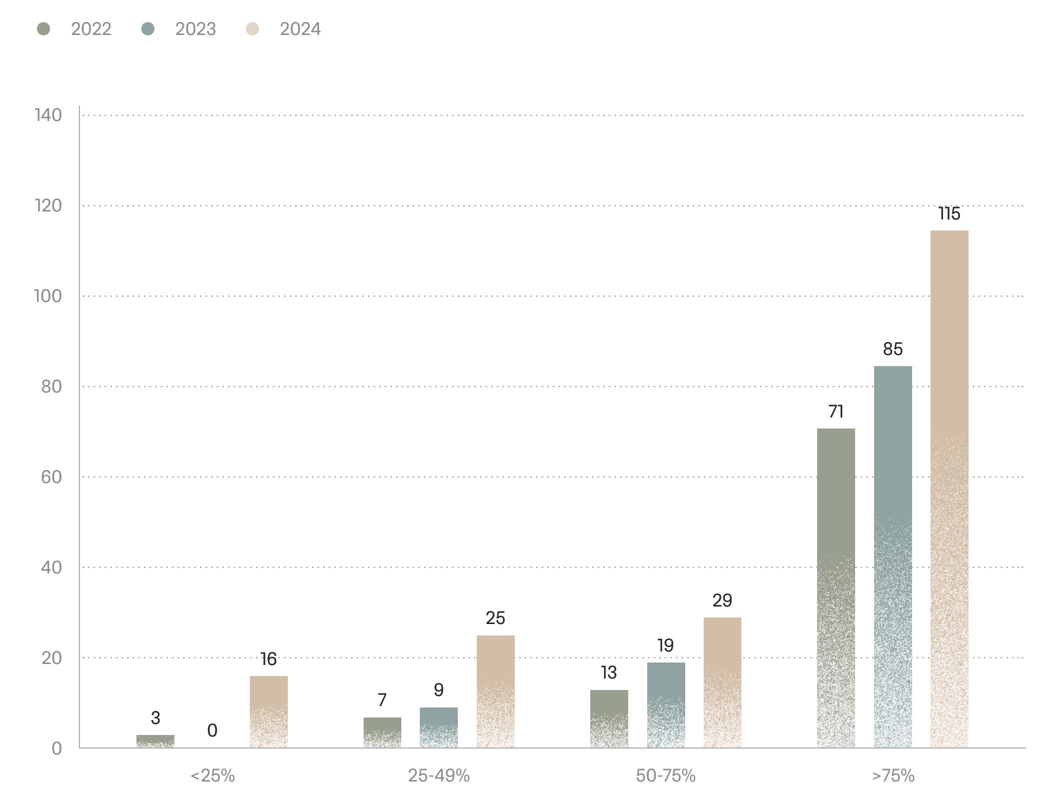
FIGURE 8.
Average Stingray coverage (y-axis: node per pen) comparing Central and Northern Norway.



Percentage of production weeks with laser nodes

Stingray recommends maintaining full coverage with laser nodes for 100% of the production cycle, from smolt stocking to harvest. In 2024, 75% of all locations covered over 75% of their production weeks with laser nodes (Figure 9). Over 50% of Stingray locations employ 100% coverage, making it the most common setup in 2024. Early laser node deployment, before a rise in preadult lice-stages, is critical for delaying the date of the first sea louse intervention.

FIGURE 9.
Number of locations vs. average Stingray node deployment length per production cycle (%).



Optimizing lice control

It is essential to maintain routine operations throughout the whole production cycle for effective lice control. Customers play a significant role in ensuring uptime over 95%, with uptime defined as the percentage of time when a laser node is active, performing regular cleaning of the laser nodes and fine-tuning fish passings for correct working angles and depth. In general, with active and recommended use, locations with laser nodes have lower lice numbers and fewer alternative treatments compared to locations without laser nodes (see results section).

Deploying multiple laser nodes across several locations within an area is expected to reduce the overall lice burden for all salmon- and trout farmers. The challenges of autumn 2024 in Northern Norway have underscored the need to further optimize lice control strategies for the years ahead. A strong focus on preventative measures to minimize parasite-host interactions should remain a priority, complemented by targeted reactive treatments if necessary.

Environmental factors affecting laser efficiency

The Stingray laser delousing system uses a surgical laser in the green spectrum to precisely target and eliminate sea lice without harming the animals. Its efficiency can be influenced by a variety of environmental factors that determine how effectively the laser pulse reaches its target.

One of the most critical factors is water clarity. In turbid water, which contains particles such as algae, sediment, or plankton [25, 26], the laser pulse can be scattered or absorbed before it reaches the sea lice. This reduces both the precision and intensity of the laser, limiting its ability to effectively neutralize sea lice. This effect is partly offset by a relatively short working range and focus point, decreasing the impact of potential particle interference. In clearer water, the pulse can travel farther and stay focused, resulting in a more efficient delousing process.

The refractive index of water, typically around 1.33 at 20°C, measures how much light bends as it transitions from air to water [27]. Minor changes in temperature, salinity, or the wavelength of light can alter this index [28] theoretically influencing the laser's path. However, this is accounted for in the production process of laser nodes.

An additional factor that can impact laser efficiency is biological fouling (biofouling). Over time, the buildup of algae or other biological matter [29] on the glass, shielding the optical components of the system, can interfere with the transmission of the laser pulse. This layer of fouling can block or scatter the laser light, significantly reducing its intensity and precision [30]. Regular node cleaning is therefore essential to maintain optimal performance.

Natural underwater light conditions can also affect the laser's operation. Strong sunlight or reflections on the water's surface can create noise that interferes with the system's ability to detect and target lice. This light interference may reduce the system's effectiveness during bright daytime conditions, sometimes causing overexposure of collected images. In contrast, low-light conditions, such as at dusk or nighttime, may enhance performance by reducing the amount of competing light, allowing the laser to function more effectively. Stingray's cameras are set to adjust for a wide range of light conditions and the amount of data collected allows for effective delousing and surveillance under most conditions.

The Stingray system is designed to operate within a focus range of 0.5 to 1.5 meters. This short range minimizes losses from scattering and absorption, allowing the laser to maintain enough energy to accurately target small lice on the fish's surface. By keeping the pulse within this confined distance, the system can also reduce distortions caused by water turbulence and environmental fluctuations, leading to better precision in delousing.

In summary, despite natural effects, such as water clarity, biofouling, and natural light interference, the Stingray system leverages advanced technology and smart software to effectively overcome these environmental factors and deliver reliable results.

Stingray Online

Transparency is and has been a cornerstone value for Stingray. Stingray Online is a web-based customer portal provided to all Stingray customers. The portal provides the customers with a comprehensive overview of both historical and current data generated by the Stingray system. Access to Stingray Online is granted to all customers who have successfully completed the relevant courses on Stingray's own training platform called Stingray Academy. Stingray Academy consolidates all essential learning materials for correct and optimal use of the Stingray system.

Stingray Online includes a variety of other tools and services. The dashboard (Figure 10) provides a quick overview of key metrics like Laser Status, Diagnostics, Biometrics, and Sea Lice Count. The Navigator tool helps users track and manage laser node placements throughout the day to optimize monitoring and system performance. The Sequence Analyzer tool is used for image-based lice counting and welfare analysis, enabling users to assess sea lice counts, wound severity, fish sexual maturity, and specific health indicators such as fin damage, scale loss, and other relevant health factors, based on parameters described in the FishWell handbook [12].

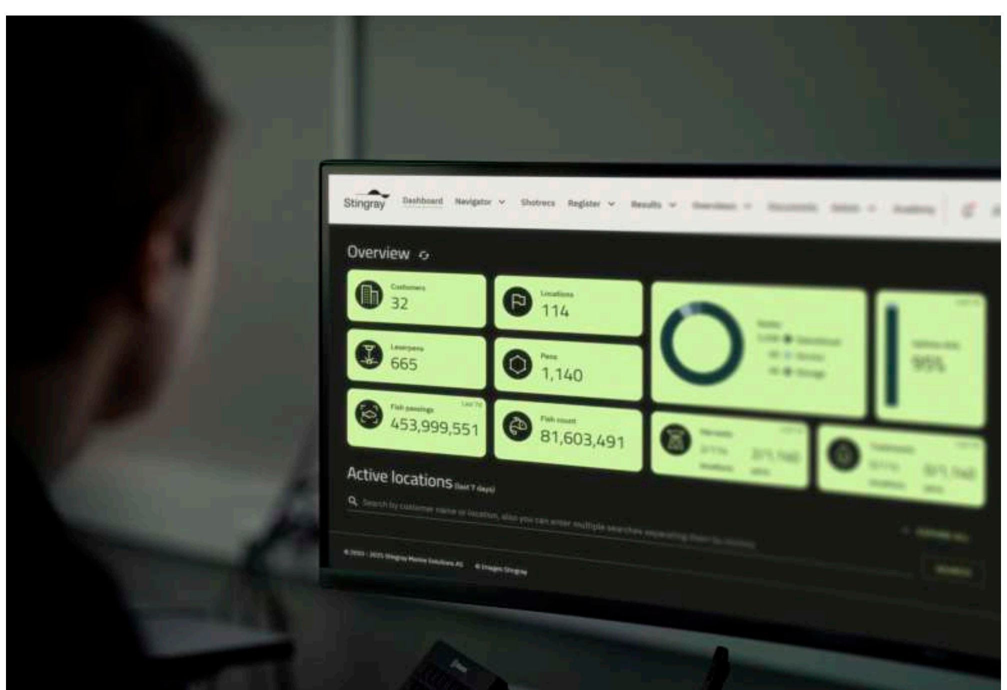


FIGURE 10.
Stingray Online overview dashboard (week 52, 2024).

The portal also includes registry forms for logging essential data such as manual lice counts, treatments, biomass measurements, and harvest reports. API integration with the customer's production systems reduces workload and minimizes human errors.

Both image-based analysis results and manually entered records are visually displayed, with charts showing operational and biological parameters. Weekly reports summarize performance and key findings for each customer on location level (Figure 11).

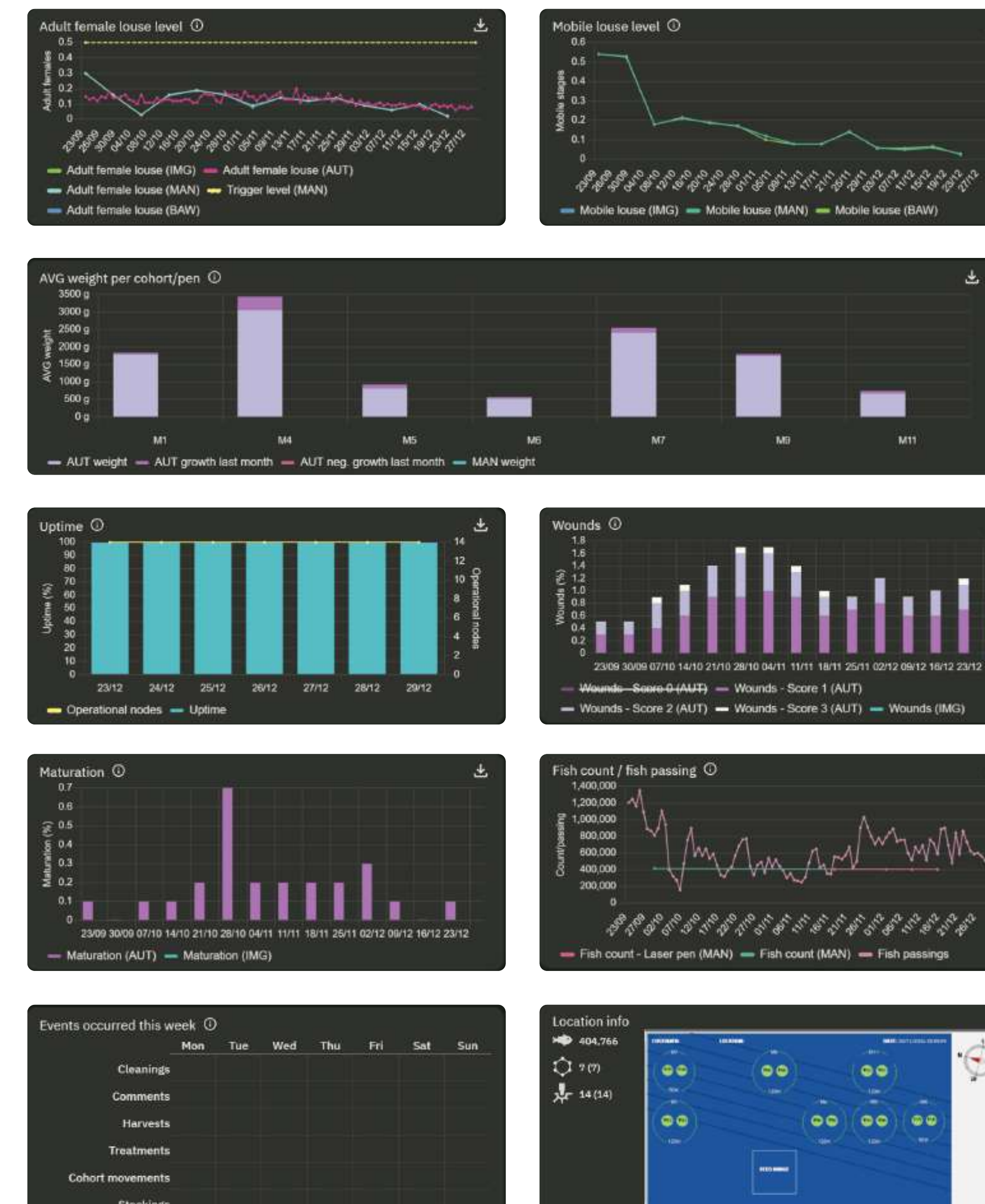


FIGURE 11.
Weekly summary report in Stingray Online.

2.4

Cleaner fish

In salmonid farming, a broad variety of fish are used as cleaner fish to help maintain lower lice levels as they are meant to graze the lice off the host fish (Table 3) [31].

TABLE 3.
Cleaner fish species overview and their use in aquaculture.

SPECIES	LATIN NAME	HABITAT	USE	WHEN	FARMED/WILD CAUGHT	COUNTRIES WILD CATCH	COUNTRIES EMPLOYED
Ballan wrasse [32]	*Labrus bergylta* Ascanius, 1767	Rocky coastal areas, kelp forests, and seagrass beds in the northeastern Atlantic Ocean, typically at depths of 1 to 50 meters.	Widely used in aquaculture as cleaner fish to control sea lice infestations on farmed salmon.	1988 - Norway 1989 - Scotland	Farmed since early 2000s. Commercial since 2010, still depended on wild caught	Norway, Sweden, UK, Ireland	Norway, Scotland, Ireland
Corkwing wrasse [33]	*Symphodus melops* Linnaeus, 1758	Sheltered coastal waters with rocky reefs, kelp forests, and eelgrass beds, typically at depths of 1 to 30 meters.	Used in aquaculture as cleaner fish to reduce sea lice on farmed salmon, valued for their efficiency in warmer coastal waters.	1988 - Norway 1989 - Scotland	Wild caught	Norway, Sweden, UK, Ireland	Norway, Scotland, Ireland
Cuckoo wrasse [34]	*Labrus mixtus* Linnaeus, 1758	Rocky reefs and areas with abundant crevices and algae, typically found at depths of 10 to 200 meters in the northeastern Atlantic.	Occasionally used as cleaner fish in aquaculture to control sea lice on farmed salmon, though they are less commonly utilized than other wrasse species.	1988 - Norway 1989 - Scotland	Wild caught	Norway, Scotland	Norway, Scotland
Goldsinny wrasse [35]	*Ctenolabrus rupestris* Linnaeus, 1758	Rocky reefs, kelp forests, and areas with mixed substrates, typically in shallow coastal waters up to 50 meters deep.	Used in aquaculture as cleaner fish to help manage sea lice on farmed salmon, particularly in shallow pens.	1988 - Norway 1989 - Scotland	Wild caught	Norway, Sweden, UK, Ireland	Norway, Scotland, Ireland
Rock Cook wrasse [36]	*Centrlabrus exoletus* Linnaeus, 1758	Rocky coastal areas and kelp forests, typically in shallow waters at depths of 1 to 20 meters.	Occasionally used in aquaculture as cleaner fish to control sea lice on farmed salmon, though less commonly than other wrasse species.	1988 - Norway 1989 - Scotland	Wild caught	Norway, Scotland, Ireland	Norway, Scotland, Ireland
Lumpfish [37]	*Cyclopterus lumpus* Linnaeus, 1758	Cold coastal waters, often near rocky substrates and kelp forests, ranging from shallow inshore areas to depths of about 300 meters.	Widely used in aquaculture as cleaner fish to control sea lice on farmed salmon, valued for their adaptability and effectiveness in colder waters. Disliked for their insatiable appetite and fast growth.	Around 2010-2016	Farmed since early 2000s. Commercial since 2010, grew steadily with increased demand and follows same decline as demand decreased	Norway, UK, Iceland, Canada	Norway, UK, Iceland, Faroe Islands, Canada

Cleaner fish use started in Norway during the 1980s [31, 38] followed by the United Kingdom during the 90s [39]. Since the use of cleaner fish does not involve any handling or mortality to the salmonids, it has been viewed as an environmentally friendly delousing method [40]. Cleaner fish use was marketed as "biological sea louse control" [41, 42] and introduced as a non-medical alternative against sea lice. Ballan wrasse and Lumpfish are considered the most effective and important cleaner fish species to date and have been extensively used in salmon aquaculture over the last few years.

For the past 5 years, the reliance on cleaner fish has steadily decreased in all the European countries using these fish in salmonid farming (Figure 12 and 13).

FIGURE 12.
Cleaner fish deployment (all species, 1998-2024), [152].

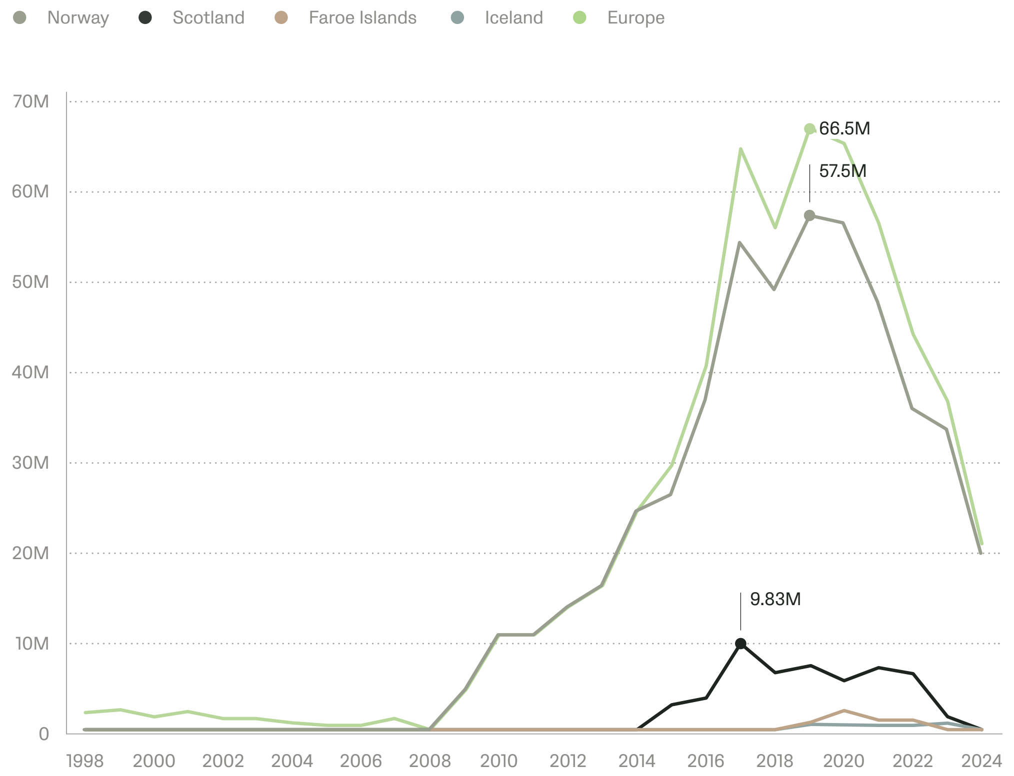
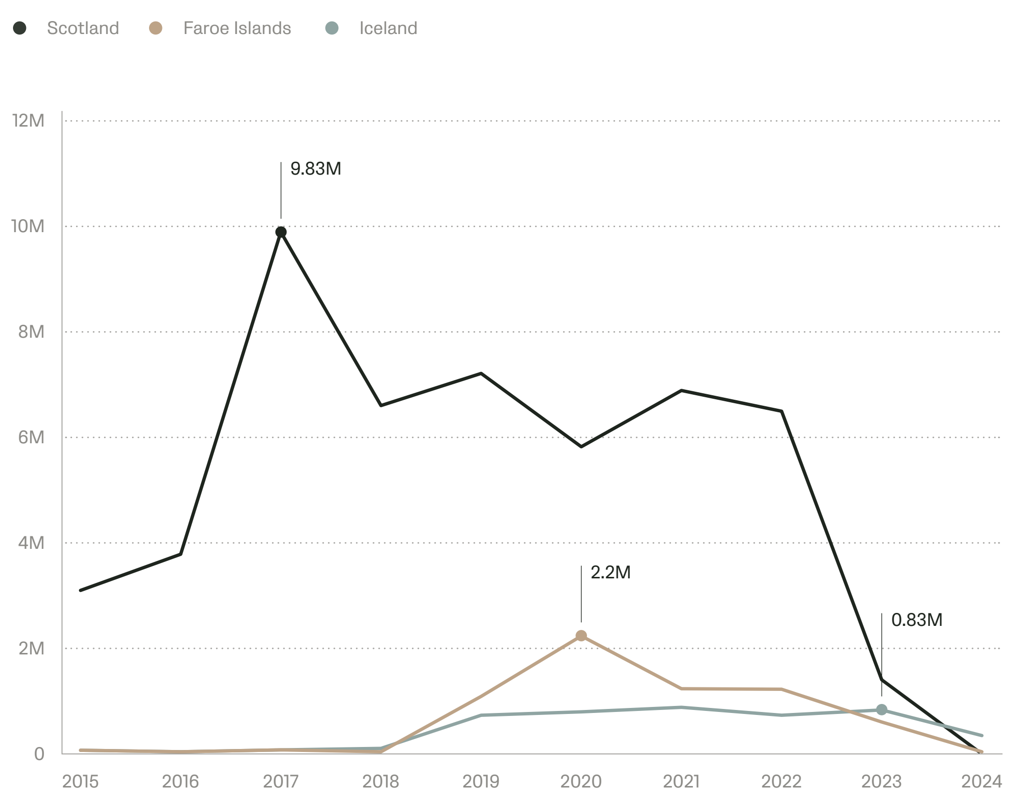


FIGURE 13.
Cleaner fish deployment (all species) in Scotland, Faroes Islands and Iceland (2015-2024).



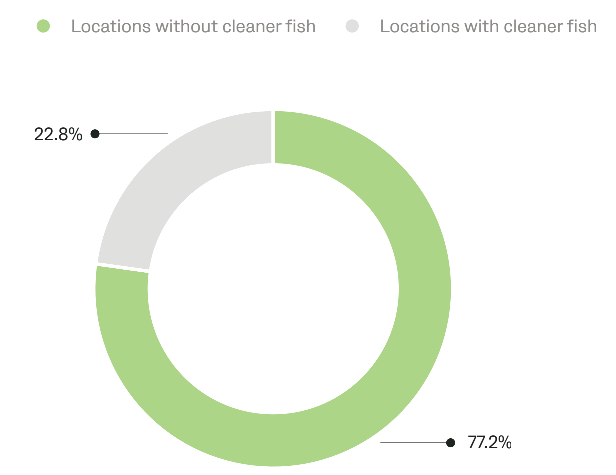
The three main reasons for this decline are serious concerns for:

- Poor cleaner fish welfare [42-45]
- Impact on wild fish populations [46]
- Varying overall delousing efficacy [47-50]

Cleaner fish status in 2024

By the end of 2024, a total of 881 operational aquaculture locations were registered in Norway, of which 201 were stocked with cleaner fish (Figure 14). This accounts for 22.8% of the market share in Norwegian aquaculture.

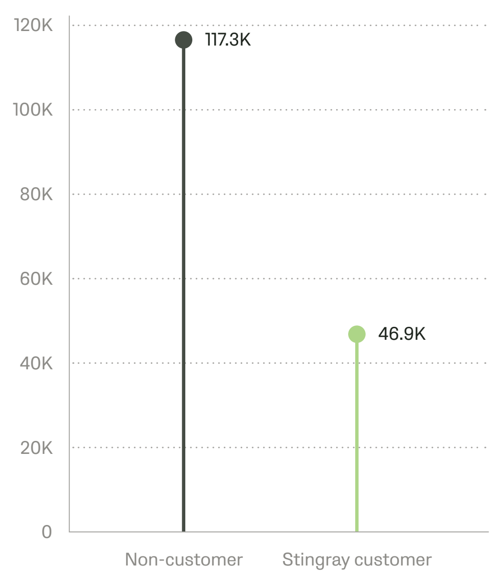
FIGURE 14.
Proportion of Norwegian aquaculture locations using cleaner fish (2024).



Stingray technology as a sustainable alternative to cleaner fish

The complete adoption to Stingray's Fish Health Hub™ as an alternative method to obtain louse control has gradually increased over the last few years. Through its mode of action, as a continuous delousing system, Stingray offers an obvious and logical alternative to cleaner fish use. Only six locations in Norway combined cleaner fish use with the Stingray system in 2024. In addition, locations stocked significantly lower cleaner fish numbers, when combining cleaner fish and the Stingray system. Locations without the Stingray system used more than twice the number of cleaner fish (+60%) (Figure 15). This highlights the efficiency and customer perception of the Stingray system to significantly reduce the overall need for cleaner fish in sea lice management.

FIGURE 15.
Cleaner fish stocking rates comparing non-customers with Stingray customers (2024).



Cleaner fish use varies by production area with some areas remaining at high use rate due to availability, higher lice infestation pressure [51] and state of traffic light system [52], while other PAs are phasing out their use altogether [53]. A clear transition from cleaner fish to alternative delousing methods can be observed (Figure 16 and 17).

FIGURE 16.
Cleaner fish market share (%) vs. Stingray market share (%) per production area in Norway (2024).

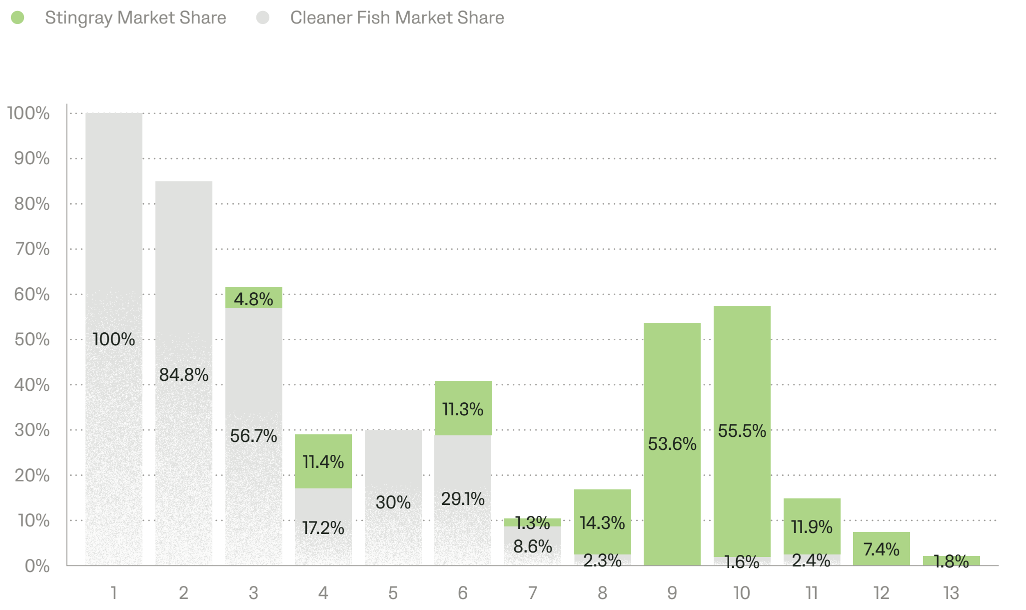
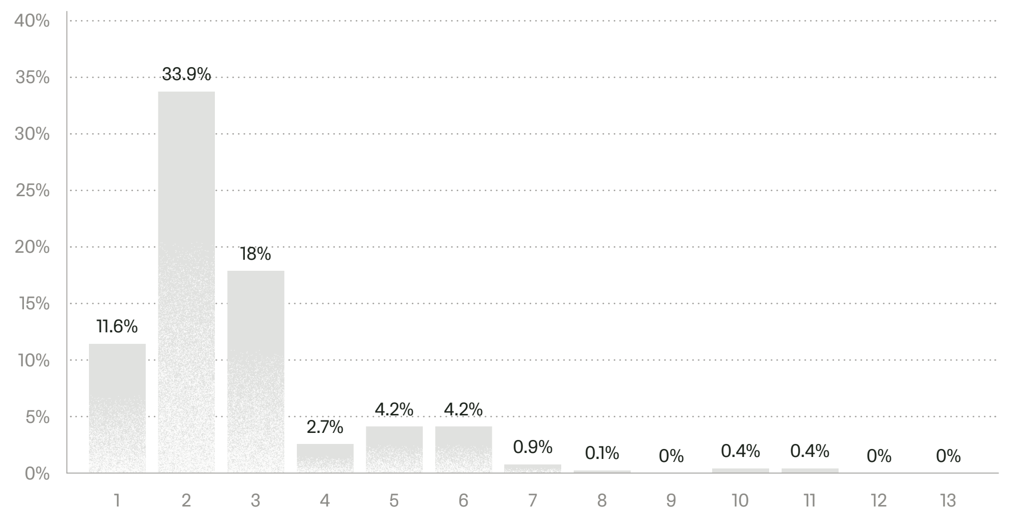
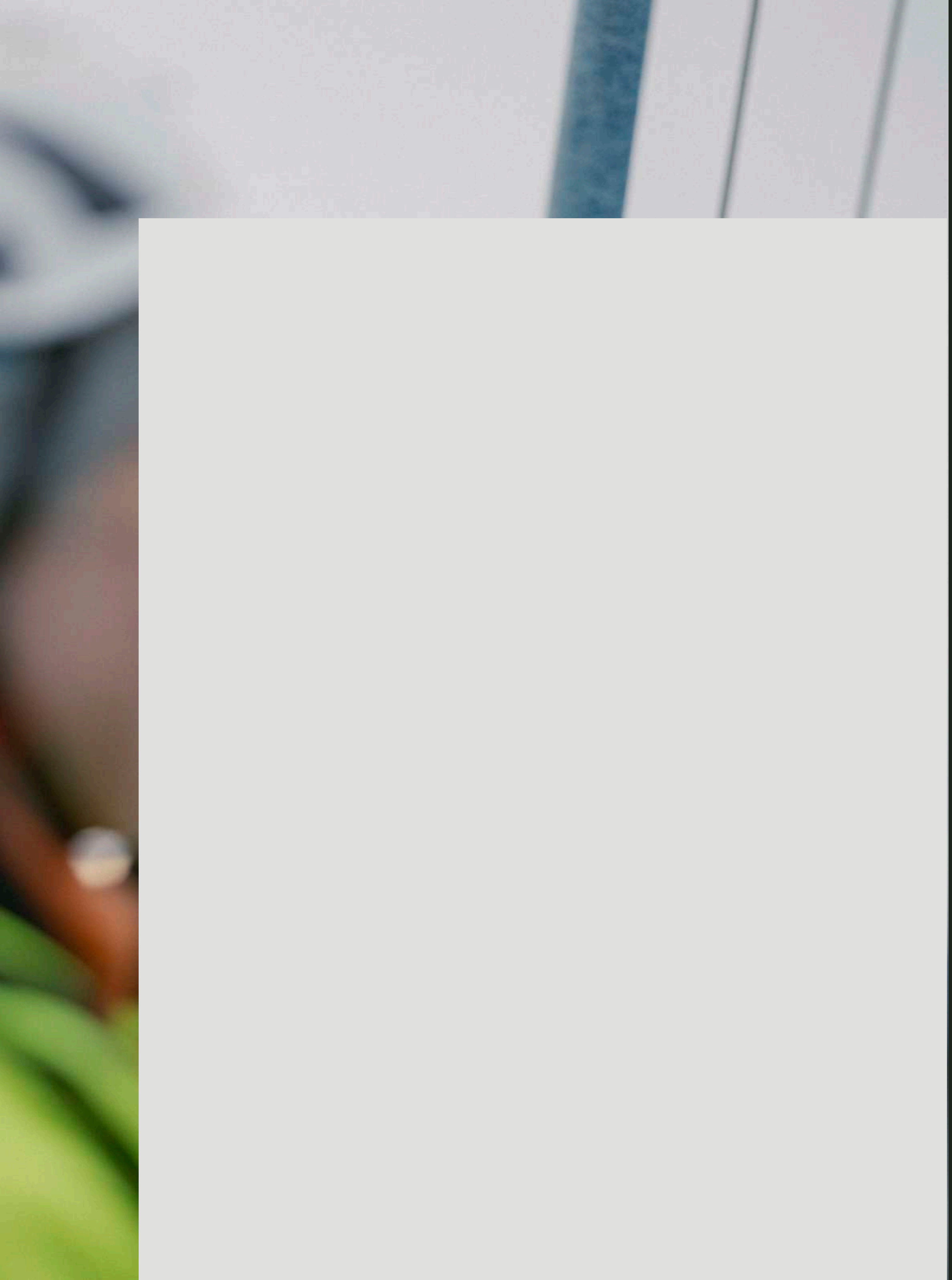


FIGURE 17.
Cleaner fish use (%) per production area in Norway (2024).



3.0

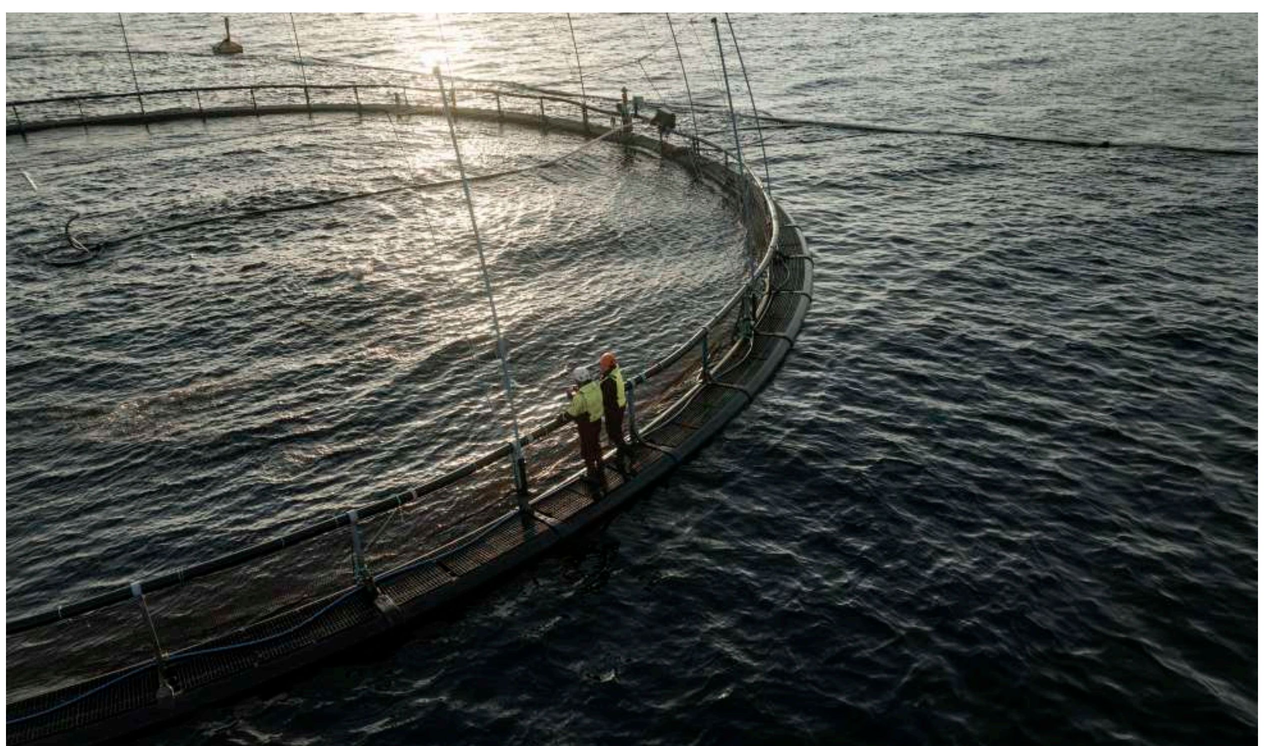
Fish Welfare - Challenge and Opportunity



Stingray monitors fish 24/7 and tracks various health indicators. Monitoring fish welfare helps Stingray, and its customers, take timely action to safeguard both fish health and economic value. Stingray's unique insight into fish behavior and the farming environment facilitates precise fish health assessment, early warning to disease outbreaks, production optimization and sea louse control.

Gentle handling promotes animal welfare

Gentle handling of fish promotes better animal welfare by minimizing stress, injury, and physiological disturbances during farming and transportation. Techniques such as reducing handling frequency, stable low lice populations, maintaining optimal water quality, and avoiding overcrowding reduce physical harm and stress-related immune suppression. Furthermore, gentle handling limits the amount of adult sea lice, and especially larvae, released into the water body. The reduction of handling procedures at aquaculture locations can minimize stress induced egg and larvae release or the dislodging of adult lice from the fish [54-56]. Implementing these practices enhances fish well-being and often results in improved growth rates and quality in aquaculture operations. By ensuring good welfare and low louse levels in farmed fish overall, the use of Stingray may also have a passive, knock-on impact on wild salmonid fish stocks. Stingray expects positive effects on wild stocks to become more obvious with an increasing market share and resulting control over farmed fish stocks.



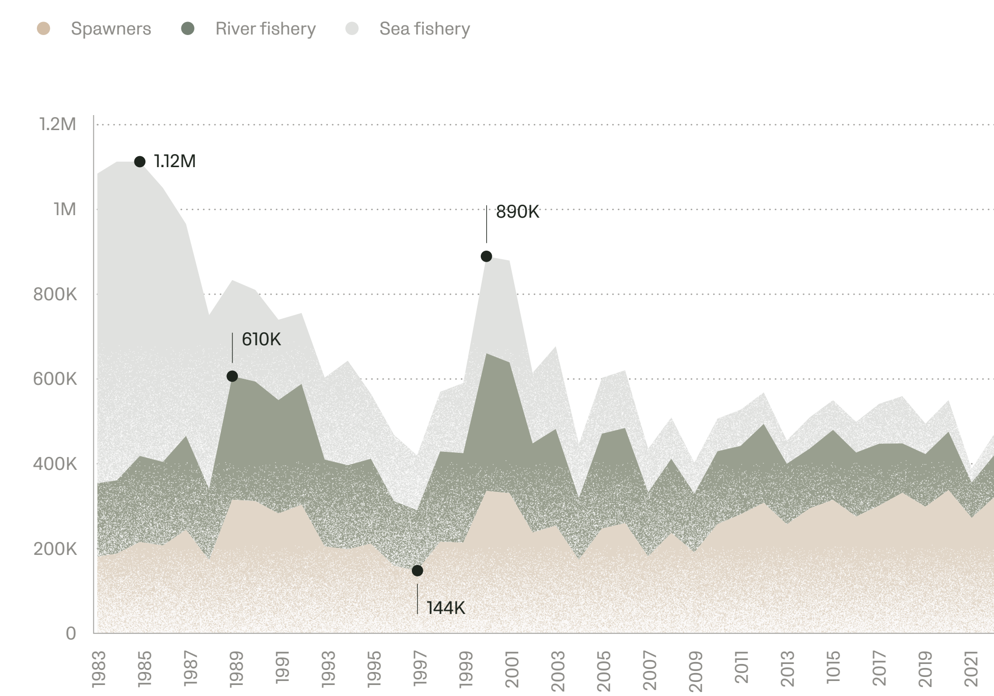
3.1

Wild salmon status 2024

Norway is home to approximately 1,300 rivers with wild salmon populations, representing 25% of the world's Atlantic salmon stocks. Wild salmon spawn in freshwater, and after smoltification they migrate to the sea to feed and grow. This migration typically occurs in spring, often during the spring floods, after juveniles have spent two to four summers in their home river. Salmon remains in the ocean for one to four years before returning to their natal river to spawn. A sizable portion of Norwegian wild salmon spend their ocean years in the area between the Faroe Islands and the island of Jan Mayen in Svalbard.

Today, wild salmon is categorized as Near Threatened (NT) on Norway's Red List of species at risk of extinction [57]. The abundance of wild salmon has declined dramatically since the 1980s [58-61], and Norwegian wild salmon is at a historically low level. The "salmon run", referring to the number of salmon returning to rivers each year as spawning fish from the sea to Norwegian rivers, was the second lowest ever recorded number of fish in 2023, at 400,000 wild salmon (Figure 18) [62].

FIGURE 18. Wild salmon return rates 1983 - 2023 [62].



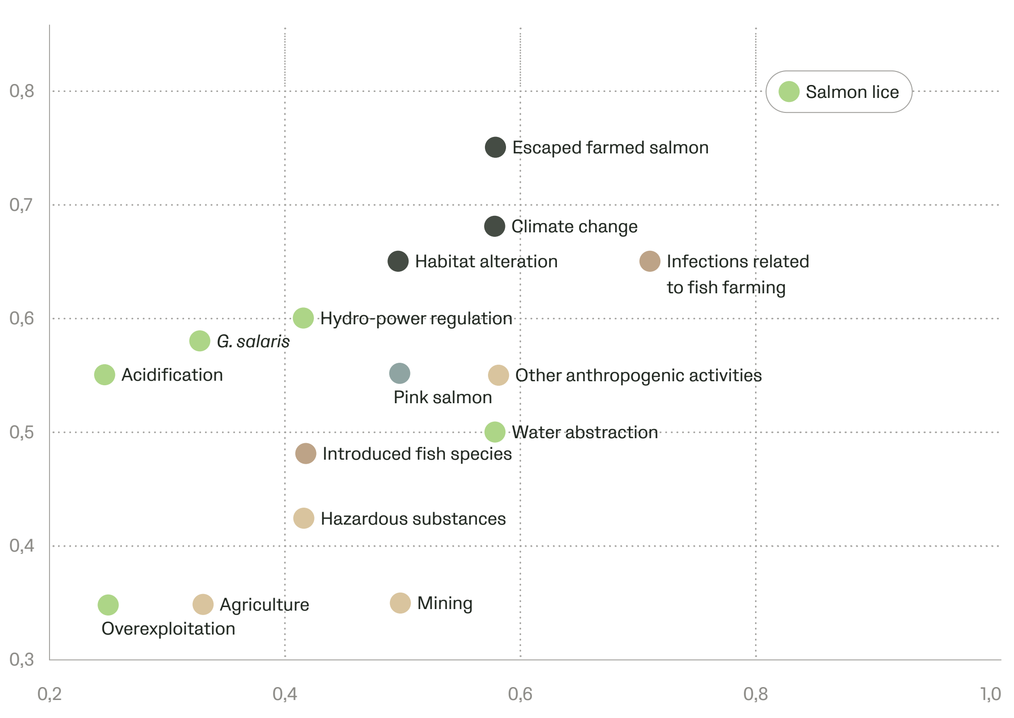
Human-caused threats

The most significant human-caused threats to Norwegian wild salmon are the impacts of aquaculture and drastic temperature changes. Scientific studies show that delayed sexual maturity in wild fish [63, 64] and the spread of salmon lice from aquaculture have led to population-level impacts. These include fewer returning spawners and reduced harvestable surpluses, particularly in Norway's most aquaculture-intensive regions [62, 65-67].

Escaped farmed salmon and infections linked to salmon farming further worsen the challenges (Figure 19) [62]. Although the number of escaped farmed salmon in Norwegian rivers has decreased in recent years, genetic changes from interbreeding with escaped salmon have been confirmed in many wild salmon populations. Infections associated with fish farming do pose a significant threat, but their impacts are not well understood, and there is substantial uncertainty about how they may develop in the future [62].

FIGURE 19.
Ranking of impact factors affecting wild Atlantic salmon stocks (2023) [62].

x-axis: negative development likelihood, y-axis: effect on wild stocks
Degree of confidence from 1 to 5 where green reflects the highest confidence



3.1

Life cycle of farmed Atlantic salmon

4-6 kg
harvest weight

The life cycle of farmed salmon begins in hatcheries, where eggs are fertilized and incubated at approximately 8°C for about 60 days. After hatching into alevins, the salmon remain in the hatchery for 4–6 weeks until they absorb their yolk sacs. Once this stage is complete, they are moved to larger freshwater tanks, where they grow for 10–16 months.

The smoltification process in farmed salmon is carefully managed using controlled lighting and feeding schedules. Once they become smolts, they are transferred to sea cages at production farms, where they grow for another 14–22 months [68] to reach a harvest weight of 4–6 kilograms.

Farmed salmon have higher growth rates than wild salmon due to selective breeding and optimal conditions, such as consistent feeding and protection from predators. Farmed salmon are usually harvested before reaching sexual maturity, while wild salmon mature naturally as part of their life cycle [68].

Legislation

Fish have been protected under the Law of Animal Welfare since 1974, well before aquaculture became a major industry in Norway [69]. Consequently, the legislation was not originally tailored to address aquaculture. In White Paper No. 12 (2002–2003) [70], the Norwegian government highlighted challenges in the law regarding fish welfare, including difficulties in interpreting body language and the absence of facial expressions. The same White Paper also mentioned uncertainty regarding whether fish experience pain in the same way as mammals but concluded that "we should act as if they do" [70]. In 2010, a new Law of Animal Welfare came into force, enforcing several new regulations related to aquaculture such as the welfare of farmed salmon [71]. The Norwegian government is currently working on a new White Paper on animal welfare, which will assess developments and knowledge related to animal welfare [72].

The Law of Animal Welfare [71] includes general regulations that also apply to fish. Key provisions, such as requirements for reporting, competence and responsibility, permits, operational practices, equipment, and technical solutions, are applicable to farmed salmon and trout. The purpose of the law is to promote good animal welfare and respect for animals. However, the law is broad in its framework, and welfare for farmed fish is not specifically mentioned. Other relevant regulations, grounded in the Law of Animal Welfare, address more specific regulations for farmed fish, such as the Aquaculture Operations Regulation [73].

The Norwegian Food Safety Authority is a governmental agency and directorate responsible for administering the Law of Animal Welfare. Promoting good animal welfare and respect for animals is one of several objectives pursued by the authority. This goal is addressed through activities such as inspections, guidance, monitoring, and surveillance. Furthermore, the authority contributes to the development of regulations to support these efforts. In its 2023 Annual Report on Animal Welfare, the Norwegian Food Safety Authority stated that it would prioritize work on a new welfare framework, with general regulations on fish welfare and specific regulations tailored to various species and stages of production. It is also noted that specific requirements must be measurable through the use of welfare indicators [74].

Welfare indicators

Fish are, as mentioned earlier, included in the Animal Welfare Act, which states that

> *“Animals have intrinsic value regardless of the benefit they may provide to humans”*
>
> **ANIMAL WELFARE ACT, 2009, §3**

Animals must be treated well and protected from unnecessary suffering and strain. This places an additional responsibility for humans toward animals kept in captivity. Fish kept in captivity lose the ability to move away from environments with poor living conditions, and it is therefore the farmer’s responsibility to ensure good welfare. Welfare needs are requirements that, when unmet or worsened, negatively impact an animal and cause distress. However, when such welfare needs are fulfilled or improved, they provide rewarding and positive feelings for the individual.

Fish that thrive in their environment, often showing greater resistance to disease, are considered to have good welfare. However, it can be challenging to define what this entails, as animal welfare is often understood as the quality of life the animal itself perceives. Nevertheless, good indications of a fish’s welfare can be obtained by observing behavior, environment, health, and physiological condition. These are indicators of the fish’s “perceived quality of life”. Such indicators are referred to as welfare indicators and are defined as any measurable or observable parameters that provide information about the fish’s welfare, whether good or poor. The use of welfare indicators is already widespread in the aquaculture industry. The first version of a standardized method for measuring welfare in salmon, called LAKSVEL, aims to facilitate quantification and comparison of welfare over time [75].

Welfare indicators can be grouped further into two categories: operative welfare indicators (OWIs) and laboratory-based welfare indicators (LABWIs). OWIs are used in daily operations and include observations of the fish’s appearance, behavior, appetite, and mortality. It is essential that operational welfare indicators provide a valid reflection of animal welfare, are easy to use, reliable, repeatable, comparable, relevant, and suitable for the intended purpose. Certain welfare indicators meet most of the operational requirements for such indicators but require sample analysis in a laboratory setting. These are referred to as laboratory-based welfare indicators (LABWI), which are also crucial for providing a robust measure of the fish’s welfare status. It is common to classify welfare indicators into direct and indirect categories: direct indicators are based on observations of the animal itself, while indirect indicators focus on the environment or resources the animal is exposed to. The responsibility for monitoring these OWIs primarily falls on farmers. The foundation for LAKSVEL comprises established methods for scoring welfare, and it is intended to serve as a scoring system for individual-based welfare indicators. A shared method for measuring welfare makes it easier to compare welfare over time, between companies, locations and countries using the same standard. This in turn enables better strategies and prevention efforts related to welfare [75].

Common welfare challenges in Norwegian aquaculture

In the 2023 *Fish Health Report* conducted by the Norwegian Veterinary Institute [6], welfare challenges in Norwegian sea-based aquaculture were examined through a survey targeting fish health professionals and employees. The survey highlights that injuries resulting from mechanical delousing are among the most prominent challenges. This method can inflict significant physical damage on the fish, compromising their health and welfare. Respondents also pointed to other critical issues, such as wound problems caused by bacteria *Moritella viscosa* (Lunder et al., 2000), especially during colder periods. Additionally, they pointed to complex gill diseases, which affect the fish’s ability to exchange oxygen. Mechanical delousing increases the risk of wound development and complex gill disease in fish. Additionally, injuries from jellyfish contact and various infectious diseases have been identified as significant stressors affecting fish welfare [6].

Welfare and Stingray

Injuries caused by delousing operations are among the most significant challenges to the health and welfare of farmed fish in Norway. Non-medicinal delousing methods, commonly referred to as mechanical treatments, frequently expose fish to considerable stress and physical injuries, such as skin abrasions and scale loss. These welfare challenges are further exacerbated by handling procedures, which can weaken the fish's immune system, increase their susceptibility to secondary infections, and lead to reduced appetite and growth [76]. Additionally, repeated exposure to such treatments negatively affects growth, behavior, and overall health. Therefore, it is crucial to implement effective preventive and control measures to minimize the need for both mechanical and medicinal delousing. Optical delousing with the Stingray system is a control measure that uses a laser to target sea lice with continuous pulses throughout the production cycle. This non-invasive method helps reduce both internal and external infection pressure.

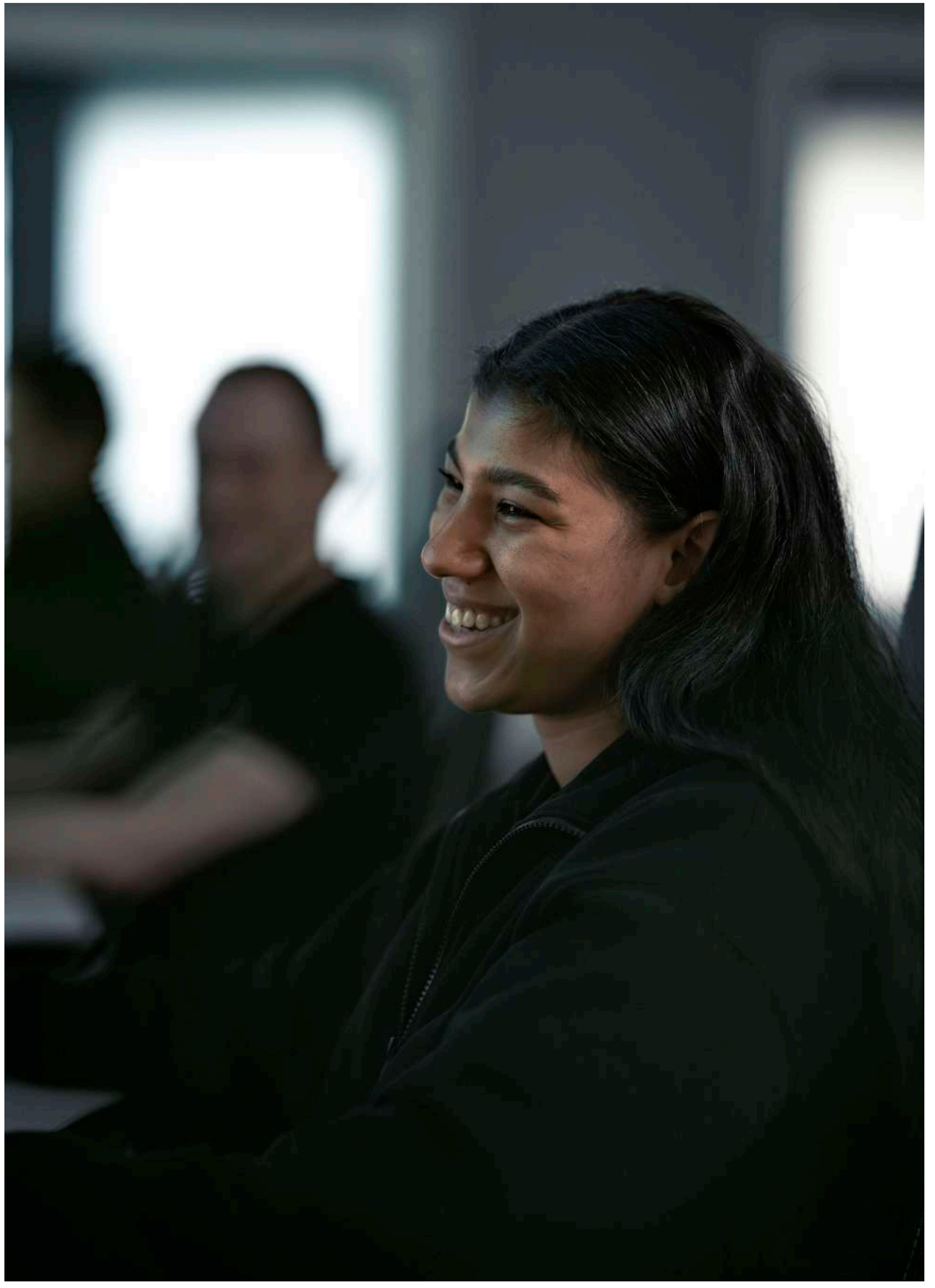
The Stingray laser node offers additional functionality beyond lice removal. Each day, the laser node captures multiple images of fish swimming past the cameras and uploads these images as sequences. One hundred sequences per laser node per day are uploaded to Stingray Online, where they are available for image-based analysis. This allows customers to conduct welfare assessments of salmon in line with the LAKSVEL standard [75] using the scores that can be assessed through image-based analysis. Consequently, the Stingray system serves as a tool for mapping the welfare of farmed fish.

In addition to image-based analysis, the Stingray system provides automated detection of wounds, sexual maturation, and weight distribution. The weight distribution detector is primarily designed for production control but can also aid in welfare monitoring by identifying abnormal weight distribution within a group of fish.

The system is equipped with a wound detector that identifies and scores wounds on a scale from 0 to 3. This offers customers an efficient method for monitoring wound status over time and can be used as an early warning system. During wound outbreaks, automated detection is a valuable tool for assessing whether the situation is deteriorating or improving.

The system's sexual maturation detector identifies morphological signs of maturation, such as hooked jaw development and darker coloration of the fish's skin. Sexual maturation can negatively affect fish health in several ways. Hormonal changes weaken their immune system, making the animal more prone to diseases. Physiological shifts reduce their ability to survive in seawater, increasing mortality if they remain in such conditions. Reduced immune capacity, physiological shifts, and behavioral changes can lead to decreased welfare and increased mortality in mature farmed salmon [12].

As such, the Stingray system offers a versatile platform for a wide range of applications, including advanced research purposes. By utilizing image-based analysis, the system provides unique insights beyond its core functionalities. These capabilities enable in-depth studies and data collection to better understand factors affecting fin condition and overall fish welfare, contributing to both academic research and practical improvements in aquaculture practices. The following study leverages the Stingray system's image-based analysis to assess the well-being of salmon in a real-world aquaculture setting, offering valuable insights into fin condition as a welfare indicator and contributing to the development of more refined monitoring techniques.



Analysis of fin indices with pictures available from the Stingray app

DR. CONSTANZE PIETSCH
ProFishCare GmbH, Switzerland, 2024

The aim of the study was the evaluation of the wellbeing of salmon originating from two pens of a Norwegian salmon production location. The appearance of the fish was evaluated via pictures downloaded from Stingray Online. Fin condition is often used as a marker for fish well-being. However, the way fin indices can be calculated differs across scientific studies and the size- or species-specific characteristics of fin indices have rarely been investigated so far. Hence, the current investigations used information available for a Norwegian salmon farm derived from Stingray Online from Sept 2022 (the time point when the fish were put to sea) until the harvest time in Dec 2023. In parallel, body samples from fish of both cages have been taken in July, Sept, and Nov 2023 for further analyses in the lab in Switzerland and development of a molecular marker of stress in the future. For the current investigations, the length of the fin rays for the dorsal, caudal, anal, pectoral and ventral fins has been measured manually by using the open-source software Fiji (available at https://imagej.net/ij/) as shown in Figure I.

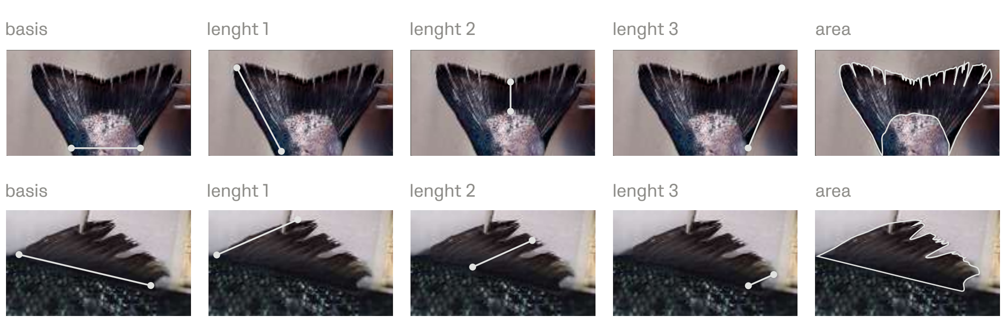


FIGURE I
Description of the fin measurements shown for the caudal and the dorsal fin of salmon.

Moreover, the total length and the standard body length of each individual fish was determined with the same software to allow the calculation of different fin indices (Figure II). These indices included the Kindschi index for which the longest fin ray is related to the total body length [77]. This index was improved by Ellis, Hoyle [78] by using the standard body length as a reference instead of the total body length. Furthermore, the index according to Good, Davidson [79] was calculated by using the longest fin ray of a fin relative to the longest distance of the fin basis to the fin tip for the caudal fin. In addition, in one of our recent studies [80], we compared these indices to area-based indices which were calculated relative to the total body length (Area index) or relative to the standard body length (Area improved). In the same study, we also investigated the suitability of an index calculated from the longest fin ray relative to the basis of the fin, since it was expected that the fin basis grows proportional to the total body length.

However, the position of the fish on the pictures derived from Stingray Online may not be optimal for taking the total body length and the standard body length as a basis for the subsequent calculations. Consequently, the eye area and the eye diameter were determined for each fish and their suitability as a reference for the calculation of fin indices was evaluated as described below. All measurements for the Norwegian salmon farm are based on pixels since a scaling parameter was not available on the pictures.

FIGURE II
Description of the measurements of the total body length and standard body length of salmon.

As mentioned above, the eye diameter and the area of the eye were recorded for each fish as well, since these parameters may be less variable for different sizes of fish and less biased on pictures. To confirm the stability of the eye area and eye diameter relative to the standard body length, their relationship was visualized (Figure III). These two graphs show that the eye area measurement is more variable for fish with a higher standard body length, whereas the eye diameter is relatively stable for fish of different sizes.

FIGURE III

Description of the relation of the eye area relative to the standard body length of salmon (px), n = 180 fish.

x-axis: standard body length (pixels), y-axis: eye area/standard body length

$y = 0.0004x + 0.1217$ $R^2 = 0.1169$

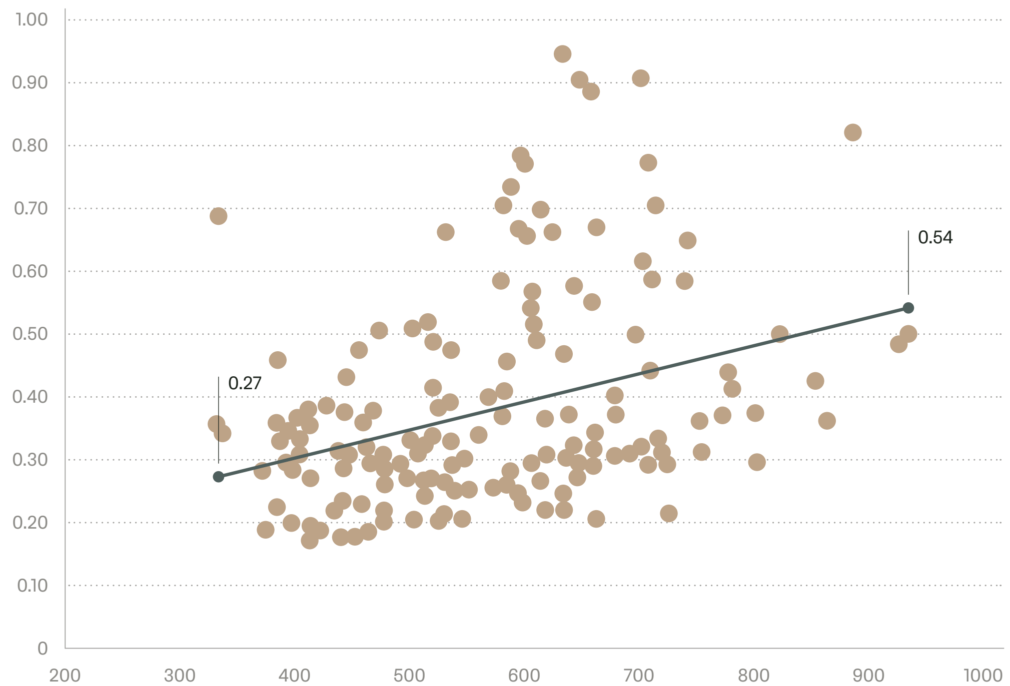
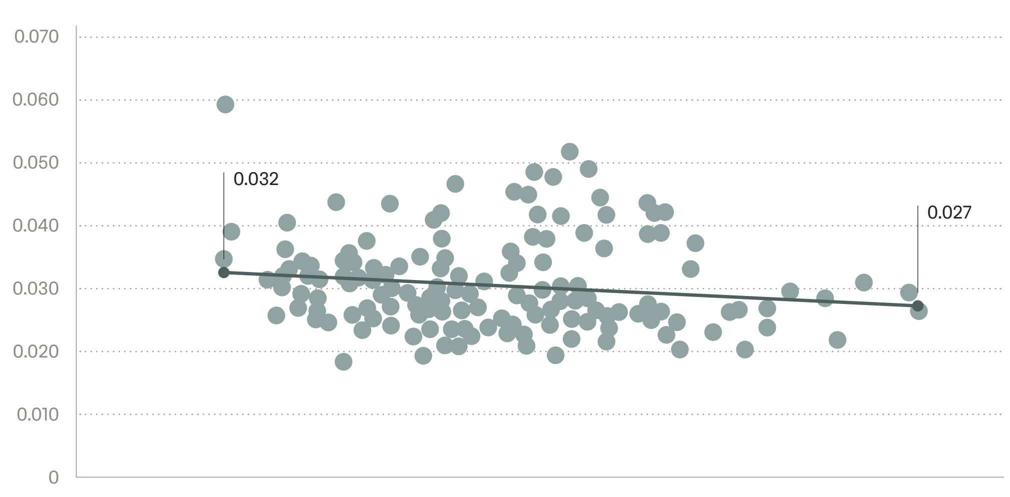


FIGURE IV

Description of the relation of the eye diameter relative to the standard body length of salmon (px), n = 180 fish.

x-axis: standard body length (pixels), y-axis: eye diameter/standard body length

$y = -8E\text{-}06x + 0.0351$ $R^2 = 0.0208$



At first, the fin indices have been calculated (currently for the period of Sept 2022 when the fish were put to sea until May 2023) based on the total body length and the standard body length. All indices were used as mean values of 10 fish per index in the correlation analyses. For the correlation analyses, further data were downloaded from Stingray Online including the percentage of wounds, the swim speed, the growth, the number of adult female sea lice on the fish, and the sea temperature. The correlation analyses show that a number of parameters was positively correlated with each other (shown in dark gray color), whereas other parameters were negatively correlated (Figure V).

FIGURE V

	mortality_ rate	sea_temp	weight	weekly_SGR	adult female	wounds	swim_speed.AVG	Kindschi_dorsal_fin	Kindschi.imp_dorsal_fin	Area.imp_dorsal_fin	Goods_dorsal_fin	ToBasis_dorsal_fin	Kindschi_caudal_fin	Kindschi.imp_caudal_fin	Area_imp_caudal_fin	Goods_caudal_fin	ToBasis_caudal_fin	Kindschi_anal_fin	Kindschi.imp_anal_fin	Area.imp_anal_fin	Goods_anal_fin	ToBasis_anal_fin
mortality_ rate	1.00	-0.84	0.43	-0.55	0.07	0.58	-0.29	-0.04	0.53	0.06	0.27	0.52	-0.74	0.43	0.12	0.10	-0.41	0.10	0.56	0.09	0.60	0.21
sea_temp	-0.84	1.00	-0.38	0.56	-0.26	-0.37	0.12	0.08	-0.54	-0.18	-0.23	-0.48	0.70	-0.46	-0.06	0.09	0.42	-0.03	-0.55	-0.08	-0.49	-0.20
weight	0.43	-0.38	1.00	0.11	-0.11	0.93	-0.32	-0.20	0.71	0.40	-0.03	0.04	-0.33	0.90	0.78	0.32	-0.59	0.38	0.88	0.54	0.50	-0.01
weekly_SGR	-0.55	0.56	0.11	1.00	0.44	-0.10	0.16	0.19	0.06	0.06	-0.15	0.09	0.65	0.19	0.19	0.16	0.35	0.11	0.04	0.01	-0.43	-0.12
adult female	0.07	-0.26	-0.11	0.44	1.00	-0.30	-0.02	0.13	0.12	-0.24	-0.08	0.62	0.26	0.12	-0.31	0.20	0.37	0.06	0.08	-0.41	-0.21	0.29
wounds	0.58	-0.37	0.93	-0.10	-0.30	1.00	-0.40	-0.19	0.66	0.36	0.02	0.05	-0.41	0.80	0.77	0.34	-0.54	0.37	0.81	0.58	0.57	-0.08
swim_speed.AVG	-0.29	0.12	-0.32	0.16	-0.02	-0.40	1.00	0.28	-0.06	0.48	0.26	0.05	0.09	-0.19	-0.03	0.28	0.29	-0.69	-0.30	0.16	-0.59	-0.55
Kindschi_dorsal_fin	-0.04	0.08	-0.20	0.19	0.13	-0.19	0.28	1.00	0.46	0.50	0.86	0.67	0.14	0.15	0.09	-0.47	-0.10	0.37	0.19	0.40	0.23	0.16
Kindschi.imp_dorsal_fin	0.53	-0.54	0.71	0.06	0.12	0.66	-0.06	0.46	1.00	0.69	0.61	0.60	-0.38	0.92	0.63	-0.14	-0.60	0.48	0.94	0.67	0.63	0.07
Area.imp_dorsal_fin	0.06	-0.18	0.40	0.06	-0.24	0.36	0.48	0.50	0.69	1.00	0.55	0.25	-0.05	0.60	0.74	0.05	-0.31	0.11	0.53	0.92	0.15	-0.38
Goods_dorsal_fin	0.27	-0.23	-0.03	-0.15	-0.08	0.02	0.26	0.86	0.61	0.55	1.00	0.61	-0.36	0.26	0.08	-0.48	-0.42	0.25	0.36	0.43	0.48	0.10
ToBasis_dorsal_fin	0.52	-0.48	0.04	0.09	0.62	0.05	0.05	0.67	0.60	0.25	0.61	1.00	-0.11	0.37	0.00	-0.27	-0.02	0.27	0.43	0.12	0.28	0.29
Kindschi_caudal_fin	-0.74	0.70	-0.33	0.65	0.26	-0.41	0.09	0.14	-0.38	-0.05	-0.36	-0.11	1.00	-0.26	0.07	0.03	0.65	0.13	-0.39	0.00	-0.59	-0.06
Kindschi.imp_caudal_fin	0.43	-0.46	0.90	0.19	0.12	0.80	-0.19	0.15	0.92	0.60	0.26	0.37	-0.26	1.00	0.77	0.05	-0.54	0.49	0.97	0.65	0.53	0.00
Area_imp_caudal_fin	0.12	-0.06	0.78	0.19	-0.31	0.77	-0.03	0.09	0.63	0.74	0.08	0.00	0.07	0.77	1.00	0.34	-0.36	0.38	0.69	0.89	0.27	-0.24
Goods_caudal_fin	0.10	0.09	0.32	0.16	-0.20	0.34	0.28	-0.47	-0.14	0.05	-0.48	-0.27	0.03	0.05	0.34	1.00	0.18	-0.50	-0.06	0.06	-0.39	-0.36
ToBasis_caudal_fin	-0.41	0.42	-0.59	0.35	0.37	-0.54	0.29	-0.10	-0.60	-0.31	-0.42	-0.02	0.65	-0.54	-0.36	0.18	1.00	-0.49	-0.66	-0.38	-0.86	-0.43
Kindschi_anal_fin	0.10	-0.03	0.38	0.11	0.06	0.37	-0.69	0.37	0.48	0.11	0.25	0.27	0.13	0.49	0.38	-0.50	-0.49	1.00	0.57	0.34	0.71	0.62
Kindschi.imp_anal_fin	0.56	-0.55	0.88	0.04	0.08	0.81	-0.30	0.19	0.94	0.53	0.36	0.43	-0.39	0.97	0.69	-0.06	-0.66	0.57	1.00	0.61	0.70	0.15
Area.imp_anal_fin	0.09	-0.08	0.54	0.01	-0.41	0.58	0.16	0.40	0.67	0.92	0.43	0.12	0.00	0.65	0.89	0.06	-0.38	0.34	0.61	1.00	0.32	-0.32
Goods_anal_fin	0.60	-0.49	0.50	-0.43	-0.21	0.57	-0.59	0.23	0.63	0.15	0.48	0.28	-0.59	0.53	0.27	-0.39	-0.86	0.71	0.70	0.32	1.00	0.56
ToBasis_anal_fin	0.21	-0.20	-0.01	-0.12	0.29	-0.08	-0.55	0.16	0.07	-0.38	0.10	0.29	-0.06	0.00	-0.24	-0.36	-0.43	0.62	0.15	-0.32	0.56	1.00

Correlation plot for the salmon parameters in one of the pens including the fin indices based on the body length of salmon, if necessary, negative correlations shown in beige and positive correlations shown in dark gray.

For the plot shown in Figure V, the standard body length and the total body length are used for the calculation of the Kindschi indices and the Area improved index. The separate values for these two indices for one pen are shown in Figure VI. However, these values may be biased by using the body length as a reference.

FIGURE VI
Index values for the Kindschi Improved Index; values based on standardised body length of fish (Sept 2022 - May 2023), based on eye area.

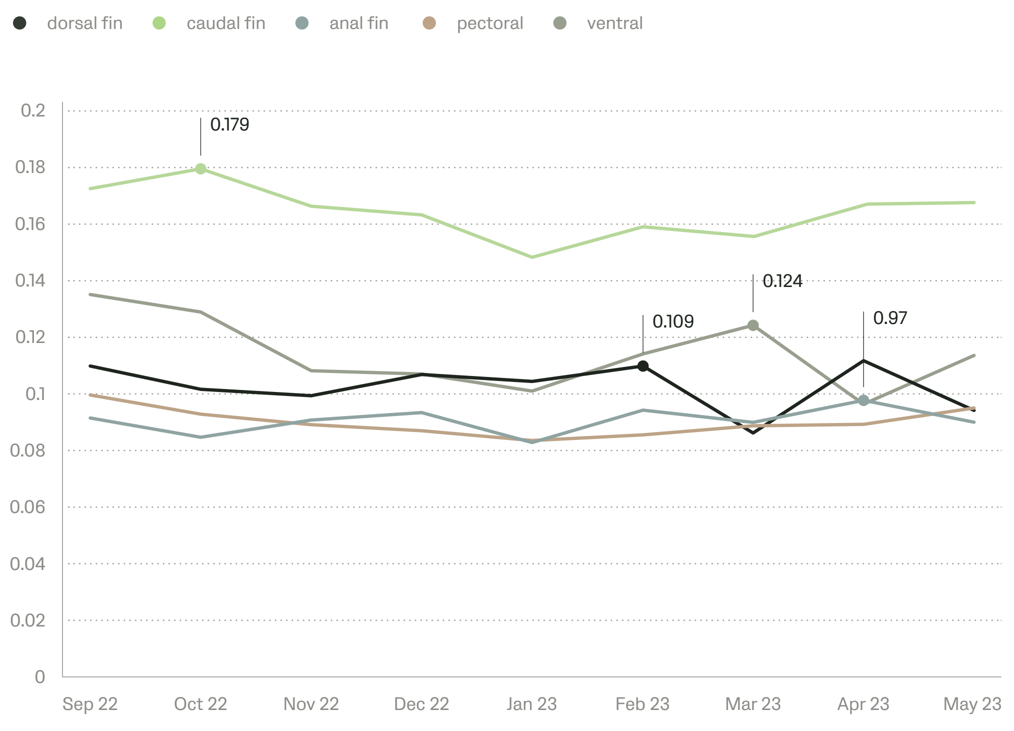
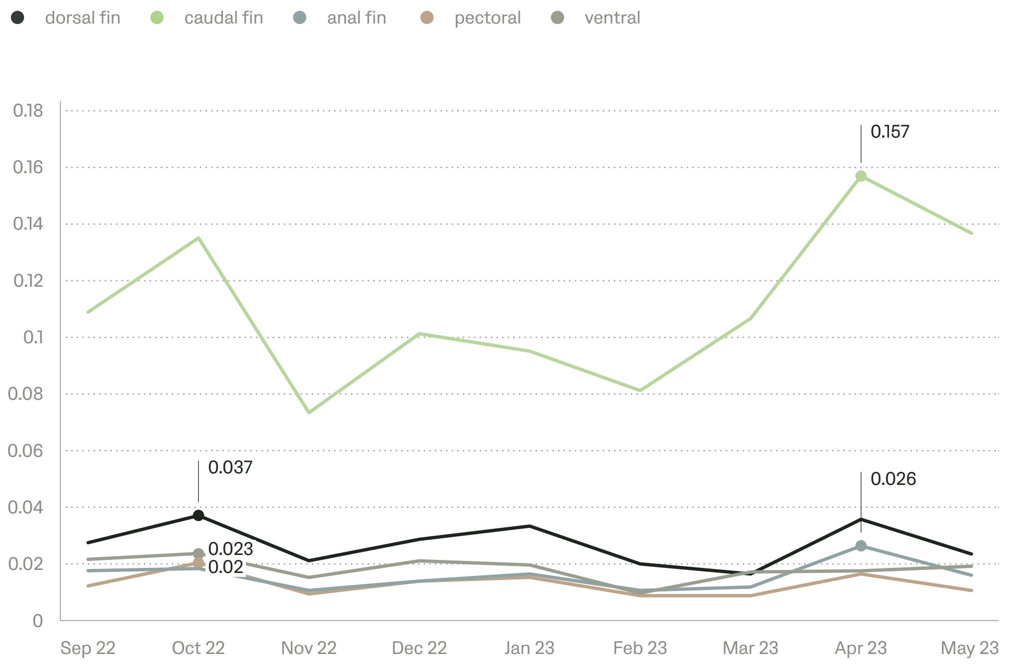


FIGURE VII
Index values for the Area Improved Index; values based on standardised body length of fish (Sept 2022 - May 2023), based on eye area.



Furthermore, from the pictures of the fish it was obvious that the pectoral and the ventral fin of the salmon were less frequently changed by the environmental conditions, and therefore, a second correlation plot was prepared omitting the indices for these fins as shown in Figure VIII.

FIGURE VIII

	mortality_ rate	sea_temp	weight	weekly_SGR	adult female	wounds	swim_speed.AVG	Kindschi_dorsal_fin	Kindschi.imp_dorsal_fin	Area.imp_dorsal_fin	Goods_dorsal_fin	ToBasis_dorsal_fin	Kindschi_caudal_fin	Kindschi.imp_caudal_fin	Area_imp_caudal_fin	Goods_caudal_fin	ToBasis_caudal_fin	Kindschi_anal_fin	Kindschi.imp_anal_fin	Area.imp_anal_fin	Goods_anal_fin	ToBasis_anal_fin
mortality_ rate	1.00	-0.84	0.43	-0.55	0.07	0.58	-0.29	-0.04	0.53	0.06	0.27	0.52	-0.74	0.43	0.12	0.10	-0.41	0.10	0.56	0.09	0.60	0.21
sea_temp	-0.84	1.00	-0.38	0.56	-0.26	-0.37	0.12	0.08	-0.54	-0.18	-0.23	-0.48	0.70	-0.46	-0.06	0.09	0.42	-0.03	-0.55	-0.08	-0.49	-0.20
weight	0.43	-0.38	1.00	0.11	-0.11	0.93	-0.32	-0.20	0.71	0.40	-0.03	0.04	-0.33	0.90	0.78	0.32	-0.59	0.38	0.88	0.54	0.50	-0.01
weekly_SGR	-0.55	0.56	0.11	1.00	0.44	-0.10	0.16	0.19	0.06	0.06	-0.15	0.09	0.65	0.19	0.19	0.16	0.35	0.11	0.04	0.01	-0.43	-0.12
adult female	0.07	-0.26	-0.11	0.44	1.00	-0.30	-0.02	0.13	0.12	-0.24	-0.08	0.62	0.26	0.12	-0.31	0.20	0.37	0.06	0.08	-0.41	-0.21	0.29
wounds	0.58	-0.37	0.93	-0.10	-0.30	1.00	-0.40	-0.19	0.66	0.36	0.02	0.05	-0.41	0.80	0.77	0.34	-0.54	0.37	0.81	0.58	0.57	-0.08
swim_speed.AVG	-0.29	0.12	-0.32	0.16	-0.02	-0.40	1.00	0.28	-0.06	0.48	0.26	0.05	0.09	-0.19	-0.03	0.28	0.29	-0.69	-0.30	0.16	-0.59	-0.55
Kindschi_dorsal_fin	-0.04	0.08	-0.20	0.19	0.13	-0.19	0.28	1.00	0.46	0.50	0.86	0.67	0.14	0.15	0.09	-0.47	-0.10	0.37	0.19	0.40	0.23	0.16
Kindschi.imp_dorsal_fin	0.53	-0.54	0.71	0.06	0.12	0.66	-0.06	0.46	1.00	0.69	0.61	0.60	-0.38	0.92	0.63	-0.14	-0.60	0.48	0.94	0.67	0.63	0.07
Area.imp_dorsal_fin	0.06	-0.18	0.40	0.06	-0.24	0.36	0.48	0.50	0.69	1.00	0.55	0.25	-0.05	0.60	0.74	0.05	-0.31	0.11	0.53	0.92	0.15	-0.38
Goods_dorsal_fin	0.27	-0.23	-0.03	-0.15	-0.08	0.02	0.26	0.86	0.61	0.55	1.00	0.61	-0.36	0.26	0.08	-0.48	-0.42	0.25	0.36	0.43	0.48	0.10
ToBasis_dorsal_fin	0.52	-0.48	0.04	0.09	0.62	0.05	0.05	0.67	0.60	0.25	0.61	1.00	-0.11	0.37	0.00	-0.27	-0.02	0.27	0.43	0.12	0.28	0.29
Kindschi_caudal_fin	-0.74	0.70	-0.33	0.65	0.26	-0.41	0.09	0.14	-0.38	-0.05	-0.36	-0.11	1.00	-0.26	0.07	0.03	0.65	0.13	-0.39	0.00	-0.59	-0.06
Kindschi.imp_caudal_fin	0.43	-0.46	0.90	0.19	0.12	0.80	-0.19	0.15	0.92	0.60	0.26	0.37	-0.26	1.00	0.77	0.05	-0.54	0.49	0.97	0.65	0.53	0.00
Area_imp_caudal_fin	0.12	-0.06	0.78	0.19	-0.31	0.77	-0.03	0.09	0.63	0.74	0.08	0.00	0.07	0.77	1.00	0.34	-0.36	0.38	0.69	0.89	0.27	-0.24
Goods_caudal_fin	0.10	0.09	0.32	0.16	-0.20	0.34	0.28	-0.47	-0.14	0.05	-0.48	-0.27	0.03	0.05	0.34	1.00	0.18	-0.50	-0.06	0.06	-0.39	-0.36
ToBasis_caudal_fin	-0.41	0.42	-0.59	0.35	0.37	-0.54	0.29	-0.10	-0.60	-0.31	-0.42	-0.02	0.65	-0.54	-0.36	0.18	1.00	-0.49	-0.66	-0.38	-0.86	-0.43
Kindschi_anal_fin	0.10	-0.03	0.38	0.11	0.06	0.37	-0.69	0.37	0.48	0.11	0.25	0.27	0.13	0.49	0.38	-0.50	-0.49	1.00	0.57	0.34	0.71	0.62
Kindschi.imp_anal_fin	0.56	-0.55	0.88	0.04	0.08	0.81	-0.30	0.19	0.94	0.53	0.36	0.43	-0.39	0.97	0.69	-0.06	-0.66	0.57	1.00	0.61	0.70	0.15
Area.imp_anal_fin	0.09	-0.08	0.54	0.01	-0.41	0.58	0.16	0.40	0.67	0.92	0.43	0.12	0.00	0.65	0.89	0.06	-0.38	0.34	0.61	1.00	0.32	-0.32
Goods_anal_fin	0.60	-0.49	0.50	-0.43	-0.21	0.57	-0.59	0.23	0.63	0.15	0.48	0.28	-0.59	0.53	0.27	-0.39	-0.86	0.71	0.70	0.32	1.00	0.56
ToBasis_anal_fin	0.21	-0.20	-0.01	-0.12	0.29	-0.08	-0.55	0.16	0.07	-0.38	0.10	0.29	-0.06	0.00	-0.24	-0.36	-0.43	0.62	0.15	-0.32	0.56	1.00

Correlation plot for a reduced number of salmon parameters in one of the pens including the fin indices (corrected) based on the body length of salmon, if necessary, negative correlations shown in beige and positive correlations shown in dark gray.

However, also the eye diameter was used as a basis for the Kindschi and the Area-improved index calculations since the eye diameter was a more promising parameter for these calculations as the eye area (as shown in Figure Ⅲ). Hence, the correlation analyses were repeated with the eye diameter for these calculations (Figure Ⅷ). The results appear to be more realistic than the indices shown in Figure VI, since they show an increasing fin ray length and fin area with ongoing growth of the fish.

FIGURE IX
Index values for the Kindschi Improved Index; values based on standardised body length of fish (Sept 2022 - May 2023), based on eye diameter.

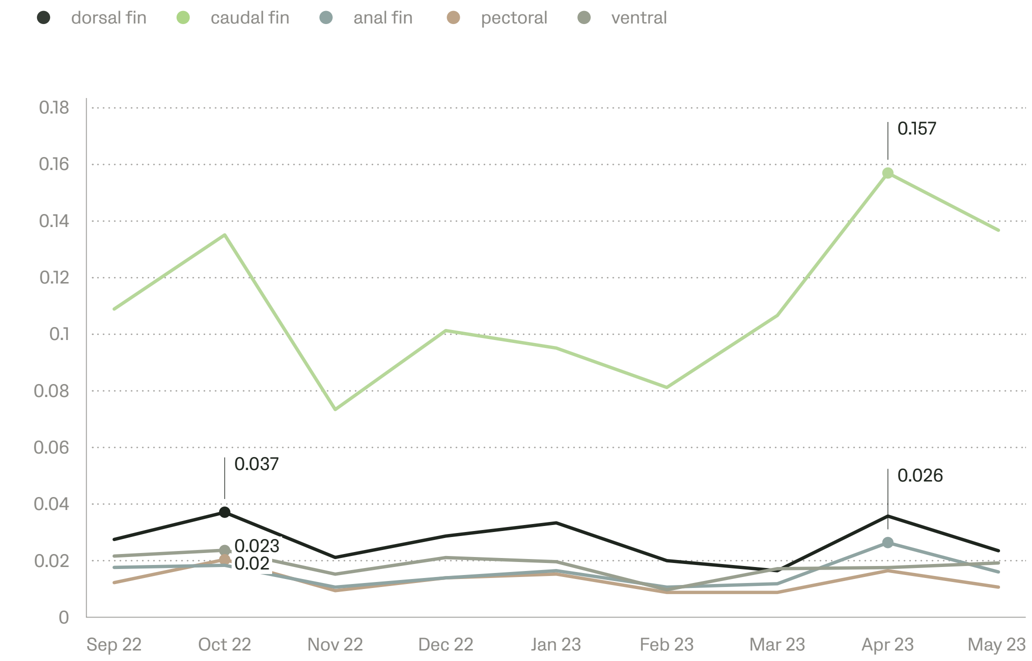
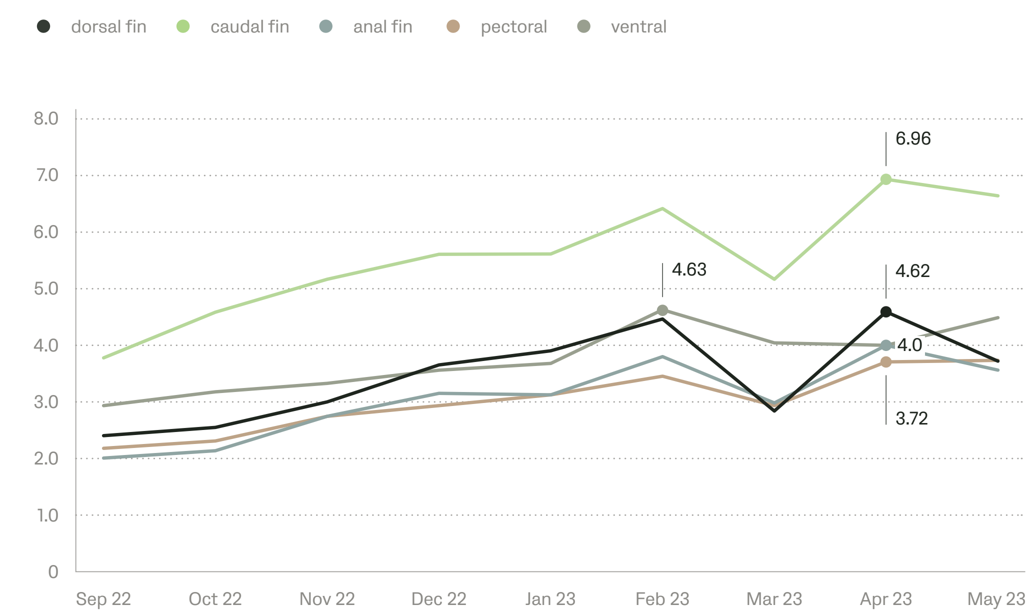


FIGURE X
Index values for the Area Improved Index; values based on standardised body length of fish (Sept 2022 - May 2023), based on eye diameter.



With the more realistic calculation of these two fin indices, the correlation analyses of the parameters shown in Figure VIII were repeated resulting in the plot shown in Figure XI.

FIGURE XI

	mortality_ rate	sea_temp	weight	weekly_SGR	adult female	wounds	swim_speed.AVG	Kindschi_dorsal_fin	Kindschi.imp_dorsal_fin	Area.imp_dorsal_fin	Goods_dorsal_fin	ToBasis_dorsal_fin	Kindschi_caudal_fin	Kindschi.imp_caudal_fin	Area_imp_caudal_fin	Goods_caudal_fin	ToBasis_caudal_fin	Kindschi_anal_fin	Kindschi.imp_anal_fin	Area.imp_anal_fin	Goods_anal_fin	ToBasis_anal_fin
mortality_ rate	1.00	-0.84	0.43	-0.55	0.07	0.58	-0.29	-0.04	0.53	0.06	0.27	0.52	-0.74	0.43	0.12	0.10	-0.41	0.10	0.56	0.09	0.60	0.21
sea_temp	-0.84	1.00	-0.38	0.56	-0.26	-0.37	0.12	0.08	-0.54	-0.18	-0.23	-0.48	0.70	-0.46	-0.06	0.09	0.42	-0.03	-0.55	-0.08	-0.49	-0.20
weight	0.43	-0.38	1.00	0.11	-0.11	0.93	-0.32	-0.20	0.71	0.40	-0.03	0.04	-0.33	0.90	0.78	0.32	-0.59	0.38	0.88	0.54	0.50	-0.01
weekly_SGR	-0.55	0.56	0.11	1.00	0.44	-0.10	0.16	0.19	0.06	0.06	-0.15	0.09	0.65	0.19	0.19	0.16	0.35	0.11	0.04	0.01	-0.43	-0.12
adult female	0.07	-0.26	-0.11	0.44	1.00	-0.30	-0.02	0.13	0.12	-0.24	-0.08	0.62	0.26	0.12	-0.31	0.20	0.37	0.06	0.08	-0.41	-0.21	0.29
wounds	0.58	-0.37	0.93	-0.10	-0.30	1.00	-0.40	-0.19	0.66	0.36	0.02	0.05	-0.41	0.80	0.77	0.34	-0.54	0.37	0.81	0.58	0.57	-0.08
swim_speed.AVG	-0.29	0.12	-0.32	0.16	-0.02	-0.40	1.00	0.28	-0.06	0.48	0.26	0.05	0.09	-0.19	-0.03	0.28	0.29	-0.69	-0.30	0.16	-0.59	-0.55
Kindschi_dorsal_fin	-0.04	0.08	-0.20	0.19	0.13	-0.19	0.28	1.00	0.46	0.50	0.86	0.67	0.14	0.15	0.09	-0.47	-0.10	0.37	0.19	0.40	0.23	0.16
Kindschi.imp_dorsal_fin	0.53	-0.54	0.71	0.06	0.12	0.66	-0.06	0.46	1.00	0.69	0.61	0.60	-0.38	0.92	0.63	-0.14	-0.60	0.48	0.94	0.67	0.63	0.07
Area.imp_dorsal_fin	0.06	-0.18	0.40	0.06	-0.24	0.36	0.48	0.50	0.69	1.00	0.55	0.25	-0.05	0.60	0.74	0.05	-0.31	0.11	0.53	0.92	0.15	-0.38
Goods_dorsal_fin	0.27	-0.23	-0.03	-0.15	-0.08	0.02	0.26	0.86	0.61	0.55	1.00	0.61	-0.36	0.26	0.08	-0.48	-0.42	0.25	0.36	0.43	0.48	0.10
ToBasis_dorsal_fin	0.52	-0.48	0.04	0.09	0.62	0.05	0.05	0.67	0.60	0.25	0.61	1.00	-0.11	0.37	0.00	-0.27	-0.02	0.27	0.43	0.12	0.28	0.29
Kindschi_caudal_fin	-0.74	0.70	-0.33	0.65	0.26	-0.41	0.09	0.14	-0.38	-0.05	-0.36	-0.11	1.00	-0.26	0.07	0.03	0.65	0.13	-0.39	0.00	-0.59	-0.06
Kindschi.imp_caudal_fin	0.43	-0.46	0.90	0.19	0.12	0.80	-0.19	0.15	0.92	0.60	0.26	0.37	-0.26	1.00	0.77	0.05	-0.54	0.49	0.97	0.65	0.53	0.00
Area_imp_caudal_fin	0.12	-0.06	0.78	0.19	-0.31	0.77	-0.03	0.09	0.63	0.74	0.08	0.00	0.07	0.77	1.00	0.34	-0.36	0.38	0.69	0.89	0.27	-0.24
Goods_caudal_fin	0.10	0.09	0.32	0.16	-0.20	0.34	0.28	-0.47	-0.14	0.05	-0.48	-0.27	0.03	0.05	0.34	1.00	0.18	-0.50	-0.06	0.06	-0.39	-0.36
ToBasis_caudal_fin	-0.41	0.42	-0.59	0.35	0.37	-0.54	0.29	-0.10	-0.60	-0.31	-0.42	-0.02	0.65	-0.54	-0.36	0.18	1.00	-0.49	-0.66	-0.38	-0.86	-0.43
Kindschi_anal_fin	0.10	-0.03	0.38	0.11	0.06	0.37	-0.69	0.37	0.48	0.11	0.25	0.27	0.13	0.49	0.38	-0.50	-0.49	1.00	0.57	0.34	0.71	0.62
Kindschi.imp_anal_fin	0.56	-0.55	0.88	0.04	0.08	0.81	-0.30	0.19	0.94	0.53	0.36	0.43	-0.39	0.97	0.69	-0.06	-0.66	0.57	1.00	0.61	0.70	0.15
Area.imp_anal_fin	0.09	-0.08	0.54	0.01	-0.41	0.58	0.16	0.40	0.67	0.92	0.43	0.12	0.00	0.65	0.89	0.06	-0.38	0.34	0.61	1.00	0.32	-0.32
Goods_anal_fin	0.60	-0.49	0.50	-0.43	-0.21	0.57	-0.59	0.23	0.63	0.15	0.48	0.28	-0.59	0.53	0.27	-0.39	-0.86	0.71	0.70	0.32	1.00	0.56
ToBasis_anal_fin	0.21	-0.20	-0.01	-0.12	0.29	-0.08	-0.55	0.16	0.07	-0.38	0.10	0.29	-0.06	0.00	-0.24	-0.36	-0.43	0.62	0.15	-0.32	0.56	1.00

Correlation plot for a reduced number of salmon parameters in one of the pens including the fin indices based on the eye diameter of salmon, if necessary, negative correlations shown in beige and positive correlations shown in dark gray.

Figure XI reveals that the fin indices calculated for the salmon so far show a number of interesting correlations with other non-fin-based parameters obtained for the salmon farm. For example, the Kindschi index and the To-basis index for the caudal fin indicated a tendency for reduced values if the mortality is increasing.

These correlations should be further explored, since they may lead to the identification of valuable parameters for future fish welfare assessments. However, the full analysis of the data sets has not yet been accomplished. Hence it will be interesting to repeat and broaden these analyses once the fin indices for June to Dec 2023 for these fish have been added to the current data sets.

For further information, please contact Constanze Pietsch at **pietsch@profishcare.com**.

3.3

Effect of laser on fish

Stingray has consistently prioritized the protection of animals in its design, developments and operations. This applies to both the actual delousing procedure using laser but also the physical properties of the hardware itself. The Stingray laser node has been designed with rounded edges, smooth surfaces, and thick, rounded cables to minimize any potential risk. Over the years, numerous hardware and software improvements have been implemented, which are all aimed at creating the safest and most efficient delousing method possible.

Laser pulses

The Stingray laser operates at a wavelength in the green region of the electromagnetic spectrum and is classified as a Class 4 laser [81]. This classification, the highest risk category, is based on the potential to cause harm to human eyes and skin [82]. While this classification specifically applies to humans, it indicates that the laser could potentially pose risks to other species if not used correctly. However, the risk of laser damage from the Stingray system is minimized due to several key physical factors associated with its design and operation:

The laser rays converge at a short range, leading to a severe divergence at longer range.

Sea water is a strong and exponential attenuator to electromagnetic radiation, including used wavelengths.

Laser pulse length, and associated exposure time, has been chosen to cause maximum impact on sea lice specifically.

The laser pulse generates enough energy to denature sea lice proteins while having a minor impact on the fish. Stingray recognizes that eyes and skin are the two most frequently discussed structures with respect to unintended laser pulses effects. To ensure the safety of fish, the Stingray system incorporates multiple safeguards and built-in safety features.

Eye detector and exclusion zone

The potential effects of the laser vary depending on species specific structures of the eye. In teleost fish, a laser pulse with a wavelength similar to that of the Stingray laser does not harm the cornea or lens. However, under certain conditions, this wavelength could pose a risk of retinal damage [83]. The likelihood and extent of any retinal damage depend on factors such as the laser's exposure time and power. Research on humans and mammals indicates that an accidental laser pulse to the eye may go unnoticed or result in temporary effects such as laser dazzle, flash blindness, and after-images on the retina. Prolonged exposure to a direct, uninterrupted laser pulse can, however, lead to long-term effects, such as localized thermal damage to the retina [84, 85].

Stingray has implemented a range of checks to avoid this from occurring. The software that identifies, targets, and tracks sea lice is equipped with multiple safety measures. It is programmed to pulse only on lice while evading other structures on the fish. Specifically, the system is trained to continuously recognize and avoid the fish's eyes, ensuring they are never targeted.

As a fish swims past the laser node, the software detects and analyses its surface before determining whether to trigger the laser. In the system's hierarchy of rules, the exclusion of eyes always takes precedence over pulsing on lice.

If an eye is detected near the laser pulse during an active laser pulse, the laser will immediately interrupt the ongoing pulse. The system continuously predicts the swimming path of the fish, but sudden swimming behavior changes may require a pulse termination.

Detections are performed continuously (every 20 ms), and eyes are tracked in the same way as lice. The system is therefore designed to interrupt a pulse before any potential contact occurs.

Eye diseases occasionally occur in farmed salmon and trout [86]. The Stingray laser does not have the technical properties to cause injuries such as gas bubbles, blindness, eye punctures, or the induction of disease.

The specifications and features of the Stingray system make eye injuries highly unlikely, considering both the limited exposure time and the system's programming. No link has ever been found between eye injuries in farmed salmon and trout, and the use of laser nodes in fish pens.

Skin

While the likelihood is low, a laser pulse might occasionally miss its target and pulse on the fish's skin. This section explores these rare instances to explain how the highest standards of safety and animal welfare are maintained.

Salmonid skin differs significantly from human skin, with one key difference being the presence of iridophores [87, 88]. Iridophores are specialized cells containing reflective guanine crystals, which can reflect both light and thermal energy [89]. These biogenic crystals are irregularly distributed throughout the salmon's skin and scales, with a higher density on the lighter belly compared to the darker back [90]. This reflective ability, sometimes referred to as the "disco ball effect," might sound whimsical but aptly describes a complex biological system. These crystals are known to provide protective benefits for the underlying skin structures [87, 88].

Another significant difference between mammalian and fish skin lies in its composition. Unlike mammals, fish skin does not have a surface layer of dead cells. Instead, it consists of living tissue covered by a protective mucus layer [91, 92]. The living epithelial cells, known as keratocytes, play a vital role in protecting against small-scale impacts, such as unintended laser pulses. Together with the mucus, they form part of the fish's innate immune system, serving as the first line of defense against microbes and other waterborne pathogens [93].

When a laser pulse impacts the mucus layer and subsequently the outermost skin layer, it likely causes a slight disruption in the skin. However, the mobility of keratocytes enables rapid cell migration, which helps to cover, seal, and heal the affected area [94]. This process significantly reduces the likelihood of microbes in the surrounding water penetrating the fish's skin.

Stingray is confident that an incidental laser pulse on a fish's skin does not cause wounds or significant damage. There is little doubt that a fish can sense a laser pulse.

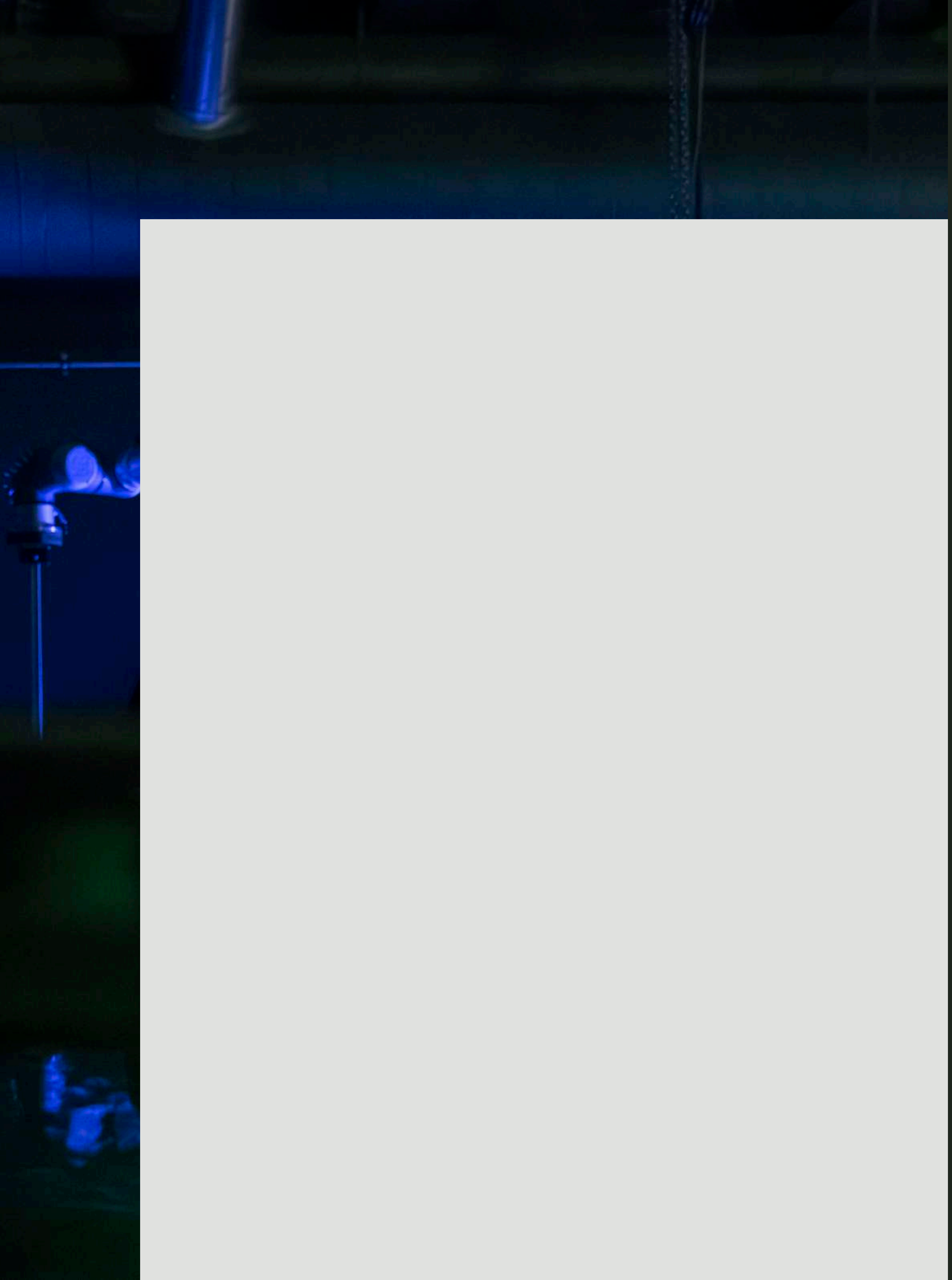
Fish possess a highly developed sensory system and rely on their skin to perceive their environment [95]. However, after more than a decade of operating in pens and studying fish-laser node interactions, Stingray has never observed panic reactions caused by the laser node's presence or its pulses. Similarly, no reports from the field have indicated that a laser pulse triggers such behavior.

There is a broad consensus on fish's ability to learn and retain memories. The capacity to detect, interpret, and respond to potential dangers is essential for the survival and welfare of any species [96]. Stingray relies on this understanding when evaluating the system's impact on fish in pens. It can thus be assumed that salmonids will display aversive behavior towards the Stingray system upon repeated pain perception. Fish typically pass the system multiple times per day. Since no such aversive behavior is observed, Stingray is confident that the fish do not associate the system with pain perception.

Stingray and its users believe that an unintentional laser pulse is a minor event compared to other aquaculture operations. According to the 2023 Fish Health Report by the Norwegian Veterinary Institute, mechanical injuries resulting from delousing treatments are the leading cause of mortality and reduced welfare in Norwegian salmon farms [6]. The Stingray system reduces reliance on these treatments, which involve crowding, pumping, and rough handling. By minimizing the need for such invasive methods, the system supports better fish welfare and health outcomes.

4.0

Precision Aquaculture



The achievements of 2024 reflect Stingray's guiding principle for the year: *Control*. Key efforts included advancing detector technology, improving analytical processes, and enhancing image quality to achieve greater accuracy and precision. Daily reporting evolved into a platform for innovation, supporting precision aquaculture with an expanding range of applications. By integrating AI-driven quantitative data with expert qualitative insights, Stingray successfully addressed the complex challenges of large-scale fish farming, driving the development of advanced technological solutions in this fast-evolving industry.

4.1

Precision in detector development

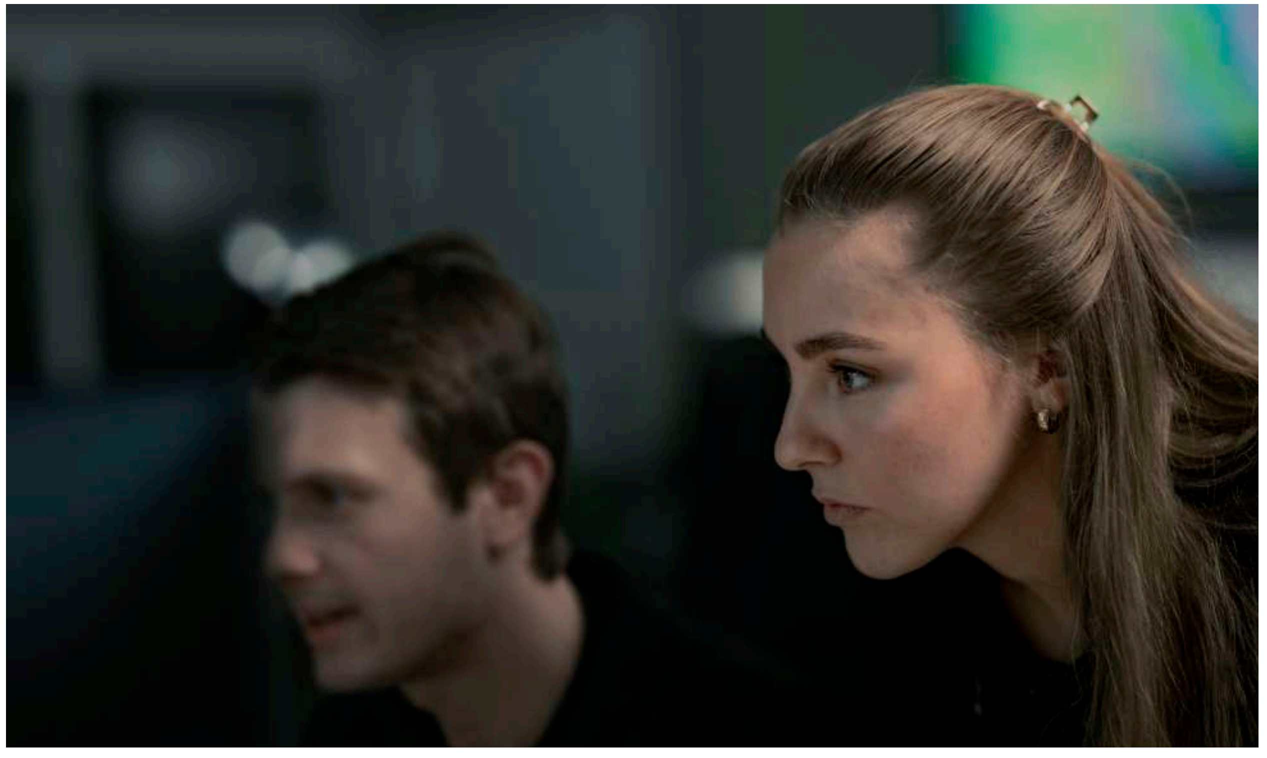
350

active laser nodes, installed across customers' fish farms in 2021

1,500

active laser nodes, installed across customers' fish farms in 2024

In 2021, Stingray employed 350 active laser nodes, installed across customers' fish farms. These laser nodes generated a steady stream of weekly data - 35,000 laser pulse videos and 35,000 sequences collected daily across approximately 150 salmonid pens. In 2024, Stingray expanded to 1,500 laser nodes, greatly increasing the volume of data and insights available for monitoring fish health. However, this growth has made the 2021 analysis methods impractical, requiring the development of new tools and approaches to efficiently manage the larger data flow.



Sequence quality

High-quality images are essential for accurately counting lice, assessing wounds and maturation, and evaluating other welfare indicators. Clear images enable precise visual assessments and improve the effectiveness of training new detection algorithms, as high quality input data makes it easier for algorithms to identify and learn the relevant structures [97]. Good image quality is also crucial for existing detectors, as it increases the likelihood of more true positive detections and fewer false positives, improving detector precision and accuracy (Table 4).

TABLE 4.
Detection result categories

TERM	ABBREVIATION	GENERAL DEFINITION	LICE DETECTION EXAMPLE
True Positive	TP	A system correctly identifies something that is there	Correctly identifies a louse on a fish when a louse is present
False Positive	FP	A system incorrectly identifies something that isn't there	Incorrectly identifies a louse on a fish when there are no lice present
True Negative	TN	A system correctly identifies that nothing is there	Correctly identifies that there are no lice on a fish when the fish is clean
False Negative	FN	The system fails to identify something that is there	Fails to detect a louse on a fish when lice are present

A random selection of fish sequences will invariably deliver images of varying quality, potentially impacting detector performance. Examples can include overexposure, underexposure, motion blur, and poor segmentation (Figure 20).

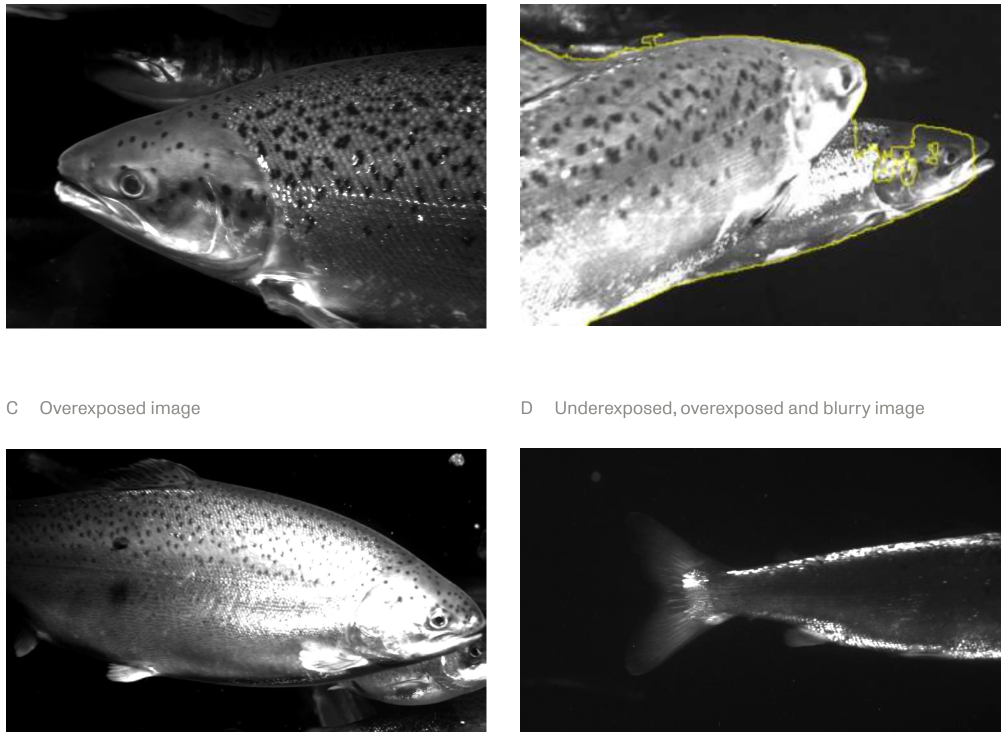
FIGURE 20.
Examples of varying image quality.

A High-quality image

B Image with poor segmentation

C Overexposed image

D Underexposed, overexposed and blurry image



High quality images have been quintessential for Stingray's success from the very beginning, and improvements have been implemented continuously over the last 10 years. Stingray's approach to better image quality through iterative improvements has led to substantial results, providing a solid foundation for further development of the sequence trigger on the laser node and improving the accuracy of all our detectors.

Measuring laser efficacy

Historically, Aqua's Analytics team has ensured laser node effectiveness by calculating a "hit rate", manually reviewing 100 random louse packages per laser node. As Stingray expanded its market share, growing data volumes necessitated reduced sample sizes and analysis frequency, emphasizing the need for a scalable approach.

To address these challenges, Stingray relies on in-house developed, bespoke software customized to evaluate the performance of laser outputs. The software ensures that detected targets are accurately hit and flags laser nodes with potential issues for maintenance. This refined approach maintains operational efficiency while monitoring performance across a growing number of laser nodes.

The demand for a precise kill rate or hit rate has been replaced by AI-powered result generation, operational control and a generally better understanding of the system and its capabilities. While periodically requested, the need for a modelled laser efficiency result based on a minimal sample size is less of a focus for Stingray and its customers in 2024 and has thus been fully replaced by result driven communication.

The "LiceKill" detector

27%

increase in true positive detection

50%

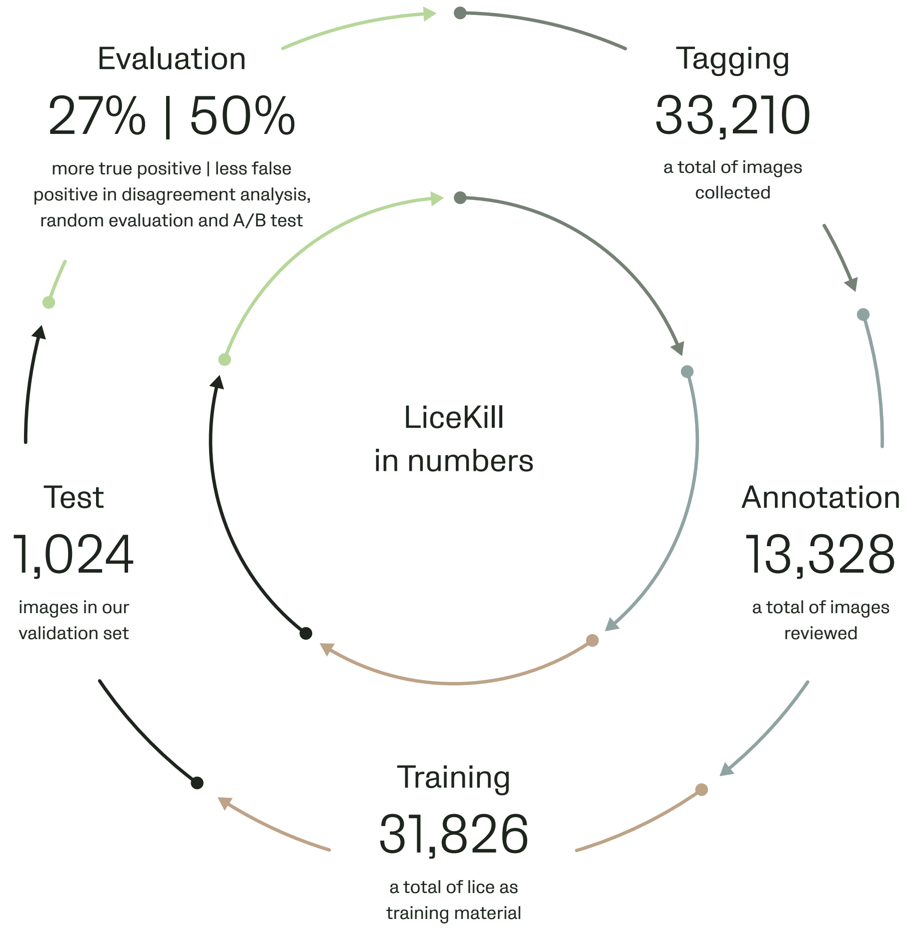
reduction in false positives

In 2024, the Analytics team, in collaboration with Software's Machine Learning and Node teams, focused on the laser detector, referred to as the "LiceKill" detector. The main goal was to increase the rate at which lice are detected, and to reduce the number of false positive lice detections (Table 4), ultimately resulting in better sea louse control.

Extensive data collection across all customers provided a wide range of sample images, including different fish size classes, environmental conditions, and varying lice abundance levels. Images of both salmon and trout were included in the data collection and analysis process. New data was collected and added to the existing detector data set, according to standardized methods to ensure consistency and quality.

Identified areas for improvement and detector refinement include analyzing randomly selected detections from each detector version and cases of disagreement. Additionally, real-world testing was conducted through a performance A/B test [98]. In this evaluation, the performance of both versions was compared over a four-day period, under commercial conditions. Consistent results across evaluations demonstrated a significant improvement in detection performance, with a 27% increase in true positive detections and a 50% reduction in false positives (Figure 21).

FIGURE 21.
Schematic illustration of the LiceKill detector development process.



Wound detection

Wounds are a major animal welfare concern and lead to significant economic losses due to mortalities and the downgrading of affected fish at harvest. Therefore, having an overview of the health state of the fish is crucial for the prevention and treatment of wounds, as it allows for proactive decision-making to either intervene or consider timely harvests.

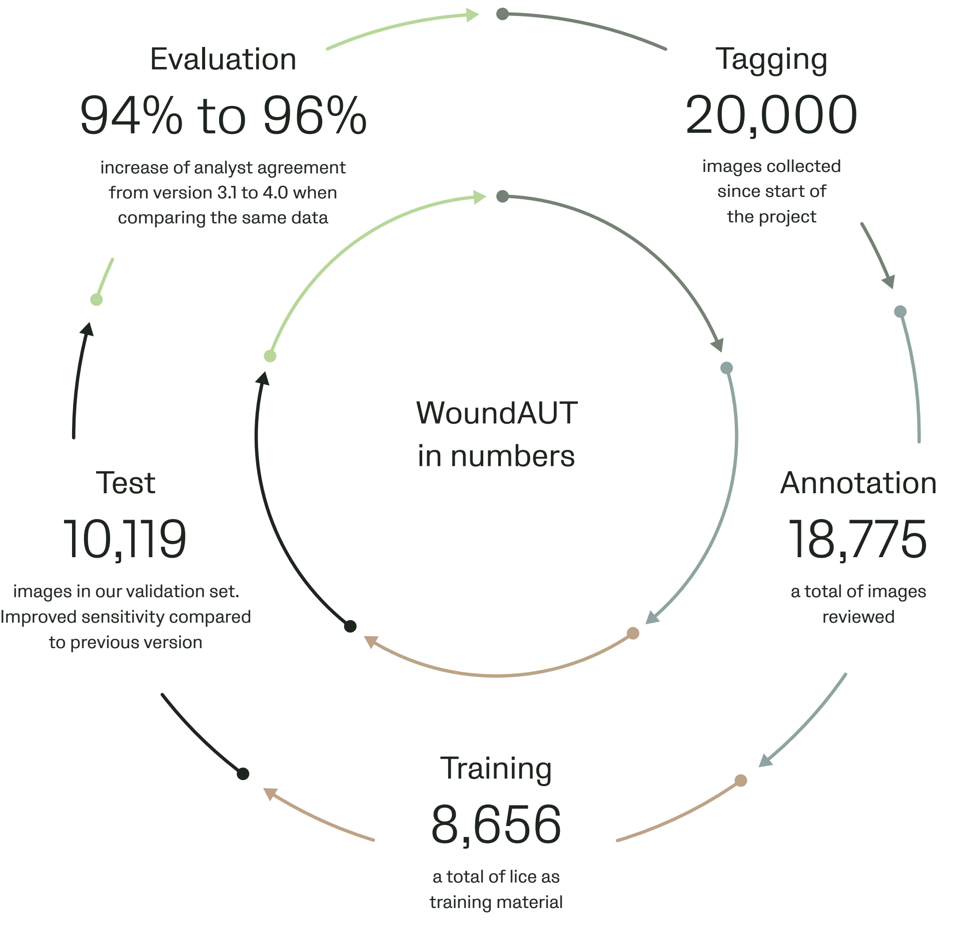
Winter ulcers, caused by the bacterium *M. viscosa* are considered one of the main welfare issues among Stingray customers. These wounds are especially common when water temperatures are low, which also causes the fish's healing process to slow down significantly. Other types of wounds can be caused by *Tenacibaculum* spp. Suzuki et al., 2001 or *Pasteurella* Trevisan, 1887. Secondary ulcerations can result from mechanical damage caused by handling procedures, delousing treatments, jellyfish blooms, net abrasions, predator attacks, etc. [6].

Traditional manual inspections for wounds are labor-intensive, impractical and inefficient for large-scale operations due to the sheer volume of fish, the challenges posed by the marine environment, as well as the welfare implications of handling the fish which can cause unnecessary stress and potential harm. Stingray's automated wound detection system offers a more efficient solution. The system provides valuable insights, both enhancing fish welfare and production efficiency.

The machine vision system for wounds has been developed using deep learning and convolutional neural networks. Images of wounds on salmon and trout with representative images with different sizes, shape and wound severity were utilized to train Stingray's wound detector, also referred to as "WoundAUT" (Figure 22 and Figure 23).

FIGURE 22.
Images of fish with wounds of varying severity. Images such as these are used for detector training and evaluation.

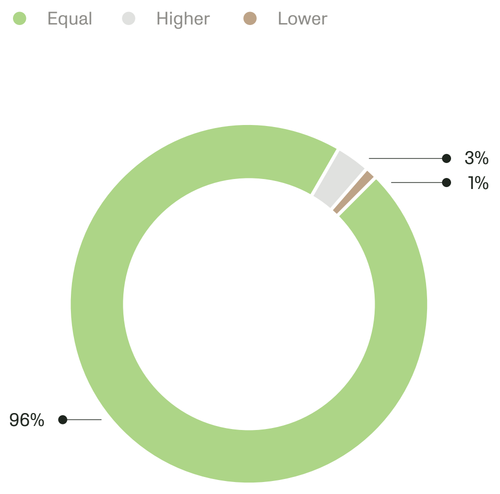
FIGURE 23.
Schematic illustration of the WoundAUT detector development process.



The detector provides an accurate overview of the health status and the severity of observed wounds on the body of the salmonids, excluding the head and fins. The severity of the wounds is estimated by comparing the size of the wounds to other body size-dependent features of the fish combined with the overall abundance of wounds per fish.

Stingray's wound detection system has a 96% agreement rate when compared with a trained human analyst, which effectively makes manual wound analysis redundant (Figure 24). The main advantage of the automated detection system is the considerable number of images the system can continuously analyze in comparison with the human analysts, thus giving more accurate results that reflect the wound situation in the whole pen.

FIGURE 24. Wound detector agreement rates between AI and human analysts.



Biometry

Biometry, from Stingray's perspective, involves gathering biological data from salmon and trout to provide customers with valuable insights into fish weight, biomass and growth estimates. In 2024, Stingray implemented significant improvements to its biometry capabilities, strengthening its role in delivering accurate and actionable data for salmon aquaculture.

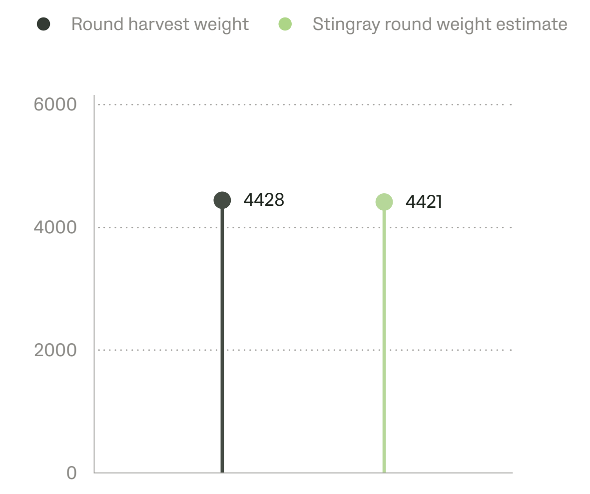
Stingray's biometric detector relies on stereo vision-based estimates of individual fish. By monitoring 80 million fish daily, the system provides weight, and biomass estimates for 100 fish per laser node per day. These insights can be analyzed at pen or fish cohort levels, offering customers flexibility in managing their operations. The detector leverages machine learning, continuously improving its accuracy by processing vast amounts of sample data. On average, Stingray's weight estimates deviate less than ±5% from manual customer estimates and feeding table estimates across all weight classes.

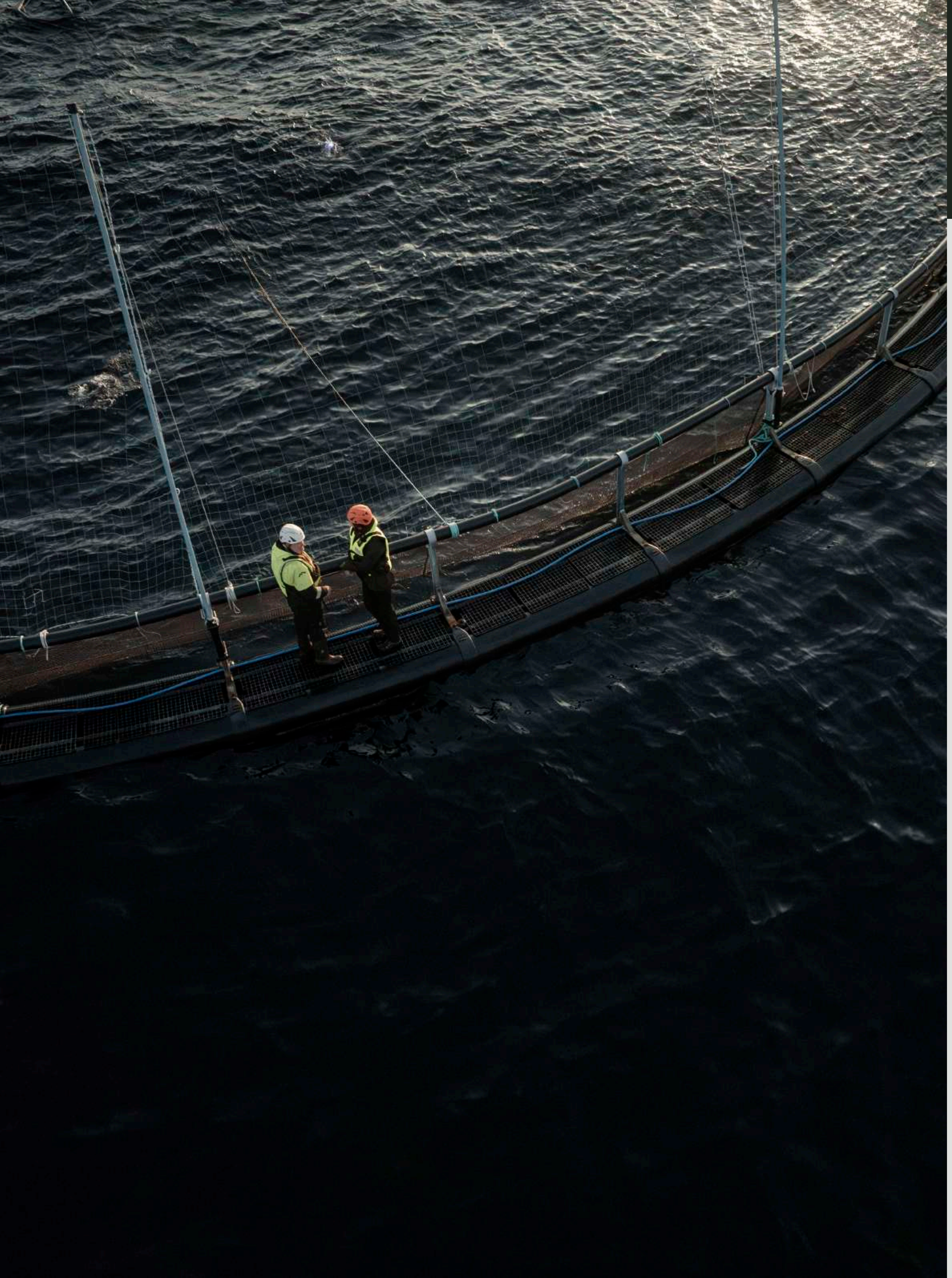
In 2024, Stingray launched integration capabilities with customers' production management systems. In Norway, this includes systems like FishTalk (Akva) and Mercatus Farmer (ScaleAQ). From 2025, customers can import data into Stingray Online through APIs provided by these production systems. This integration enables automated access to average weight values from the production systems. Stingray laser nodes estimate daily average fish weight, which can now be directly compared with production system calculations. This allows customers to validate estimates from stocking to harvest. The integration also facilitates daily updates on fish counts per pen, enhancing analyses such as the impact of biomass and density on laser node efficiency and the proportion of fish population passing laser nodes daily. Sudden deviations between customer and Stingray estimates may signal potential issues, such as inefficient feed conversion due to, for example, low oxygen levels or disease.

Analyzing deviations between Stingray's weight estimates and customer-calculated weights can reveal inaccuracies in feed conversion rate (FCR) models used for growth predictions. Collaboration on these models improves maximum allowable biomass (MAB) utilization and biomass reporting.

Stingray's harvest loss estimate, introduced in 2024, calculates harvest weight and weight class distributions based on live weight measurements. Customers can now utilize harvest results via Stingray Online, enhancing the system's ability to refine algorithms for average weight prediction. Shared harvest data results in more precise actual harvest results, giving customers a clearer picture of production outcomes. Harvest weight is likely the only metric that is known with complete accuracy. By sharing the average harvested weight, a comparison can be made between the estimates from the customer's system and the Stingray laser nodes (Figure 25).

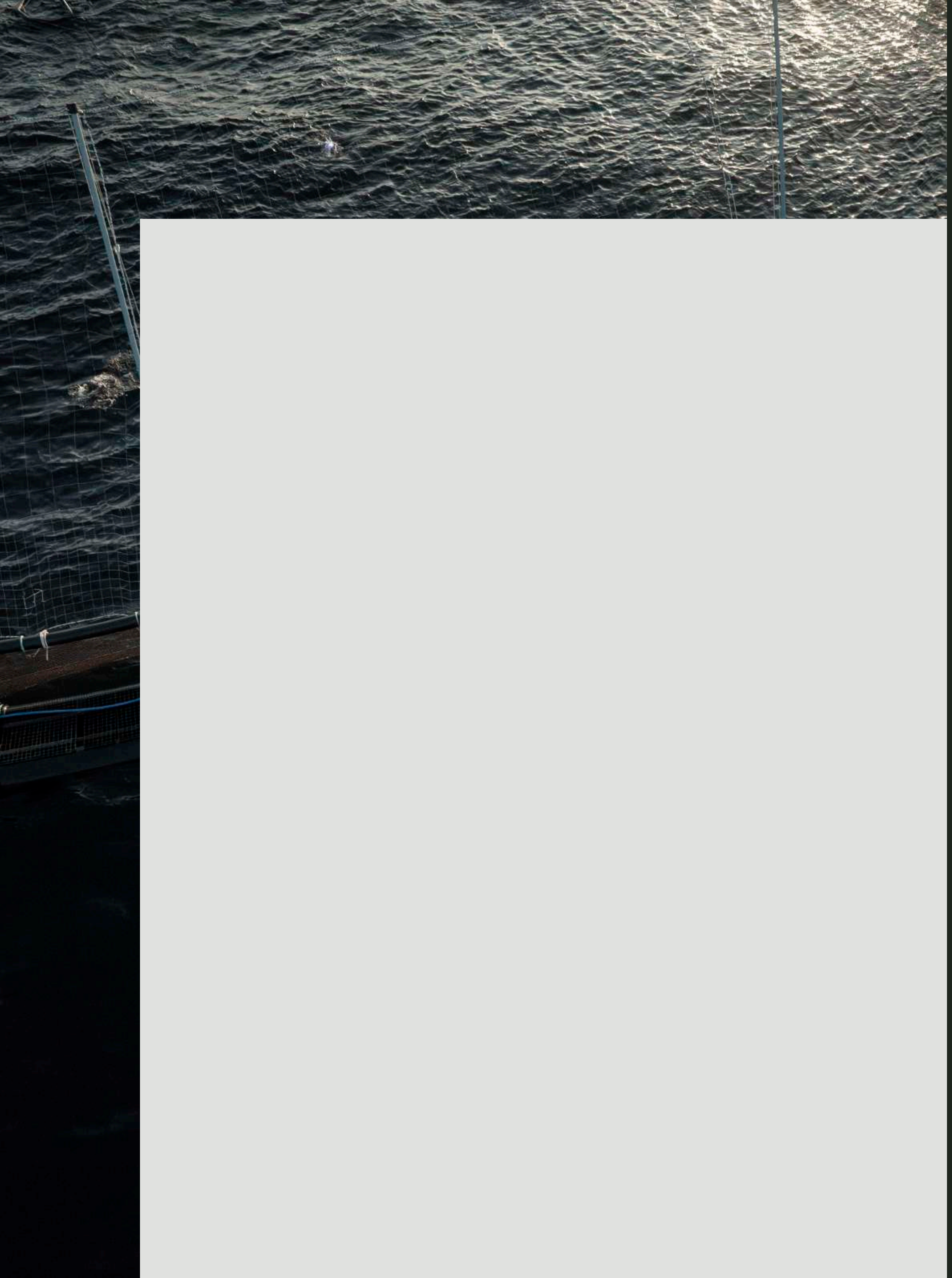
FIGURE 25. Comparison of 220 individual harvest report weights vs. correlating Stingray weight estimates (gram).





5.0

The Future of Lice Counting



Stingray's leadership in promoting non-invasive sea louse counting reflects the company's commitment to advancing fish health monitoring through innovative solutions, such as automated and image based sea louse counting. By contributing to the development of national standards and supporting the industry's adoption of cutting-edge technology, Stingray continues to pave the way for a more sustainable and effective approach to managing fish welfare in aquaculture.

5.1

Manual sea louse counting

Under Norwegian regulations, fish farmers must perform weekly manual lice counts and report the results to the authorities. This process involves sampling a fixed number of 20 fish per pen, which can limit statistical representativeness and reduce the reliability of lice prevalence estimates. The welfare implications of manual lice counting are significant. Stress from handling and netting can lead to physiological disruptions, such as increased cortisol levels and compromised immune function. Physical injuries, including scale loss and abrasions, are also common during netting and transfer. These effects can exacerbate existing health issues, particularly for fish that are already weakened or carrying a high lice burden [99, 100].

Standard sampling procedure for manual sea louse counting.

01

Sampling for manual counts typically starts by hand feeding in the pen to attract fish closer to the surface.

02

Once a group of fish is within reach, a sweep net or individual netting is used to catch fish for sampling. Fish are inherently stressed when caught in a net, as this disrupts their natural behavior and exposes them to potential injury.

03

After netting, the fish are sedated to enable handling and inspection. This step, while necessary for safety and precision during counting, adds stress to an already disruptive process.

04

Once sedated, lice on the fish are counted, either by lifting one fish at a time by hand or by using a nearby counting table.

05

A tank with fresh seawater is used after counting for sedation recovery, before returning the fish to the pen. However, recovery outcomes can vary depending on the fish's initial condition and the efficiency of the process.

06

If the number of adult female lice exceeds the regulatory threshold, delousing becomes mandatory to protect both wild and farmed salmon populations from further infestations.

The potential for sampling bias presents challenges for effective lice management. If the sampled fish are not representative of the broader population, treatment decisions may be based on skewed data, leading to either over- or under-treatment. Over-treatment can result in unnecessary stress for the fish and higher operational costs, while under-treatment may allow infestations to persist, compromising fish health and welfare over time.

Issues with representativeness and biases inherent to the current practice of manual counting have been highlighted by Thorvaldsen, Frank [101]. These include variations in the choice of equipment, different weather and lighting conditions, and differences in time allocation, experience, and competence of farm staff. Error rates during manual counts may increase with increasing lice abundance, and between-observer reliability is acknowledged to be imperfect. Stronger and healthier fish with fewer lice are casually attracted to food for sampling, while small fish with poor health are often excluded from counting. The counting of lice that have fallen off their host inside the sedation tanks is also considered to be unreliable. Furthermore, manual counting procedures cannot account for lice that detach from their host during crowding or netting and therefore do not end up in the sedation tank in the first place. Ten to 38% of mobile lice stages detach and are lost depending on crowding time [102, 103], highlighted at the 2024 FHF Lice Conference.

Manual louse counting needs to be performed weekly. The process is labor intensive and physically demanding, requiring skilled personnel to operate the crane, handle the fish, and finally, count the number of lice and categorize them into correct categories [104]. Adverse weather conditions, the nature of working on or from boats, and the associated safety considerations, further complicate routine manual louse counting procedures.

While manual sea lice counting remains a critical tool for monitoring and regulatory compliance, it is essential to recognize its impact and consider novel solutions. Continuous improvement in sampling techniques, handling protocols, and the adoption of alternative monitoring methods, such as non-invasive image-based technologies, play a vital role in reducing stress and improving accuracy in aquaculture operations. By addressing these challenges, the industry can better balance effective lice management with the health and welfare of farmed fish. Since 2021, Norwegian authorities have allowed exemptions from manual counting, permitting the use of image-based methods for lice monitoring. These regulatory allowances have paved the way for innovative technologies that enhance efficiency and accuracy in lice management (Table 5).

TABLE 5. Comparison statistics of manual vs. non-invasive counting (2024).

METRIC	DETAILS
Sea louse count	135,600 individual fish counted daily by Stingray laser nodes
Fish Welfare	300,000 fish saved from sedation, handling, and stress
Time Saved	7,631 hours per person saved (assuming 20 minutes per pen)
Statistics - manual count	Nationwide counting ~ 2.1 million fish per year
Statistics - Stingray automatic count	34,098,146 fish automatically counted

5.2

Automatic sea louse counting

Norwegian regulatory agencies have recognized the potential of automated solutions to overcome the limitations of manual lice counting and have encouraged their use across the aquaculture industry [105]. In response, fish farmers are increasingly exploring these innovations, due to greater accuracy, efficiency, and welfare-friendly monitoring. Automated lice counting not only helps meet regulatory requirements but also enhances fish welfare, operational efficiency and safety, representing a significant step forward for the industry [106].

Stingray has developed an automated machine vision system, referred to as "LiceAut", designed to simplify and improve lice monitoring in aquaculture. The detector is leveraging advancements in image-based analysis and AI, such as supervised learning and convolutional neural networks. It analyses image sequences of fish, providing detailed, head-to-tail analyses of each fish without human intervention and provides an automated sea louse count per individual.

Detector development is a continuous process, starting with its initial release in 2018, which was focused on detecting and counting adult female lice. Over successive iterations, the system has been refined through rigorous cycles of image collection, annotation, training, testing, and evaluation (Figure 26). At Stingray, new versions are released only after documenting measurable improvements over previous iterations, ensuring the system consistently delivers reliable results.

Building on this foundation for adult female salmon lice, recent efforts have focused on detecting adult female Caligus and mobile salmon lice stages. These advancements reflect steady progress in extending the system's capabilities to address a broader range of monitoring needs. Our commitment to ongoing refinement and robust evaluation underpins LiceAut's role as a versatile, welfare-friendly, and efficient solution for aquaculture.

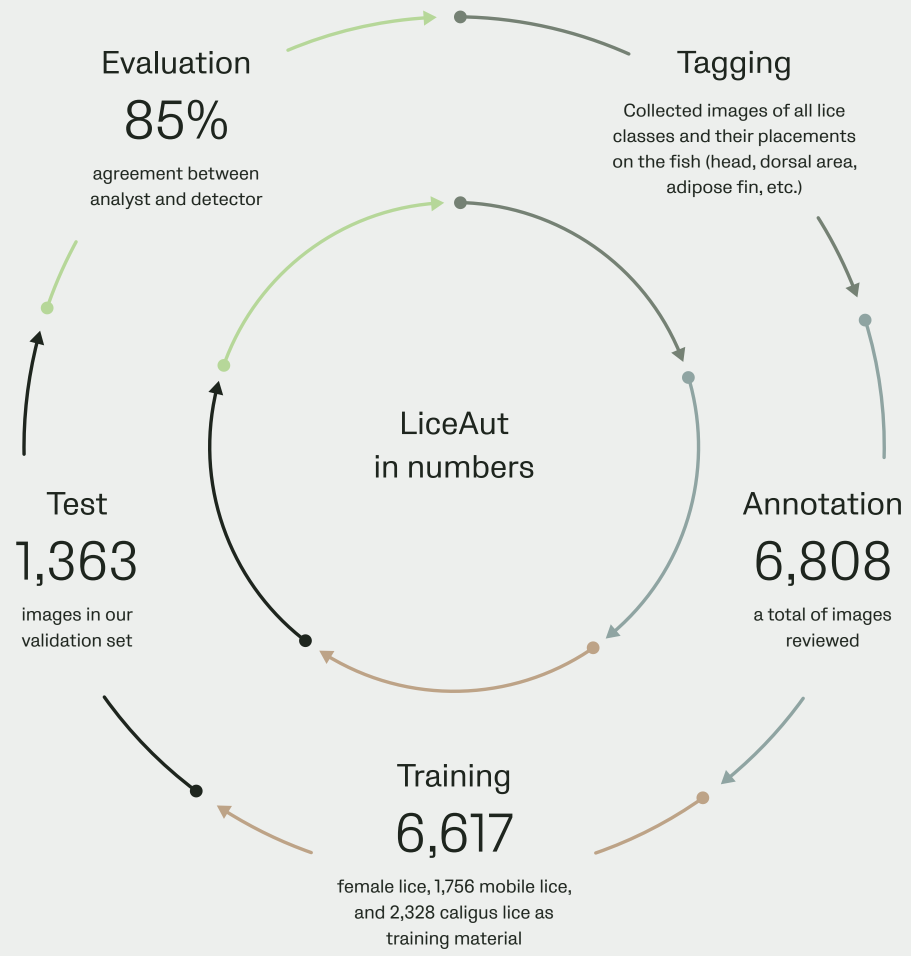


FIGURE 26.
Schematic illustration of the LiceAut detector development process.

5.3

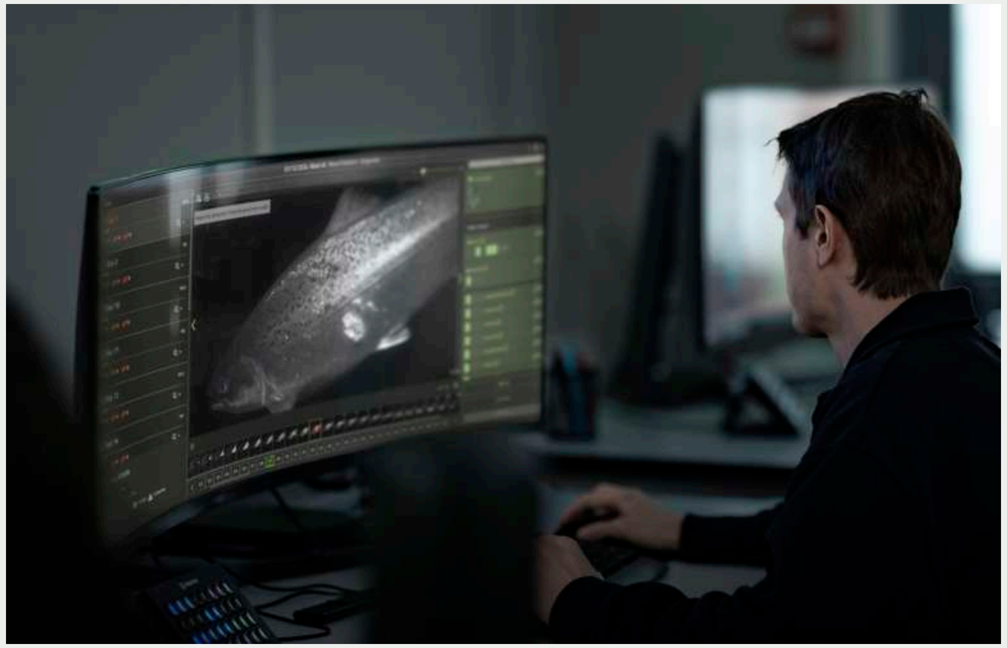
Verification of automated lice counting

While automated systems like LiceAut represent significant advancements in lice monitoring, any machine vision technology faces challenges when applied to underwater imaging of small structures like lice. Detecting and classifying lice in complex aquatic environments is inherently difficult due to variability in image quality, lighting, and background noise [107]. Factors such as particles in the water or wild fish in the pen can potentially contribute to false positives, making it challenging to ensure flawless detection under all conditions.

Additionally, systems that calculate lice levels directly from images without allowing users to review the data, risk being perceived as "black boxes", i.e. providing results that cannot be verified. This lack of transparency can undermine confidence in results, particularly when the evaluation images deviate from other counting methods. Transparency and traceability are essential to build trust, enabling users to validate results and address potential discrepancies.

To address these challenges, Stingray provides a system that combines automated detection with the ability for users to verify results through visual inspection. Using the Sequence Analyzer application in Stingray Online, users can review sequences of images capturing entire fish, from head to tail (Figure 27). This allows analysts to validate automated results, ensuring lice counts, as well as wound and maturation counts, are accurate, traceable, and aligned with regulatory standards.

FIGURE 27.
Image from Sequence Analyser to verify detector results.



The Stingray Online Sequence Analyzer is designed to support robust verification and presenting results in a clear and actionable format. Counts are categorized (e.g., adult females, mobile lice) to allow for a detailed review, while finalized results are locked to maintain data integrity and regulatory compliance. This ensures that the system is not only fish welfare-friendly and efficient but also supports operational excellence and regulatory adherence.

5.4

Stingray's search for the «real louse number»

The transition to new image-based lice-counting methods will benefit the welfare of fish, avoiding stressful handling, as well as facilitate farm-work routines, and improve the statistical basis for management and regulation of the lice situation in Norway. Naturally, the counts obtained by new methods must reflect the true lice situation in a production unit [108]. However, the currently mandated way of counting lice manually

represents a compromise between practical feasibility and regulatory requirements that does not take the underlying statistical complexities sufficiently into account.

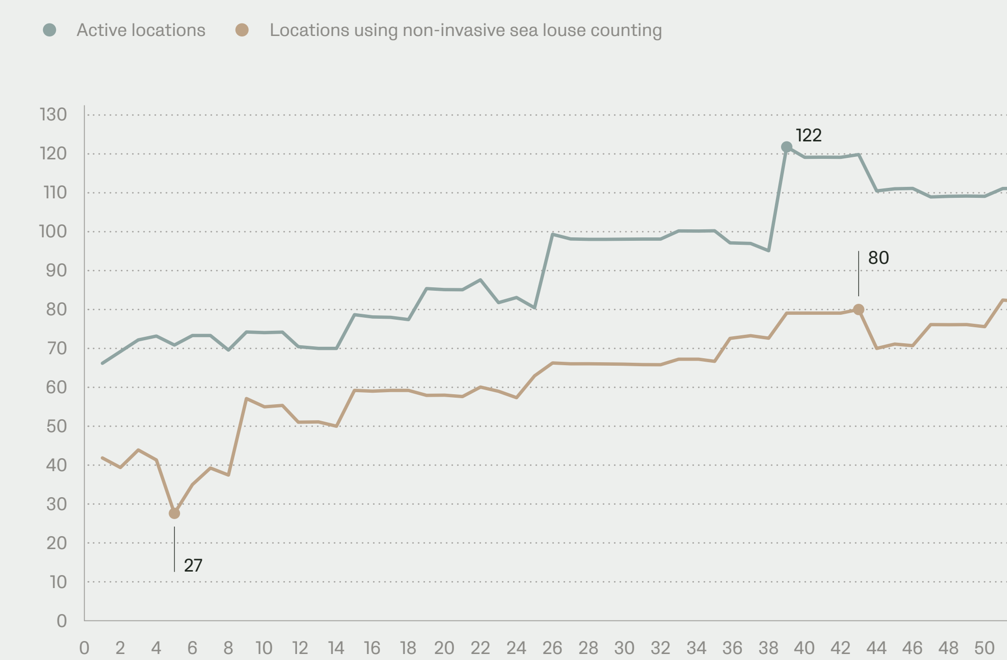
The true lice situation in any given production unit therefore remains unknown.

The Norwegian authorities implicitly acknowledge this by stating that new lice-counting methods may even provide a more correct picture of the real lice situation [108].

In 2022, a committee led by Standard Norge, in collaboration with the Norwegian Food Safety Authority, was established to create a national standard for non-invasive lice counting. This standardization initiative aims to eliminate the need for legislative "dispensations from manual louse counting" by introducing a unified framework for all non-invasive lice counting systems. Stingray has played a pivotal role in this process, acting as the committee lead and contributing to key discussions by addressing critical parameters such as sample size, representative sampling, equipment mobility, and acceptable error margins.

Between 2021 and 2023, the adoption of non-invasive lice counting technology and the issuance of dispensations has grown significantly among Stingray customers. This trend demonstrates increased acceptance of Stingray's technology within the aquaculture industry. In 2024, Norsk Regnesentral (NR) estimated that approximately 180 active aquaculture locations in Norway had received dispensations from the Norwegian Food Safety Authority [109]. Stingray alone had registered 639 locations with the right to dispensation, of which 94 were active, showing the significant market share of Stingray (Figure 28).

FIGURE 28.
Stingray customer adoption level of non-invasive lice counting methods per week in 2024.



For practical purposes, the legislative wish for alternative counting methods and the practical shortcomings of traditional counting complicate validating new counting methods. Since statistical inadequacies and biases are associated with all available counting methods today, no objective gold standard, generally referred to as the “ground truth”, exists for quantifying the true lice situation. For providers of image-based and non-invasive counting methods like Stingray, this is both a challenge and an opportunity for setting new standards and improving control over the lice situation along the Norwegian Coast.

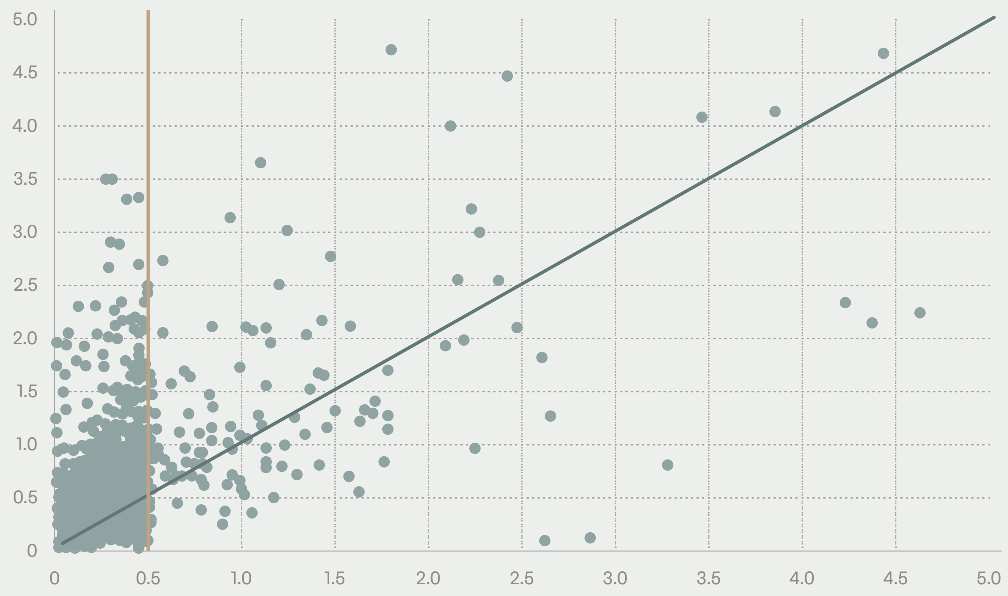
The most obvious challenge for camera-based solutions is that they do not observe the entire fish and can therefore miss sea lice located on the camera-opposed side of the fish. Currently, a static correction factor is employed to adjust the estimated number of lice to account for those that cannot be observed by the camera system. Any such correction factor is a single coefficient applied to the final count. It is derived from an understanding of lice distribution on fish and the anatomical regions that require compensation. However, sea lice abundance and distribution on host fish varies depending on factors such as rearing conditions and fish size [110]. An adequate correction factor should therefore be dynamic and include added predictor variables such as overall lice abundance, delousing effects, fish species, health status, and fish size.

However, while some proportion of lice will not be accessible by stereo cameras, it appears that image-based lice counts frequently arrive at higher estimates than manual counts [111, 112] (Figure 29).

BarentsWatch

The BarentsWatch [113] website displays all official sea louse data for Norway and provides a nationwide basis for sea louse analysis in Norway.

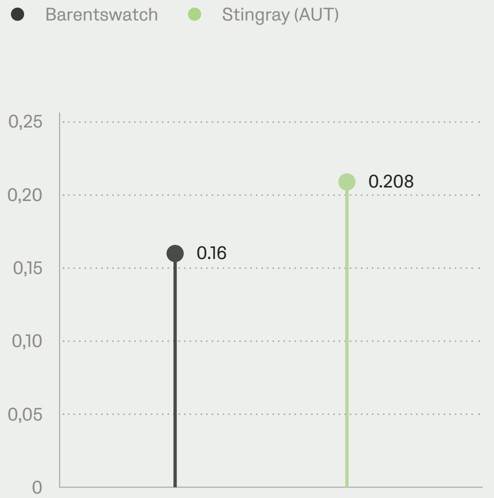
FIGURE 29. BarentsWatch vs. Stingray lice counts (adult female lice 2024).



Location-level comparison between BarentsWatch-reported manual counts (x-axis) and Stingray automated counts (y-axis) of adult female lice per fish. The vertical line represents the angle bisector on which all data points were found if both measurements always came to the same conclusion. The vertical beige line represents the legal lice threshold. Observation period: 01.01.2024 - 30.12.2024. Axis truncated at 5 adult females per fish.

To conform to the results from manual counting, a correction factor of 0.77 would currently have to be applied to retrofit automated sea louse counts by Stingray. This number is the average difference between automated and manual counts from January 2021 until December 2024 and is derived from a total of 10,270 manual counts from BarentsWatch and the corresponding 88,717,436 automated sea louse counts by Stingray (Figure 30).

FIGURE 30. Difference in reported adult female lice per fish between Barentswatch and Stingray.



Although this is an oversimplification of the underlying statistical complexities, it suggests that the occlusion bias, for which a correction factor should apply, appears to be negligible compared with the effects of physical restraints, statistical inadequacies, inaccuracies, and biases that occur during manual counting and reporting.

Manual lice counts are therefore ill-suited to confirm that image-based methods faithfully represent the true lice situation in a production unit.

Statistical issues

Today, lice counts are reported to the Norwegian government as weekly location-level averages. However, the statistically meaningful level of analysis is at pen level, because the differences in lice abundance between pens can be significant [114-116]. Like other parasites, sea lice disproportion-ately infest a small subset of the population, resulting in a skewed distribution of lice on fish [114, 117, 118]. Since the sample sizes that are legally required for manual lice counts are very small compared with the number of fish in a pen, the uncertainty that is attached to the resulting estimates is significant and results must be interpreted with appropriate caution [119]. The combined effects of low sample sizes and a skewed distribution of lice on fish have implications for the interpretation of lice-counting results and the comparison of different lice-counting methods. The lower the true lice numbers in a pen or location, the larger the relative deviation one must expect in the resulting estimate [120]. For rigorous assessment of the lice situation, it is therefore recommended to include additional measures like prevalence or intensity of infestation when lice abundance is low [121].

Several types of bias

Although Norwegian law requires a representative sample of fish to perform mandatory counting on [15], representativeness is not adequately defined. Simply increasing the sample sizes obtained with a particular method does not prevent biases that may be inherent to that method. Such biases can be introduced consciously or unconsciously, due to human- or animal behavior, counting- or handling procedures, or technical limitations of a particular method. The swimming behavior and vertical distribution of fish in sea cages is not random, and neither is the propensity of individual fish to become infested with sea lice. Among the self-sorting mechanisms that have been described in many species of fish, both fish size and parasite-infestation load contribute to the organization of a fish shoal [122]. As infective copepodites of the salmon louse mostly reside within the upper few meters of the water column, infection pressure for fish near the surface is significantly increased [123]. Atlantic salmon in sea cages exhibit vertical self-sorting behavior, with larger individuals occupying deeper water layers [124-126]. This makes larger individuals less prone to infestation with salmon lice, and heavily infested fish may even seek to occupy deeper layers to avoid further parasite burden [127]. Consequently, it is a well-established notion that fish that are sampled from deeper water layers have fewer lice [101]. This means that estimates of lice abundance in a pen, independently of whether lice are counted image-based or manually, are prone to biases, unless self-sorting mechanisms among fish are carefully considered during sampling.

In addition, biases towards lower lice abundances in un-audited self-reported manual counts have been identified in British Columbia, Canada [128]. More recently, Jeong, Arriagada [129] demonstrated the presence of a "cliff effect" that occurred at the respective thresholds of 0.2 and 0.5 adult female lice per fish in Norway (Figure 31 and 32). This "cliff effect" was suggested to result from sea-lice population dynamics under strictly mandated regimes of frequent delousing [130]. However, a comparison with Stingray's automated counts shows a pronounced "cliff effect" only for manual counts (Figure 31 and 32). Given that above-threshold lice counts are directly associated with costly delousing operations, and, more indirectly, a reduction in production capacity enforced via the "traffic light system", this suggests that the results from manual counts may not be suitable for the validation of new counting methods. Although physically inspecting fish for lice appears in theory to be the most rigorous and therefore most reliable process for quantifying lice in a production unit, the legally required sampling procedures in practice do not guarantee a statistically solid estimate, and several biases of manual counts point towards underestimating the actual number of lice.

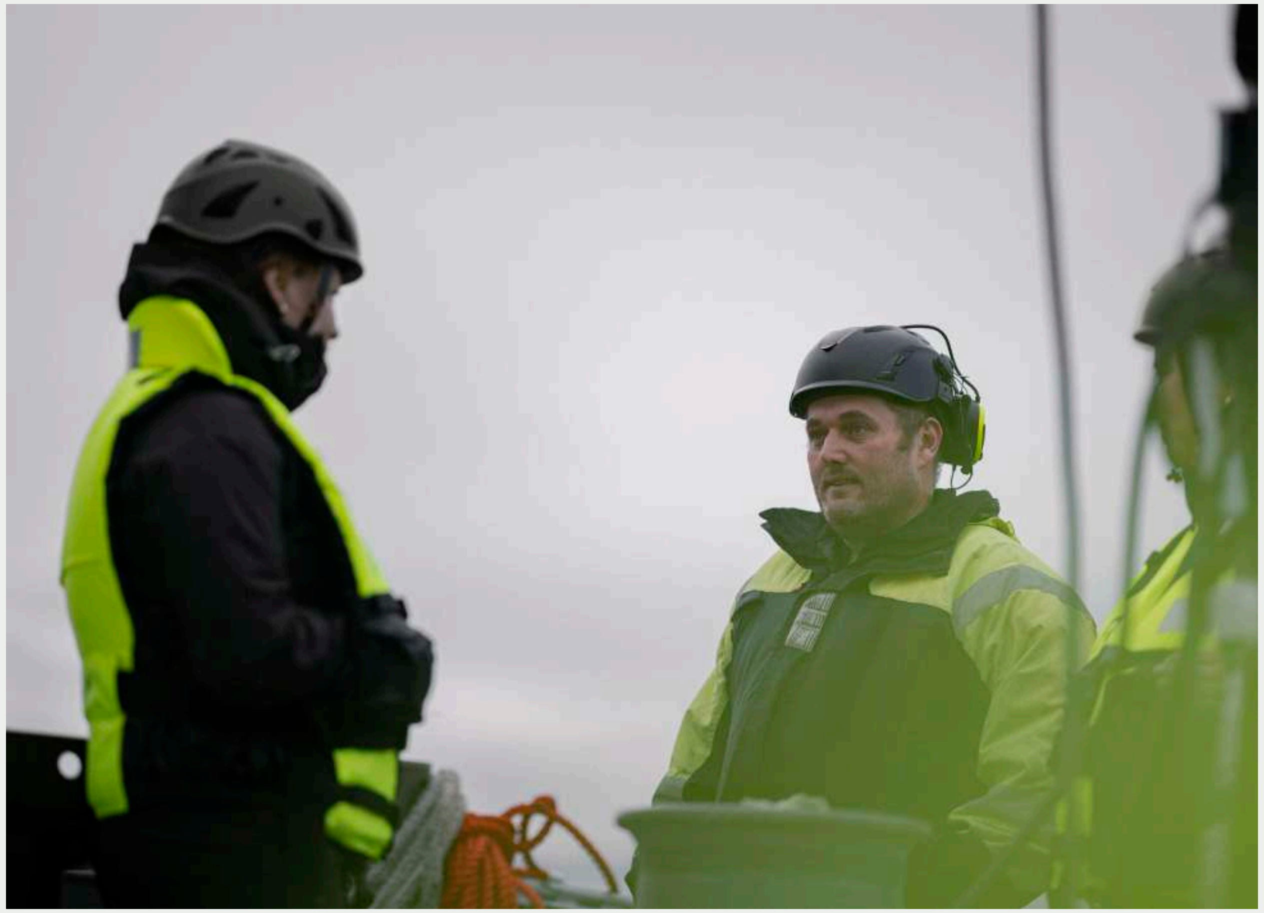
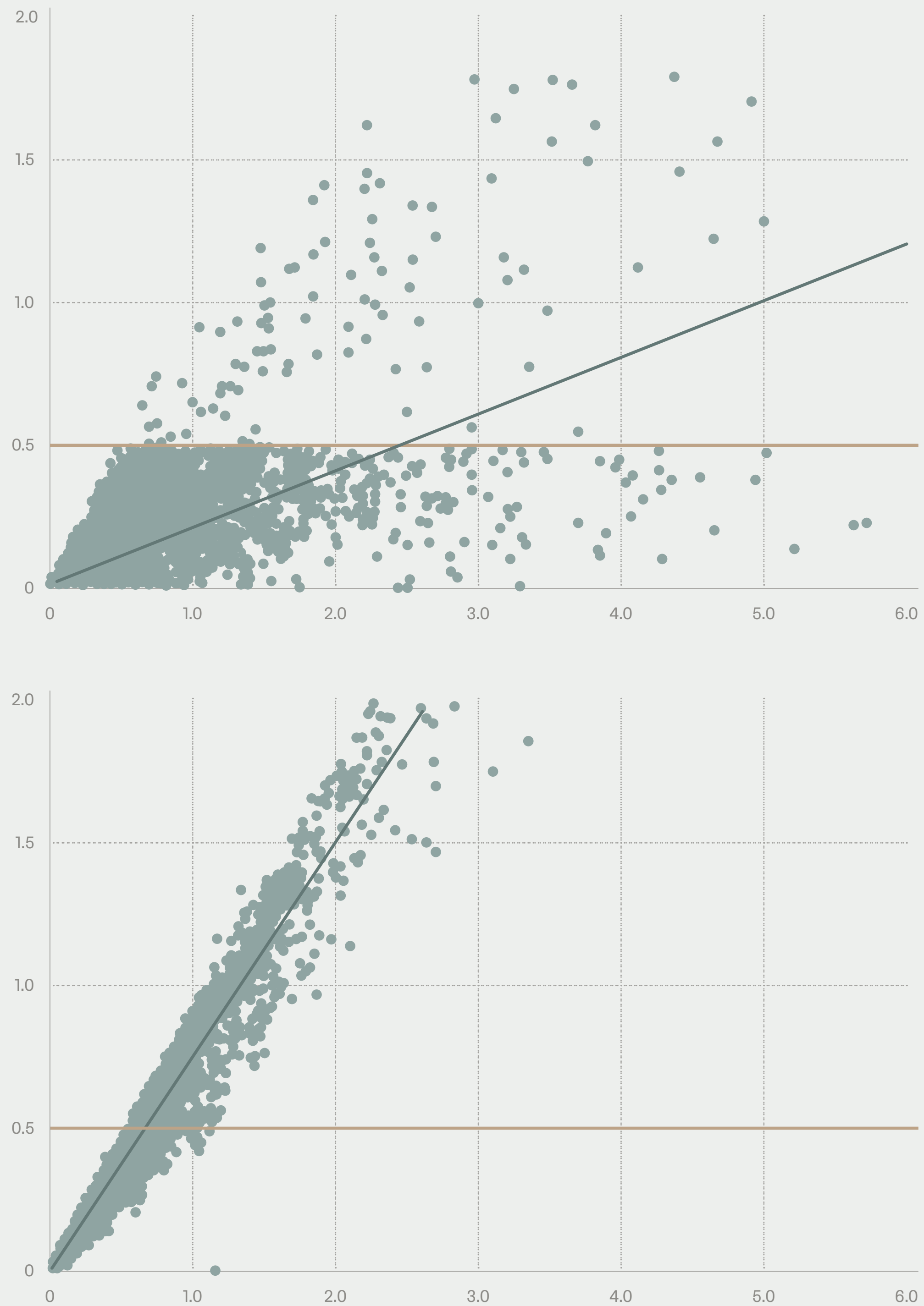


FIGURE 31 AND 32.
Cliff effect differences comparing BarentsWatch and Stingray automated lice count (2024).

x-axis: total mobile abundance, y-axis: adult female abundance



Reproduction of the "cliff effect" [129] based on manual counts from BarentsWatch data (upper panel). Stingray automated lice counts show no sign of a "cliff effect" (lower panel). Observation period: 01.01.2024 - 30.12.2024. Axis truncated at two adult females and six total mobiles.

Comparing different methods

A comparison between Stingray automated lice counts and manual counts from BarentsWatch shows that the image-based method reports on average more lice despite the occlusion bias (Figure 31 and 32). It also shows that automated counts are virtually never zero and visualizes a marked "cliff effect" at 0.5 adult female lice per fish in manual counts. Since the deviations between the two methods are due to multiple biases that work in different directions, they cannot be accounted for by applying a simple correction factor to the entire data set. As such,

Stingray does not recommend the retrofitting of its detector results via a correction factor due to the dynamic prerequisites such a factor will have to address and the weaknesses in manual counts that would serve as a reference.

When comparing lice-counting methods, it is important to distinguish between validating a new method and testing the agreement between two existing ones [131]. In the absence of a ground truth concerning the "real lice situation" in a production unit, it is not possible to confirm a new counting method by means of calibration against an existing one. Since manual counts are subject to statistical uncertainties and biases, they cannot be considered a calibration standard of known accuracy. If two methods agree, this implies that they may be used interchangeably, irrespective of whether they report the truth. To what extent two methods need to agree to be considered equivalent is a value judgement and does not follow from the analysis.

In the case of reportable lice counting, this value judgement should be derived and communicated by the relevant authorities after considering all facts and weighing the interests of all relevant stakeholders. However, requiring a new method to agree with an old one with obvious flaws, is to actively forego the chance of improving control over the lice situation. Stingray suggests circumventing this ground-truth problem by deriving attachment probabilities based on lice-settlement preferences from spatial distribution heatmaps of different types of lice on salmon and trout under various production conditions. Given sufficient data, it can be estimated how many lice were left uncounted based on the proportion of the fish that was observed by a stereo camera and correct for unseen areas accordingly.

5.5

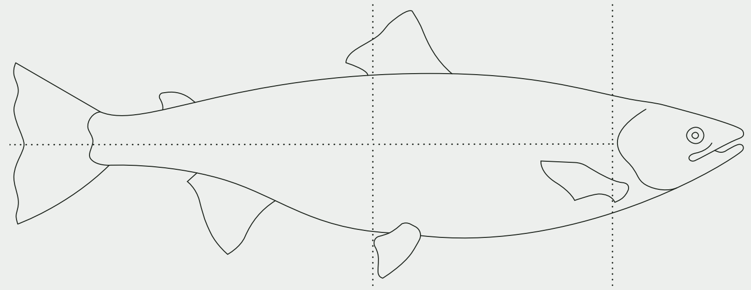
Heatmaps of lice-attachment preferences

Since image-based lice counts in Stingray are based on image sequences rather than still images of individual fish, the total accessible area for sea louse examination is not limited by the area visible on a single photo. Additionally, the visible proportion of a fish's body surface is not the only relevant criterion for finding an adequate correction factor for occluded lice because not all areas of the fish are equally attractive for lice attachment [132]. For example, lice located on prominent areas like the dorsal ridge or the region behind the adipose fin are visible from both sides of the fish and thus may be overrepresented when multiplied with a static correction factor. Stingray has taken steps to ensure the best possible exposure by actively positioning the cameras to cover the most densely populated skin areas on salmon and trout during optical delousing.

Earlier scientific work on preference maps

Several scientific studies confirm that the settlement of *L. salmonis* depends both on the demographics of the parasite and the morphological and physiological properties of the host fish [110, 133-138]. There are clear differences in attachment location with a preference for the dorsal areas of the fish [132], and most lice are found in only relatively few areas on wild and commercially held Atlantic salmon [110, 134]. The most recent reference on lice-attachment preferences by Bui, Geitung [132] (Figure 33) proposes a simplified differentiation of host fish into geometric quadrants that do not take into account any biological properties of either salmonids or sea lice. The study was performed in small test cages, on a single cohort of small, post-smolt Atlantic salmon that did not yet show the shoaling behavior typical for salmonids in production cages [139], and with an average lice abundance that exceeded the commercial delousing threshold of 0.5 adult female lice per fish [110, 133-138]. There are clear differences in attachment location with a preference for the dorsal areas of the fish [132], and most lice are found in only relatively few areas on wild and commercially held Atlantic salmon [110, 134].

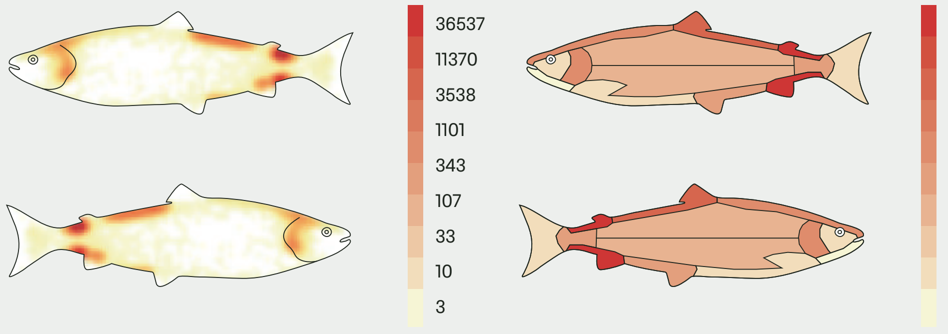
FIGURE 33.
Quadrant-based template for the quantification of lice attachment preferences on small post smolt Atlantic salmon by Bui, Geitung [132].



Sea louse attachment preferences

Based on earlier scientific studies featuring more fine-grained subdivision of host fish into attachment preference areas on Atlantic salmon [110, 134], as well as on an internal analysis of more than 430,000 image sequences from commercial aquaculture pens, Stingray has developed a more detailed map of lice-attachment preferences [110, 134, 140]. The Stingray map includes 15 anatomical areas that are rooted in physiological and morphological features of the salmonid host and considers behavioral preferences in line with the life cycle of the salmon louse and literature-derived scientific knowledge (figure 34). Stingray results are based on drastically increased sample sizes and data set. While the results are mostly in line with previous findings from the scientific literature, some specifications and distinctions are necessary to turn the simplified quadrant-based approach by Bui, Geitung [132] into a heatmap of lice-attachment preferences that can be used for the purpose of deriving a correction factor for image-based louse counting techniques.

FIGURE 34.
Stingray 2D heatmap of sea louse attachment preferences. Sample size: 224,002.



Stingray preferences map of adult female salmon lice attachment on farmed Atlantic salmon. Left: Heatmap of detector-based louse positions confirmed by human analysts. Right: Settlement intensities within the outlines of 15 preference areas on the fish. Data are color-coded on a logarithmic scale [141].

While the head region in general might be favorable for the ease of feeding on scaleless skin [142], the majority of lice are found on the opercula, and, to a lesser extent, on the forehead of the fish, whereas few lice settle on the lower jaw and the areas immediately around the eyes. The operculum is a strategically important region for females to attract mates via pheromones [143] and mating pairs are therefore frequently found on the head. Thus, the head quadrant, on which Bui, Geitung [132] found large amounts of pre-adult and adult sea louse stages, must be further differentiated into smaller areas. Also, under commercial conditions, very few lice will settle along the lateral side of a fish, while their abundance is increased along the dorsal midline (see also Jaworski and Holm [110], Todd, Walker [134]).

In general, lice infestation is more intense on posterior parts of the fish, which can be attributed to more favorable hydrodynamic boundary conditions for attachment towards the tail [144, 145]. Several authors have therefore recorded high abundances of pre-adult and adult stages along the dorsal posterior part of host fish [110, 133, 134, 137]. Simplified attachment models cannot capture hotspots of infestation such as the areas behind the adipose and anal fins that account for the majority of lice in the Stingray preference map. The area behind the adipose fin has earlier been described as a high preference area for sea lice in pre-adult and adult stages [134, 135, 146] and adult females in particular [110]. An attachment preference in this area is consistent with the function of the adipose fin as a hydrodynamic vortex dampener [147] that provides a sheltered area to the parasite. Also the area around the anal fin has been described as a preference area by several authors [110, 134, 137, 146], a finding strongly supported by Stingray's heatmap data, especially for farmed trout [134, 135, 141, 146] and adult female salmon lice in particular [110].

Stingray 3D heat map

While the 2D Stingray preference map was assembled manually by trained analysts during a period of 12 months, an automated lice detection system designed to identify lice in a sequence of 2D images allows the same amount of data to accumulate within just a few days. The detected lice are subsequently mapped onto a 3D model of a fish (Figure 35). By aggregating these mapped observations across multiple fish, it becomes possible to generate heatmaps that visualize the spatial distribution of lice on the fish under different rearing conditions. This approach offers a significant advantage over the manual placement of lice observations on images, as it helps with the collection and analysis of substantially larger datasets.

Detailed heatmaps of lice-attachment preferences allow to assign region-specific coefficients that reflect the probability of lice detection for each anatomical area and to correct for unseen lice on the camera-opposed side of the fish. Overall, the implementation of heatmaps on 3D-fish models will also make it possible to determine the precise areas on which lice were detected by the system, and which areas need to be corrected for.

By incorporating these dynamic adjustments, the system will produce a more exact estimate of lice distribution and abundance, thereby enhancing the reliability of the data for further analysis and decision-making without a need for manual reference counts.

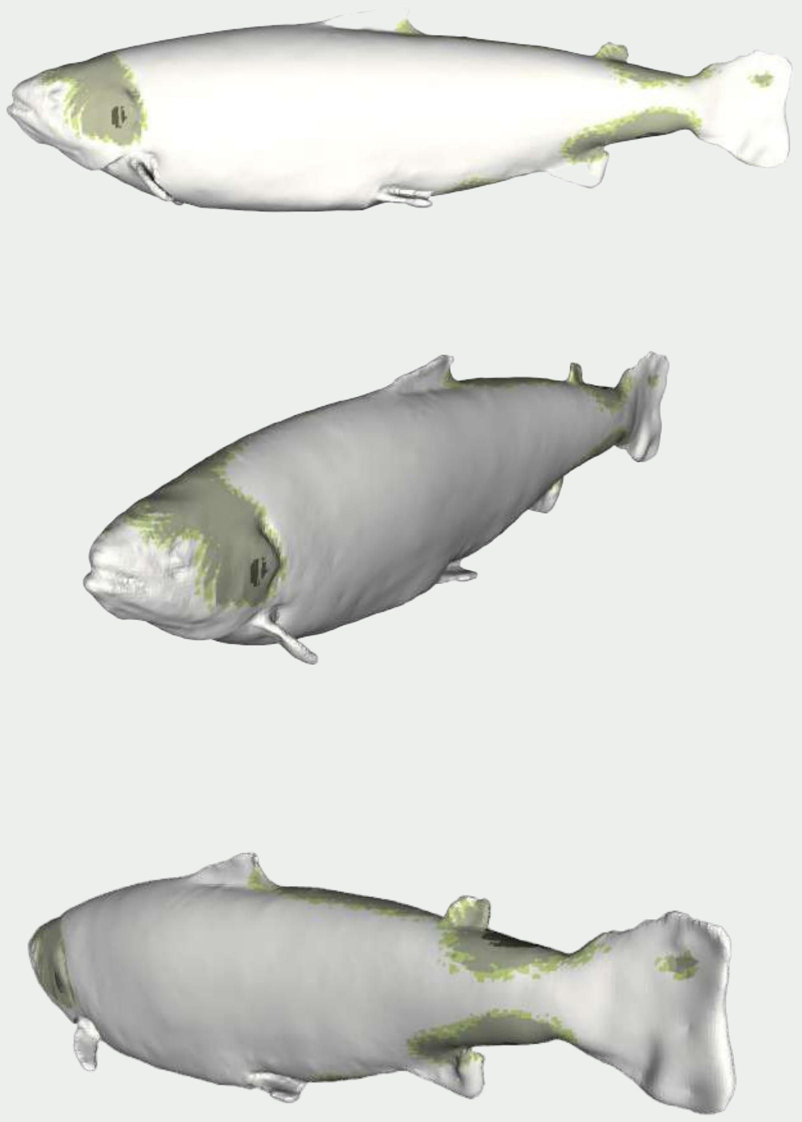


FIGURE 35.
Stingray 3D heatmap of sea louse attachment preferences. Automated sea louse detections are mapped on a 3D model of an Atlantic salmon.

5.6

Sea lice prediction model 2024

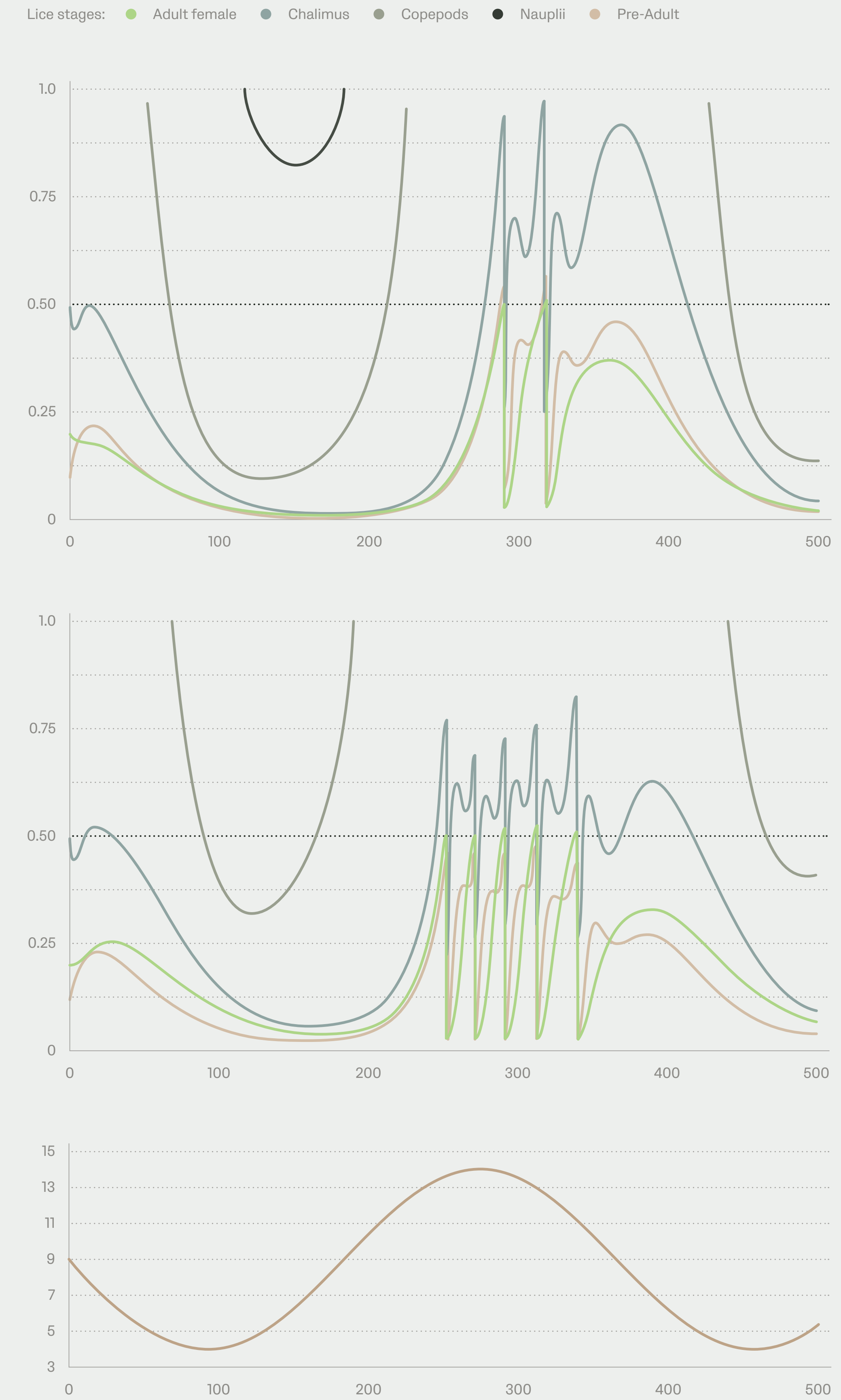
Due to the environmental and economic impacts of sea lice originating from aquaculture locations, several academic institutions have developed models to predict the development of these parasites in sea cages. Researchers from the Norwegian Institute of Marine Research, for instance, have coupled an advanced lice-development model to a hydrodynamic model to predict the abundance of infective planktonic lice larvae in the water column along the Norwegian coast. Results from this model inform the decisions behind the Norwegian Traffic Light System, which in turn regulates the growth opportunities of the salmon farming industry in terms of maximum allowable biomass in the thirteen production areas in Norway [148].

Salmon-lice models are based on our knowledge about the biology of the parasite, such as reproductive potential in relation to environmental factors like water temperature and salinity. By using stage-structured models, it is possible to determine the abundance of each stage of the parasite based on their development and mortality rates [149]. Increasing temperature will thereby lead to faster development and therefore shorter generation times [150]. Here, optical delousing introduces an additional mortality factor for the mobile and adult female louse stages targeted by laser nodes in aquaculture production cages.

Stingray incorporates operational data from the Stingray system including fish passings, laser pulses, and hit rates, into salmon lice-population models. Eventually, this helps scale the requirements for the use of laser nodes during a production cycle for a particular geographic location (Figures 36, 37 and 38). Short-term predictions can be used to forecast a range of possible scenarios for salmon-lice development that can be used as a decision tool to optimize performance indicators and stay in control of the lice situation at a particular farm (Figure 39).

Results from a model simulation spanning a 500-day production cycle in a single pen with fish deployed in autumn and two active laser nodes (upper panel). The lower panel depicts the expected development of sea temperature (beige) for the prediction period. The mid panel depicts the predicted abundance of lice per fish over time, color-coded for the different lice stages. Based on the chosen parameters, the abundance of adult female lice (gray-green) would exceed the legal 0.5 lice threshold twice, causing two delousing operations, accordingly. Omitting laser-induced mortality from the model would result in a total of five necessary delousings in this scenario (mid panel).

FIGURE 36, 37, 38.
Sea louse development model output (days).



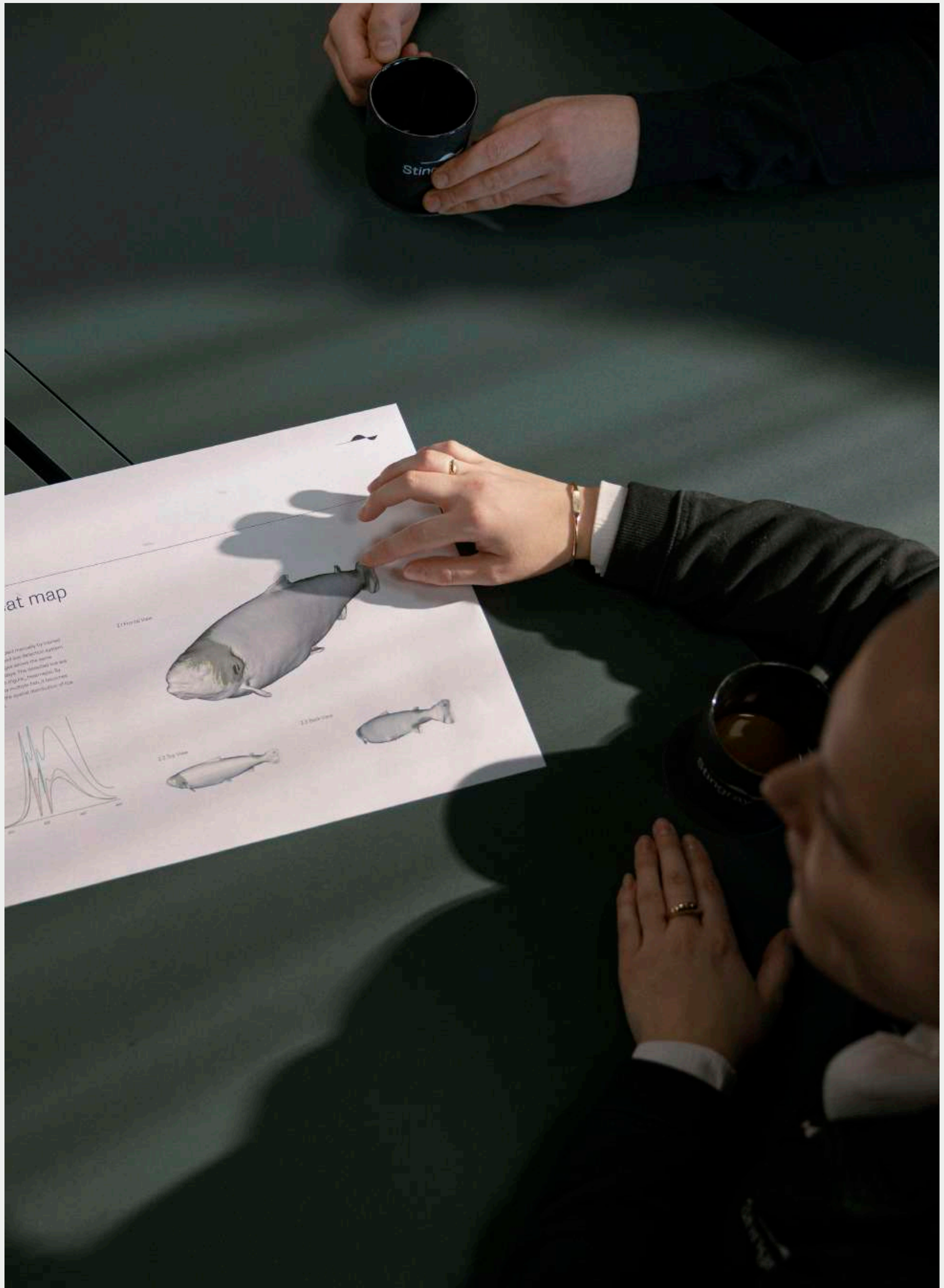
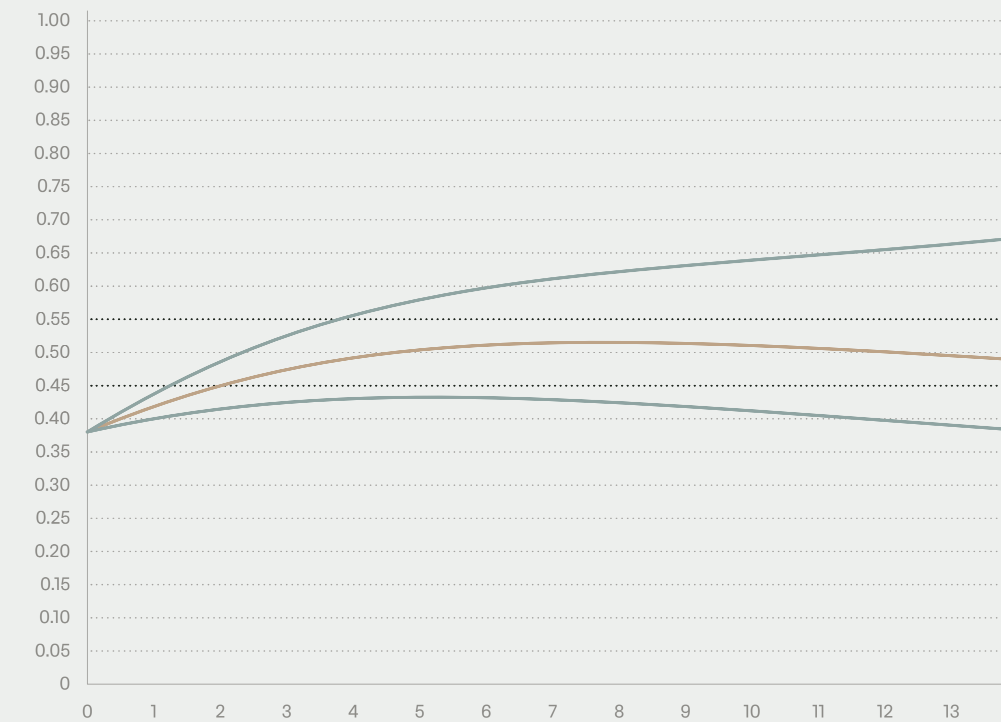


FIGURE 39.
Example of a short-term sea louse prediction model (14 days).

Scenarios: Adult female · Lower estimate · Upper estimate

Estimated lice after 14 days: 0.46 adult femles per fish
Estimated of required fish passings per node assuming 0.8 pulses per passing to
- achieve mandated lice level of 0.5 AF per fish: 41,000 per day; 1,708 per hour
- achieve desired lice level of 0.45 AF per fish: 54,000 per day; 2,250 per hour
- keep lice level constant at 0.35 AF per fish: 89,000 per day; 3,708 per hour

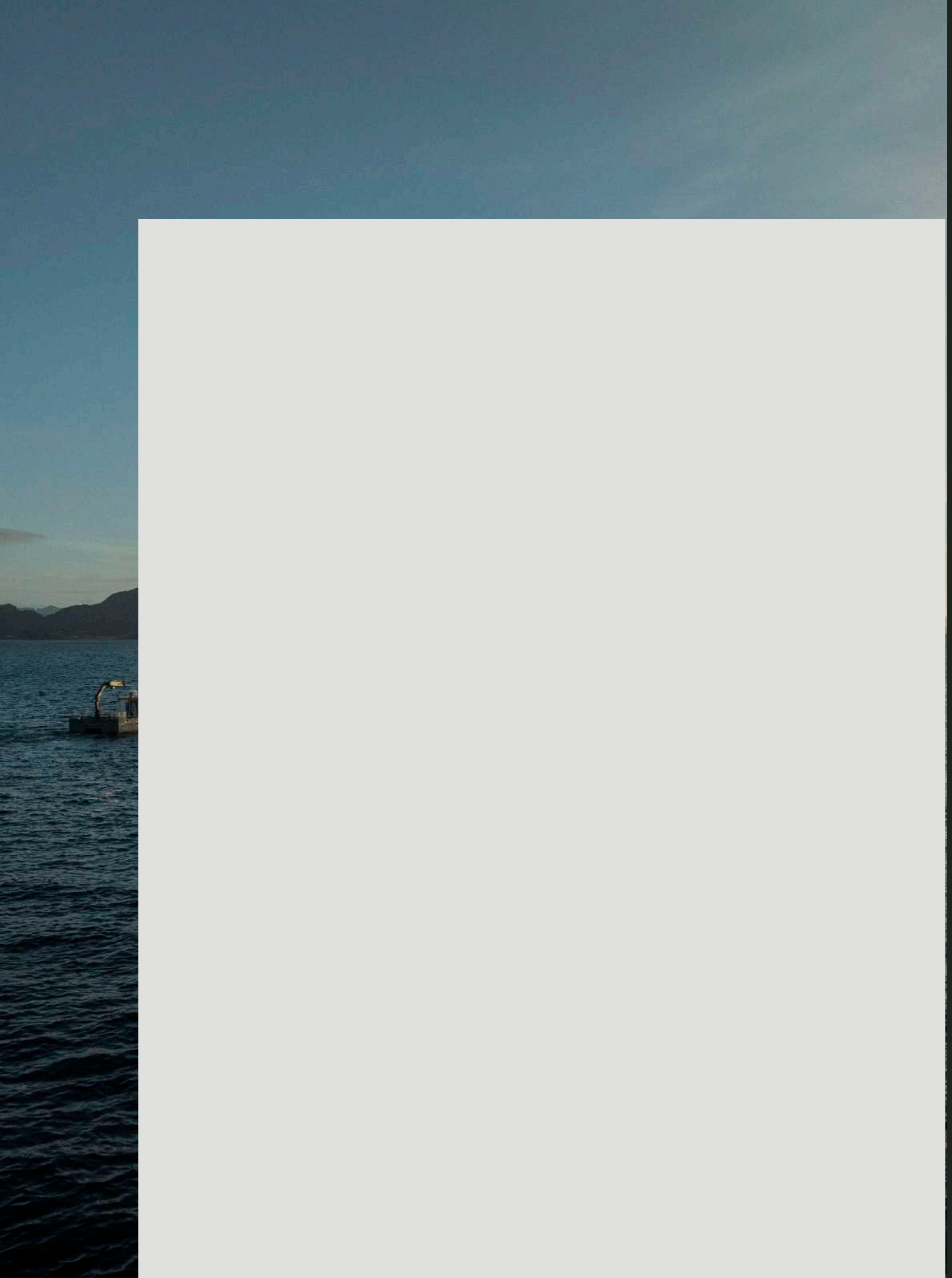


Results from a short-term scenario of salmon lice development in a single pen with two active laser nodes. Based on the prediction, the abundance of adult female lice per fish (beige) is likely to remain below the legal 0.5 threshold limit. Upper and lower estimates (gray-green) represent the error margin of the prediction. Assuming a constant ratio of laser pulses per fish passing, the model returns the amount of passings per laser node and time necessary to remain below the legal lice limit, keep lice abundance constant, or remain below a pre-defined lice level.

Salmon-lice models are based on many variables and assumptions such as growth, mortality, and infection rates, and virtually all of them are associated with uncertainties. Complexity increases even further when single pens are considered as a part of a network of pens or locations within a region, where external infection pressure from close-by fish farms needs to be taken into account [151]. Modeled predictions must therefore always be interpreted with caution. However, they make it possible to disentangle the importance of individual factors to see how small improvements in detection or performance may improve the value of the Stingray system.

6.0

Stingray Results 2024



Stingray's Fish Health Hub™ collects sensor and detector data, which can be grouped into operational, environmental and fish health parameters. API integrations allow Stingray to combine its own substantial data material with customers' production parameters. Continuous live monitoring allows operators to track behavioral changes and monitor fish cohorts closely. This level of control enables Stingray to detect, analyze, interpret and present a range of effects and trends, making a real difference for 80 million fish at over 100 different locations in Norway and Iceland.

6.1

Stingray market share

18.1%

peak coverage of all locations across Norway

Throughout the course of 2024, Stingray was able to expand its market share in line with its production capabilities, reaching a peak coverage of 18.1% of all locations across Norway, resulting in an overall operational uptime of 15.4% of all production weeks throughout 2024. High customer demand for the product was driven by overwhelmingly positive results in 2023 [141], a reputation for clear and honest follow-up and a robust and reliable hardware platform (Figure 40, 41 and 42). Stingray is proud to report that, at its peak, over 80 million fish from 32 unique customers at 111 locations have been under continuous surveillance throughout 2024 (Table 6).

FIGURE 40. Weekly Stingray market share (number of locations).

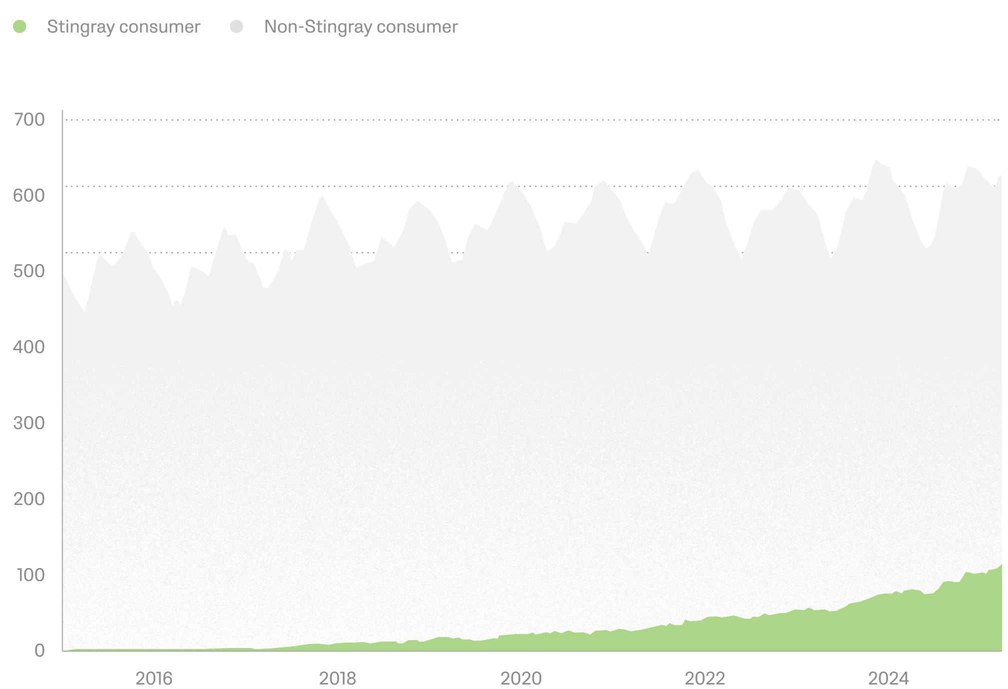


FIGURE 41. Monthly Stingray market share (%).

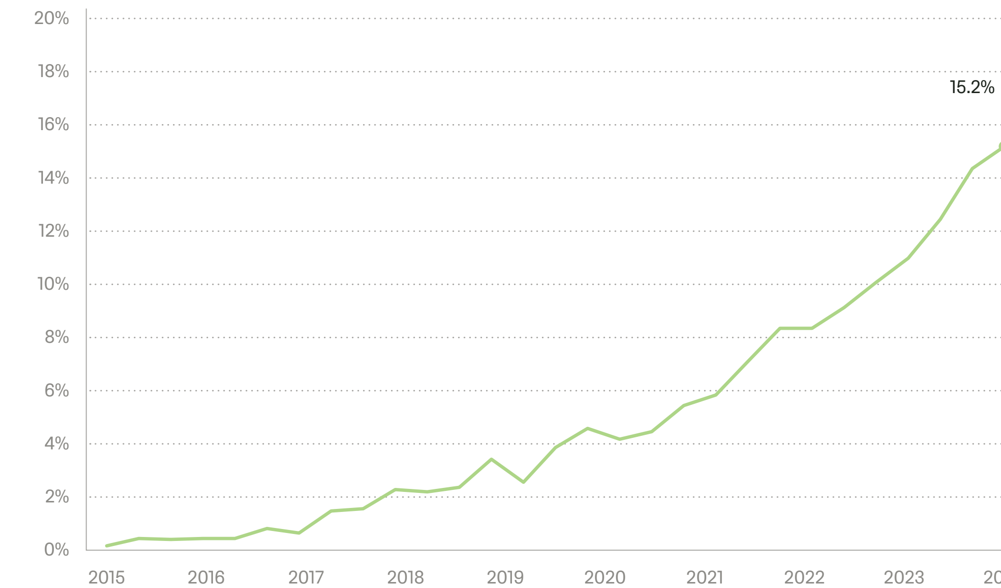


FIGURE 42. Stingray market share 2024 (% active weeks per production area).

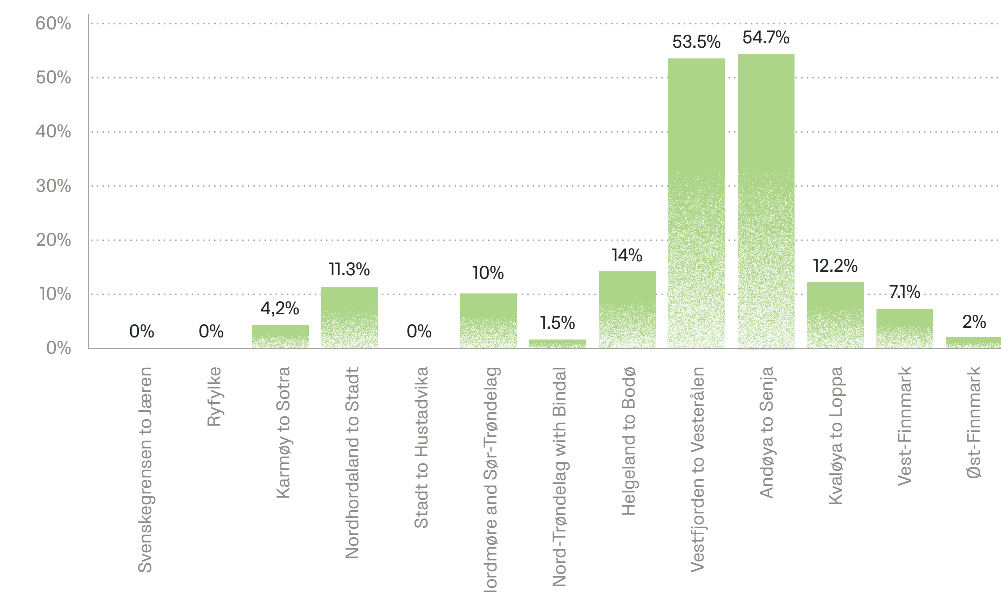


TABLE 6.
Stingray operational data 2024.

YEAR	PULSES	PASSINGS	MAX FISH COUNT	MAX ACTIVE CUSTOMER	MAX ACTIVE LOCATIONS	MAX ACTIVE PENS	MAX ACTIVE NODES
2022	6,558,483,848	9,012,458,867	32,158,556	24	51	275	560
2023	11,158,008,516	13,807,278,207	41,527,168	27	70	444	913
2024	25,103,033,479	267,451,841,44	81,917,314	32	111	667	1,548

Stingray Academy

433

users in Stingray Academy

All of Stingray's 32 customers have currently registered a total of 433 users in Stingray Academy (Table 7). Introduced in 2017, Stingray Academy is a dedicated learning and training platform, offering a comprehensive range of resources, including reading materials, videos, and visualizations, to demonstrate the functionality of the Stingray system. Certificates are issued for completed courses, highlighting their importance in both internal and external training programs and supporting continued education and professional development.

In 2024, Stingray Academy was integrated into Stingray Online, streamlining customer training and user access to materials, exams, certificates, and company data.

TABLE 7.
Academy Course Overview.

COURSE	DESCRIPTION	CHAPTERS	TARGET GROUP	USERS
Health, Safety & Daily Routines	Mandatory Health, Safety & Daily Routines course. Exam and certificate needed to operate the nodes.	13	All users working with the system	433
Image-based Analysis	Course on image-based sea louse and welfare counting. Information on biosafety, laser node relocation, fish health and welfare, sexual maturation and wound management.	11	Fish health personnel	198
Navigator	Required for remote operation of the system. Information on fish behavior, laser node management, environmental factors affecting fish detection, and troubleshooting techniques.	6	Stingray Pilots	232
Stingray Online	Provides instructions on manual data input, use of API and how to navigate the customer portal.	12	Stingray Online users	268

6.2

Good biology equals good economy

The use of non-invasive, continuous delousing methods offers several advantages over traditional methods, which are often linked to higher mortality, slower growth, and quality downgrades. Stingray regularly conducts economic analyses regarding this topic. In this 2024 analysis, the examples and calculations are based on the Spring 2023 generation (S1 23G) in production areas with the highest Stingray market share to date (Table 8).

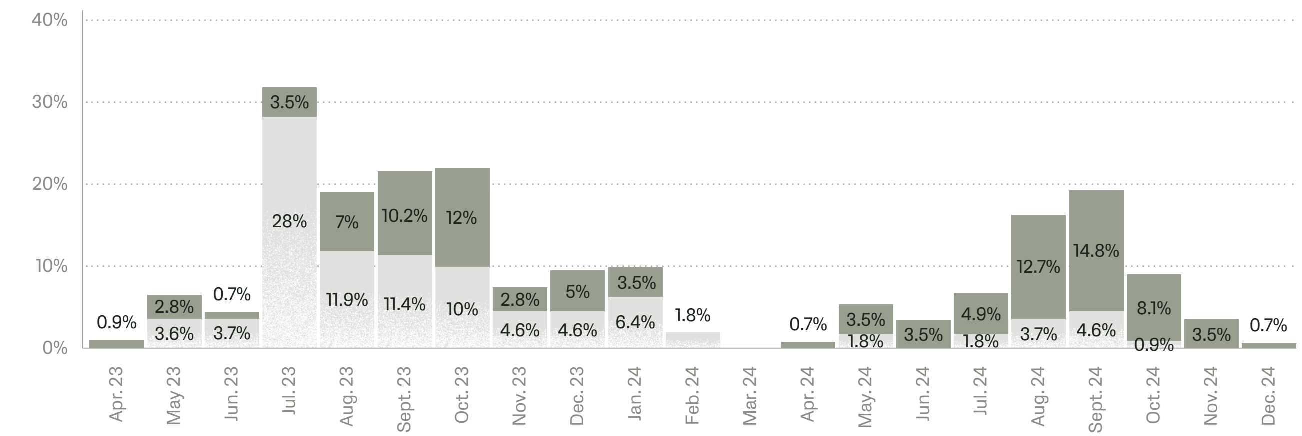
TABLE 8.
Location overview (PA9 & PA10, 2024).

PA9 & PA10, 2024	STINGRAY CUSTOMERS	NON-CUSTOMERS
Total amount of locations	30	38
Average operational locations	15	14
Peak operational locations	26	34

Delousing frequency and mortality

The delousing frequency for the selected production areas (Figure 43) is broadly representative of Norway and aligns with the reproductive biology of sea lice. Early in the production cycle, in-feed treatments dominate, transitioning to mechanical methods by the second year. Treatment activity typically peaks during summer and autumn, reflecting the population dynamics and biology of sea lice.

FIGURE 43.

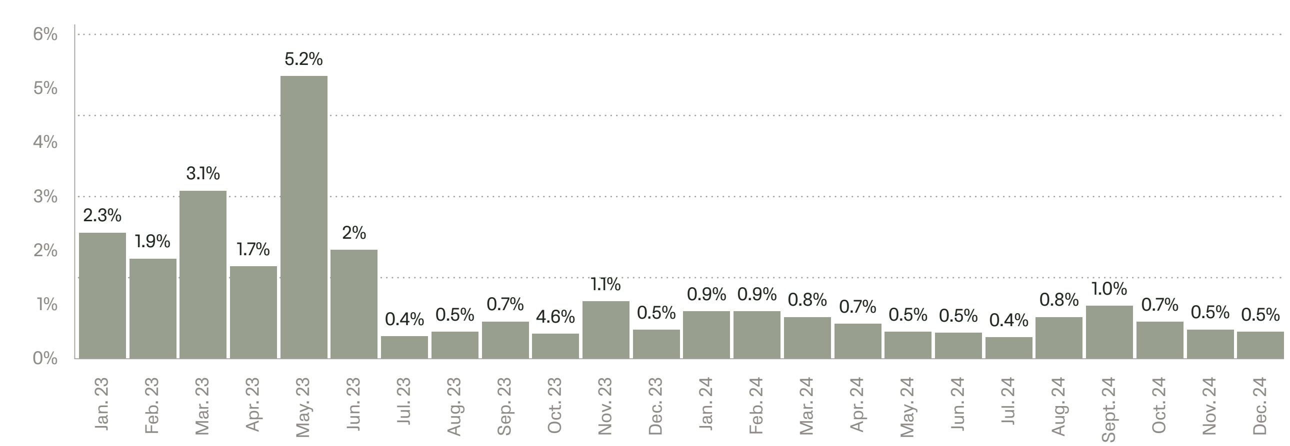


Frequency of delousing method. Monthly distribution of feed and mechanical/bath treatments (PA9 and PA10) [113].

Mechanical delousing poses a high risk of fish mortality. Stingray estimates a conservative 0.5% increase in mortality during delousing weeks, attributed to factors such as handling, stress related injuries, and potential secondary infections.

From November 2023 to November 2024, the average mortality rate for PA9 and PA10 across all locations was 9.1% (Figure 44). However, this number doesn't account for differences between Stingray and non-Stingray locations. Stingray locations required 51%-62% fewer treatments compared to non-Stingray customers (Table 9). Since more treatments are linked to higher mortality, the 9.1% baseline mortality is likely overstated due to the poorer performance of non-Stingray locations. More accurate estimates will become possible once data granularity for public/non-customer information improves, and Stingray's new API integration is fully implemented.

FIGURE 44.



Monthly average mortality rates (%) for S1 23G in PA9 and PA10. Directorate of Fisheries [152].

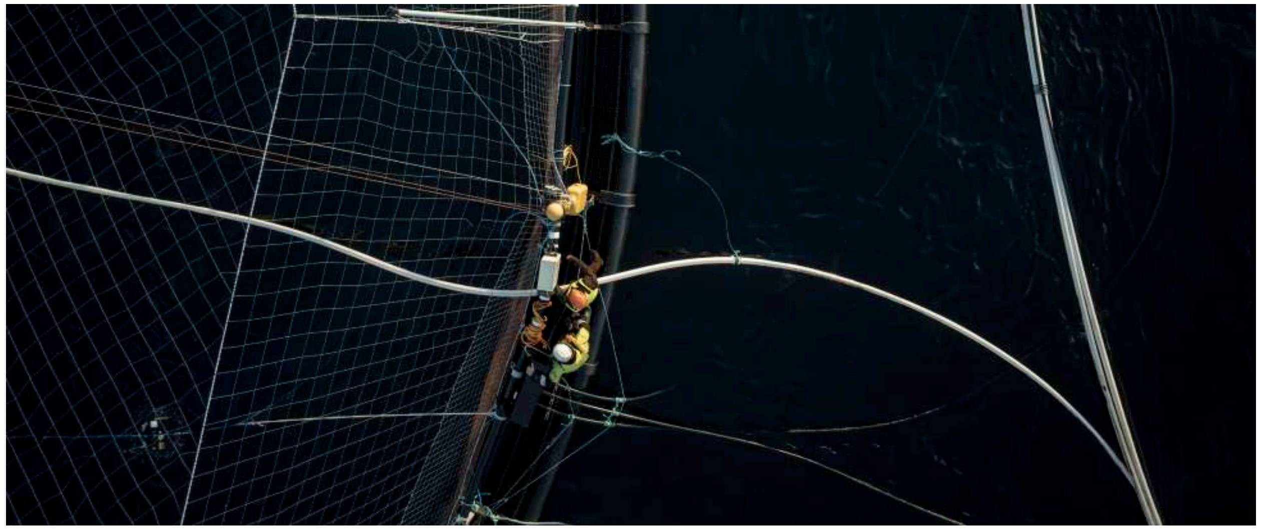
TABLE 9.
Treatment data overview (PA9 & PA10, Nov 2023 - Nov 2024).

PA9 & PA10	STINGRAY CUSTOMERS	NON-CUSTOMERS
Sea louse treatments	61	152
Treatments/location (average–max)	2.3 - 4.1	4.5 - 10.9
Estimated mortality due to delousing (average-max)	1.1 – 2.1%	2.3 – 5.5%

Starvation losses

Walde, Stormoen [153] estimates that mechanical delousing can cause a growth loss of up to 200 grams per fish for a 3-kilogram salmon at 10°C. On average, Stingray assumes that each delousing results in seven starvation days. This includes days without feeding before and during the treatment, as well as stress-related feed refusal afterward.

More treatments lead to more starvation days, resulting in longer production times and/or reduced biomass at harvest.



Harvest quality

In Norway, salmonid harvest grades are categorized based on the quality and condition of the fish [154] (Table 10 [154-156]).

The 2023 *Fish Health Report* from the Norwegian Veterinary Institute [6] highlights wounds and injuries as the main reason for downgrading fish to production grade, noting that only 82-83% of salmon harvested in 2023 were classified as superior grade. The report also identifies mechanical delousing as the primary welfare issue in Norwegian fish farming, linking it to outbreaks of winter wounds [6].

Preventing mechanical delousing is undoubtedly economically beneficial. Simulations by Walde, Stormoen [153] indicate that salmon farmers can invest up to € 535,313 per pen in a spring stocked production cycle to offset four thermal delousing events, before it ceases to be economically viable. This highlights a significant incentive for farmers to transition to more efficient delousing methods such as Stingray.

TABLE 10.
Norwegian salmon harvest grade categories.

HARVEST GRADE	DESCRIPTION	USAGE
Superior Grade	Fish of the highest quality, exhibiting excellent condition without visible defects such as wounds, deformities, or significant scale loss. These fish meet stringent standards set by Norwegian authorities [154, 155].	Primarily exported to premium markets requiring top-quality products, including sushi and sashimi preparations.
Ordinary (Standard) Grade	Fish with minor imperfections, such as small wounds or slight discoloration, that do not significantly affect overall quality. These fish comply with Norwegian regulations for safe consumption.	Suitable for various processed products, including smoked salmon and frozen fillets, catering to a broad consumer market.
Production Grade	Fish exhibiting notable quality issues, including larger wounds, deformities, or handling damage, which may impact appearance and flesh quality. These fish are subject to regulatory oversight to ensure safety.	Utilized in secondary processing, such as the production of fishmeal, oil, or other non-premium food products.
Reject Grade	Fish deemed unsuitable for human consumption due to severe defects, disease, or contamination, as determined by the Norwegian Food Safety Authority [155].	Typically diverted to non-food industries or disposed of following environmental and safety regulations.

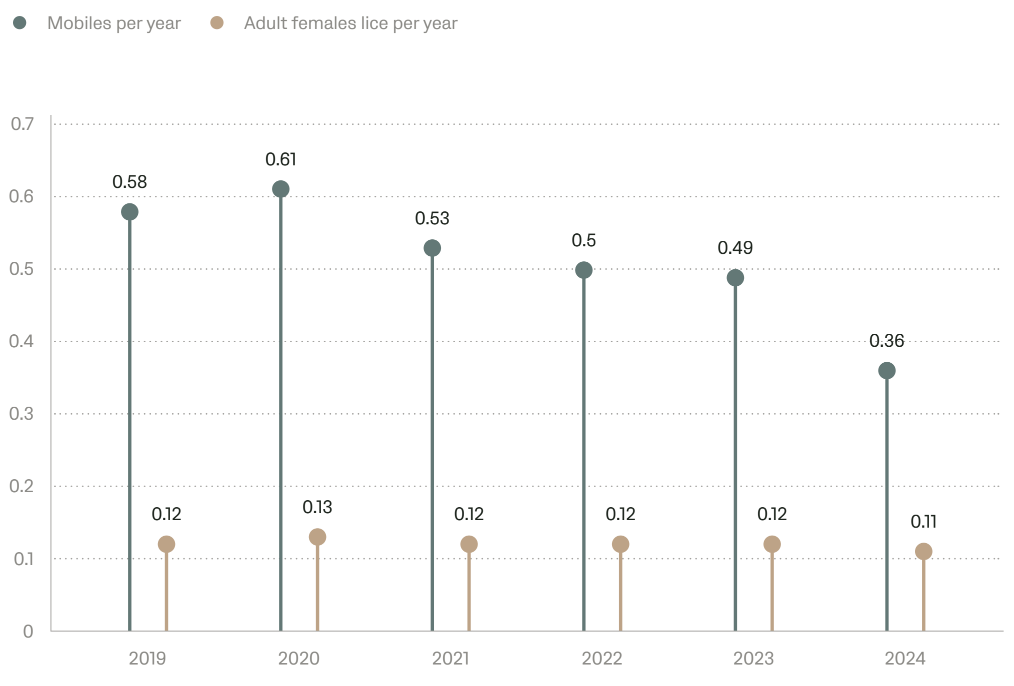
6.3

Sea louse status - Norway 2024

Significant changes in sea louse abundance and infestation pressure have been observed over the last few years in Norway due to a combination of changing treatment regimes, changing operational practices and temperature anomalies.

During the first half of the year 2024, the aquaculture industry has experienced a significant decline in the number of mobile lice per fish compared to previous years, while the levels of adult female lice have remained stable. (Figure 45).

FIGURE 45.
Average sea lice per fish, Q1-Q2 (2019 - 2024).



The second half of the year is defined by higher sea temperatures and consequently increased infection pressure of sea lice [22]. The second half of 2024 showed a notable higher level of adult female lice compared to previous years (Figure 46). This is directly correlated with higher sea temperatures from mid-July to end of September compared to historical data for the same period (Figure 47).

FIGURE 46.
Average adult female lice per fish, Q3-Q4 (2019 - 2024).

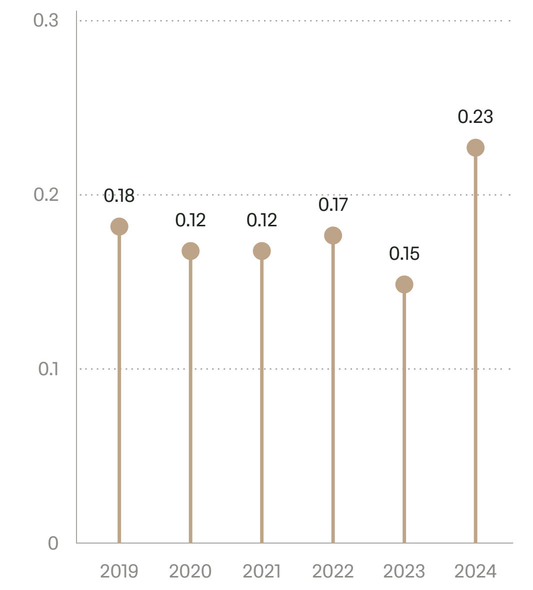
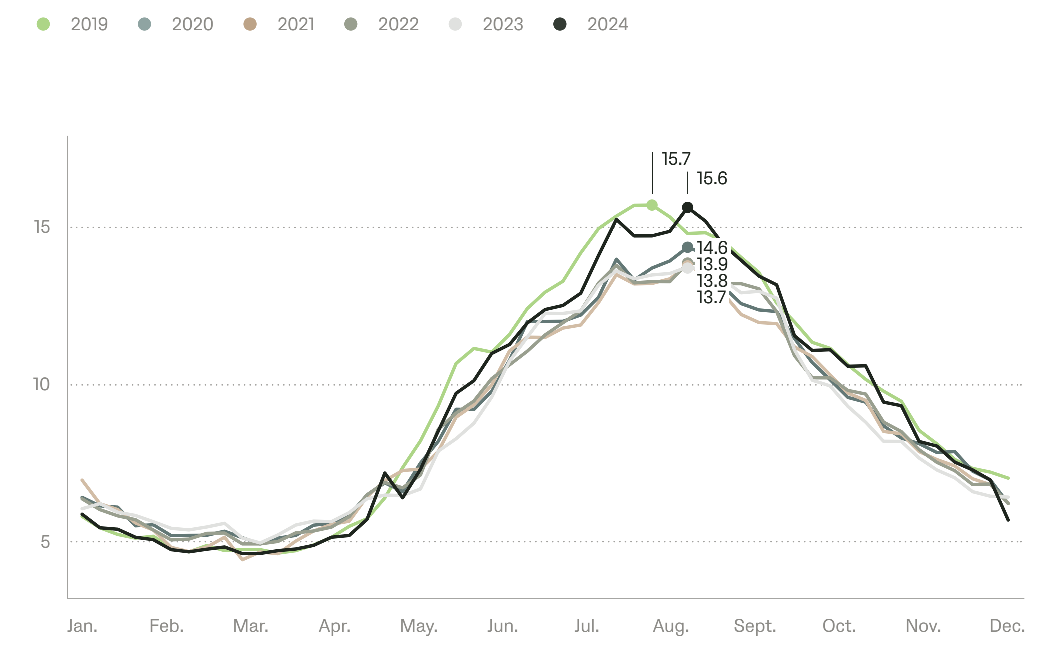
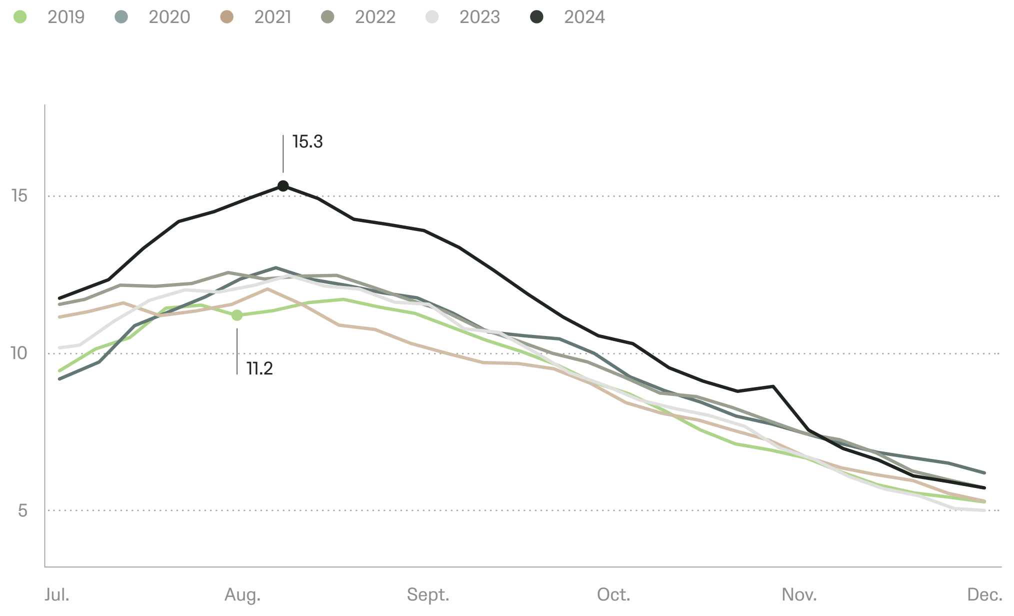


FIGURE 47.
Average sea temperature (°C), Norway (2019 - 2024).



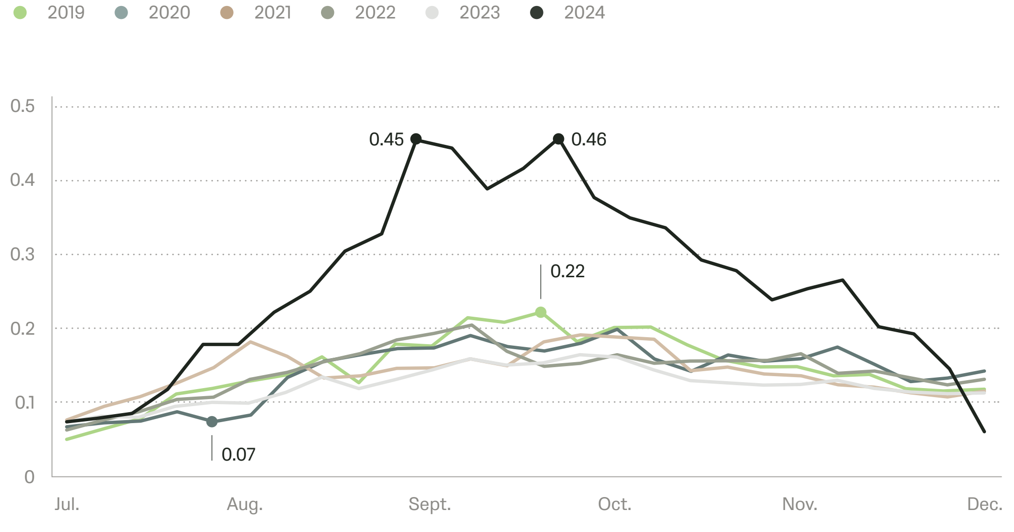
An analysis of publicly available data shows that production areas 8–13 in Northern Norway were the primary contributors to the increase in both lice levels and average sea temperatures. In week 33, the average sea temperature climbed to 15.3°C, a significant rise compared to 12.5°C during the same week in 2023 (Figure 48).

FIGURE 48.
Average sea temperature (°C), Northern Norway, PA8 -13 (2019 - 2024).



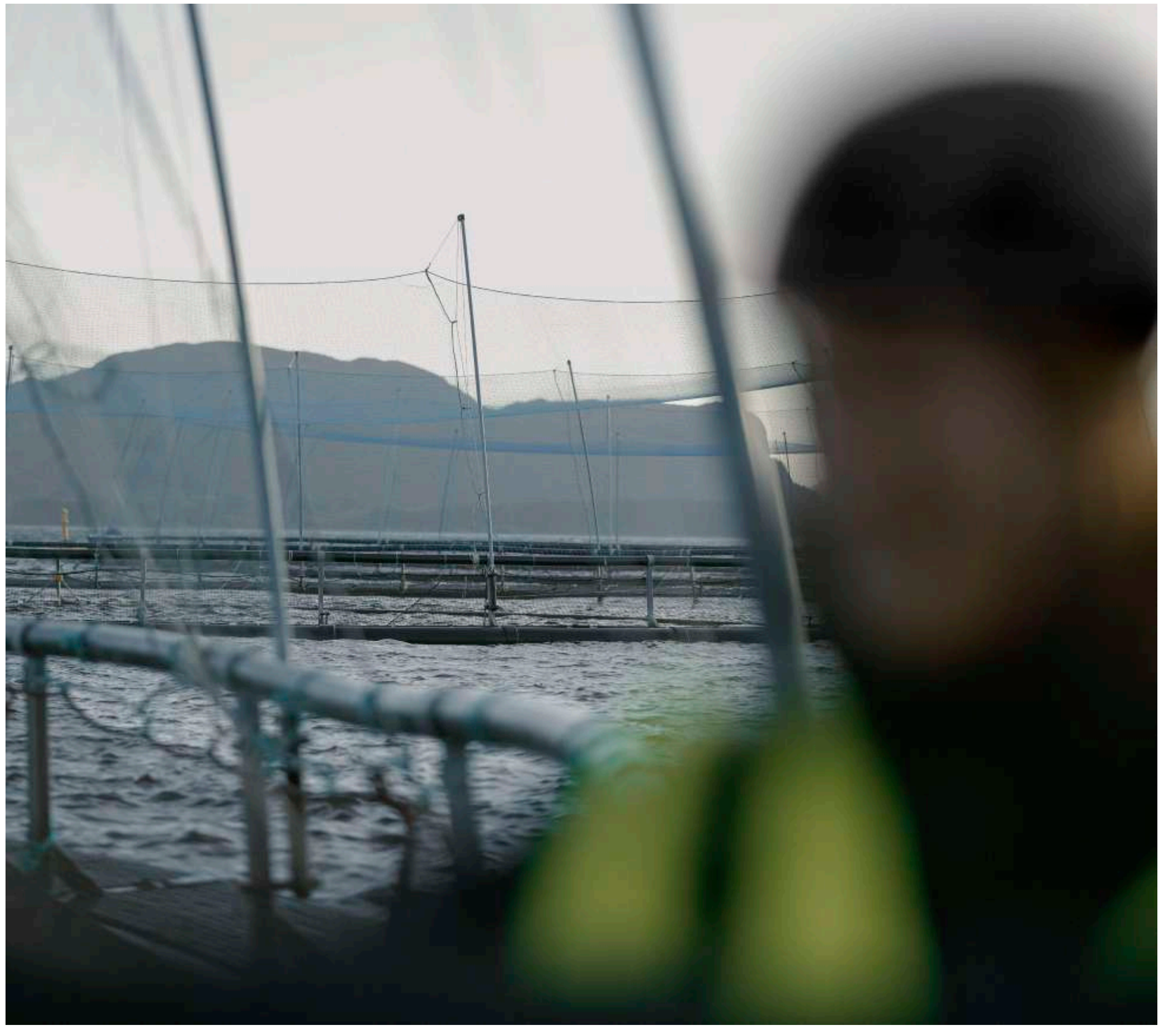
This sharp increase in temperature accelerated the development rate of sea lice, shortening their reproduction cycle by 30% [22]. With sea temperatures four to five degrees above normal, these elevated conditions became the dominant factor driving the unusually high lice levels observed in the summer of 2024 (Figure 49).

FIGURE 49.
Average sea lice per fish, Northern Norway, PA8 -13 (2019 - 2024).



As a result of these unprecedented environmental conditions, the region has faced a surge in demand for treatment capacity, far exceeding the available resources [157]. While climate researchers have long warned of rising temperatures in the north, the rapid pace of change has outstripped expectations. Consequently, the industry has struggled to develop adequate treatment capacity to manage the increased lice pressure. This has compelled many fish farms to harvest large quantities of fish earlier in the year to mitigate further losses. Additionally, limited capacity at processing facilities has led to fish with high lice levels remaining in pens while awaiting transport [158].

There is growing concern that such elevated temperatures may become the new norm. This is forcing the aquaculture industry to prepare for higher lice pressures in the future [158], a trend reflected in an ever-increasing Stingray market share, especially in the north of Norway.



6.4

Control through Optical Delousing

Stingray's optical delousing system employs five key strategies for effective lice control, aimed at promoting sustainable practices and enhancing both fish welfare and production efficiency:

Control the number of adult female lice per fish.

Decrease the frequency of reactive treatments.

Minimize the need for spring delousing.

Lower farmer's reliance on cleaner fish.

Maximize the "area effect" by deploying Stingray systems in interconnected farms.

To evaluate results, these strategies can be compared across several contexts: previous generations at the same location, locations within the same area, neighboring locations with similar conditions, or individual pens within the same location.

While Stingray systematically analyzes results, conducting comparative analyses remains complex. Publicly available data is often inconsistent and insufficient across locations, companies, and geographical regions. One major challenge is the lack of a clear definition for what constitutes a sea lice treatment, making it difficult to determine the actual number of treatments (quantitatively) and assess the extent or scope of each treatment once performed (qualitatively). This is further compounded by varying treatment strategies, such as single-pen versus whole-location treatments, short- versus long-term approaches, and the range of treatment methods employed.

To address the variability in production areas and methods, as well as the lack of clarity in public data on the number and extent of sea lice treatments, Stingray introduced a new parameter called "treatment weeks". This metric calculates the percentage of active locations undergoing treatment during a given week, providing a standardized way to monitor and compare treatment activity.

Treatment Weeks

A parameter introduced by Stingray to address inconsistencies in public data regarding sea lice treatments. This metric represents the percentage of active locations undergoing treatment within a given week, offering a standardized approach to analyzing and comparing treatment activity across regions and conditions.

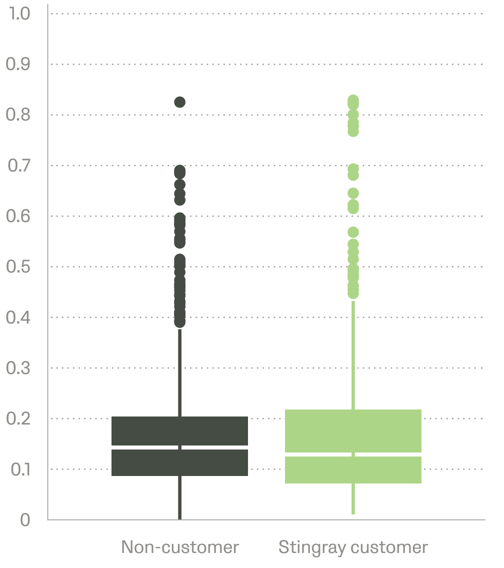
Stingray's effect on sea louse numbers

Average adult female lice per fish reported to the Norwegian Food Safety Authority (Figure 50) show that Stingray customers have a lower adult female louse abundance median compared to non-customers. Non-customers have a slightly higher median but exhibit a lower overall spread in reported lice counts. In contrast, the distribution is higher among Stingray customers. The increased spread is indicative of a higher proportion of Stingray locations achieving low lice numbers, a finding reflected by the lower median.

The median

The median is a measure of central tendency that represents the middle value in a dataset, dividing it into two equal halves, with 50% of the data points below and 50% above when arranged in ascending order.

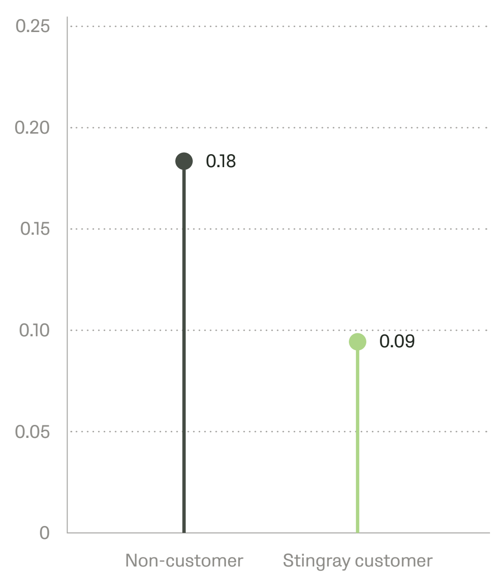
FIGURE 50.
Adult female lice per fish for non-customer and Stingray customer.



The boxplot displays the median (horizontal line inside the box) and the distribution of the dataset; the middle of 50% of the data (the box itself), whiskers that are still considered as non-outliner (line extended from the box) and outliers (data points beyond the whiskers).

The difference is most evident in production area 8. Stingray customers in PA8 reported an average of 0.09 adult female lice per fish in 2024, compared to 0.18 among non-customers (Figure 51). In addition, 0% of the weeks for Stingray locations exceeded the lice limit, compared to 3.64% of weeks of lice limit violations among non-customers.

FIGURE 51.
Average adult female lice per fish in PA8 for Stingray customers and non-customers (2024).

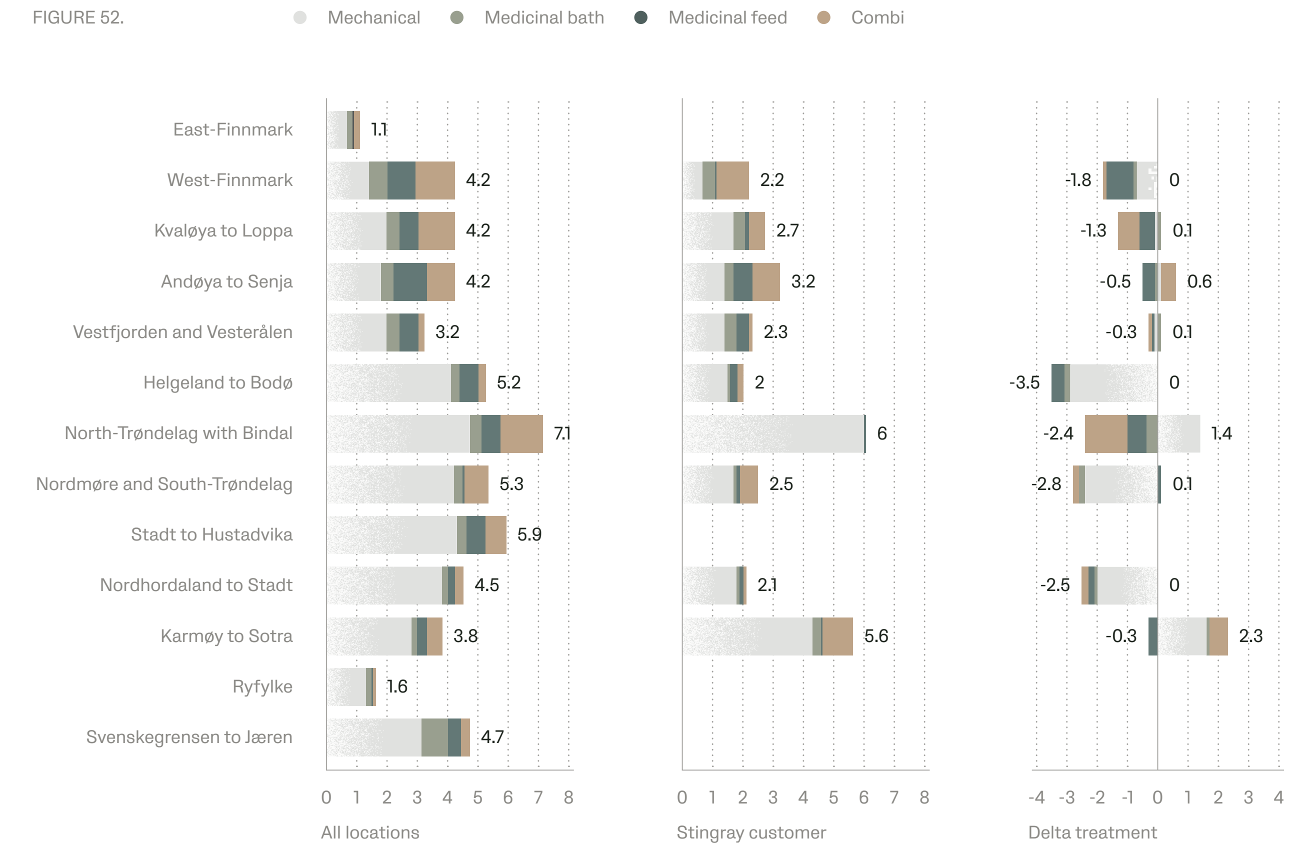


Total number of delousings

Figure 52 illustrates the delta-treatment, defined as the difference in treatment weeks between Stingray customers and non-customers for each delousing category. A negative delta indicates fewer treatment weeks for Stingray customers compared to non-customers. Production areas 12 and 13 have weak negative deltas, while PA9 and 10 have almost no difference.

In contrast, PA4, PA6, and PA8 show substantial improvements; PA4 has two fewer treatment weeks, PA6 has 2.2 fewer treatment weeks and PA8 has three fewer mechanical treatment weeks. However, PA3 and PA11 display an increase in treatment weeks. Stingray has a market share of only 1.3% in production area 7, results in that PA are therefore not representative.

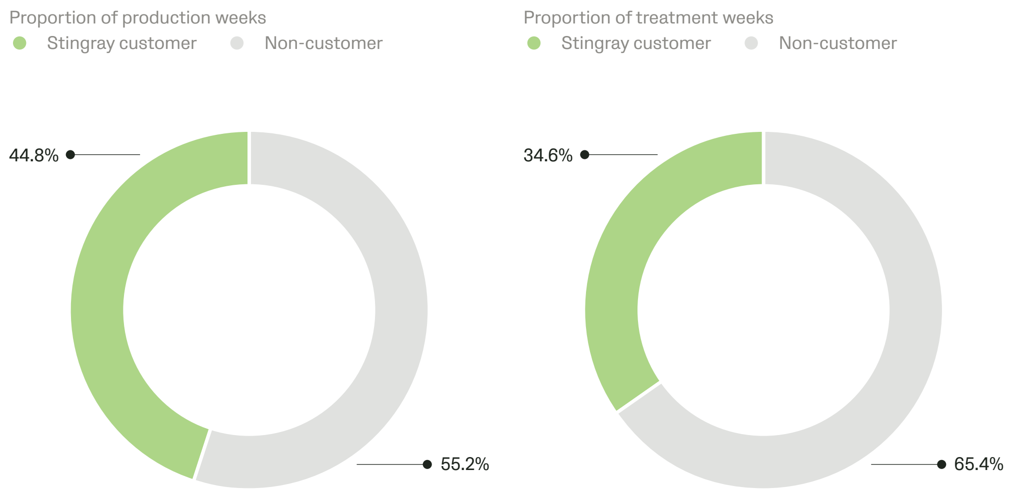
FIGURE 52.



Treatment overview and Stingray effects in 2024. Numbers indicate the total of treatment weeks. Left panel: Average treatment weeks per location for all locations for each delousing category. Mid-panel: Average treatment weeks per location for Stingray-customers for each delousing category. Right panel: Delta treatment per location between Stingray customers and non-customers for each delousing category.

Overall, this year's results are not as pronounced as those observed in 2023 [140] when all areas using Stingray technology experienced fewer treatment weeks than non-customers. This setback in average treatment weeks per location underscores the challenging louse situation encountered this year. However, Stingray's high marked share helped alleviate louse pressure in the most affected areas in 2024. This is best visualized for PA9 and PA10, where 44.8% of the production weeks had laser nodes employed as a primary control measure for sea lice, but accounted only for 34.6% of all treatment weeks (Figure 53). Although 2024 could not match the outstanding operational results of 2023 for certain production areas, Stingray has ultimately reduced the number of delousing operations and helped alleviate the challenges associated with an extraordinarily warm year.

FIGURE 53. Proportion of production and treatments weeks, comparing Stingray customers with non-customers, PA9 &10 (2024).



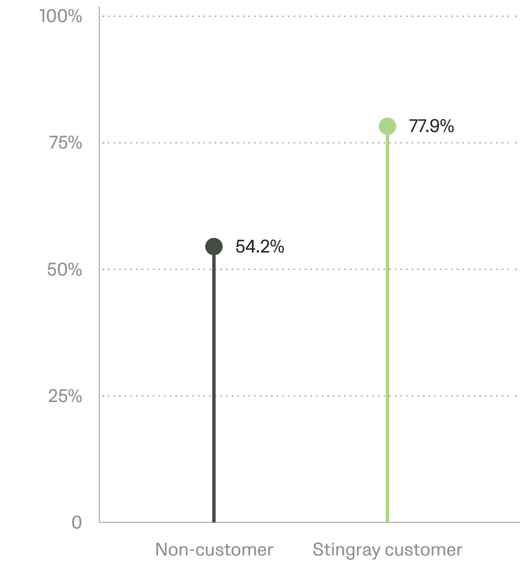
Winter months and spring delousing

Minimizing handling during cold periods is essential for maintaining fish welfare. Stress and mechanical damage can compromise the fish's skin barrier and immune system, making them more vulnerable to infections and diseases [159]. Adding to the challenge, pathogen pressure and bacterial growth are highest during the winter months [160]. Compounding the issue, colder temperatures slow the fish's metabolism and immune response, resulting in slower wound healing [159].

A successful strategy should focus on reducing lice levels without physical handling, ensuring low lice levels in early spring and minimizing lice development in summer and autumn. Since sea lice reproduce more slowly in cold temperatures [22], locations equipped with laser technology can often significantly reduce lice levels and avoid the need for delousing during the winter.

In the first half of 2024, 77.9% of Stingray customers avoided treatment, compared to 54.2% of non-customers (Figure 54).

FIGURE 54. Locations without treatments (%) comparing Stingray customers with non-customer, Q1-Q2 (2024).



In order to protect wild salmon during their peak smolt migration in spring, the legally mandated lice limit has been reduced from 0.5 to 0.2 adult female lice per fish for a limited period in spring [161]. Treatments to reduce lice numbers during this period are referred to as "spring delousing".

Spring delousing periods in Norway

REGION	SPRING DELOUSING PERIOD	PRODUCTION AREAS
Southern Norway	Week 16 to Week 21	PA1 – PA7
Nordland, Troms, and Finnmark	Week 21 to Week 26	PA8 – PA13

Spring delousing frequency

To analyze effects of Stingray use on spring delousing frequency, the actual spring delousing period plus the two preceding weeks are included in the data presented.

In Southern Norway, 82.6% of the Stingray locations avoided spring delousing, compared to 58.3% of non-customers (Figure 55). In the northern regions, the proportions were 91.0% and 69.0%, respectively (Figure 56).

FIGURE 55.
Locations without spring delousing (%) comparing Stingray customers with non-customer, Southern Norway (2024).

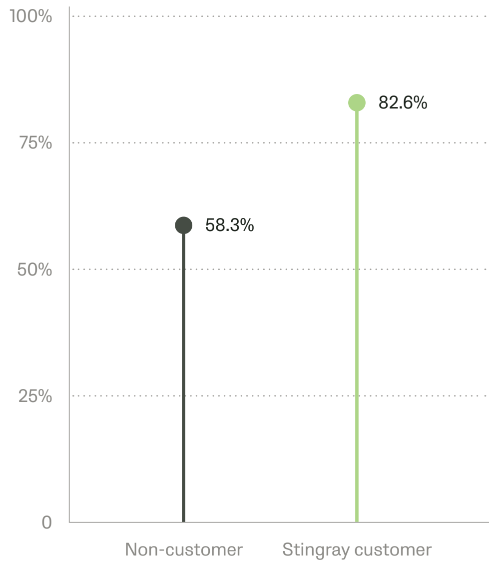
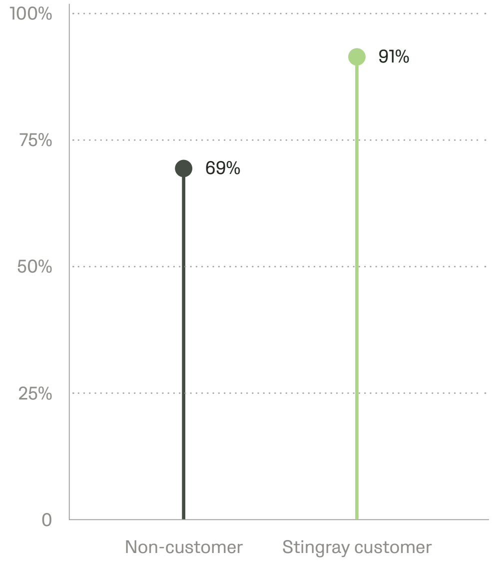


FIGURE 56.
Locations without spring delousing (%) comparing Stingray customers with non-customer, Northern Norway (2024).



As Stingray's market share grows, the need for spring delousing continues to decline. In the first half of 2024, 75.8% of locations using Stingray systems in PA8-12 avoided delousing treatments for fish that were initially stocked in spring 2023, compared to only 34.6% of non-customer locations (Figure 57). This significant improvement is linked to

Stingray's impressive 42.6% market share for this generation in the area, a strong indicator of the system's widespread adoption and effectiveness (Figure 58). The results also highlight the advantage of deploying the Stingray system at the time of smolt stocking, enabling compounded benefits later in the production cycle.

FIGURE 57.
Locations (%) without treatments in the first half of 2024, comparing Stingray customers with non-customers in PA8-12 (spring 2023 generation).

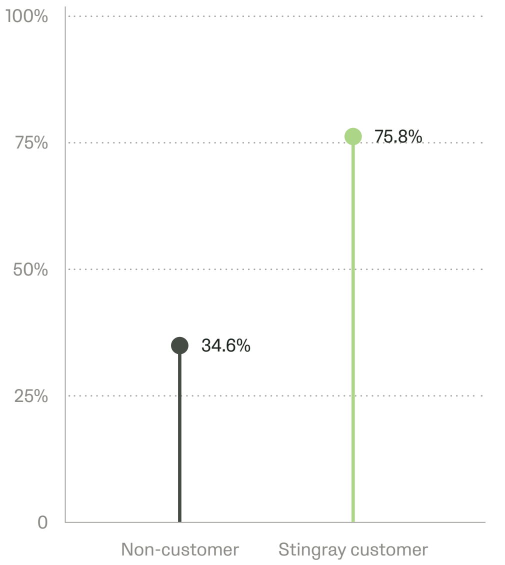
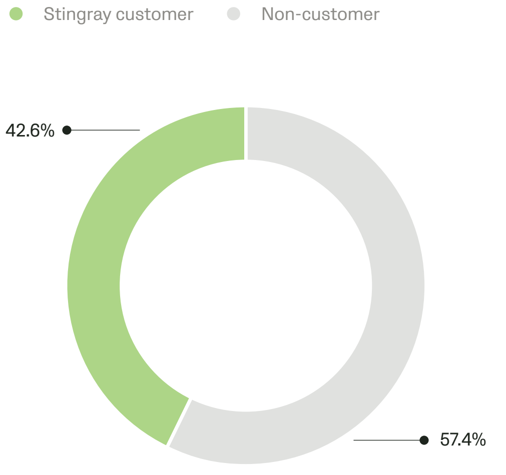


FIGURE 58.
Stingray market share (%) for locations stocking spring 2023 generation fish, Q1-Q2 2024.



To summarize, maintaining fish welfare during winter requires strategies that minimize handling while effectively controlling lice levels. While the Stingray system provides benefits year-round, additional advantages can be observed in spring, particularly during the critical smolt migration period when lice limits are tightened to protect wild salmon. These benefits are most evident in regions and fish generations with higher Stingray coverage, demonstrating the system's effectiveness for single location as well as area control - and its growing role in sustainable lice management.

6.5

Monitoring Wounds and Recovery

Background

Fish skin is a vital organ that plays a crucial role in the overall health and survival of the fish. It provides both physical and chemical protection and serves as the largest and primary barrier against a constantly changing and often challenging environment [162]. Understanding the structure and function of fish skin is essential to addressing the challenges posed by injuries and infections in aquaculture.

The fish's skin is composed of multiple layers with distinct functions. The outermost layer, the epidermis, is primarily made up of epithelial and mucus-secreting cells that help prevent water loss and play a crucial role in wound healing. When the skin is injured, these cells form tight bonds over the surface to repair the damage [159]. The mucus is not just a physical barrier but part of the innate immune system that actively deals as a first line of defense against microbes and other pathogens in the water [93]. Beneath the epidermis lies the dermis, a collagen-rich layer that provides strength and elasticity. This inner layer also contains the fish's scales, which offer further mechanical protection [159]. Injuries to these layers can have a significant impact on the fish's overall health status.

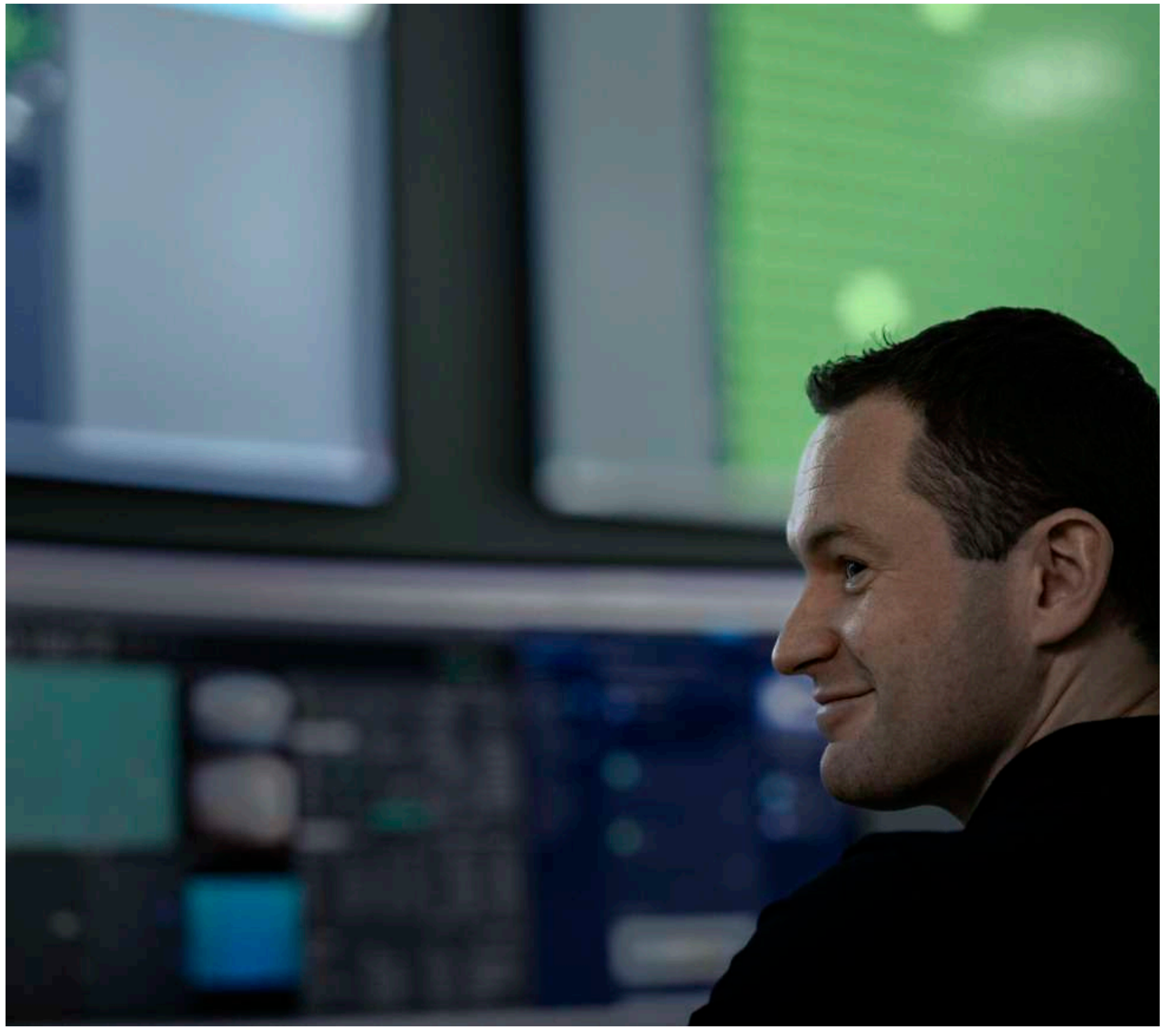
In aquaculture, injuries to fish skin are a common issue, often linked to environmental factors, diseases, and handling practices. These injuries weaken the fish's first line of defense, making them more vulnerable to infections and stress. Aside from gill disease, mechanical damage associated with non-medicinal delousing and winter ulcer disease are the two leading causes of mortality and reduced animal welfare in the aquaculture industry [6]. The combination of physical injury and stress during handling significantly weakens the fish's immune defenses, underlining the importance of minimizing handling to improve fish welfare and health [159].

During autumn and winter [6] wounds are often caused by winter ulcer disease, with the causative agent *M. viscosa* [92]. This bacterium thrives in cold temperatures and primarily affects the lateral scale-bearing areas of the fish. Fish, being ectothermic animals, reflect the surrounding environment's temperature. Cold temperatures reduce their metabolic rate and consequently slow wound healing [159]. Vaccines are available and represent an important prophylactic strategy, however, they do not provide complete protection [160].

In contrast to winter ulcer disease, wound outbreaks caused by the bacterium *Tenacibaculum finnmarkense* Olsen et al. 2020 primarily affect the skin without scales, particularly on the head and fins of small, newly stocked fish [163]. Larger fish can also develop wounds when small injuries in the skin become colonized by *Tenacibaculum* spp., leading to larger lesions. These wounds, often referred to as non-classical winter ulcers [164], are included in Stingray's wound detection system if they result in outbreaks on the fish's body. Currently, there is no vaccine available for this condition, making a better understanding of the transmission process and preventative methods the most effective tools for reducing its prevalence [160].

Environmental factors, such as jellyfish blooms, pose additional challenges to wound management alongside bacterial infections. String jellyfish blooms, observed consistently over the past three years, typically occur in late autumn between October and December. These blooms can cause direct damage to fish by leaving sting marks on their skin or indirect harm by inducing stress responses, such as panic or escape behavior [165].

Traditionally, best practices for assessing wound quantity and quality have relied on fragmented knowledge and subjective assessments on both live fish and fish collected during routine mortality collection. Systematic and well-defined documentation of wounds is essential for improving control over fish health and predicting and avoiding losses. This is crucial, not only for individual fish groups but also for identifying more precise trends throughout a production cycle.



Results

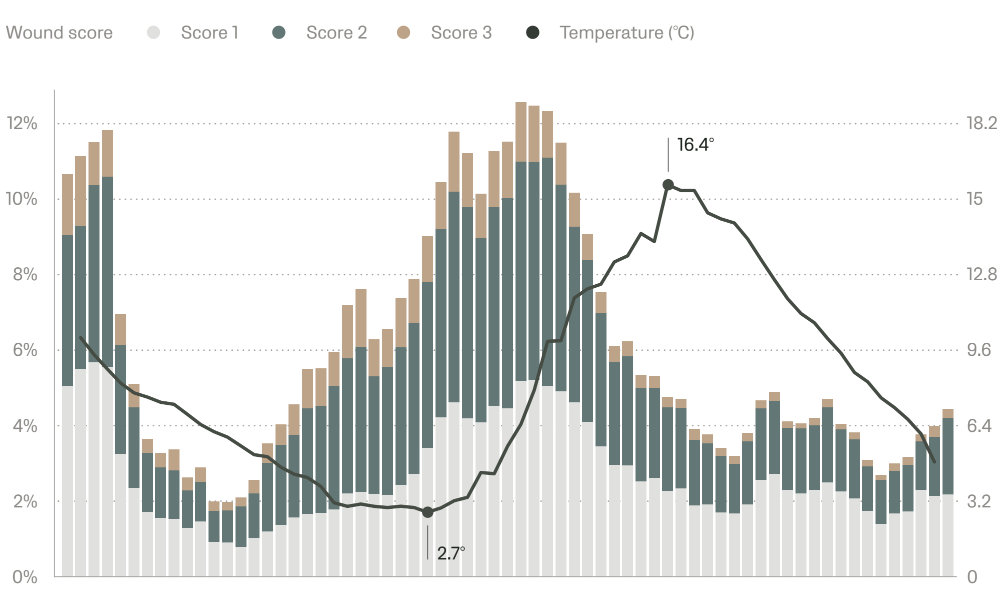
The results presented here are derived from wound detector registrations in production area 10 (PA10), which has the largest market share, providing a substantial sample size to ensure statistically robust outcomes. Consequently, these findings can be considered broadly representative of most aquaculture regions in Norway.

A distinct difference in wound abundance is evident across the two stocking strategies, spring vs. autumn stocking. Smolts stocked in autumn 2023 had a higher percentage of wounds upon transfer to the sea as shown in Figure 59. This vulnerability stems from the transition to a new environment, during which the skin is exposed to unfamiliar conditions, and the immune system experiences a temporary suppression. However, this reduction in immunity is brief, as the skin's barrier function generally recovers over time [159]. During this period, emaciated fish may either be removed manually or succumb to mortality. The recovery process is reflected by a noticeable decline in wound prevalence within one month after stocking.

Looking at the aggregated data for G23 autumn-stocked salmonids, the fish reached a peak in wound prevalence at a sea temperature of approximately 9-10℃ in early June 2024. An increase in the number of wounds was noted already at 5℃, followed by a steady increase towards summer. A high incidence of wounds at the time of stocking (autumn), may mask the possibility that the actual increase of winter ulcers begins already from 10℃, as recorded by Stingray for spring-stocked salmonids.

By Q3, both frequency and severity of wounds generally decline, driven by higher sea temperatures, natural healing processes and the removal of severely affected fish. The graph shows a decrease in wound abundance from 9-10℃ when sea temperatures are on a rising trend, which is applicable to all Stingray wound scores (Figure 59).

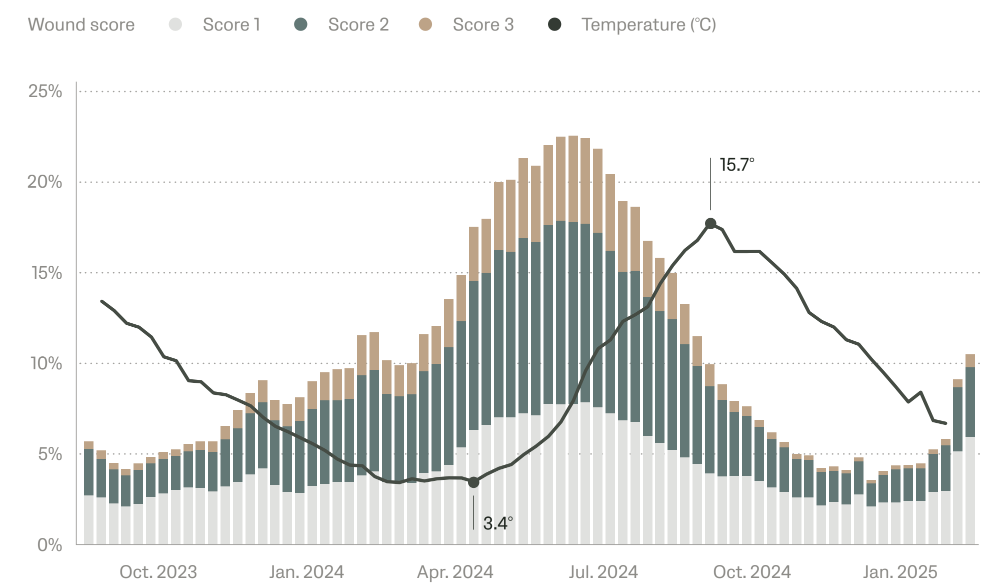
FIGURE 59.
Wound development (% of wound score) and average sea temperature for Autumn stocked fish (2023 generation, PA10).



Spring-stocked 2023 generation of salmonids exhibit a more predictable cycle of wound development and healing, following similar trends to autumn-stocked salmonids. Unlike autumn salmonids, however, spring fish typically avoid smolt transfer wounds but rather experience other causes of wound formation. Due to their longer time in the sea, these fish are more likely to experience skin damage caused by handling and environmental conditions in the pens. As a result, there are substantially higher registrations of wounds during their first winter at sea, peaking at 25% wound abundance compared to 17% for autumn-stocked salmonids.

For the spring-stocked 2023 generation, an increase in wound prevalence was already observed at 10℃ in autumn, as temperatures decline toward the first winter at sea. This trend is evident for both wound scores 1 and 2, whereas an escalation in wound score 3 was recorded slightly later, around 8℃. A further and more pronounced increase occurred when temperatures dropped to 3℃, the lowest recorded mean temperature (Figure 60).

FIGURE 60.
Wound development and average sea temperature for spring stocked fish (2023 generation, PA10).



The analysis emphasizes the importance of continuous wound monitoring in aquaculture for managing wound development across different stocking strategies. Autumn-stocked salmonids are more vulnerable to wounds shortly after sea transfer due to temporary immune suppression, while spring-stocked salmonids experience higher wound prevalence during their first winter, driven by handling and environmental factors.

Moreover, there is a clear indication of an increased wound risk once temperatures approach 10℃ during autumn. This constitutes a critical factor when considering fish handling and implementing preventive measures.

Continuous wound monitoring provides valuable insights into these trends, allowing producers to anticipate periods of increased wound prevalence and implement timely interventions. It also supports efforts to understand the factors driving wound reductions, such as natural healing and fish removal, enabling better predictions and strategies for maintaining fish welfare.
By tracking wound dynamics in real-time, aquaculture operations can proactively address challenges, optimize stocking strategies, and improve overall fish health and sustainability.

Quotes from Stingray employees

“2024 has been a transformative year for our team and company. We have successfully embraced new ways of collaboration, unified departments into a single Control vertical, and enhanced our capabilities with new talent and innovative tools. Challenges along the way have pushed us to grow and adapt. These moments, however, have inspired us to achieve new levels of excellence.

This year’s milestones reflect not only growth but also the collaborative efforts that have laid the foundation for long-term success, driven by adaptability and innovation. With optimism, I look to the future, confident that we are poised to achieve even greater success and continue delivering exceptional value to our customers.”

DOMAGOJ MAKSAN,
Control Manager – Stingray Marine Solutions AS

“We expected a hectic year in 2024 as we increased production by 85% compared to the previous year. Looking back at the success of 2024 now, it was not hectic but rather the result of a well-oiled machine driven by skilled employees. This is particularly impressive considering that this is the first full year of operation in the new factory.”

ØYVIND MATHIAS FJELD,
Hardware Manager – Stingray Marine Solutions AS

“The most important thing is continuing to help fish farmers improve their sustainability for fish and people - through application of our technology.”

GEIR INGE RØDSETH,
CFO – Stingray Marine Solutions AS

“People are at the heart of our mission to improve fish health. In 2024, we took major steps on the HR front - expanding our workforce by 45 % across the company, digitalizing our processes and maintaining a laser focus on developing our talented employees. As we continue to support those working to enhance fish health for our customers, we remain committed to fostering a strong, future-ready workforce.”

CECILIE KNUDSEN,
Head of HR – Stingray Marine Solutions AS

"In addition to continuously enhancing our laser and automated detection technologies, the rapid expansion of our operational nodes and locations demands full focus on system infrastructure and architectural performance. While our requirements remain exceptionally high, the Stingray ecosystem has grown significantly over the past year. To meet these demands, we have prioritized scalability in throughput capacity, improved the quality of our project processes, maintained system modularity and transparency, ensured clear separation of concerns, and enhanced usability for both external and internal use cases. In 2024, we successfully achieved these goals and remain committed to staying ahead of future challenges."

ESPEN BØRRUD,
Software Manager – Stingray Marine Solutions AS

"Throughout 2024, the growing number of new and active locations has significantly increased the workload, making monitoring quite demanding. Fortunately, our systems continue to improve, becoming more efficient and user-friendly. We have a strong collaboration with our customers, who are highly engaged and eager to learn–sometimes requiring a careful balance in how much information we share.

On a personal note, customers have gotten used to me being around early in the morning, and there is always plenty to dive into as soon as my day begins. Fortunately, I'm part of a fantastic team where we always have each other's backs and I am looking forward to welcoming new colleagues as the workload continues to grow."

HILDE ENDRESEN,
Monitoring Operator – Stingray Marine Solutions AS

"Over the years, deploying nodes in the open sea has become a well-refined process. However, with demand continuing to grow, we are now installing at an accelerated pace.

To support this expansion and ensure smooth operations, we have nearly doubled our technical team, enabling continuous 24/7 operations.

Our ability to maintain exceptionally high uptime in 2024 was driven by close collaboration with customers and a hands-on approach at every level. Additionally, significant upgrades to our on-site infrastructure have strengthened our capabilities. With over 110 sites now online, we can accurately monitor performance in order to further optimize our operations."

ANDERS FJELLVANG,
Operations Manager – Stingray Marine Solutions AS

Bibliography

1. Fiskeridepartementet, *Hva er trafikklyssytemet?*
2. Regjeringen, *Ny fargelegging i trafikklyssystemet for havbruk*. 2024.
3. Myklebust, I.E., et al., *Rapport om hvordan Trafikklyssystemet påvirker arbeidet med å oppnå målene satt i Kvalitetsnorm for villaks*. 2024.
4. Regjeringen, *Nå er forskriften som regulerer laksevekst fastsatt*. 2024.
5. Boxshall, G.A. and D. Defaye, *Pathogens of wild and farmed fish: sea lice*. 1993: CRC Press.
6. Sommerset I, W.-N.J., Moldal T, Oliveira VHS, Svendsen JC, Haukaas A and Brun E., *Norwegian Fish Health Report 2023*. Veterinærinstituttets rapportserie nr. #8b/2024, 2024: p. 12.
7. Björnsson, B., et al., *The State and Future of Aquaculture in Iceland*. 2023.
8. Hemmingsen, W., et al., *Caligus elongatus and other sea lice of the genus Caligus as parasites of farmed salmonids: a review*. Aquaculture, 2020. **522**: p. 735160.
9. Øverli, Ø., et al., *Ectoparasitic sea lice (Lepeophtheirus salmonis) affect behavior and brain serotonergic activity in Atlantic salmon (Salmo salar L.): perspectives on animal welfare*. Physiology & behavior, 2014. **132**: p. 44-50.
10. Bowers, J., et al., *The physiological response of Atlantic salmon, Salmo salar L., to a single experimental challenge with sea lice, Lepeophtheirus salmonis*. Journal of Fish Diseases, 2000. **23**(3): p. 165-172.
11. Grimnes, A. and P. Jakobsen, *The physiological effects of salmon lice infection on post-smolt of Atlantic salmon*. Journal of Fish Biology, 1996. **48**(6): p. 1179-1194.
12. Noble, C., et al., *Welfare Indicators for farmed Atlantic salmon: tools for assessing fish welfare*. 2018, Nofima.
13. Bui, S., et al., *Optimising delousing strategies: developing best practice recommendations for maximal efficacy and positive welfare-Final Report*. Rapport fra havforskningen, 2023.
14. Overton, K., et al., *Salmon lice treatments and salmon mortality in Norwegian aquaculture: a review*. Reviews in Aquaculture, 2019. **11**(4): p. 1398-1417.
15. Lovdata, *Forskrift om bekjempelse av lakselus i akvakulturanlegg, N.-o. fiskeridepartementet*, Editor. 2012: Lovdata.
16. Wall, R. and D. Shearer, *Veterinary ectoparasites: biology, pathology and control*. 2008: John Wiley & Sons.
17. Fiskeridirektoratet, *Akvakulturstatistikk: laks, regnbueørret og ørret (offisiell statistikk)*. 2023.
18. Hamre, L.A., et al., *The salmon louse Lepeophtheirus salmonis (Copepoda: Caligidae) life cycle has only two chalimus stages*. PloS one, 2013. **8**(9): p. e73539.
19. Piasecki, W., B.A. Venmathi Maran, and S. Ohtsuka, *Are we ready to get rid of the terms "chalimus" and" preadult" in the caligid (Crustacea: Copepoda: Caligidae) life cycle nomenclature?* Pathogens, 2023. **12**(3): p. 460.
20. Piasecki, W., *Cykl rozwojowy Caligus elongatus von Nordmann, 1832 [Crustacea, Cepopoda, Siphonostomatoida]*. Rozprawy. Akademia Rolnicza w Szczecinie, 1995. **165**.
21. Ugelvik, M.S., S. Maehle, and S. Dalvin, *Temperature affects settlement success of ectoparasitic salmon lice (Lepeophtheirus salmonis) and impacts the immune and stress response of Atlantic salmon (Salmo salar)*. J Fish Dis, 2022. **45**(7): p. 975-990.
22. Dalvin, S. and F. Oppedal, *Utvikling av lakselus ved ulik temperatur og lys-TEMPLUS*. Rapport fra havforskningen, 2019.
23. Skern-Mauritzen, R., et al., *Parasite development affect dispersal dynamics; infectivity, activity and energetic status in cohorts of salmon louse copepodids*. Journal of Experimental Marine Biology and Ecology, 2020. **530**: p. 151429.
24. Heuch, P., J. Nordhagen, and T. Schram, *Egg production in the salmon louse [Lepeophtheirus salmonis (Krøyer)] in relation to origin and water temperature*. Aquaculture research, 2000. **31**(11): p. 805-814.
25. Abdelrhman, M.A., *Modeling water clarity and light quality in oceans*. Journal of Marine Science and Engineering, 2016. **4**(4): p. 80.
26. Capuzzo, E., et al., *Decrease in water clarity of the southern and central North Sea during the 20th century*. Global change biology, 2015. **21**(6): p. 2206-2214.
27. Tengesdal, Ø.A., *Measurement of seawater refractive index and salinity by means of optical refraction*. 2012, The University of Bergen.
28. Schiebener, P., et al., *Refractive index of water and steam as function of wavelength, temperature and density*. Journal of physical and chemical reference data, 1990. **19**(3): p. 677-717.
29. Bixler, G.D. and B. Bhushan, *Biofouling: lessons from nature*. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 2012. **370**(1967): p. 2381-2417.
30. Hoeher, P.A., et al., *UVC-Based Biofouling Suppression for Long-Term Deployment of Underwater Cameras*. IEEE Journal of Oceanic Engineering, 2023.
31. Tully, O., et al., *Use of cleaner-wrasse (Centrolabrus exoletus (L.) and Ctenolabrus rupestris (L.)) to control infestations of Caligus elongatus Nordmann on farmed Atlantic salmon*. Aquaculture, 1996. **142**(1-2): p. 11-24.
32. Hesthagen T, W.R., Bjelland O, Byrkjedal I, Fiske P, Lynghammar A, Nedreaas K og Straube N. *Fisker: Vurdering av berggylt Labrus bergylta Ascanius, 1767*. Rødlista for arter 2021 2021 [cited 2024; Available from: https://artsdatabanken.no/lister/rodlisteforarter/2021/29377
33. Artsdatabanken. *Grønngylte Symphodus melops (Linnaeus, 1758)*. [cited 2025 January 16]; Available from: https://artsdatabanken.no/taxon/Symphodus%20melops/43044.
34. Artsdatabanken. *Blåstål Labrus mixtus Linnaeus, 1758*. [cited 2025 Januray 16]; Available from: https://artsdatabanken.no/taxon/Labrus%20mixtus/43035.
35. Artsdatabanken. *Bergnebb Ctenolabrus rupestris (Linnaeus, 1758)*. [cited 2025 January 16]; Available from: https://artsdatabanken.no/taxon/Ctenolabrus%20rupestris/43042
36. Artsdatabanken. *Gressgylte Centrolabrus exoletus (Linnaeus, 1758)*. [cited 2025 January 16]; Available from: https://artsdatabanken.no/taxon/Centrolabrus%20exoletus/43040
37. Artsdatabanken. *Rognkjeks Cyclopterus lumpus Linnaeus, 1758*. [cited 2025 January 16]; Available from: https://artsdatabanken.no/taxon/Cyclopterus%20lumpus/42937
38. Bjordal, Å. *Cleaning symbiosis between wrasses (Labridae) and lice infested salmon (Salmo salar) in mariculture*. 1988. ICES.
39. Misters, A.a.P., D, *Use of "cleaner fish" in UK aquaculture: current use, concerns and recommendations*. 2021.
40. Blanco Gonzalez, E. and F. de Boer, *The development of the Norwegian wrasse fishery and the use of wrasses as cleaner fish in the salmon aquaculture industry*. Fisheries Science, 2017. **83**(5): p. 661-670.
41. Pincinato, R.B.M., et al., *Biological control of a parasite: The efficacy of cleaner fish in salmon farming*. Ecological Economics, 2025. **227**: p. 108359.
42. Gutierrez Rabadan, C., et al., *Development, validation and testing of an Operational Welfare Score Index for farmed lumpfish Cyclopterus lumpus L*. Aquaculture, 2021. **531**.
43. Imsland, A.K.D., P. Reynolds, and L. Boissonnot, *Effects of different feeding regimes on growth, cataract development, welfare, and histopathology of lumpfish (Cyclopterus lumpus L.)*. Aquaculture, 2024. **578**.
44. Reynolds, P., A.K.D. Imsland, and L. Boissonnot, *Causes of Mortality and Loss of Lumpfish Cyclopterus lumpus*. Fishes, 2022. **7**(6).
45. Imsland, A.K.D., et al., *Improving survival and health of lumpfish (Cyclopterus lumpus L.) by the use of feed blocks and operational welfare indicators (OWIs) in commercial Atlantic salmon cages*. Aquaculture, 2020. **527**.
46. Halvorsen, K.J., Terje; Ruud, Marthe Marie; Skiftesvik, Anne Berit, *Kunnskapsstøtte og råd for regulering av fisket etter leppefisk i 2024*, in *Rapport fra Havforskningen*. 2023. p. 40.
47. Barrett, L.T., et al., *Effect of cleaner fish on sea lice in Norwegian salmon aquaculture: a national scale data analysis*. International journal for parasitology, 2020. **50**(10-11): p. 787-796.
48. Engebretsen, S., et al., *Salmon lice (Lepeophtheirus salmonis) in the stomach contents of lumpfish (Cyclopterus lumpus) sampled from Norwegian fish farms: Relationship between lice grazing and operational conditions*. Aquaculture, 2023. **563**: p. 738967.
49. Imsland, A.K.D., et al., *It works! Lumpfish can significantly lower sea lice infestation in large-scale salmon farming*. Biology Open, 2018. **7**(9): p. bio036301.
50. Imsland, A.K.D. and P. Reynolds, *In lumpfish We Trust? The Efficacy of Lumpfish Cyclopterus lumpus to Control Lepeophtheirus salmonis Infestations on Farmed Atlantic Salmon: A Review*. Fishes, 2022. **7**(5).
51. Nilsen, R., et al., *Lakselusinfestasjon på Vill Laksefisk Våren 2022*, in *Framdriftsrapport til Mattilsynet*, G.L. Taranger and K.K. Boxaspen, Editors. 2022, Institute for Marine Research. p. 27.
52. Sandlund, N., et al., *Fiskeri og bruk av rensefisk i norsk oppdrett, in Kunnskapsstatus*, G.L. Taranger, Editor. 2024, Institute of Marine Research. p. 44.
53. Vatlestad, J., *Derfor slutter Salmar med rensefisk*. 2024, Intrafish: Bergen.
54. Powell, M.D., P. Reynolds, and T. Kristensen, *Freshwater treatment of amoebic gill disease and sea-lice in seawater salmon production: Considerations of water chemistry and fish welfare in Norway*. Aquaculture, 2015. **448**: p. 18-28.
55. Rabe, B., et al., *Searching for sea lice: surveillance to assess environmental infection pressures to model and inform sea lice infestation management*. Aquaculture Environment Interactions, 2024. **16**: p. 241-262.
56. Geitung, L., et al., *Crowding Causes Detachment and Loss of Mobile Sea Lice: Fine-Meshed Crowding Nets May Mitigate Spread*. Available at SSRN 5019534.
57. Hesthagen T, W.R., Bjelland O, Byrkjedal I, Fiske P, Lynghammar A, Nedreaas K og Straube N Fisker: *Vurdering av laks Salmo salar for Norge. Rødlista for arter 2021. Artsdatabanken*. 2021 [cited 2024 December 23rd]; Available from: https://artsdatabanken.no/lister/rodlisteforarter/2021/8149.
58. Kellogg, K.A., *Salmon on the edge*. Trends in Ecology & Evolution, 1999. **14**(2): p. 45-46.
59. Noakes, D.J., R.J. Beamish, and M.L. Kent, *On the decline of Pacific salmon and speculative links to salmon farming in British Columbia*. Aquaculture, 2000. **183**(3-4): p. 363-386.
60. Torrissen, O., et al., *Salmon lice–impact on wild salmonids and salmon aquaculture*. Journal of fish diseases, 2013. **36**(3): p. 171-194.
61. North Atlantic Salmon Conservation Organization, N. *State of North Atlantic Salmon*. 2019 [cited 2024; Available from: https://nasco.int/wp-content/uploads/2020/05/SoS-final-online.pdf.
62. Vitenskapelig råd for lakseforvaltning. *Status of wild Atlantic salmon in Norway 2024*. 2024; 19:[Available from: https://www.vitenskapsradet.no/Nyheter/status-of-wild-atlantic-salmon-in-norway-2024.
63. Gallagher, B.K., S. Geargeoura, and D.J. Fraser, *Effects of climate on salmonid productivity: A global meta-analysis across freshwater ecosystems*. Global Change Biology, 2022. **28**(24): p. 7250-7269.
64. Åsheim, E.R., et al., *Atlantic salmon (Salmo salar) age at maturity is strongly affected by temperature, population and age-at-maturity genotype*. Conservation Physiology, 2023. **11**(1): p. coac086.
65. Shephard, S. and P. Gargan, *Wild Atlantic salmon exposed to sea lice from aquaculture show reduced marine survival and modified response to ocean climate*. ICES Journal of Marine Science, 2021. **78**(1): p. 368-376.
66. Vollset, K.W., et al., *Impacts of parasites on marine survival of Atlantic salmon: A meta-analysis*. Fish and Fisheries, 2016. **17**(3): p. 714-730.
67. Vollset, K.W., et al., *Direct evidence of increased natural mortality of a wild fish caused by parasite spillback from domestic conspecifics*. Proceedings of the Royal Society B, 2023. **290**(1991): p. 20221752.
68. Lerøy Seafood Group, L. *How do we produce salmon?* [cited 2024 December 4th]; Available from: https://www.leroyseafood.com/en/about-us/about-leroy/how-do-we-produce-salmon/.
69. Lovdata, *Lov om dyrevern*, L.-o. matdepartementet, Editor. 1974: Lovdata.
70. Norwegian Ministry of Agriculture and Food, *St.meld. nr. 12 (2002-2003) Om dyrehold og dyrevelferd*, L.-o. matdepartementet, Editor. 2002-2003: regjeringen.no.
71. Lovdata, *Lov om dyrevelferd*, L.-o. matdepartementet, Editor. 2009.
72. Regjeringen, *Dyrevelferdsmeldingen*, L.-o. matdepartementet and N.-o. fiskeridepartementet, Editors.: regjeringen.no.
73. Lovdata, *Forskrift om drift av akvakulturanlegg (akvakulturdriftsforskriften)*, N.-o. fiskeridepartementet, Editor. 2008.
74. Mattilsynet, *Mattilsynets arbeid med dyrevelferd: Årsrapport 2023*. 2024.
75. Fiskeri- og havbruksnæringens forskningsfinansiering, F., *LAKSVEL; utvikling og evaluering av metode for rutinemessig velferdsovervåkning*. 2022.
76. Segner, H., et al., *Health of farmed fish: its relation to fish welfare and its utility as welfare indicator*. Fish physiology and biochemistry, 2012. **38**: p. 85-105.
77. Kindschi, G.A., *Method for quantifying degree of fin erosion*. The Progressive Fish-Culturist, 1987. **49**(4): p. 314-315.
78. Ellis, T., et al., *Further development of the "Fin Index" method for quantifying fin erosion in rainbow trout*. Aquaculture, 2009. **289**(3-4): p. 283-288.
79. Good, C., et al., *The effects of ozonation on performance, health and welfare of rainbow trout Oncorhynchus mykiss in low-exchange water recirculation aquaculture systems*. Aquacultural engineering, 2011. **44**(3): p. 97-102.
80. Konrad, J. and C. Pietsch, *Critical review of common approaches to evaluate fin condition of farmed fish*. Bulletin of the European Association of Fish Pathologists, 2024.
81. International Electrotechnical Commission, I., *Safety of laser products - Part 1: Equipment classification and requirements*, in IEC 60825-1. 2014: International Standard. p. 220.
82. Laser Safety Facts. *Laser classification table*. 2023 [cited 2024 December 4th]; Available from: https://www.lasersafetyfacts.com/laserclasses.html.
83. Carleton, K.L., et al., *Seeing the rainbow: mechanisms underlying spectral sensitivity in teleost fishes*. J Exp Biol, 2020. **223**(Pt 8).
84. Lund, D.J. and B.J. Lund, *Laser-induced ocular effects in the retinal hazard region*. ch, 2020. **9**: p. 171-186.
85. Robbins, C., et al., *Assessing topical treatment interventions on Scottish salmon farms using a sea lice (Lepeophtheirus salmonis) population model*. Aquaculture, 2010. **306**(1-4): p. 191-197.
86. Noble, C., et al., *Welfare indicators for farmed rainbow trout: tools for assessing fish welfare*. 2020.
87. Gur, D., et al., *Light Manipulation by Guanine Crystals in Organisms: Biogenic Scatterers, Mirrors, Multilayer Reflectors and Photonic Crystals*. Advanced Functional Materials, 2016. **27**(6).
88. Levy-Lior, A., et al., *Guanine-based biogenic photonic-crystal arrays in fish and spiders*. Advanced Functional Materials, 2010. **20**(2): p. 320-329.
89. Eyal, Z., et al., *Controlled pH Alteration Enables Guanine Accumulation and Drives Crystallization within Iridosomes*. BioRxiv, 2024: p. 2024.07.20.604036.
90. Harris, J. and S. Hunt, *The fine structure of iridophores in the skin of the Atlantic salmon (Salmo salar L.)*. Tissue and Cell, 1973. **5**(3): p. 479-488.

91. Sveen, L., C. Karlsen, and E. Ytteborg, *Mechanical induced wounds in fish–a review on models and healing mechanisms.* Reviews in Aquaculture, 2020. **12**(4): p. 2446-2465.
92. Takle, H.R., et al., *Sårproblematikk og hudhelse i laks-og regnbueørrettoppdrett.* 2015.
93. Dash, S., et al., *Epidermal mucus, a major determinant in fish health: a review.* Iranian journal of veterinary research, 2018. **19**(2): p. 72.
94. Elliott, D.G., C.M. Conway, and L.J. Applegate, *Evaluation of fast green FCF dye for non-lethal detection of integumental injuries in juvenile Chinook salmon Oncorhynchus tshawytscha.* Diseases of aquatic organisms, 2009. **84**(2): p. 139-150.
95. Mogdans, J., *The processing of hydrodynamic stimuli with the fish lateral line system, in Oxford Research Encyclopedia of Neuroscience.* 2022.
96. Fernö, A., et al., *Inside the fish brain: cognition, learning and consciousness.* The welfare of fish, 2020: p. 149-183.
97. Wang, T.-s., et al., *Hierarchical Image Quality Improvement Based on Illumination, Resolution, and Noise Factors for Improving Object Detection.* Electronics, 2024. **13**(22): p. 4438.
98. Kohavi, R., D. Tang, and Y. Xu, *Trustworthy online controlled experiments: A practical guide to a/b testing.* 2020: Cambridge University Press.
99. Agledal, T.H., *Digital velferdsovervåking og effekt av kameradybde på estimert skadefrekvens hos Atlantisk laks (Salmo salar) i en oppdrettsmerd.* 2022, The University of Bergen.
100. Nilsson, J., et al., *Laksvel-Standardisert operasjonell velferdsovervåking for laks i matfiskanlegg.* Rapport fra havforskningen, 2022.
101. Thorvaldsen, T., K. Frank, and L.M. Sunde, *Practices to obtain lice counts at Norwegian salmon farms: status and possible implications for representativity.* Aquaculture Environment Interactions, 2019. **11**: p. 393-404.
102. Dalvin, S., et al., *Salmon lice detached during aquaculture practices survive and can reinfest other hosts.* preprint.
103. Geitung, L., et al., *Crowding causes detachment and loss of mobile sea lice - Fine-meshed crowding nets may mitigate spread.* preprint.
104. Thorvaldsen, T., K. Frank, and L.M. Sunde, *Lusetellingsmetoder i lakseoppdrett-en beskrivelse av dagens status.* 2018.
105. Nedrejord, R. *Mattilsynet ønsker automatisk lusetelling – mener den manuelle tellingen er gått ut på dato.* 2022.
106. Mattilsynet. *Veileder for søknader om nye metoder for telling og rapportering av lakselus.* 2023; Available from: https://www.mattilsynet.no/fisk-og-akvakultur/fiskesykdommer/lakselus/veileder-for-soknader-om-nye-metoder-for-telling-og-rapportering-av-lakselus.
107. Saleh, A., et al., *Applications of deep learning in fish habitat monitoring: A tutorial and survey.* Expert Systems with Applications, 2024. **238**: p. 121841.
108. Mattilsynet, *Veiledning om kravene til søknader om å bruke nye metoder for å telle og rapportere lakselus.* 2020.
109. Vandeskog, S., et al., *Sammenlikning av automatiske lusetellingssystemer under varierende forhold, in Norsk fiskeoppdrett.* 2024, kyst.no.
110. Jaworski, A. and J.C. Holm, *Distribution and structure of the population of sea lice, Lepeophtheirus salmonis Krøyer, on Atlantic salmon, Salmo salar L., under typical rearing conditions.* Aquaculture Research, 1992. **23**(5): p. 577-589.
111. Andersen, M.F., *Fallacy of a correction factor in automated computer vision-based lice counting.* 2023, The University of Bergen.
112. Bui, S., et al., *Standardisation of manual louse counts for validation of automatic camera systems, in Rapport fra Havforskningen.* 2024, Institute of Marine Research.
113. BarentsWatch. *Norwegian Fish Health.* [cited 2024-2025; v.25.1.19:[Available from: https://www.barentswatch.no/.
114. Heuch, P.A., G. Gettinby, and C.W. Revie, *Counting sea lice on Atlantic salmon farms — Empirical and theoretical observations.* Aquaculture, 2011. **320**(3-4): p. 149-153.
115. Revie, C.W., et al., *Clustering of parasites within cages on Scottish and Norwegian salmon farms: alternative sampling strategies illustrated using simulation.* Prev Vet Med, 2007. **81**(1-3): p. 135-47.
116. Revie, C.W., et al., *Evaluating the effect of clustering when monitoring the abundance of sea lice populations on farmed Atlantic salmon.* Journal of Fish Biology, 2005. **66**: p. 773-783.
117. Baille, M., et al., *The use of prevalence as a measure of lice burden - A case study on Scottish Atlantic salmon farms.* Journal of Fish Diseases, 2009. **32**(1): p. 15-25.
118. Jeong, J. and C.W. Revie, *Appropriate sampling strategies to estimate sea lice prevalence on salmon farms with low infestation levels.* Aquaculture, 2020. **518**: p. 734858.
119. Helgesen, K.O. and A.B. Kristoffersen, *Telling av lakselus - hvordan forstå og håntere usikkerheten i telleresultatene*, Veterinærinstituttet, Editor. 2018, Veterinærinstituttet.
120. Jeong, J., et al., *Imperfect Estimation of Lepeophtheirus salmonis Abundance and Its Impact on Salmon Lice Treatment on Atlantic Salmon Farms.* Frontiers in Marine Science, 2021. **8**.
121. International Organization for Standardization (ISO), *Methods for sea lice surveillance on marine finfish farms*, in *International Standard*. 2015.
122. Couzin, I.D. and J. Krause, *Self-organization and collective behavior in vertebrates, in Advances in the study of behavior*, P.J.B. Slater, et al., Editors. 2003, Academic Press: Amsterdam Boston London New York Oxford Paris San Diego San Francisco Singapore Sydney Tokyo. p. 1-75.
123. Hagemann, A., B. Kvæstad, and B. Venås, *Effect of diel light cycles on vertical migration patterns of Lepeophtheirus salmonis (Krøyer, 1837) copepodids measured in an in situ mesocosm.* Aquaculture International, 2024.
124. Nilsson, J. and O. Folkedal, *Sampling of Atlantic salmon Salmo salar from tanks and sea cages is size-biased.* Aquaculture, 2019. **502**: p. 272-279.
125. Nilsson, J., et al., *PIT tagged individual Atlantic salmon registrered at static depth positions in a sea cage: Vertical size stratification and implications for fish sampling.* Aquacultural Engineering, 2013. **55**: p. 32-36.
126. Sauphar, C., et al., *Atlantic salmon (Salmo salar) distribution and vertical size-stratification in a commercial sea cage: A case study.* Aquaculture, 2024. **581**.
127. Bui, S., et al., *Sea lice infestation level alters salmon swimming depth in sea-cages.* Aquaculture Environment Interactions, 2016. **8**: p. 429-435.
128. Godwin, S.C., et al., *Bias in self-reported parasite data from the salmon farming industry.* Ecological Appllications, 2021. **31**(1): p. e02226.
129. Jeong, J., G. Arriagada, and C.W. Revie, *Targets and measures: Challenges associated with reporting low sea lice levels on Atlantic salmon farms.* Aquaculture, 2023. **563**: p. 738865.
130. Sævik, P.N. and A.D. Sandvik, *Suspicious patterns in self-reported sea lice data may be explained by population dynamics.* Aquaculture, 2023. **576**.
131. Bland, M.J. and D.G. Altman, *Statistical Methods for Assessing Agreement between Two Methods of Clinical Measurement.* The Lancet, 1986. **327**(8476): p. 307-310.
132. Bui, S., et al., *Salmon lice survive the straight shooter: a commercial scale sea cage trial of laser delousing.* Preventive veterinary medicine, 2020. **181**: p. 105063.
133. Bui, S., et al., *Where art thou louse? A snapshot of attachment location preferences in salmon lice on Atlantic salmon hosts in sea cages.* J Fish Dis, 2020. **43**(6): p. 697-706.
134. Todd, C.D., et al., *Infestations of wild adult Atlantic salmon by the ectoparasitic copepod sea louse Lepeophtheirus salmonis - Prevalence intensity and spatial distribution.* Hydrobiologia, 2000. **429**(1/3): p. 181-196.
135. Jackson, D. and D. Minchin, *Aspects of the reproductive output of two caligid copepod species parasitic on cultivated salmon.* Invertebrate Reproduction & Development, 1992. **22**(1-3): p. 87-90.
136. Bjørn, P.A. and B. Finstad, *The development of salmon lice (Lepeophtheirus salmonis) on artificially infected post smolts of sea trout (Salmo trutta).* Canadian Journal of Zoology, 1998. **76**(5): p. 970-977.
137. Urquhart, K., et al., *Prevalence, abundance, and distribution of Lepeoptheirus salmonis (Krøyer, 1837) and Caligus elongatus (Nordmann, 1832) on wild sea trout Salmo trutta L.* ICES Journal of Marine Science, 2008. **65**(2): p. 171-173.
138 . Pike, A.W. and S.L. Wadsworth, *Sealice on salmonids: their biology and control.* Adv Parasitol, 1999. **44**: p. 233-337.
139. Oppedal, F., T. Dempster, and L.H. Stien, *Environmental drivers of Atlantic salmon behaviour in sea-cages: A review.* Aquaculture, 2011. **311**(1-4): p. 1-18.
140. Stingray Marine Solutions, *Stingray Fish Health report 2023*, S.M.S. AS, Editor. 2024, Stingray Marine Solutions AS: Oslo.
141. Stingray Marine Solutions, *Stingray Aqua Annual Report 2023*, S.M.S. AS, Editor. 2024, Stingray Marine Solutions AS: Oslo.
142. Jónsdóttir, H., et al., *The histopathology associated with the pre-adult and adult stages of Lepeophtheirus salmonis on the Atlantic salmon, Salmo salar L.* Journal of Fish Diseases, 1992. **15**(6): p. 521-527.
143. Ingvarsdottir, A., et al., *Role of semiochemicals in mate location by parasitic sea louse, Lepeophtheirus salmonis.* J Chem Ecol, 2002. **28**(10): p. 2107-17.
144. Yanase, K. and P. Saarenrinne, *Boundary layer control by a fish: Unsteady laminar boundary layers of rainbow trout swimming in turbulent flows.* Biol Open, 2016. **5**(12): p. 1853-1863.
145. Yanase, K. and P. Saarenrinne, *Unsteady turbulent boundary layers in swimming rainbow trout.* J Exp Biol, 2015. **218**(Pt 9): p. 1373-85.
146. Dalvin, S., et al., *Rainbow trout Oncorhynchus mykiss skin responses to salmon louse Lepeophtheirus salmonis: From copepodid to adult stage.* Fish Shellfish Immunol, 2020. **103**: p. 200-210.
147. Reimchen, T.E. and N.F. Temple, *Hydrodynamic and phylogenetic aspects of the adipose fin in fishes.* Canadian Journal of Zoology, 2004. **82**(6): p. 910-916.
148. Myksvoll, M.S., et al., *Evaluation of a national operational salmon lice monitoring system-From physics to fish.* PLoS One, 2018. **13**(7): p. e0201338.
149. Stien, A., et al., *Population dynamics of salmon lice Lepeophtheirus salmonis on Atlantic salmon and sea trout.* Marine Ecology Progress Series, 2005. **290**: p. 263-275.
150. Hamre, L.A., et al., *Development of the salmon louse Lepeophtheirus salmonis parasitic stages in temperatures ranging from 3 to 24 C.* Aquaculture Environment Interactions, 2019. **11**: p. 429-443.
151. Huserbråten, M.B.O. and I.A. Johnsen, *Seasonal temperature regulates network connectivity of salmon louse.* ICES Journal of Marine Science, 2022. **79**(4): p. 1075-1082.
152. The Norwegian Directorate of Fisheries, *Statistics for aquaculture*. 2024.
153. Walde, C.S., et al., *How delousing affects the short-term growth of Atlantic salmon (Salmo salar).* Aquaculture, 2022. **561**: p. 738720.
154. Standard Norge, *NS 9402:2020 - Standard for quality grading of fish*, in *Norwegian Standards*. 2020: Oslo.
155. Norwegian Food Safety Authority. *Norwegian Food Safety homepage*. [cited 2025 January 15]; Available from: www.mattilsynet.no.
156. Norwegian Seafood Council. *Norwegian Seafood Council homepage*. [cited 2025 January 15]; Available from: www.seafood.no.
157. Horjen, H.W. *Urolig for lusesituasjonen i Nord-Norge.* 2024; Available from: https://sjomatnorge.no/urolig-for-lusesituasjonen-i-nord-norge/.
158. Viken, O., et al. *Eksplosjon av lakselus i Nord-Norge: – En epidemi.* 2024.
159. Ytteborg, E., L. Sveen, and C.R. Karlsen. *Verdt å vite om laksens skinn.* 2024; Available from: .
160. Karlsen, C.R. and L. Sveen. *Verdt å vite om bakterielle sår på laks.* 2023; Available from: .
161. Mattilsynet. *Lågare lakselusgrense om våren: teljing og handheving.* 2023; Available from: https://www.mattilsynet.no/fisk-og-akvakultur/fiskesykdommer/lakselus/lavere-lusegrense-om-varen.
162. Takle, H., et al., *Sårproblematikk og hudhelse i laks- og regnbueørrettoppdrett.* 2015, Nofima.
163. Olsen, A.B., et al., *Tenacibaculum piscium sp. nov., isolated from skin ulcers of sea-farmed fish, and description of Tenacibaculum finnmarkense sp. nov. with subdivision into genomovars finnmarkense and ulcerans.* International Journal of Systematic and Evolutionary Microbiology, 2020. **70**(12): p. 6079-6090.
164. Norwegian Veterinary Institute. *Tenacibaculose*. 2021; Available from: https://www.vetinst.no/sykdom-og-agens/tenacibaculose.
165. Falkenhaug, T. and T.M.W. Oldman. *Tema: Perlesnormanet.* 2023; Available from: https://www.hi.no/hi/temasider/arter/perlesnormanet.

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