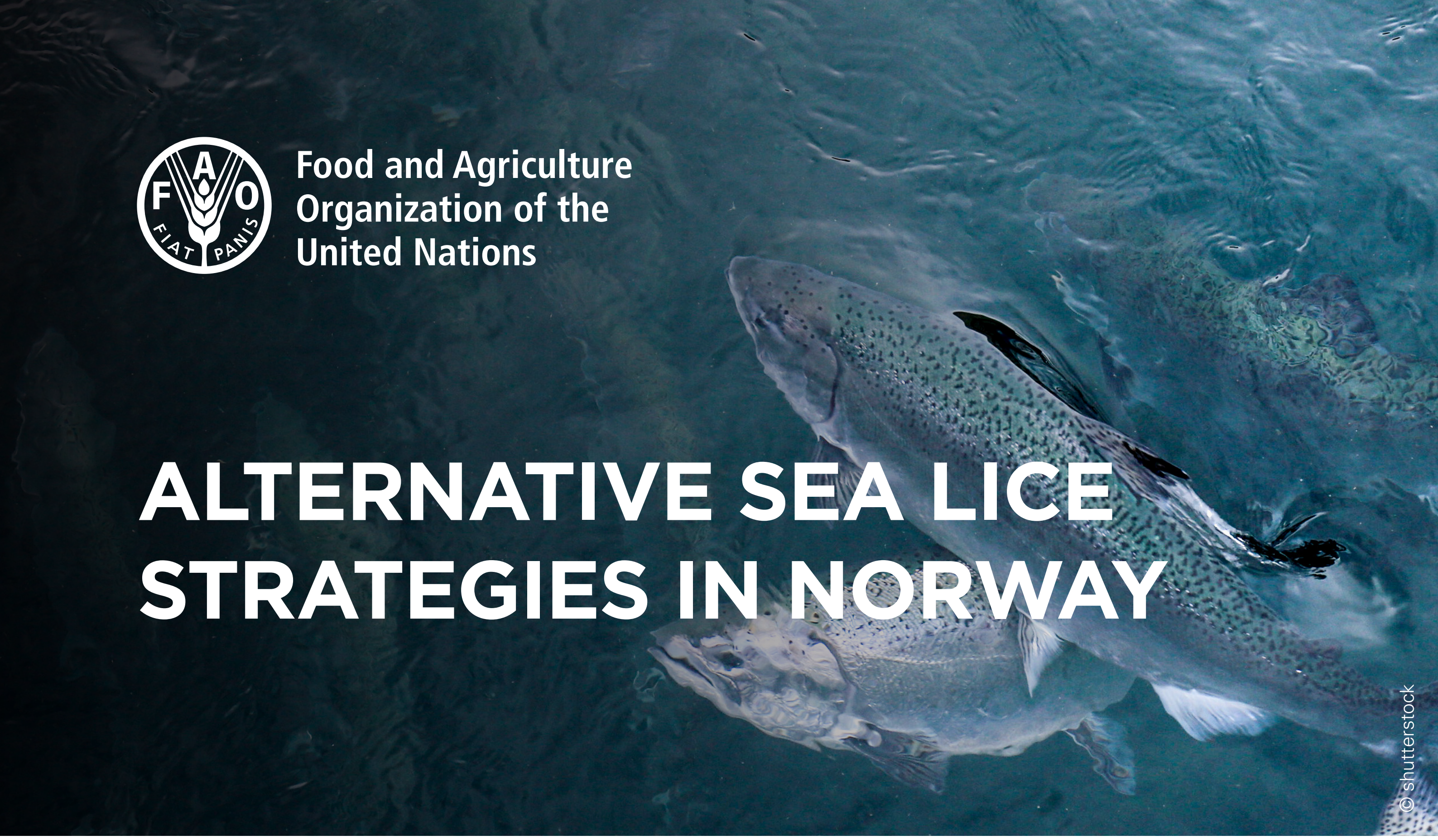

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ALTERNATIVE SEA LICE STRATEGIES IN NORWAY

The use of medicinal treatments to rid salmon of parasitic sea lice was once standard practice in Norway's aquaculture sector, but they now account for less than 20 percent of treatments, following the development of a range of alternatives, including biological and mechanical options.

In Asia, significant economic losses are caused by parasites in general – and sea lice in particular – in pond and cage culture systems of grouper (*Epinephelus* spp.), seabass (*Lates calcarifer*), pompano (*Trachinotus* spp.) and tuna (*Thunnus* spp.) among other species (Shinn *et al*., 2015). Lessons can be learned from the salmon sector's sea lice prevention, monitoring and treatment systems, although poor water clarity in Asia may pose difficulties for the direct transfer of some technologies.

The salmon louse (*Lepeophtheirus salmonis*) is the most common ectoparasitic crustacean copepod parasite of Atlantic salmon (*Salmo salar*) in the northern hemisphere. There are also outbreaks of another closely related, but smaller species, *Caligus elongatus*, in Norway and Scotland. This is parasitic of many fish species besides salmon and is more seasonal.

Having evolved to survive on the low densities of wild salmon in the oceans, sea lice thrive in crowded salmon cages, posing a continuous challenge to salmon farmers. Costello (2009) estimated that the global cost of sea lice monitoring and treatment in 2009 was USD 480 million, while Abolofia, Asche and Wilen (2017) estimated that the cost of sea lice damage to the Norwegian salmon industry alone was USD 436 million annually.

If left unchecked, sea lice can reduce the marketability of fish because of unsightly skin wounds, reduce growth rates by typically 5 percent to 15 percent, increase food conversion ratios (typically 5 percent more feed is needed) and lower profit margins. Salmon farmers conduct weekly lice counts and treat lice before they cross pre-determined thresholds set for the region or country.

For animal welfare reasons, when salmon in Norway and Scotland exceed the sea lice threshold, fish farmers are legally obliged to cull the salmon to prevent suffering, with heavy fines for violation. In 2016, a fish farmer was fined NOK 1.4 million by the Norwegian Food Safety Authority after sampled salmon were found with more than 40 times the maximum allowed lice level because emergency culling had been delayed.

Adult female *Lepeophtheirus salmonis* on an adult wild salmon captured in Scotland. The pink colouration is due to erosion of the epidermis and bleeding of lesions caused by sea lice damage

TECHNIQUE AND APPROACH USED

The multiple chemical treatments of sea lice include:

- bath treatment with organophosphates
- bath treatment with hydrogen peroxide
- bath treatment with azamethiphos
- bath treatment with pyrethroids
- bath treatment with neonicotinoids in conjunction with a system that cleans treatment water after salmon delousing, so that none of these chemicals are released back into the environment
- medicated feeds, containing compounds such as emamectin benzoate and benzoylureas
- synchronized water treatment within distinct geographic areas such as bays

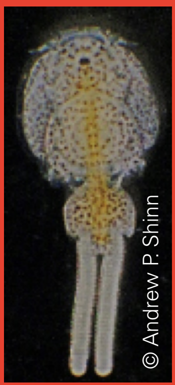
Funds are being channelled into the development of vaccines against sea lice, although the efficacy of the vaccines produced to date has been limited. The development of novel medicinal treatments is also ongoing. Traditionally medicinal products were used as the first tool to treat sea lice, rather than as a last resort. This has resulted in drug-resistant parasites – for example the reduced susceptibility of sea lice to hydrogen peroxide (Aaen, 2016).

With concerns over long-term environmental impacts and the likelihood of increased resistance to medical treatments, there has been a move towards non-medicinal alternatives:

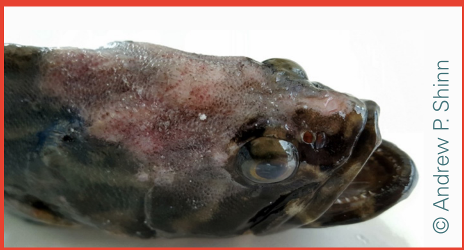
Approach	Method
Avoidance	Zoning. Government support for identifying the best site locations to reduce the likelihood of sea lice outbreaks.
	Farm siting. The move towards higher energy and open ocean sites (as opposed to sheltered sites in fjords) in which the high rates of water exchange should help to disperse sea lice.
	Genetic selection programmes to breed salmon that are less attractive to sea lice or less susceptible to sea lice infection.
	The rising cost of lice treatments is one of the reasons that more salmon producers are growing smolts to larger sizes in land-based units before transferring them to the sea. This shortens the time they are exposed to the parasites and reduces mortality.
Prevention	Life cycle stage (3 planktonic stages and 5 parasitic instar stages) management of sea lice, including fallowing sites. This is often combined with synchronized stocking of cages within geographic zones after fallowing.
	The use of skirts around the top section of pens to reduce sea lice entry as the lice tend to operate in the top few metres of the water column. The downside of these skirts is that they become fouled with algae, so require cleaning. They also reduce dissolved oxygen levels in the pens.
	Depth profiling for the distribution of larval sea lice has shown that manipulation of the swimming depth of the salmon by lighting and feeding locations can reduce the likelihood of infection with larval sea lice (Frenzl, 2014). This has led to the creation of snorkel cages, which keep the salmon at a depth below normal lice level for most of the time, yet provide a lice-free route to the surface that the salmon can use when they need to top up the air in their swim bladders.
	Stocking of cleaner fish like the ballan wrasse (*Labrus bergylta*) and lumpfish (*Cyclopterus lumpus*) as biological controls of sea lice. Approximately 50 million cleaner fish were stocked in 2017 across two-thirds of Norway's salmon farms.
	The increased use of semi-closed-containment cages in which the salmon are protected from lice by an impermeable barrier around the pen.
	Underwater traps are being piloted which, the developer claims, entice sea lice into them. Once trapped they can be removed and disposed of away from the salmon cages.
Treatment	Use of underwater cameras and software for digital lice counting. Units with software that recognizes lice and then 'shoots' them with lasers, although opaque water can reduce the efficacy of the lasers.
	Bathing salmon in freshwater either in well-boats or by putting tarpaulins round their pens and adding freshwater.
	Short-term (20 seconds to 30 seconds) exposure of salmon to warmer seawater (28 °C to 34 °C) while passing through a pipe system on a treatment vessel beside the cages.
	The use of a low-pressure water jet system used at the cage site to dislodge sea lice from salmon.
	Ongoing research is investigating the use of a combination of different ultrasound frequencies and infrared lighting periods. It is hoped that the infrared light and ultrasound will cause the sea lice to detach from the salmon by warming them up, vibrating them and possibly bursting their cells.

SCOPE AND SCALE OF APPLICATION

Under Norwegian law, every salmon farm is required to have and implement a plan for the prevention, monitoring and treatment of sea lice. The Norwegian Government has divided the country's coastline into 13 aquaculture production zones, using a traffic light system where expansion of aquaculture production is sanctioned, frozen or needs reduction – in green, yellow and red zones respectively (Stien *et al.*, 2020). The Norwegian Government sets seasonally adjusted sea lice thresholds on farms, depending on the main migration times of wild salmon smolts. The scheme is designed to both protect the welfare of cultured salmon and to restrict the spread of sea lice from farms to wild salmon and sea trout. For example, for farms in southern Norway the limit is 0.2 adult female sea lice per salmon from weeks 15 to 21 and 0.5 adult female sea lice per salmon outside this period (Stien *et al.*, 2020).



Adult *Caligus epidemicus*



Grouper with *Caligus epidemicus* epithelial skin damage and adult sea lice under the right eye

COMPLEXITY AND ACCESSIBILITY

Most salmon farms currently use a combination of both medicinal and non-medicinal approaches to prevent, monitor and treat sea lice infections and it is likely that this approach will continue into the near future. While hydrogen peroxide treatment of salmon in well-boats for 30 minutes was previously found to be particularly effective, sea lice are becoming less susceptible to this treatment (Aaen, 2016).

The sea lice prevention, monitoring and treatment systems currently used in Norway and Scotland are mainly at farm or cage levels, although there are some coordinated activities like the synchronized fallowing and stocking of cages conducted at geographic area scale such as bay areas. Collaboration and communication are also required among salmon farmers, sharing coastal bays and fjords to coordinate salmon delousing, as the displaced lice can be carried by water currents to other farms.

Many of the non-medicinal methods use improved technologies like cameras, software, artificial intelligence and algorithms, which require access to high-speed internet connections. Some of the approaches require significant investments in equipment.

Although the innovations in the salmon sector's sea lice prevention, monitoring and treatment systems are already being used or trialled, not all of them may be viable in Asian systems due to cost or technical issues. One example is that camera identification technology and use of removal methods such as water jets or lasers may not work in situations where there is high phytoplankton or turbidity that result in poor water clarity in Asia.

THE OUTCOME AND BENEFIT

The prevention and treatment of sea lice has become a significant cost component in the production of farmed salmon with different impacts, depending on country-specific contexts (Abolofia, Asche and Wilen, 2017). Iversen *et al*. (2020) estimated that Norway's lice prevention, monitoring and treatment costs were USD 517 million in 2019.

The key benefits of sea lice prevention, monitoring and treatment programmes are improved salmon health and welfare, with far fewer secondary infections caused by lice breaching the epithelium. This also means fewer rejections and downgrades of the salmon during processing and therefore improved profits.

Left unmonitored and untreated, however, *L. salmonis* will negatively impact on salmon welfare. Costello (2009) estimated that the cost of sea lice to the salmon industry was USD 0.10 to USD 0.20 per kilogram of cultured salmon, but without sea lice prevention, monitoring and treatment measures the cost to the salmon industry would be fourfold greater, costing USD 0.40 to USD 0.80 per kilogram of cultured salmon.

Significant progress has been made in the Norwegian salmon industry in moving from medicinal treatment to non-medicinal treatment, with 82 percent of all Norwegian sea lice treatments being non-medicinal in 2020 (Mowi, 2020). However, some of these novel treatments raise other issues – mechanical methods have been associated with fish welfare concerns, as has the use of cleaner fish as biological controls.

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