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Rethinking EU Aquaculture

FOR PEOPLE, PLANET, AND ANIMALS

A report by Compassion in World Farming International, 2023

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COMPASSION IN WORLD FARMING INTERNATIONAL (CIWFI) is the leading international farm animal welfare charity. It was founded in 1967 by British dairy farmer Peter Roberts and now operates globally, including in Europe, the US and Asia. Our mission is to end factory farming. We work with policymakers, food businesses and civil society to protect animals and the environment, driving shifts to regenerative and sustainable food systems that produce nutritious food, respect animal welfare, and work with nature.

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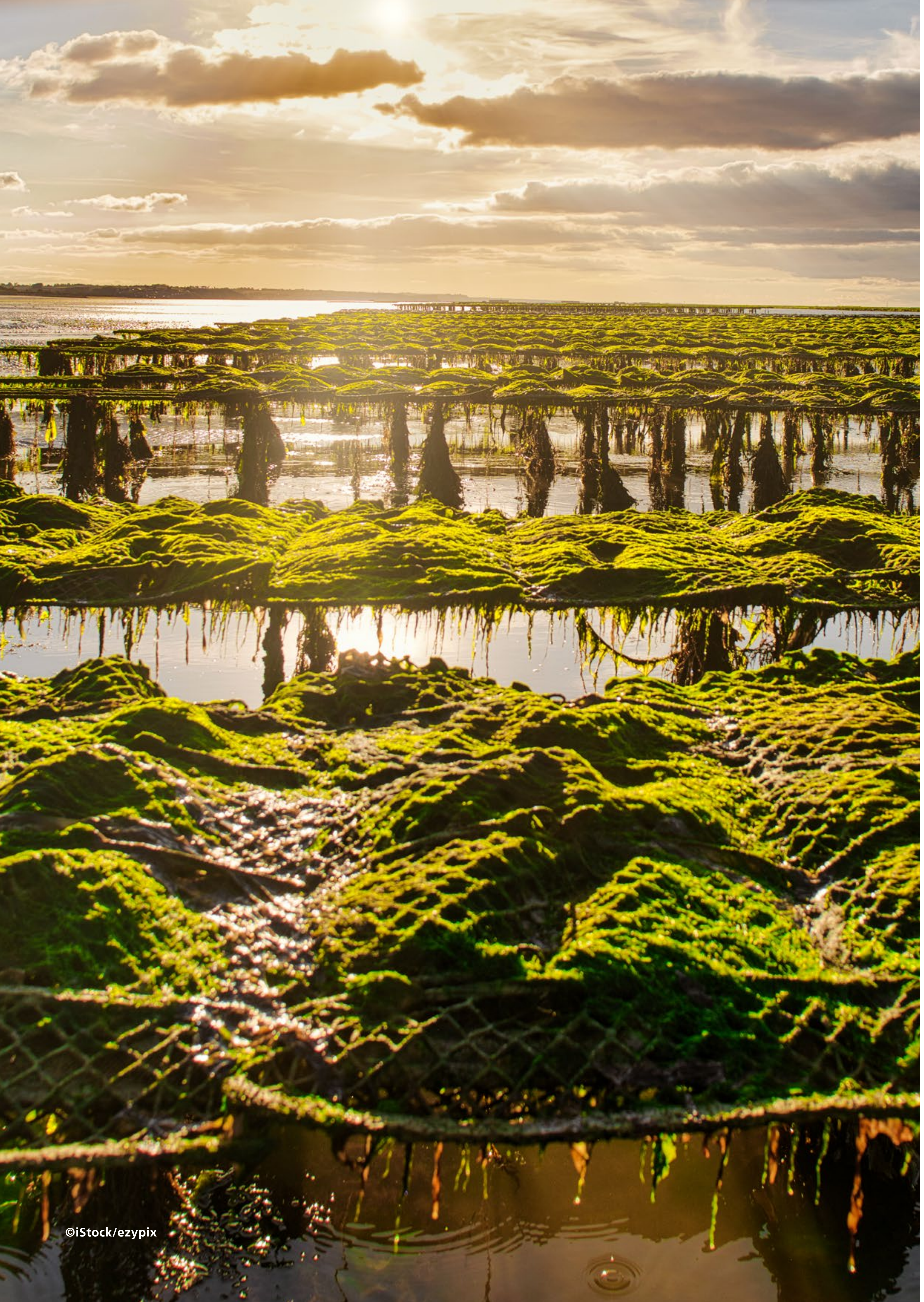
Special thanks to Lorenzo Fruscella for providing helpful comments on the draft report while volunteering for CIWFI.

PUBLISHED IN JANUARY 2023.



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Executive summary

OVEREXPLOITATION OF WILD FISH. Seafood plays a significant role in feeding the growing human population worldwide. However, nearly 90% of assessed wild fish stocks are overfished or fished at their maximum yields. To meet the future demands of seafood, aquaculture is heralded as a solution. Over half of the fish eaten directly by humans already comes from aquaculture (1), however production often comes at the cost of people, planet and animals.

FARMING CARNIVORES IS WASTEFUL. An increasing proportion of global and European aquaculture production is intensive and fed (farmed species are given feed during rearing), with reliance on high-quality feed inputs (1). Largely, this involves farming carnivorous species that eat feed containing wild-caught forage fish (as well as farmed plant ingredients) and this therefore directly adds to the fishing pressure on wild populations. It is also an inefficient use of resources, resulting in a net loss of food. An estimated 72-86% of the high-quality protein and 75-94% of calories used in farmed aquatic animal feeds are lost in the farming process (2), which is extremely wasteful, given that an estimated 90% of the wild fish used in feeds could instead be eaten directly by humans (3). Fisheries targeting forage fish for aquaculture feeds, therefore, impact food security, with farmed animal production competing with human consumption (4).

CONSERVATION ISSUES. In some cases, fisheries are supplying aquaculture with animals to fatten before slaughter, despite some of those species being endangered. Not only can this present biodiversity and conservation problems, but there are welfare implications as fish are taken from the wild via stressful capture processes and confined for long periods on farms (5,6).

ANIMAL WELFARE IS NOT WELL PROTECTED. Indeed many aquaculture systems do not properly address welfare, and there are almost no detailed legal protections for farmed aquatic animals, despite that fish are recognised as sentient animals in European legislation (7). This shortcoming is serious, given that as many as 1.2 billion fish are farmed every year in the EU without adequate protection (8). To maximise profit, they are commonly reared intensively at high stocking densities, and are often killed inhumanely without prior stunning.

ENVIRONMENTAL DAMAGE. Current aquaculture production systems can also damage the environment, with consequences including alteration/destruction of natural habitats, environmental pollution from fish wastes and chemicals, loss of biodiversity, diseases outbreaks, and misuse of antibiotics (9–12).

SOLUTIONS RESPECTING PEOPLE, PLANET, AND ANIMALS. In contrast, extensive systems farming low trophic organisms (i.e. those lower in the food chain), such as bivalves, seaweeds, and pond fish, are able to produce highly nutritious food with no/low feed inputs. Unfed aquaculture (e.g. fish reared in a pond eating plants growing in the pond, with no feeds added by farmers) has huge potential to expand (2) and play an important role in a sustainable EU food system. Such solutions must take a holistic approach, working to protect the environment, biodiversity, and future food security, while producing healthy food for people.

POLICYMAKERS CAN DRIVE CHANGE. Our 15 policy recommendations are cantered on ways European policies can lead the EU aquaculture industry towards sustainable production of low-trophic aquatic species, in extensive systems that do not harm the environment (and can even provide ecosystem benefits), that help mitigate climate change, and contribute to food security. Moving away from the intensive, feed-based production of aquatic animals, which results in a net loss of food, is essential for aquaculture to work in the long term for people, planet, and animals.

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Glossary

ALGAE: diverse group of photosynthetic organisms that range in size from single cells to large spreading seaweeds.

AQUAPONICS: food production system that joins aquaculture with hydroponics (cultivating plants in water) whereby the nutrient-rich water from aquaculture is used as fertiliser for the cultivated plants.

BIVALVES: any marine or freshwater mollusc that has a laterally compressed body, a shell consisting of two hinged valves, and gills for respiration. The group includes clams, cockles, oysters, and mussels.

CARBON SEQUESTRATION: the process of capturing and storing atmospheric carbon dioxide.

EUTROPHICATION: excessive richness of nutrients in a lake or other body of water, which causes a dense growth of plant life and is often harmful to species in the affected ecosystem.

EXTENSIVE AQUACULTURE: systems that use low stocking densities and no supplementary feeds, although fertilisation may be done to stimulate the growth and production of natural food in the water.

FEED CONVERSION RATIO (FCR): the amount of feed required to raise 1kg of farmed product accounting for all other feed losses. It is a commonly used indicator of production and feed use efficiency.

FISHMEAL AND FISH OIL (FMFO): commercial products made from whole wild-caught fish, bycatch and fish by-products. Fishmeal is a brown powder or cake obtained by drying the fish or trimmings, often after cooking, and then grinding them. Fish oil is extracted by pressing.

FORAGE FISH: a term used for a variety of small pelagic (open sea) fish due to their position at lower trophic levels in marine ecosystems. Many feed directly on phytoplankton or zooplankton species and are important in providing prey for the higher trophic levels in those ecosystems.

INTEGRATED MULTITROPHIC AQUACULTURE (IMTA): farming, in proximity, of species from different trophic levels and with complementary ecosystem functions in a way that allows one species' uneaten feed and wastes, nutrients and by-products to be recaptured and converted into fertiliser, feed and energy for the other crops, and to take advantage of synergistic interactions among species while bio-mitigation takes place.

INTENSIVE AQUACULTURE: systems that are managed by the use of inputs (mainly feeds, fertilisers, and pesticides) and manipulation of the environment primarily by way of water management (e.g. use of pumps and aerators). There are also semi-intensive systems, which vary in degree in terms of stocking densities, level of supplementary feeding and manipulation of the environment.

PROPHYLACTIC: a medicine or course of action used to prevent disease.

RECIRCULATING AQUACULTURE SYSTEMS (RAS): farming systems with technology to recycle and reuse water after mechanical and biological filtration and removal of suspended matter and metabolites. This method is used for high-density culture of various species of fish.

RESTOCKING: generally referring to human interventions to help increase fish populations by release of wild-caught or hatchery-reared fish into an area.

SUSTAINABLE DEVELOPMENT: farming of aquatic species in a way that contributes to meeting the needs of the present, without compromising the ability of future generations to meet future needs. This conserves land, water, natural resources and biodiversity, while being environmentally non-degrading, technologically appropriate, economically viable, socially acceptable and ensures animal health and welfare.

TRIMMINGS: heads, bones, and other fish parts that are left over from fish processing and aren't typically sent to market for human consumption.

TROPHIC LEVEL: the position of an organism in a food chain. The first trophic level consists of primary producers and has the highest energy concentration, which is transferred to organisms at higher trophic levels.

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Introduction

One of the big challenges that humanity is facing is how to feed a growing world population, expected to approach 9.7 billion by 2050 (13), in a healthy and sustainable way (9). The capacity of agriculture to meet future food demands is predicted to become limited by land and freshwater availability (14). Reducing greenhouse gas emissions, promoting biodiversity, and achieving a healthy environment whilst responding to this increasing demand for food is also a significant challenge (9). The Sustainable Development Goals (SDGs) adopted by the United Nations are a call by all countries to take global action to protect the planet, end poverty and inequality, and improve the lives of everyone, everywhere (15). They recognise the importance of protecting the environment, especially the ocean, which is an essential global resource and a key feature of a sustainable future (15). The solution requires food production systems that do not push planetary boundaries past their thresholds while providing a healthy diet (16). We must apply this principle to both land and sea.

According to the Food and Agriculture Organization of the United Nations (FAO), nearly 90% of assessed wild fish stocks are overfished or fished at the maximum yield (1), leading to fish population reductions, species extinctions, and the collapse of marine ecosystems (16), so there is limited scope to catch more fish. Therefore, future expansion of food from the sea is expected to come from aquaculture. Aquaculture, the farming of aquatic animals (e.g. fish, crustaceans, shellfish), algae (e.g. seaweed) and plants, has been the fastest growing animal food production sector in recent decades (17), growing around 5.3% each year (average for the period 2001–2018) (1). In fact, aquaculture production is expected to increase from 60 million tonnes in 2010 to 100 million tonnes in 2030, and up to 140 million tonnes by 2050 (9). Over half of the fish eaten directly by humans now comes from aquaculture (1), which is expected to produce more fish than all capture fisheries (including for non-food uses) by 2024, according to FAO estimates (1).

In this report we show that, although aquaculture may provide a potential solution to the limitations on wild seafood production, it often comes with serious consequences from an environmental and social standpoint. For example, it can cause biodiversity loss, ecological damage, pollution, antibiotic overuse, unsustainable use of resources, human rights abuses (18–21), animal welfare issues (22–24) and overfishing for feed ingredients (25). With an increase in intensive, feed-based systems with high input requirements, there are increasing ethical, environmental, and social issues that are closely linked to animal welfare. For example, high stocking density and inefficient feeding can result in poor animal welfare, and also cause toxic wastewater from fish farms (26); and disease outbreaks in fish farms are linked to poor health, nutrition, and rearing conditions (6). Alternatively, higher welfare standards in production systems should lead to less pollution, healthier fish, reduced need for antibiotics, and improved global food security (27,28).

Different farming practices have different economic, social, and environmental impacts (19). Intensive systems with high feed inputs and costly outputs for the environment represent a major jeopardy from this industry. The aquaculture sector has the opportunity to help deliver the SDGs and it should be economically, socially, and environmentally friendly. We make 15 policy recommendations with the aim of moving the EU aquaculture industry along a more sustainable and responsible path. Truly sustainable solutions will have a positive long-term outlook, contribute to community, health and well-being, and will promote a thriving and biodiverse ecosystem.

EU aquaculture's contribution to food production

In 2017, global production of aquatic animals was 179 million tonnes, with 97 million tonnes caught from the wild and over 82 million tonnes produced by aquaculture (1). Almost all of the 32.4 million tonnes of aquatic algae was farmed (1). Aquaculture is diverse, farming around 425 different species, although three quarters of global production volume is focused on just 22 of these (18). Asia dominates in the sector, producing 92% of farmed seafood (1), while European aquaculture contributed 4% of the global volume in 2017 (29).

Aquaculture contributed 22% of the total seafood produced in the EU during 2019, farming 1.36 million tonnes (30). Most of this (98.2% in 2014 (31)) is finfish and molluscs, and it involves a significant number of animals. For example, an estimated 560 million to 1.3 billion farmed fish were slaughtered for food in the EU in 2017 (8); including 240–320 million gilthead seabream (95 million tonnes), 160–200 million European seabass (79 million tonnes), 87–460 million rainbow trout (172 million tonnes) and 30–150 million common carp (74 million tonnes) (8). The shellfish industry produces mainly mussels, oysters and clams (32). Algae and crustacean production is relatively small (8,31).

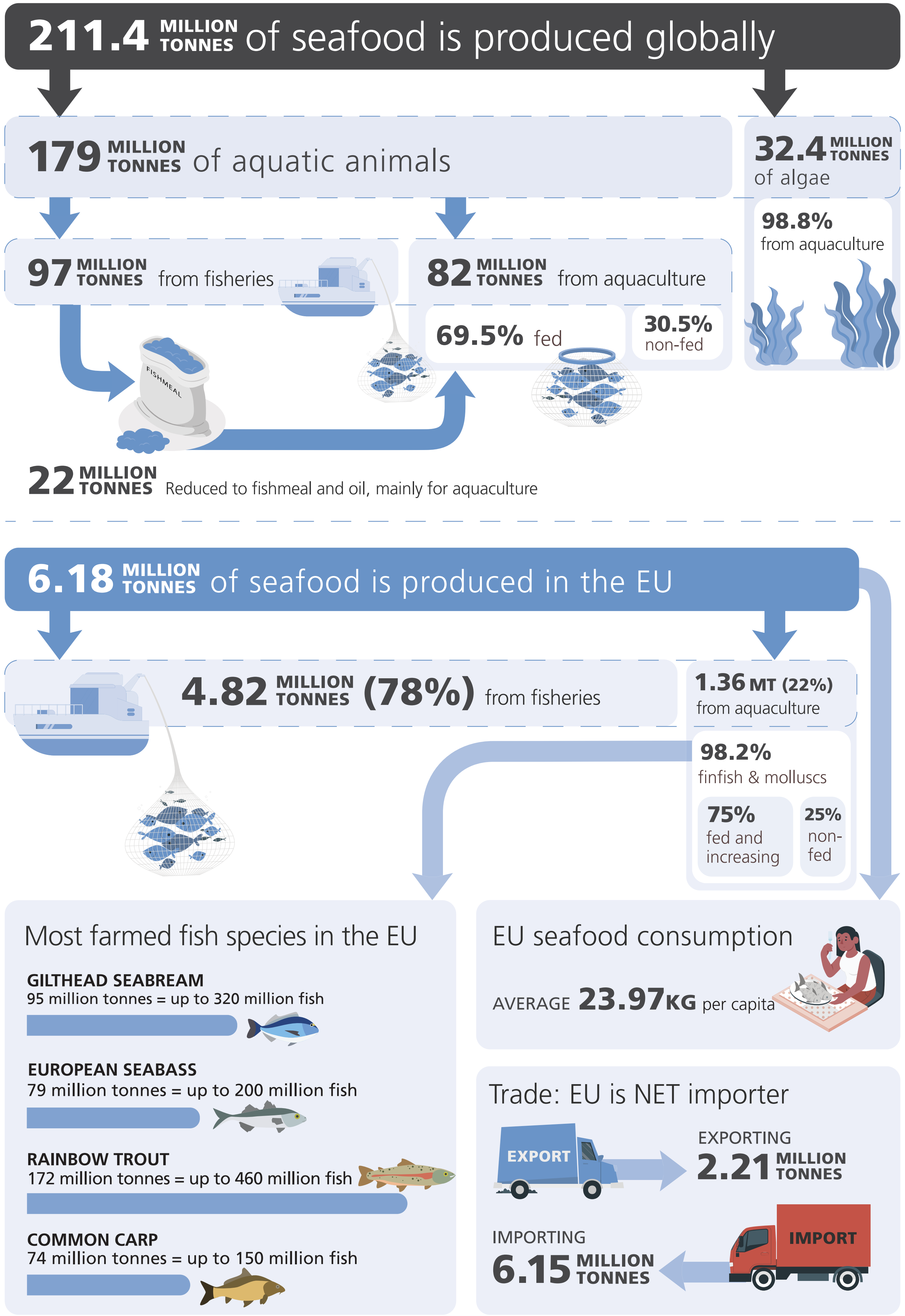
In 2019, per capita apparent consumption in the EU was estimated at 23.97kg of live weight, of mostly wild-caught products. Portugal stands out as the major EU consumer, followed by Spain and France (30). In 2019, the top six seafood products that were consumed the most in the EU were tuna (mostly wild), salmon (mostly farmed), cod (mostly wild), Alaska pollock (wild), shrimps (half was farmed), and mussels (mostly farmed) (30).

EU production was forecast to increase 56% in volume from 2014 to 2030 (33), despite only moderate annual growth over the past few decades (17). However currently the EU is a net importer of seafood, importing 6.15 million tonnes, and exporting 2.21 million tonnes in 2020 (30). Atlantic salmon is the top species imported, accounting for 16% of imports, mostly from Norway and the UK (30).

The aquaculture sector consists of various species and production systems. Some systems have great potential to contribute to sustainable European food production, and others have harmful effects on the environment and effectively waste natural resources. Sustainable intensification has become the mantra for aquaculture development (34). According to the FAO, sustainable intensification of aquaculture must: (a) advance socioeconomic development; (b) provide safe, nutritious food; (c) increase production of fish relative to the amount of land, water, feed, and energy used; and (d) minimise environmental impacts, fish diseases, and escapes (34).

However, EU fish farming often results in a net loss of food; many of the main finfish species farmed are carnivorous and produced intensively with feed added to the systems (35). They are fed with commercial feed comprising high-quality plant components such as soya, but also fish in the form of fishmeal and fish oil (FMFO), sourced largely from wild-caught fisheries. The amount of fed aquaculture (farmed species are given feed during rearing) has been increasing over time in Europe, and now makes up three quarters of the sector (1). This reflects global trends; 69.5% of aquaculture is fed and only 30.5% is now from non-fed production (farmed species are not given feed, instead taking nutrients from their environment) (1). The use of feed and intensification of freshwater systems has risen; these days an estimated 92% of tilapia, 57% of Chinese carp and 81% of catfish are fed with supplementary feeds, in addition to the naturally occurring food in their systems (18). However an estimated 90% of the wild fish used in feeds could instead be fed directly to humans (3). Feeding human-edible resources to farmed animals is wasteful, as energy is lost at each step in the food chain.

With almost 90% of global fish populations exploited or overfished, aquaculture could alleviate pressure on marine life (1). However systems using FMFO directly rely on the exploitation of wild fish populations so are instead contributing to that pressure (36). There is also increased reliance on land-grown ingredients (18). On the other hand, the potential for seaweed and bivalves to support global nutritional security is underexploited (18).



How efficiently does aquaculture produce food?

With finite resources with which to feed 8 billion people, efficient food production, responsible consumption, and minimising food wastage are key. Farmed fish are often touted as more efficient than land-based farmed animals (2). Indeed, fish generally burn relatively less energy moving around due to their cold-blooded bodies that are supported in water, but this can still be a misleading comparison for several reasons (2).

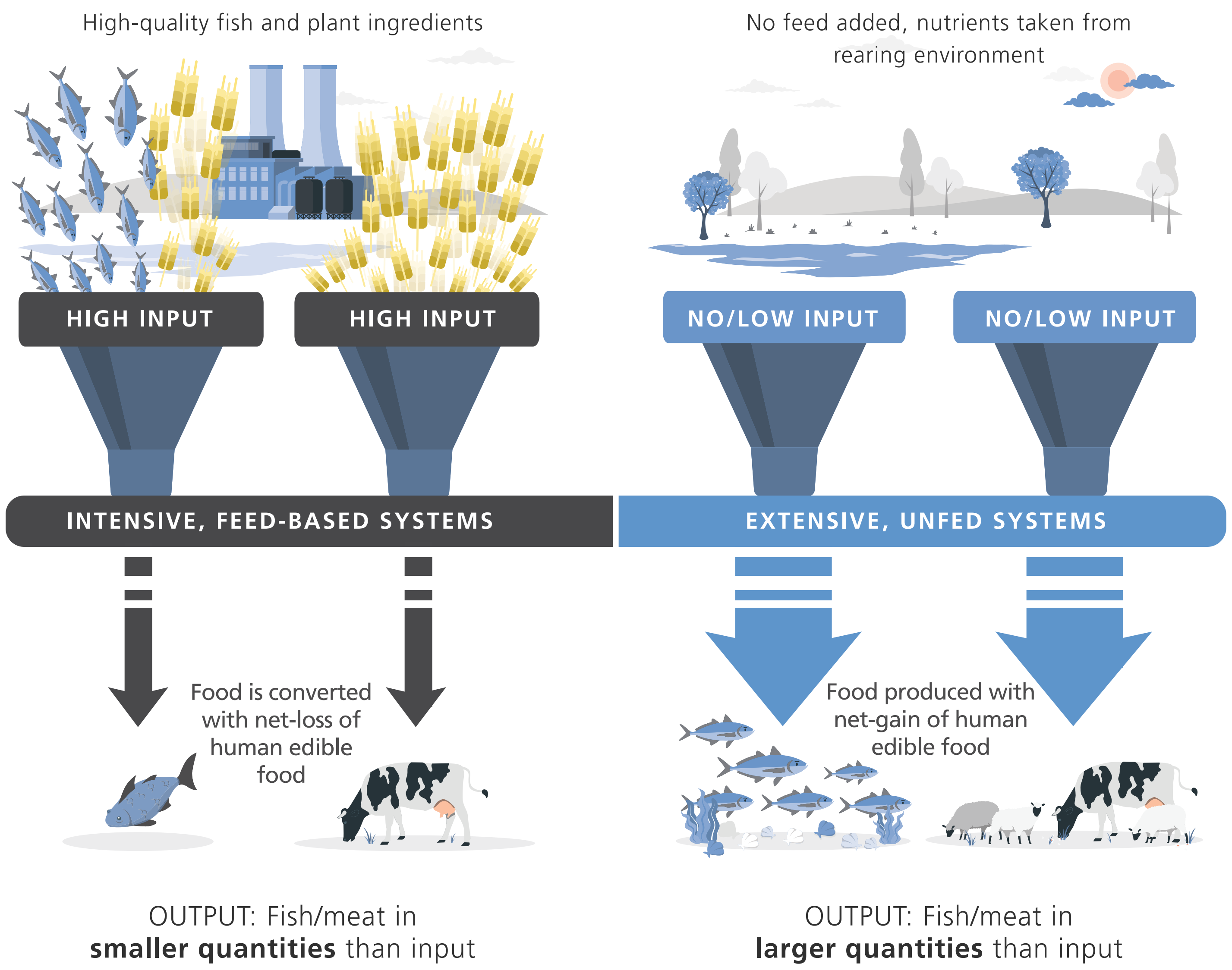
The feed conversion ratio (FCR) is a commonly used indicator of production and feed use efficiency, but it does not give the full picture (2). The FCR is the amount of feed required to raise 1kg of farmed product accounting for all other feed losses, e.g. if 1.8kg of feed was used to produce 1kg of farmed fish, the FCR would be 1.8 (37). Therefore a lower FCR is more efficient (37). Using this measure, fish often appear much more efficient than animals farmed on land, such as pigs and cattle (2).

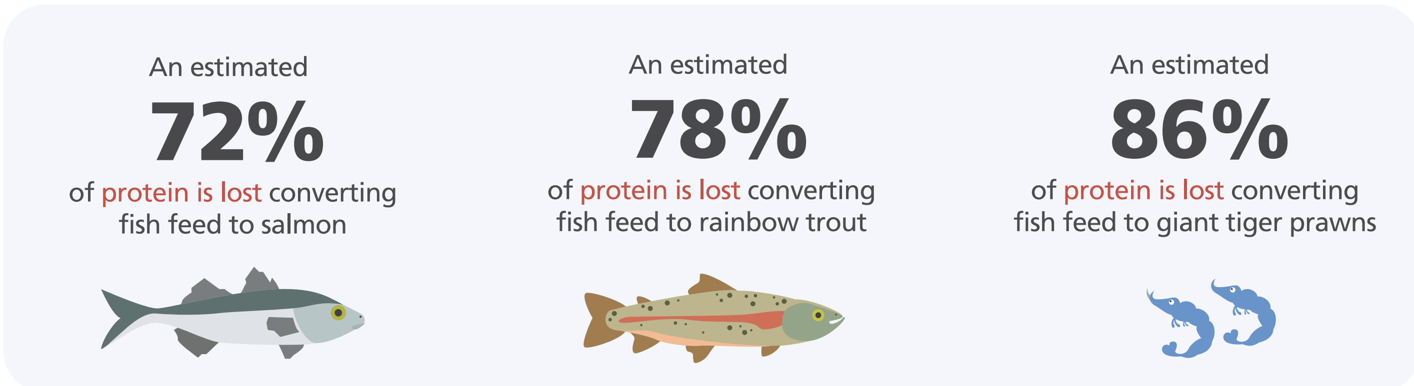
However, the FCR only accounts for the weight of feed inputs and not the nutritional content of the feed, the portion of the animal that is inedible, or the nutritional quality of the final product (2). As part of the production of many aquafeeds, fish (caught from the wild, or trimmings) are reduced (via cooking, pressing, extraction and drying) to fishmeal and fish oil (FMFO), which results in a smaller, more nutritionally concentrated end product. Amounts vary by species, but on average 1,000kg of wild fish are reduced to approx. 225kg of fishmeal and 50kg of fish oil (38). Atlantic salmon, one of the most 'efficient' fish, are quoted as having a FCR of 1.2–1.5 (2), but taking the amount of wild-caught fish into account, the ratio for the fish component of the diet is over 4 (calculated using publicly available data on: salmon weight (39), forage fish weight (40), feed breakdown (41), trimmings and salmon FCR (42).

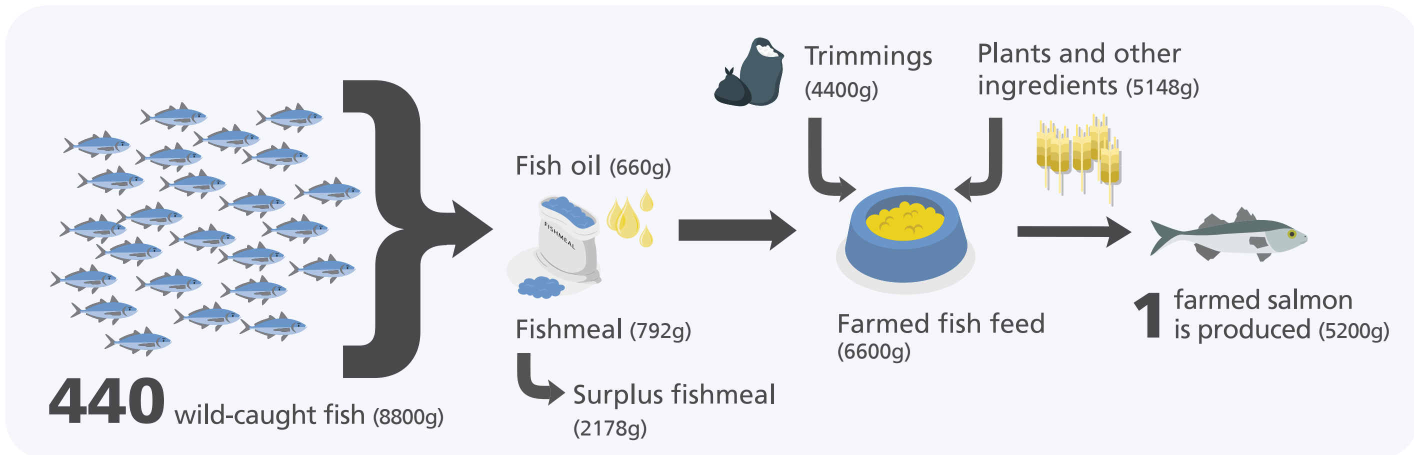
Fry et al. (2018) calculated that only 28% of the protein and 25% of the calories in fish feed end up as human-edible salmon (2). Likewise rainbow trout convert only 22% of protein and 16% of calories from feed, and giant tiger prawns convert only 14% of the protein and 6% of the calories into food for people to eat (2). This means that typically 72–86% of the high-quality protein and 75–94% of calories used in farmed aquatic animal feeds are lost (2). Calculations for land-based animals (cattle, pigs, chickens) found that 63–87% of protein and 73–93% of calories were lost, and the authors concluded that aquatic species, taken together, have little or no efficiency benefit over land-based livestock (2).

Furthermore, when you consider that cattle left to graze (rather than fed grain in feedlots), can convert grass (inedible for humans) to human-edible meat (despite their relatively high FCR), while carnivorous farmed fish are converting fish (often human-edible) and plant materials (often human-edible) to smaller amounts of human-edible fish, the comparison is less useful. Moving beyond comparing aquaculture with terrestrial farming, the focus should instead be on fed versus unfed systems, and the ability to produce a net profit of products that humans can eat. Even as the aquafeed industry reduces the proportion of FMFO in fish feeds, the amount of plant ingredients is increased to compensate. Using crops (e.g. soya) in animal feeds which could otherwise be used to feed humans directly also represents inefficiently used resources, and introduces further production impacts, e.g. land clearing for growing crops. Systems that use more human-edible food than they produce are simply unsustainable.

In contrast, extensive systems that farm lower trophic level organisms such as bivalves, seaweeds and pond fish are producing animal protein with no/low feed inputs. The rate of production may be lower, but they are resulting in a net gain of human-edible food because instead of converting one type of animal protein into another, they can convert inedible materials into human-edible flesh. Seaweeds produce their own protein, carbohydrate and lipids using solar energy, carbon dioxide, water, and assorted minerals (43); bivalves such as mussels feed by filtering phytoplankton from the water (44) herbivorous/omnivorous fish can consume plant foods from their environments (25). Unfed aquaculture can therefore create highly nutritious food without feed inputs, and has huge potential to expand (2).







Feeding Europe's farmed fish

Production of higher-value species, such as shrimp, salmon, and trout, is projected to continue growing (1), and these species are fed diets containing fishmeal and fish oil (FMFO). In fact about 70% of fishmeal, and 75% of fish oil produced globally, is used as feed in aquaculture (18). The main species caught to produce FMFO are forage fish such as anchovy, sardines, herring, and mackerel (4), although FMFO is also produced from by-products or trimmings from the processing of wild and farmed fish (1).

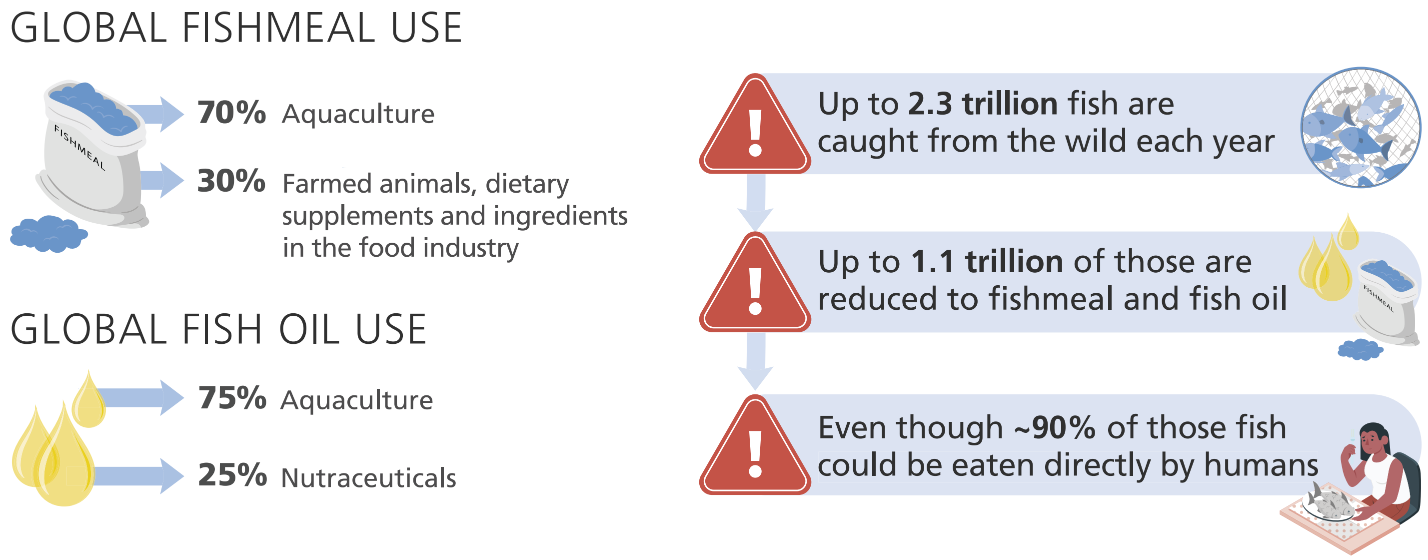
Fisheries targeting forage fish impact food security and marine ecosystems (4). Forage fish are crucial in transferring energy from primary producers to higher trophic-level species including large fish, marine mammals, and seabirds (4). For many countries, forage fish are important sources of protein and income, therefore the use of forage fish for animal production competes with human consumption and puts the food security of these coastal communities at risk. In fact, it has been estimated that 90% of the wild fish used in feeds could instead be used directly for human consumption (3).

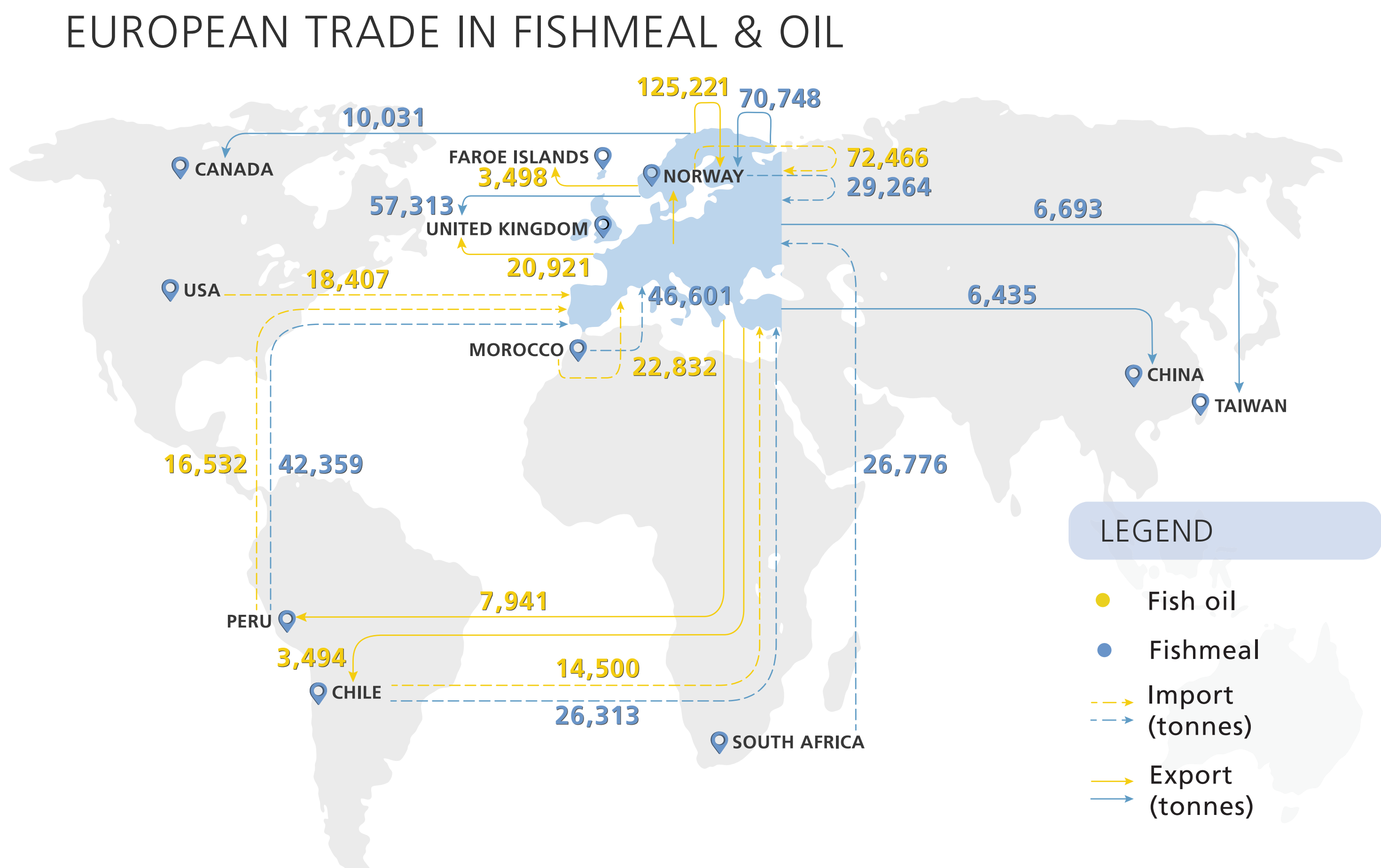
The largest global producers of FMFO are some South American and Asian countries (45). Europe produces around 475–540 thousand tonnes of fishmeal and 130–200 thousand tonnes of fish oil each year (45). Denmark is the largest producer of FMFO followed by Spain (45). A large amount of FMFO consumption in the EU is supplied by imports from non-EU countries; in 2019, the top three suppliers were Morocco, Peru, and Norway (45). A large amount of FMFO is sourced from countries in North and West Africa and Latin America, where the reduction industries are placing significant pressure on ecosystems, the environment and food security.

It is unclear from trade data if the imported FMFO comes from sustainable fisheries and there are no current legislative instruments regulating the sourcing and origin of FMFO, meaning that no regulation drives towards more sustainable supply chains and improved practices in production. There is also very little transparency about which factories and fisheries the FMFO comes from. This lack of information is sustained by an intricate web of actors in complex supply chains (46). Research shows that, despite commitments to sustainability and transparency, fishmeal producers and major aquafeed companies disclose little information about the origin, quantity, or sustainability of the wild- caught fish used in their feed (46).

EU aquaculture currently uses around 450,000 tonnes of fishmeal and 250,000 tonnes of fish oil annually. The industry is considering alternatives to FMFO, such as a range of plant sources, some novel animal proteins (e.g. insect meals), and microbial products (e.g. micro-algae and single-celled proteins). These alternatives may serve as short-term solutions for the farming of carnivorous species, but better long-term solutions are needed to address the systemic problems of the intensive farming model. Also, it is crucial that new feed formulations do not compete with ingredients that could be used directly for human consumption and do not harm the environment.

Recently, the use of mesopelagic fish (fish that live between 200 and 1,000m depth) and krill (small crustaceans) to produce FMFO has also been considered. Yet these fisheries would introduce high environmental risks since these organisms play pivotal roles in marine food webs and in global carbon cycles (47,48). Therefore, the increasing commercial interest shown in these areas is highly concerning.





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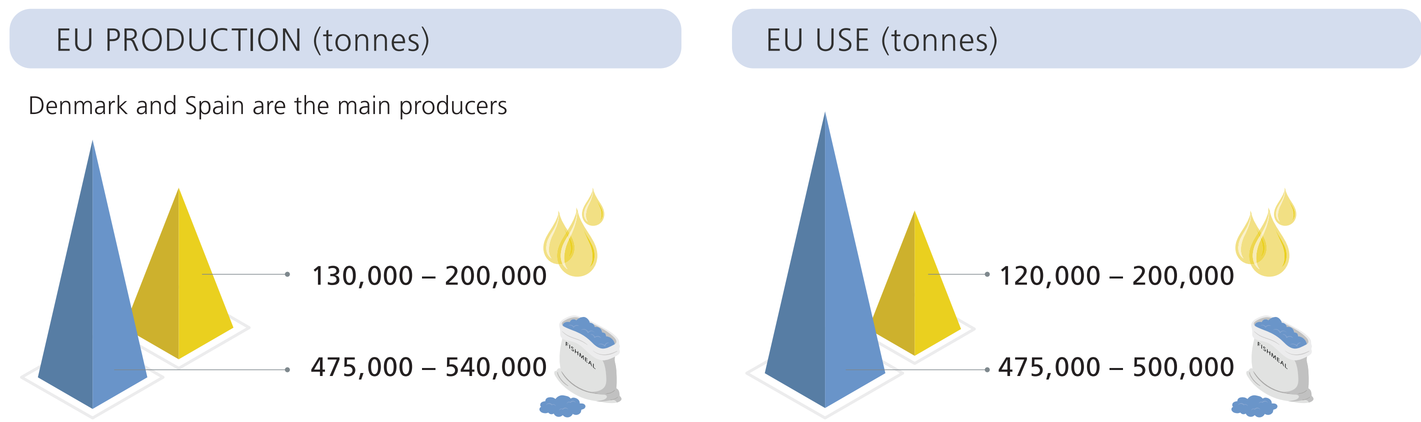


Catching overfished species to supply aquaculture

In addition to catching wild fish for fishmeal and oil (FMFO), in some cases wild fish are used to supply aquaculture; where the reproductive cycle has not been closed in captivity (or breeding is not commercially viable), farms are stocked with wild-caught individuals for further fattening. This adds pressure to the wild populations and has welfare implications, as fish are taken from the wild via stressful capture processes and kept for long periods in farm environments (6). The consequences of this may be more serious for species that are already overfished, endangered, or unsuited to farming, as described in the examples below.

BLUEFIN TUNA FARMING

The global decline of wild bluefin tuna populations, as a result of heavy fishing pressure, has made tuna farming an attractive alternative to fisheries. Tuna farming is based on the capture of wild juveniles for fattening in sea cages (34). More mature (>30kg) tuna are reared for a shorter period of time (generally between 4 and 9 months), while younger individuals (<25kg) are fattened for more than a year, e.g. in Croatia 5–25kg wild-caught tuna are kept in cages for more than 20 months (35). During 2017, 7,393 tonnes of bluefin tuna were farmed in Europe, 15,900 tonnes in Japan, 5,722 tonnes in Mexico, and 8,100 tonnes in Australia (36).

Bluefin tuna are key predators in marine food webs, requiring large inputs of marine based proteins (34). In farms, they are fed a diet of forage fish, sardines, mackerel or herring, and some cephalopods (34). The feed conversation ratio (FCR), meaning the kilogrammes of fish needed to obtain 1kg of tuna are very high and range between 10–20:1 (37). Globally, 37,115 tonnes of bluefin tuna were farmed in 2017. Yet it has been estimated the global demand for forage fish to feed bluefin tuna in farms was between 168 and 362 thousand tonnes in 2014 (34).

Farmed tuna feed relies on large amounts of fish that could be used for human consumption, and therefore this represents a waste of resources. The use of wild-caught fish in aquaculture is not only an unsustainable practice, but also creates food security issues. Also, we need to keep in mind that tuna farming means that we put one of the big marine predators in cages, they can reach a length up to 3 metres, weigh up to 65kg and reach speeds of 80km/h. Also, they are migratory animals that swim thousands of kilometres and dive more than 1,000 metres. This data shows how bizarre it is to put these animals in cages where they cannot migrate further than the cage walls.

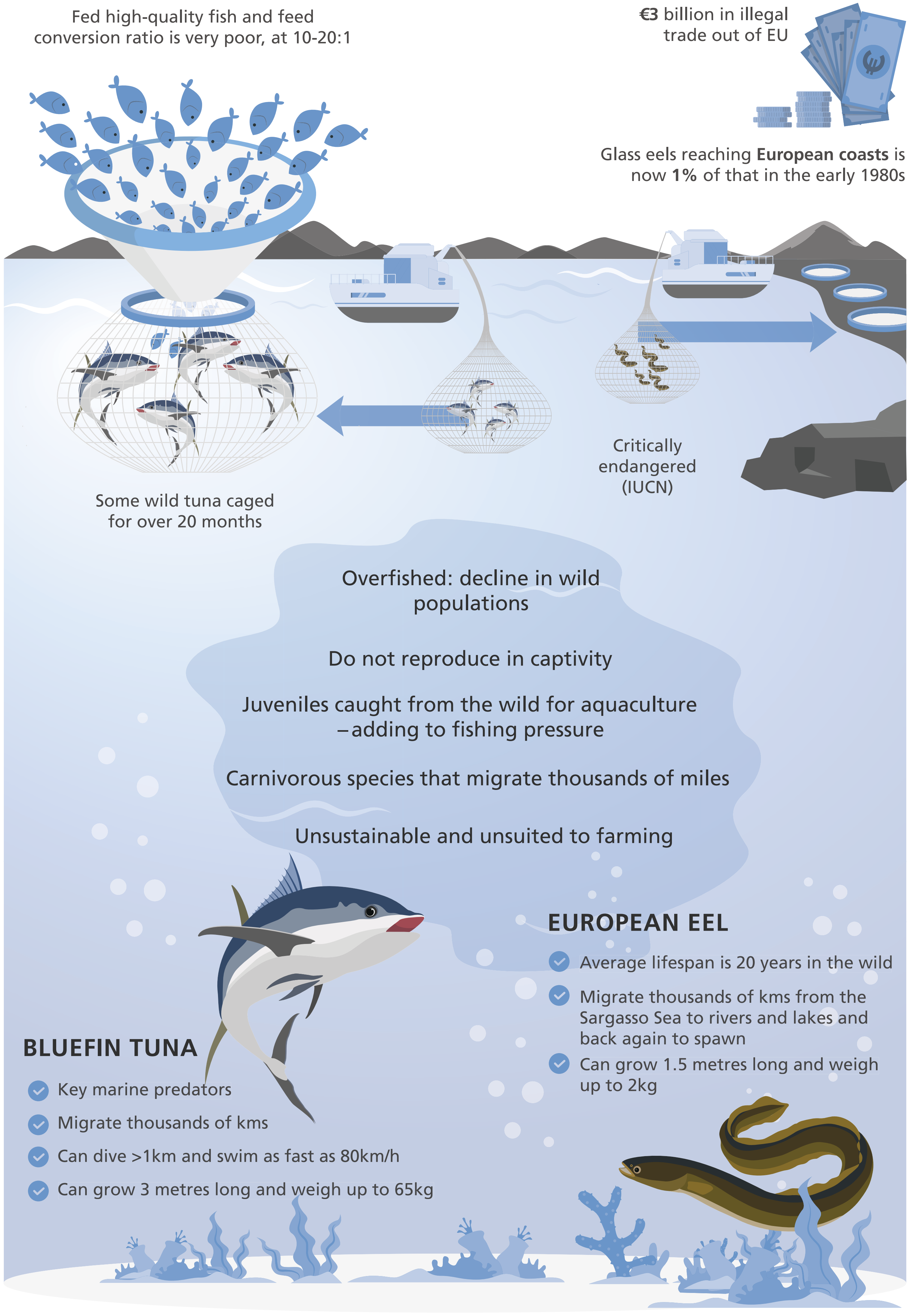
EUROPEAN EEL FARMING

European eels have been eaten by humans for many centuries, but recent human activity has been catastrophic for this species. Eels were overfished in the early-to-mid 1900s, and development of aquaculture in the 1980s added further pressure: younger 'glass eels' are still caught to supply farms, predominantly rearing them intensively in recirculating aquaculture systems (RAS) (52). European eels are red-listed as 'critically endangered' by the International Union for Conservation of Nature (IUCN) (53). The number of glass eels reaching European coasts is now 1% of that in the early 1980s (54–57).

European eels have a complex lifecycle: beginning in the Sargasso Sea, migrating huge distances to inland water bodies to mature and grow for several years before returning to the Sargasso to reproduce. Eels can grow as long as 1.5 metres and weigh as much as 2kg, and their average lifespan is 20 years (58). Sexual maturation is long (males: 7–13 years, females 10–19 years) and eels appear to die after spawning making it impossible to catch only those that have had the opportunity to mate (59). Therefore, the species is particularly vulnerable to overfishing and unsuitable for sustainable farming. Reproduction in captivity is currently not possible. Other human activities negatively impacting eels include the addition of many obstructions (e.g. hydropower plants, weirs, dams) to upstream and downstream migrations (60).

In 2007, the EU adopted the European Eel Regulation (61) requiring that all eel-fishing member states with natural habitats for eels must have national eel management plans. So far none of the Baltic Sea countries are close to achieving their plans' objectives (62). Restocking programmes transfer captured glass eels from estuaries to areas inland. However, the net benefit of restocking is unknown and goes directly against advice from the ICES (International Council for the Exploration of the Sea): zero catch in 2022 and cessation of restocking, as it increases eel mortality without any proven net benefit to eel reproduction (63).

Exporting glass eels outside the EU was banned in 2010, but demand from the Asian market (following a 90% decline in Japanese eel population over 30 years (59)) has resulted in one of the most lucrative illegal trades of protected species worldwide, according to Europol (64). Illegal profits have been estimated as being up to €3 billion in recent years (64).



Animal welfare should be at the heart of sustainable production

Fish are recognised as sentient animals in European legislation (7). Strong scientific evidence shows that fish can feel pain, suffering (65–67) and other emotions (68). Fish are also intelligent and can learn many things, e.g. how to solve problems (69), memorise journeys (65) and avoid situations that previously caused pain (70–72). Some fish have numerical skills (73), use tools (74), collaborate (75–78), and show signs of 'self-consciousness' (79,80). Yet, fish are covered only generally by welfare legislation for farmed animals in the EU (81–83) and are currently exposed to significant suffering, during rearing and slaughter.

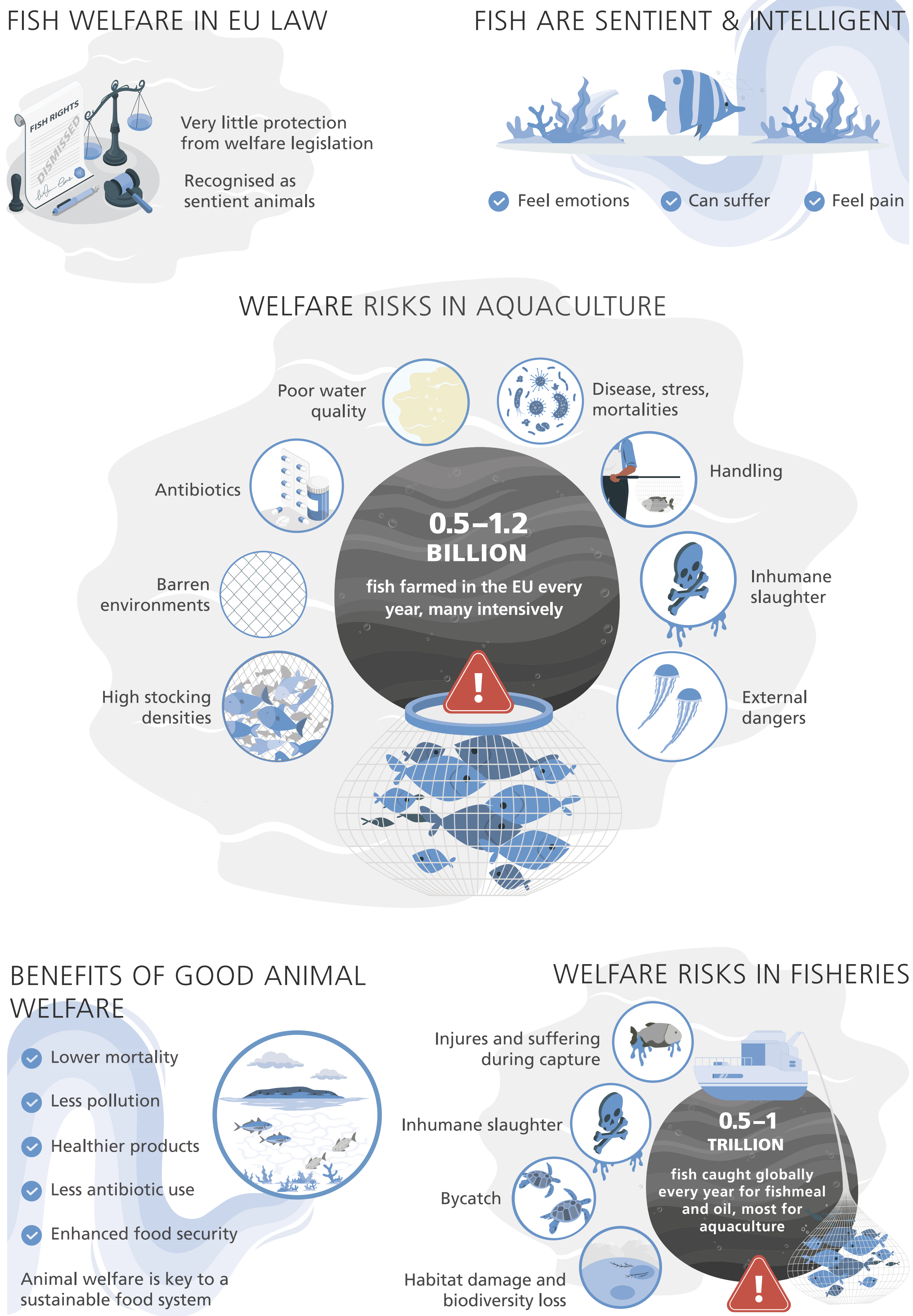
Between 0.5 and 1.2 billion fish are farmed every year in the EU (8). To maximise profit, they are commonly reared intensively, at high stocking densities. This can cause poor water quality (84), facilitate disease spread, and increase stress which lowers fish resistance to disease (85,86). Intensive aquaculture has led to an increase in the use of antibiotics (20,87) which can result in the emergence of antibiotic-resistant bacteria (88). Intensive farms are often barren, contrasting with the complex and varied environments that fish experience in the wild (89). This can prevent various natural behaviours, result in less robust fish, and may cause boredom (89). Confined in cages, farmed fish are unable to evade natural dangers such as algal blooms, jellyfish, and predators, which can injure or kill them (22,90–92). Sometimes fish escape from farms, which can have negative consequences for wild populations (e.g. competition for food, disease spread) (93).

Current aquaculture practices involve numerous stressful events; for example, grading, handling, vaccination, stripping and transportation (84). These commonly involve netting or pumping fish from their cages, often exposing them to air. These practices can result in abrasions, scale loss, injuries to eyes and fin erosion, and are highly stressful (94). Poor conditions during transport, such as overcrowding and poor water quality, can result in accumulation of metabolites leading to suffering and mortality (95,96). Farmed fish are often starved before handling, transport or slaughter (97). If starved for too long welfare is impaired and there can be more aggression and injuries (98). Chronic stress can compromise an animal's health and defence against disease (99).

Many fish do not survive on farms and will die before slaughter. Mortality rates can be strikingly high for farmed fish, estimated at ~15%–80% for some of the most commonly farmed species (100). This indicates great suffering but also a huge waste of resources (both the farmed fish that did not survive and the feed they consumed) that could otherwise have fed millions of people. Despite farmed fish being included in the EU Slaughter Regulation (82), requiring they be spared any avoidable pain, distress or suffering during their killing and related operations, many slaughter methods used in the EU are performed without pre-stunning and are therefore inhumane: suffocation in air or ice slurry, exposure to carbon dioxide in water, gutting and bleeding (101). These cause considerable pain, fear, and suffering and death can be extremely prolonged (102).

When fishmeal and fish oil (FMFO) are fed to aquatic animals, aquaculture also causes suffering for huge numbers of wild fish and contributes to overfishing. The typical capture, landing and killing practices of wild fisheries are inhumane and do not take animal welfare into consideration, and there is no legislation in place to protect wild-caught animals at this time (103,104). Every year, an estimated 0.5 to 1 trillion fish are killed for reduction to fishmeal and oil (FMFO) globally, largely for aquaculture feeds (40). An additional (estimated) 0.3 to 1.3 trillion are caught for human consumption (105). Wild fisheries are environmentally destructive and the key cause of marine biodiversity loss (106,107). This is yet another reason to develop sustainable, non-fed aquaculture rather than relying on feed supplies from fisheries.

Improving farmed animal welfare often comes with benefits that also enhance sustainability (27,28). For example lower mortality rates (and therefore less resource waste), less pollution, healthier products, lower antibiotic use and enhanced food security (108). Animal welfare has traditionally been left out of the narrative in aquaculture, yet it is increasingly recognised as an essential component of a sustainable food system (23).The EU Commission's *Farm to Fork Strategy* highlights benefits, stating that there is an "urgent need…to improve animal welfare", with clear demand from EU citizens (109). Further, the new Strategic Guidelines for more sustainable and competitive EU aquaculture (110) contain a section on fish welfare.



Environmental impacts of aquaculture

The UN's Sustainable Development Goals (SDGs) of the 2030 Agenda makes conservation and sustainability of marine resources a global priority, along with food security, responsible consumption and production and ending malnutrition (15). Aquaculture can contribute to healthy and sustainable diets. However, it should not threaten key Earth system processes (1) or contribute to transgression of key planetary boundaries (73) such as nitrogen and phosphorus cycles, biodiversity loss or climate change.

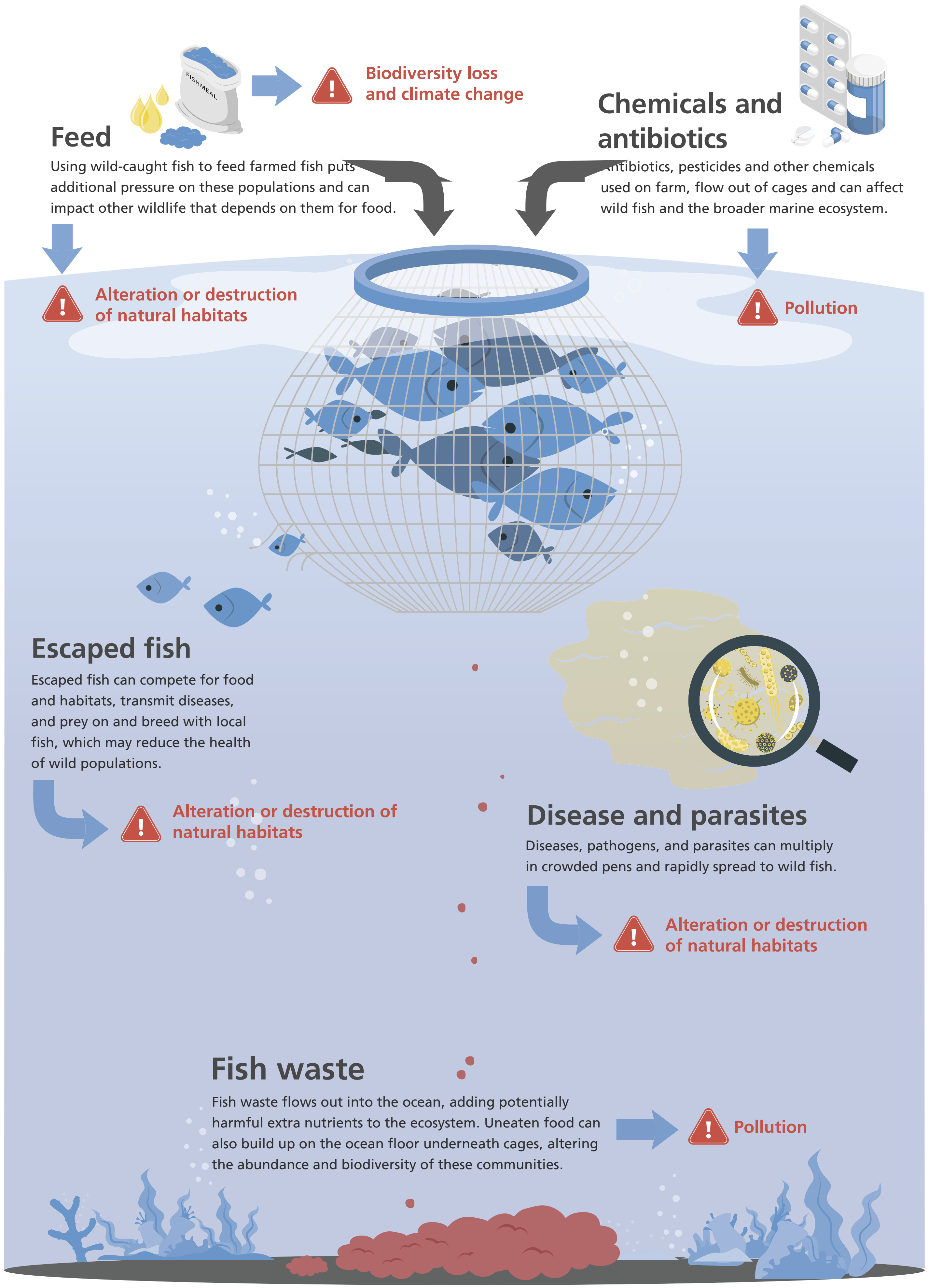
According to Food and Agriculture Organization (FAO) assessment, nearly 90% of assessed stocks are overfished or fished at maximum yield, which has led to fish population reductions, species extinctions, and the collapse of marine ecosystems (16). Aquaculture can provide an alternative source of seafood, however it still relies on the use of natural resources and can harm the environment (16). The most common negative environmental problems that have been associated with aquaculture include decreased water quality and eutrophication, alteration or destruction of natural habitats, chemical and antibiotic pollution, impact on biodiversity and wildlife, greenhouse gas emissions, and the introduction and transmission of aquatic animal diseases (19).

One of the most concerning issues is that intensive aquaculture has promoted the growth of several bacterial diseases, which has led to an increase in the use of antibiotics (87,111). Antibiotics are widely applied in aquaculture for therapeutic and prophylactic purposes around the world (20). In the EU there is legislation (112,113) controlling the use of antibiotics in aquaculture and there has been a blanket ban on the use of antibiotics as growth promoters since 2006 (114). However, antibiotics are still widely applied in Europe (11).

The open nature of aquaculture production systems has led to antibiotic residue build-up in the culturing and adjacent waters, wild fish, plankton and sediments (20). The overuse of antibiotics has also resulted in the emergence of antibiotic-resistant bacteria, which can pose serious risks to public health (115). The consequences of antimicrobial resistance include adverse drug reactions and development of antibiotic resistance for clinically-important bacterial pathogens (88), resulting in negative consequences for livelihoods and food security (115). Therefore, there is an urgent need to reduce antibiotic use in aquaculture facilities given the environmental, food security and health risks associated. First steps are being taken by the European Commission, which has included the objective to reduce the use of antibiotics by 50% by 2030 for farmed animals and aquaculture in the *Farm to Fork Strategy* (109).

It is important to move the sector toward more environmentally friendly aquatic farming. Alternative aquaculture productions systems, such as integrated multitrophic aquaculture (IMTA), recirculating aquaculture systems (RAS) and aquaponics have been developed, which address some environmental impacts (19). For example, RAS are closed environments on land and therefore there is more control over what is released into the environment (19). However there are also significant downsides to these systems, e.g. they consume large amounts of energy, leading to a large carbon footprint (19). Also, regardless of the type of system, the farming of carnivorous species still relies on wild fish populations and so does not solve issues with overfishing and waste of resources, and animal welfare can be further compromised. For example, in RAS, the environments are barren, and the stocking densities are commonly extremely high in order for these more expensive systems to make profit (116).

Finally, plastic contamination has been suggested as a global threat to seafood (117,118 tonnes). It has been estimated that more than 10 million tonnes of plastic enter the oceans annually (119). Abandoned, lost or otherwise discarded fishing gears (ALDFG), also called "ghosts nets", are considered the main source of plastic waste by the fisheries and aquaculture sectors (120). Microplastics are of particular concern since they can quickly disperse far in the environment, and can enter the food chain and become more concentrated with increasing trophic levels (119). Therefore, plastic contamination may be of key importance to marine wildlife and human health (19).



Alternative vision

There are alternatives to intensive production of carnivorous, high trophic species. The cultivation of low trophic plant and animal species can even provide ecological services and help mitigate climate change, as well as providing healthy and nutritious food and addressing food security (121).

LOW TROPHIC-LEVEL FISH

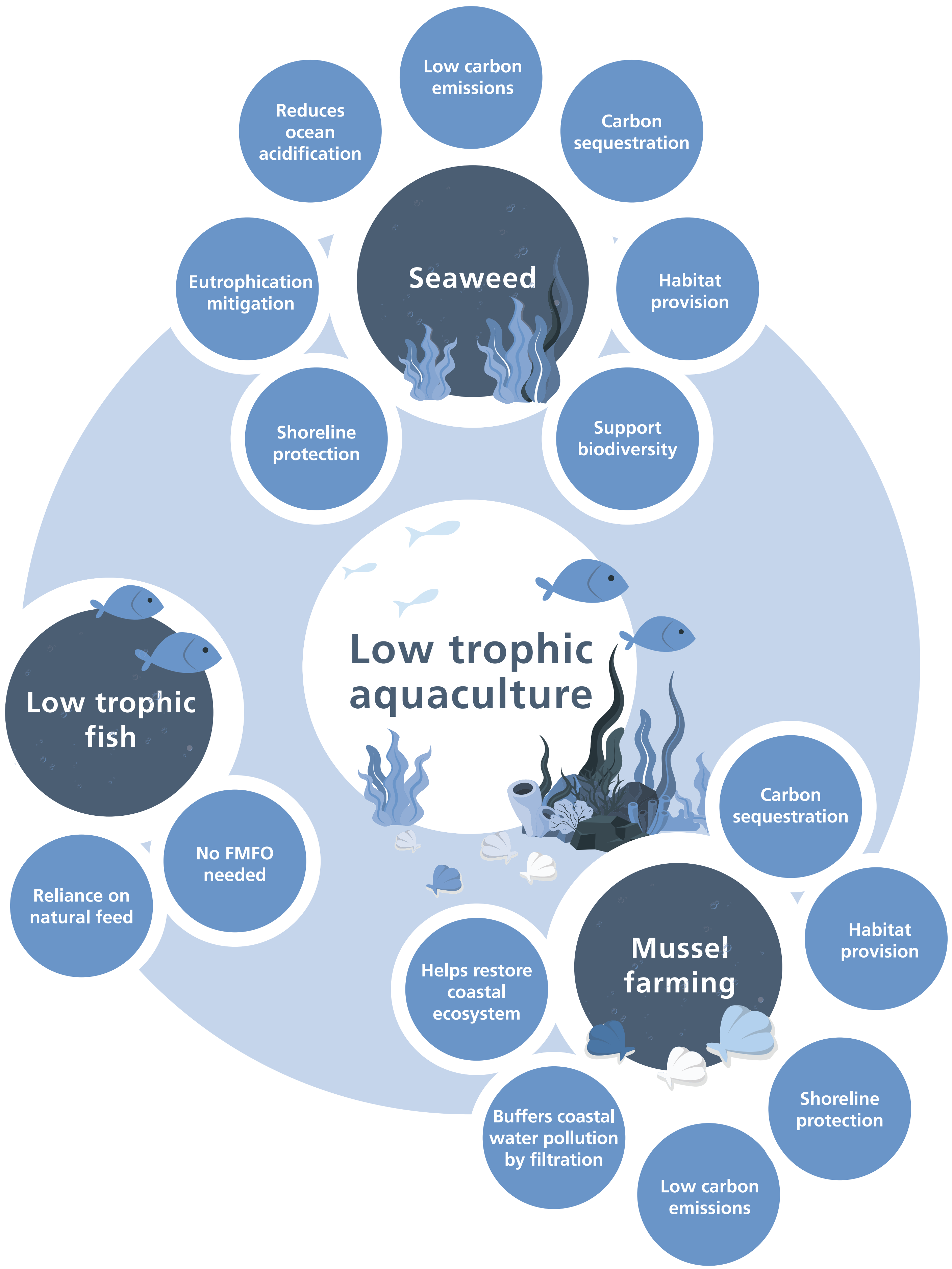
Fish farming should move away from its reliance on both fishmeal and oil (FMFO) and human edible or environmentally damaging plant ingredients for feed, with added benefits as species are farmed at lower trophic levels. Current systems farming carnivorous species are inefficient and at odds with the sustainability objectives for aquaculture (122–125). As a first step, this should involve a move from carnivorous species to naturally herbivorous/omnivorous fish. Naturally herbivorous and omnivorous species should not be given FMFO, as is commonly done to increase their growth (25). They should be reared in extensive systems where feed is not required or, if given some supplementary feed, it should not contain plant materials that are human edible, instead making use of wastes, by-products, or alternative resources (providing they can be created without environmental harm). In addition, the suitability of the species to farming and potential for achieving high animal welfare should be examined and given full regard while searching for suitable candidates for aquaculture.

BIVALVE MOLLUSCS

Farming bivalve molluscs in extensive systems requires no feed, fertilisers, herbicides, chemicals, drugs, or antibiotics (126). Also, bivalves such as clams, oysters, mussels, and scallops, often have a higher protein content per calorie compared with many meats and plant crops, as well as high levels of omega-3 fatty acids, iron, zinc, vitamin B12 and vitamin A (126). Bivalve farming also has a smaller environmental footprint than most other foods, using up almost no land or freshwater, relying on seawater instead, having lower carbon emissions than many cereal crops, and helping to restore and protect coastal ecosystems (126). A proper assessment of the influence of bivalve farming on the surrounding environment is needed and best management practices are required (18,126). Bivalves accounted for almost half of global aquaculture in the 1980s but despite the benefits, due to the explosion in finfish farming, bivalves only account for around 30% of production in recent years (127). This trend is moving in the wrong direction for animal aquaculture to lead to a more food secure, sustainable, and humane future.

SEAWEED AQUACULTURE

Algae include seaweeds (i.e., marine macroalgae) and microalgae, which are photosynthetic aquatic organisms. Algae provide various environmental benefits and ecosystem services, such as eutrophication mitigation, carbon capture or sequestration, ocean acidification amelioration, habitat provision and shoreline protection, among others (128). In aquaculture, seaweeds are used for a growing range of applications ranging from food products and animal feed to cosmetics and chemicals for various industries (129). As food, seaweed is rich in some health-promoting molecules and materials such as, dietary fibre, omega-3 fatty acids, essential amino acids, and vitamins A, B, C and E (130). Also, seaweed aquaculture offers several opportunities to mitigate and adapt to climate change and provide a range of important ecosystem services (129). In fact, seaweed is responsible for much of the CO_2 capture in marine vegetated habitats (131). Seaweed can also be used for raw materials and biofuels and it provides coastal protection, nutrient removal and nursery grounds, therefore, supporting biodiversity (132,133). Seaweed farming practices should be optimised and promoted given the ecosystem services that they provide. Europe is in fact perfectly placed to develop a strong seaweed aquaculture production given that its coastal regions have been assessed as "high opportunity" based on factors such as the environmental and socioeconomic benefits (129). The *Farm to Fork Strategy* seems to support this by stating that algae industry should become an important source for a sustainable food system and global food security (109).

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Our policy recommendations for EU aquaculture

Transform the industry to sustainable production of low-trophic aquatic species, in extensive systems that do not harm the environment and potentially provide ecosystem benefits, that help mitigate climate change and contribute to food security.

1. Direct economic support for EU aquaculture towards producers who are innovating, sustainably growing and/or transitioning to mussel and seaweed farming, with neutral or positive environmental impacts.

2. Refocus fish production to responsible farming of herbivorous/omnivorous fish species in extensive systems that meet the welfare needs of the fish, require no/low feed inputs and are environmentally friendly.

3. Urge that if supplementary feeds are used, they should be based on by-products and wastes from other industries, rather than human-edible resources.

4. Facilitate research into any new species proposed for aquaculture before commercial farming commences. Require that industry first establishes that animal welfare needs can be met in captivity (e.g. behavioral needs can be met, humane slaughter is available, etc.) and that no negative environmental costs are associated. Some species may be unsuitable and subsequently should not be farmed, e.g. octopus farming should be banned (134).

Move away from the intensive, feed-based production of aquatic animals

5. Phase out intensive, feed-based production (especially with feed containing wild-caught fish) of existing industries and prevent new industries of this kind from emerging.

6. Require that where carnivorous species are farmed, only semi-intensive, or preferably extensive, systems should be used. Any fishmeal and oil in the diet should only be sourced from trimmings, and other feed materials should be based on by-products and wastes from other industries, rather than human-edible resources. Encourage a significant reduction in the production of carnivorous species in order to meet this requirement.

7. Prohibit the use of purpose-caught (i.e., by reduction fisheries) wild fish (including mesopelagic fish), krill and other species for feed.

8. Prohibit the use of wild-caught animals to stock aquaculture farms, particularly when the species are endangered and overfished, e.g. European eel. Further, efforts to close the reproductive cycle in captivity should also be opposed if the species are unsuited to farming, e.g. bluefin tuna.

Make aquaculture better for people, animals, and the planet

9. Better integrate human health, sustainability, environment, and animal welfare policies at national and EU-wide levels. For example, ensure that public diet policies recommending seafood consumption specify sustainable seafood farmed lower in the trophic chain, and a decrease in carnivorous species consumption, and communicate the benefits of this to help shift consumer preferences over time.

10. Ensure that industry regulations prevent aquaculture from causing ecosystem damage, biodiversity loss or contributing to climate change, and require that aquaculture production operates within key planetary boundaries.

11. Include aquaculture in the scope of the Industrial Emissions Directive (IED) in order that the emissions footprint of the industry can be monitored and controlled.

12. Require responsible, transparent, and minimal use of chemicals and pharmaceuticals (such as antibiotics) in aquaculture, and facilitate processes to record, and make publicly available, national and EU-wide data on usage levels.

13. Fund and support innovations that aim to increase animal welfare alongside efficiency in systems, and novel alternative feeds that can replace human-edible resources (e.g. microbial proteins and oils) or produce food without welfare issues (e.g. cell-based fish).

14. Recognise the important role of animal welfare in sustainable food production; introduce species-specific legislative requirements for rearing, transport and slaughter, to protect aquatic animals farmed in the EU, with parallel requirements for imported seafood – driving up standards for countries outside the EU and ensuring a level playing field.

15. Fund and support research into humane rearing, transport, and slaughter of farmed fish. Set up an EU Reference Centre dedicated to the welfare of farmed fish, facilitating collaboration between expert stakeholders across EU member states to develop better practices, provide training courses, disseminate scientific findings, and facilitate enforcement of legislation.

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Conclusion

A responsible and holistic approach is needed in the EU aquaculture sector, along with strong political actions that will guide the industry in a truly sustainable direction. Production of carnivorous finfish species is expanding due to its profitability, but this is concerning, considering the wider perspective of European food security: the need to produce sustainable food with efficient use of resources, preserve coastal ecosystems, reduce the use of antibiotics, reduce greenhouse gas (GHG) emissions, and protect animal welfare. As shown in this report, growth of the extensive sector, restorative farming practices, and innovations toward more sustainable aquatic farming are instead needed.

As part of the European Green Deal (2019) (135), the European Commission has outlined a set of policy initiatives aiming to reduce GHG emissions by at least 55% by 2030 compared with 1990. Since food systems account for one-third of GHG emissions, the *Farm to Fork Strategy* (109) is an integral part of the European Green Deal, outlining actions that aim to make food systems fair, healthy, and environmentally friendly. In fact, the Strategic Guidelines for the sustainable development of EU aquaculture (SAGs) (110) bring forward several positive points, including promotion of low environmental impact and climate change friendly aquaculture, a steer to reduce the use of fishmeal and fish oil (FMFO), and suggests that EU aquaculture diversifies into new species, particularly non-fed, and low-trophic species. In this report we have highlighted the importance of the direction set by these EU policies and lay out 15 key recommendations that could transform the industry for the benefit of people, planet and animals.

EU aquaculture should ultimately provide species-diverse and nutrient-diverse food sources that are accessible and appropriate to people across regions and economies (136). The aquaculture industry must urgently phase out its use of forage fish for aquafeeds. It is crucial that feed for farmed animals does not consist of ingredients that could be used directly for human consumption, and do not harm the environment in their production. Most importantly, further expansion of aquaculture should focus on the cultivation of low trophic-level species. Technology and innovation should drive more sustainable aquaculture development, including to reduce aquaculture's environmental impact. Public food policies should also favour farming low-trophic species and shift consumer preferences towards these, promoting the sustainability benefits of these species, in addition to affordability and taste.

The human health and environmental policies should be harmonised, e.g. to ensure that dietary recommendations to increase seafood consumption do not lead to further overexploitation of fisheries and intensification of aquaculture (16). Increased consumer awareness of issues related to overfishing, aquatic animal welfare and ocean health is needed, as well as understanding of sustainable and healthier seafood alternatives.

To conclude, in order to fulfil the demands of the future, aquaculture must protect the environment, respect animal welfare, and be socially responsible. Policy makers and stakeholders should commit to improved aquaculture production systems that do not threaten the already overfished marine ecosystems, do not pollute, do not contaminate with chemicals or antibiotics, do not disrupt the marine habitats, and take into account the welfare of the animals involved. Potential solutions and better alternatives do exist. The farming of low trophic species can provide ecological services and are key to a sustainable future.

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