

**CAUTION!**

*The of dark side*  
**AQUACULTURE**



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## ABOUT BLOOM

BLOOM is a non-profit organization founded in 2005 that works to preserve the ocean and a socio-economic balance in the fishing sector. We run advocacy, education and awareness campaigns and conduct scientific research. BLOOM's actions are meant for the general public as well as policy-makers and economic stakeholders.

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## ABSTRACT

This report dives into the world of ‘reduction fisheries’, i.e. the transformation of wild fish into fishmeal and fish oil to supply the aquaculture sector, as well as pig and poultry farming.

Despite high impacts on marine ecosystems and coastal communities, this topic is vastly overlooked by researchers, civil society and public authorities. Overall, little independent information is available, and the reduction fishing industry remains opaque and adverse to cooperation. This sector of activity and its consequences on the sustainability of farming require closer observation and more independent scientific investigations.

The overall pattern of reduction fisheries is questionable when considering the global process of ‘fishing down marine food webs’, the expansion of fleets into the waters of developing countries, and the final use of the product (fishmeal), which feeds a mostly unsustainable aquaculture scheme of predatory fish and forms an unnecessary input into the diet of non-piscivorous species such as pigs, poultry or mink (farmed for fur).

In this report, we show that reduction fisheries were developed as a result of our inability to sustainably manage abundant traditional fish stocks. We demonstrate that the ‘fishing down’ process from species high in the food chain to species lower in the food chain also occurs within reduction fisheries themselves, which are shifting from typical pelagic species such as anchovy, sandeel and herring to new, hitherto ‘undesirable’ species such as boarfish and lanternfish (Myctophids).

**We highlight two urgent issues with dire social and environmental consequences that need to be addressed:**

- Overall, 90% of the fish reduced into fishmeal and fish oil are perfectly fit for human consumption. Instead of contributing to food security, especially in developing countries where pelagic species are often captured, these fish are used to farm salmon for developed countries (as a result of the massive overfishing and eventual collapse of wild salmon populations);
- The fastest growing type of aquaculture, which produces predatory species that match the taste and demand of consumers in developed countries, is the most problematic one with the highest impact on the ocean, ecosystems and humans. The growth of this sector simply corresponds to business opportunities supported by strongly questionable labelling schemes such as the Marine Stewardship Council (MSC) and the Aquaculture Stewardship Council (ASC), although solutions that should be encouraged do exist to minimize the impact of reduction fisheries and fish farming on humans and the environment.



Here we argue that only integrated multi-trophic aquaculture (IMTA) should be sought for by entrepreneurs and supported by public authorities, while direct consumption of wild fish should be a top priority of the global agenda.

## KEY FINDINGS



- Aquaculture supplied 9.8 kg of fish per year and per inhabitant in 2012, i.e. close to 50% of all fish consumed by humans around the world;
- China is by far the most prominent country engaged in aquaculture, with around 50% of the global production;
- Carnivorous species, such as Atlantic salmon, Atlantic cod, Atlantic bluefin tuna and tropical shrimp are either produced in or exported to developed countries, and rely heavily on 'reduction fisheries', i.e. fisheries whose catches of fish and krill are turned into fishmeal and fish oil;
- Fishmeal and fish oil are also increasingly used to boost the growth of herbivorous species;
- Between 1950 and 2013, 25% of the world's catch of wild fish was reduced into fishmeal and fish oil;
- Three families of fish (i.e. Engraulids, Clupeids and Carangids) accounted for 78% of all reduction fisheries;
- 90% of the reduced catch consist of food-grade fish. The role of small pelagic fish in human food systems has recently shifted from direct to indirect consumption;
- Almost half of all biomass removals from reduction fisheries are destined for non-aquaculture use and enter the diet of animals that do not naturally eat fish such as pigs and poultry. A small proportion of fishmeal is even used in pet foods and as food for mink to produce fur.
- Industrial reduction fisheries in the EU have only accounted for 12% of the total catch since 1950. Denmark (including the Faroe Islands) leads this sector, with 71% of total EU reduction fisheries. However, aquaculture is rapidly developing in the EU so these figures might change substantially in the near future;
- A rise in reduction fisheries occurred when fleets started turning their attention from collapsing wild fish stocks captured for human consumption to species that could be reduced to fishmeal and fish oil in order to farm the species that were overfished in the wild;
- Even 'traditional' forage fish species such as anchovy and sandeel are now being fished down to the extent that fleets need to develop target fisheries for new, hitherto unwanted species such as boarfish, lanternfish and krill;
- Over a third of the total catch destined to be reduced comes from poorly managed fisheries;
- Forage species play a crucial role in the food web, converting energy from phytoplankton and zooplankton into a useable form for predatory fish, such as marlin, tuna, cod etc., as well as seabirds and marine mammals;
- Pelagic fish are an essential component of the developing world's diet but the demand for these fish by the fishmeal sector directly threatens the food security of local populations;
- Bioconversion initiatives set forth a possible sustainable future for aquaculture: a fully beneficial cradle-to-cradle recycling scheme which allows feeding farmed animals with virtually no negative impacts on the environment and possibly even solutions for ecological problems such as waste management. For example, blood collected from slaughterhouses or organic waste are used to feed insect larvae, which are then turned into feeds;
- Certifying as 'sustainable' fisheries that reduce fish to produce fish and pose stark food security problems is in total contradiction with the FAO Code of conduct for responsible fisheries and elementary ethics. It simply serves as a stamp of 'sustainability' approval to controversial yet certified aquaculture schemes.

## KEY RECOMMENDATIONS

Instead of rolling over by default a pattern of serial depletion (over-fishing one stock and moving on to the next), it is imperative to take a step back and reflect on how to make current fisheries sustainable instead of blindly encouraging the development of unsustainable aquaculture schemes.

### We suggest six key recommendations to achieve this:

- 1 Consumer's demand for carnivorous fish species, pigs and poultry should decrease;
- 2 Food-grade fish species (such as herring) should be solely used for direct consumption and not for reduction;



Herring (*Clupea harengus*). © A. Fraikin

- 3 The EU should be a role model by refusing to reduce fish to produce fish. Legislation prohibiting the use of fishmeal in animal feed should be enacted;
- 4 Reduction fisheries should not be eligible for “sustainable” certification;
- 5 The EU can decide to reverse the current trend of unsustainable aquaculture by setting ambitious standards of practice;
- 6 Cradle-to-cradle solutions such as insect farming, resulting in waste problem management and protein production, must be developed.

# OVERVIEW OF GLOBAL REDUCTION FISHERIES

## THE NEW ERA OF AQUACULTURE

Aquaculture has been promoted as one way to alleviate pressure on wild populations and improve food security.<sup>[1-5]</sup> In Europe in particular, it is presented as a way to fill the gap between a rising seafood demand and declining catches of wild fish.<sup>[6; 7]</sup> However, **this report will demonstrate that this is clearly not the case.**

Large-scale aquaculture and intensive farming in marine environments are relatively recent phenomena, with 106 marine species being domesticated between 1987 and 1997.<sup>[8]</sup> In 2013, 575 taxa of plants (mostly seaweed) and animals (mostly fish, crustaceans and mollusks) were farmed, according to the Food and Agriculture Organization of the United Nations (FAO).<sup>[9]</sup> China is a historical player in aquaculture<sup>[10]</sup> and by far the most prominent country engaged in fish farming, with around 50% of the global production (**Figure 1**).

The large-scale industrial aquaculture being developed nowadays is hardly reminiscent of the earliest aquaculture,<sup>[10]</sup> believed to have begun in Asia, between 2,000 and 1,000 B.C. with the small-scale farming of freshwater common carp (*Cyprinus carpio*).<sup>[11]</sup> Once used to provide food for small villages, aquaculture now supplies **close to 50% of all fish directly consumed by humans around the world.**<sup>[12]</sup> In terms of global per capita fish consumption, capture fisheries (including fisheries targeting freshwater species inland) provided 9.8 kg per year in 2012, whereas 9.4 kg per year was sourced from both inland and marine aquaculture.<sup>[12]</sup>

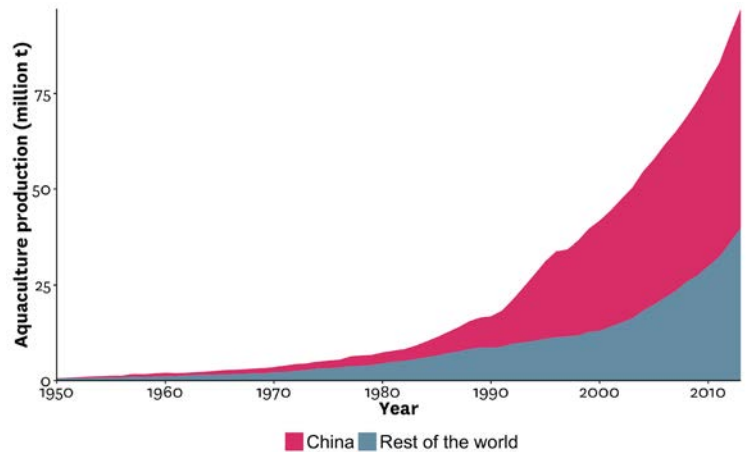


Figure 1: Official aquaculture production by China and other countries, 1950-2013.<sup>[9]</sup>

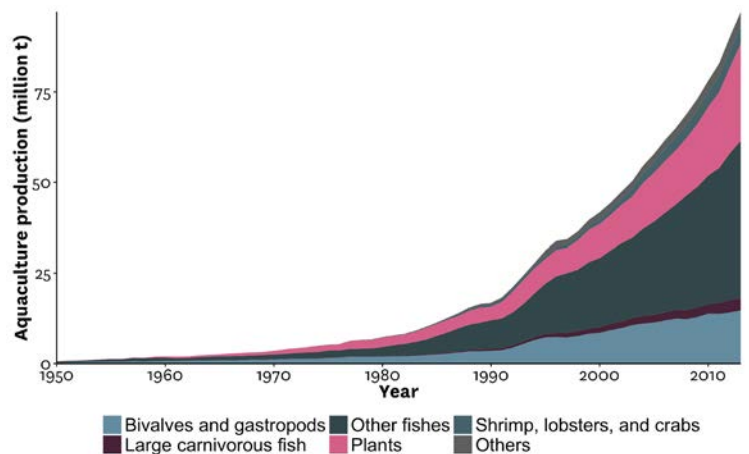


Figure 2: Official aquaculture production in the world by large taxonomic group, 1950-2013.<sup>[9]</sup>



In developed countries, most farmed species are **carnivorous**, such as Atlantic salmon (*Salmo salar*), Atlantic cod (*Gadus morhua*), and Atlantic bluefin tuna (*Thunnus thynnus*). Other species such as tropical shrimp species (e.g. giant tiger prawn, *Penaeus monodon*, farmed in Thailand) are also exported to developed countries. **These species rely heavily on feed that is produced with wild-caught marine species ('reduction fisheries').**

On the contrary to the farming of carnivorous species, **growing herbivorous species has the potential to promote economic and food security in developing countries.**<sup>[13]</sup> The growing industrialization of the aquaculture sector, including herbivorous fish farming, is nonetheless a cause of concern due to various detrimental effects, such as the important use of antibiotics, the overfertilization of surrounding waters etc. Many Asian countries (including Vietnam and China) and increasingly African countries rely on herbivorous farmed fish, which are not fed with wild-caught fish ('reduction fisheries'), although this is less and less true.<sup>[14]</sup>

### WHAT IS A REDUCTION FISHERY?

The term 'reduction fisheries' designates **fisheries whose catches of fish and crustaceans (essentially krill) are turned into fishmeal and fish oil.** These species of fish are sometimes referred to as 'forage fish' and are almost exclusively small pelagic species<sup>1</sup> such as anchovies, herring, sprat, and sardines.<sup>[15]</sup> Small pelagic fish are capable of rapid reproduction and growth, and therefore are generally considered resilient to massive removals by fisheries. However, they are also highly sensitive to environmental factors such as El Niño and La Niña.

Krill and forage fish are found all over the world's oceans, with the major regions supporting reduction fisheries located off the West Coast of South America, the United States (East Coast and Alaska), around northern Europe, West Africa, and Antarctica (for krill).

**FORAGE FISH** are bait fish preyed on by larger predators such as carnivorous fish (tuna, cod), seabirds and marine mammals. They are close to the bottom of the oceanic food web, and include species such as herring, sardine, anchovy and sprat.



Herring (*Clupea harengus*) and sprat (*Sprattus sprattus*). © A. Fraikin

The role of small pelagic fish in human food systems has shifted over time from direct to indirect consumption. Historically, small-scale artisanal fishers have targeted stocks of small pelagic fish, in part because it can be less costly to fish schooling species that aggregate in large groups.<sup>[16]</sup> It was not until the 1950s that industrialization of these fisheries occurred. **Today, almost 70% of landed forage fish are not directly consumed,<sup>2</sup> but rather processed into fishmeal and fish oil.**<sup>[12]</sup>

Overall, biomass removals from reduction fisheries are considerable: **between 1950 and 2013, 25% of the world's catch of wild fish (excluding discarded catch, subsistence and recreational fisheries) was reduced into fishmeal and fish oil (Figure 3).**<sup>[17]</sup> Three families (i.e. Engraulids, Clupeids and Carangids) accounted for 78% of all reduction fisheries, with 41%, 29%, and 8% respectively (Figure 4). Overall, Peruvian anchoveta (*Engraulis ringens*, an Engraulid) made up 35% of the reduction fisheries catch.

<sup>1</sup> Pelagic fish are those found in the mid to upper levels of the ocean. Small demersal species such as blue whiting and sandeels are also targeted.

<sup>2</sup> This figure is based on the data underlying Cashion et al. (2017)'s paper. For this estimate, we extracted

the list of species that accounted for 90% of the reduction fisheries (excluding 'Marine fish nei' and 'Carangids' groups, which were too broad to be meaningful) since 1950. For this list of species, we then calculated the percentage of the catch destined for reduction, compared to the catch

destined for direct human consumption. This list included the following taxa: *Ammodytes* sp., *Brevoortia patronus*, *Clupea bentincki*, *C. harengus*, *C. pallasii pallasii*, *Dosidicus gigas*, *Engraulis capensis*, *E. encrasicolus*, *E. japonicus*, *E. ringens*, *Leiognathids*, *Mallotus villosus*, *Micromesistius*

*poutassou*, *Nemipterids*, *Sardina pilchardus*, *Sardinella longiceps*, *Sardinops sagax*, *Scomber japonicus*, *S. scombrus*, *Sprattus sprattus*, *Trachurus murphyi*, *Trichiurus lepturus*, and *Trisopterus esmarkii*.



### REDUCE THAT FISH!

Fishmeal is a brown flour-like powder that is produced by cooking, pressing, drying and grinding whole fish and fish trimmings, i.e. leftover scraps of fish from processing plants.<sup>[18-21]</sup> Fish oil is extracted during the cooking and pressing process. In the early 2000s, 6.2 million tonnes of fishmeal and about 1.3 million tonnes of fish oil were produced at about 400 reduction plants worldwide, out of about 30 million tonnes of wild capture reduction fisheries catch. This corresponds to a conversion factor of 25%.<sup>[20; 22-23]</sup>

### WHY GIVE FISH TO PIGS AND CHICKENS?

Fishmeal and fish oil are highly desired feeds for the fish and livestock production industry because they have reported immunity and health benefits,<sup>[24]</sup> are easily digestible, and may increase 'feed appeal' through improved palatability.<sup>[25-29]</sup> However, it has also been pointed out that fishmeal and fish oil do not contain any unique nutrient (i.e., **they are replaceable**) but are just convenient delivery packages for the nutrients required for animal production.<sup>[30]</sup>

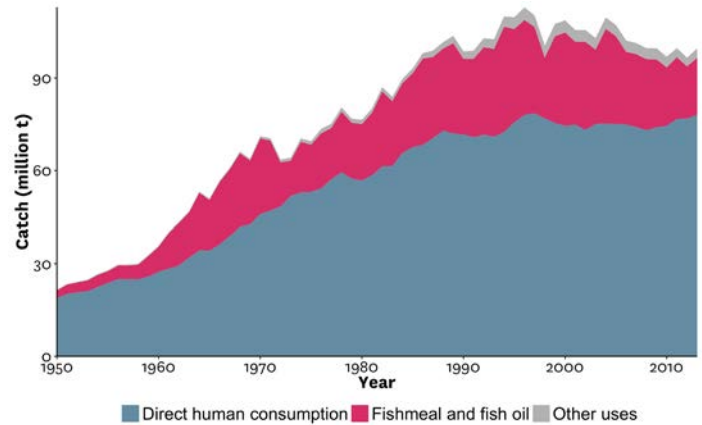
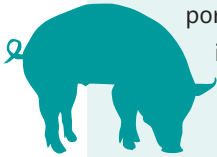


Figure 3: End use of global industrial and artisanal marine landings (i.e. excluding discarded catch and recreational fisheries), 1950-2013.<sup>[17]</sup>

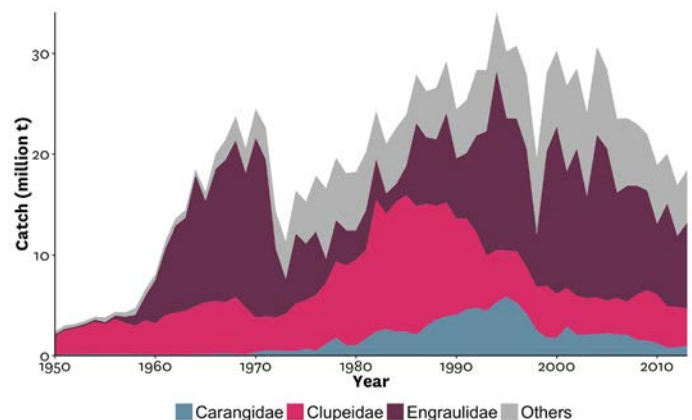


Figure 4: Global catches of forage species by family, 1950 to 2013. The large drop in catches of Engraulidae in the late 1990s is due to a strong El Niño event.<sup>[17]</sup>



*Troubling fact: 90% of the reduced catch consist of food-grade fish, which is perfectly fit for direct human consumption.*<sup>[17]</sup>

### TOUCHING THE BOTTOM: KRILL FISHERIES

Krill (almost exclusively Antarctic krill *Euphausia superba*) are targeted by reduction fisheries in order to produce fish oil used for aquaculture and agriculture purposes, but also health supplements for human consumption. The vast majority (89.2%) of the krill catch comes from the Antarctic part of the Atlantic Ocean, and Eurasian countries account for almost all of it. Norway is currently the main actor, with 70.3% of the global catch since 2000.<sup>[9]</sup>

These fisheries could have tremendous implications on the functioning of ecosystems, as krill forms the very first component close to the bottom of the oceanic food chain.<sup>[31-32]</sup>

### SALMON FARMING: A POSTER-CHILD OF AQUACULTURE UNSUSTAINABILITY

Since the 1970s, catches of North Atlantic salmon have dramatically decreased from almost 13 000t in the early 1970s to 1 100t in 2014.<sup>[33]</sup> There was virtually no farming then but today, the vast majority (already close to 95% in the late 1990s) of salmon available on markets comes from aquaculture.<sup>[34]</sup> **Instead of rebuilding collapsed wild populations that have been fished almost to extinction, extensive salmon farming started, using fishmeal made of wild species lower on the food chain.**

On top of its heavy use of fishmeal and fish oil, salmon farming is widely criticized for a range of problems including the use of antibiotics,<sup>[35-36]</sup> parasitism of wild populations by sea lice,<sup>[37-39]</sup> farmed fish escaping from pens and interfering with wild individuals,<sup>[40-41]</sup> and organic matter pollution from the farms.<sup>[42]</sup>

### A SLIGHTLY DECLINING TREND

Since 2004, the proportion of fish reduced into fishmeal and fish oil has reduced from 28% to 19%, because:

- An increasing proportion of fishmeal and fish oil is based on by-products and waste from processing (around 25-35%),<sup>[43]</sup> rather than on whole wild-caught fish.<sup>[44-47]</sup> However, products derived from these 'trimmings' are of a lesser and more variable quality, so it is likely that trimmings will never entirely replace whole fish in the feeding scheme.
- Some species have also been increasingly consumed directly, such as herring and blue whiting in Europe. Other species such as mackerel are also sometimes exported to Africa for direct consumption, where they form an extremely valuable source of protein.<sup>[16; 48]</sup>

**However, this encouraging trend is expected to reverse in the future due to the increasing use of fishmeal and fish oil to boost the growth of herbivorous species.**<sup>[14]</sup>

### THE FISHMEAL AND FISH OIL MARKET

The two biggest fishmeal producing countries are Peru and Chile.<sup>[21]</sup> Their production, along with that of Panama and Argentina, makes South America the leader of the global fishmeal market with around 50% of the production (**Figure 5**). Continental Europe (including Russia, Norway, and Iceland) is the world's third largest producer, generating about 16% of the global fishmeal and fish oil supply, which represents around 500,000 tonnes per year.

In the European Union, only Denmark is a significant actor, with 5% of global fishmeal production. Trimmings are thought to make up around a third of Europe's fishmeal production.<sup>[21; 45]</sup>

Fish reduced to fishmeal and fish oil are used as feed for three main animal production sectors: pig, poultry and fish farming. In 2008, it was estimated that about 57% (and increasing) of the global production of fishmeal supplied the aquaculture sector, 22% supplied the pig farming sector, and 14% the poultry-farming sector (**Figure 6**).<sup>[23]</sup> In other words, **almost half of all biomass removals from reduction fisheries are still destined for non-aquaculture use and enter the diet of animals that had never been fed fish before. A small proportion (but increasing quantities) of fishmeal produced**

is also used in pet foods and as food for farmed mink to produce fur.<sup>[15; 20; 22; 49]</sup>

These proportions represent a dramatic shift in sector demand from only a decade ago, where only 17% of all fishmeal produced went to aquaculture feeds (**Figure 6**).<sup>[50]</sup>

Fish oil (including that produced with krill) used to be principally used for direct consumption by humans,<sup>[18]</sup> but the overwhelming majority of global production now goes to supplying the aquaculture market, with only about 13% supplying 'other' markets.<sup>[23; 51]</sup> Increasingly, though, fish oil is coming back into the 'neutraceutical' market for human consumption as omega-3-rich dietary supplements.<sup>[44; 52-54]</sup> **Other markets include land animal feeds and industrial purposes such as engine oils and fertilizers.**<sup>[51; 55]</sup> <sup>3</sup> Overall, about 40% of the world's

fish oil supply goes to feeding farmed Salmonids (i.e. salmon and trout species).<sup>[56]</sup>

The EU is a net importer of fishmeal and fish oil, with respectively 442,000 tonnes and 63,000 tonnes imported annually in the mid-2000s.<sup>[57]</sup> In 2004, the EU utilized 18% of the global fishmeal supply and 19% of the global fish oil supply.<sup>[52]</sup>

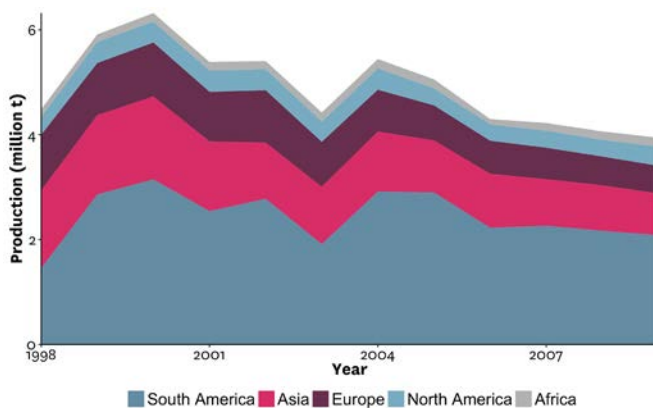


Figure 5: Fishmeal production by continent (compiled from Seafish).<sup>[58]</sup>

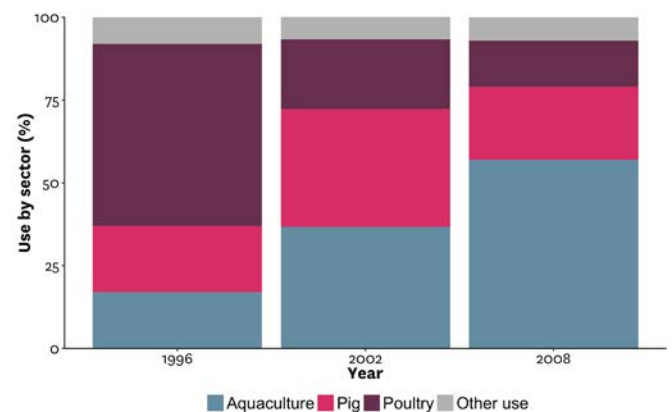


Figure 6: Proportion of global fishmeal supply used by different sectors.<sup>[23; 50; 59]</sup> A more complete and recent time-series was requested to the International Fishmeal and Fish Oil Organisation (IFFO) but not obtained.

<sup>3</sup> Before reduction fisheries expanded and reached the scale we know today the use of fishmeal as fertilizer was common.

pêches maritimes 24, tome VI (fasc. 4), Office scientifique et technique des pêches maritimes (OSTPM), Paris (France). pp. 328-500.

## EUROPEAN REDUCTION FISHERIES

Both seines and trawls are used to target and catch fish species destined for reduction.<sup>[52; 60]</sup>

**Purse seine nets can be larger than 600 meters in length. Fishing vessels are fitted with hydro-acoustic sounders capable of estimating biomass** and species composition of fish schools under the boat.<sup>[22]</sup> Some European reduction fishery vessels have on-board reduction capabilities — where processing is done at sea — and others land the fish at processing plants on shore.<sup>[22; 61]</sup> Trawlers can be more than 100m in length, with 100m-wide and 60m-high trawls.<sup>[61]</sup>

Industrial reduction fisheries in the EU have only accounted for 12% of the total catch since 1950 (**Figure 7**). Denmark (including Faroe Islands) leads this sector, with 71% of total EU reduction fisheries.<sup>4</sup> It has been asserted that 41% of all fishers in Denmark rely in some way or another on reduction fisheries.<sup>[52]</sup> For this country alone, there were over 10,000 mid-water trawl trips made in 1999 for reduction species.<sup>[62]</sup>

Ammodytids (sandeels), Clupeids (herrings and sprat) and Gadids (Norway pouts, blue whiting) account for 97% of the catch (**Figure 8**). **Overall, the reduction fisheries catch has decreased since 1995 when it peaked slightly below 2 million tonnes per year.**

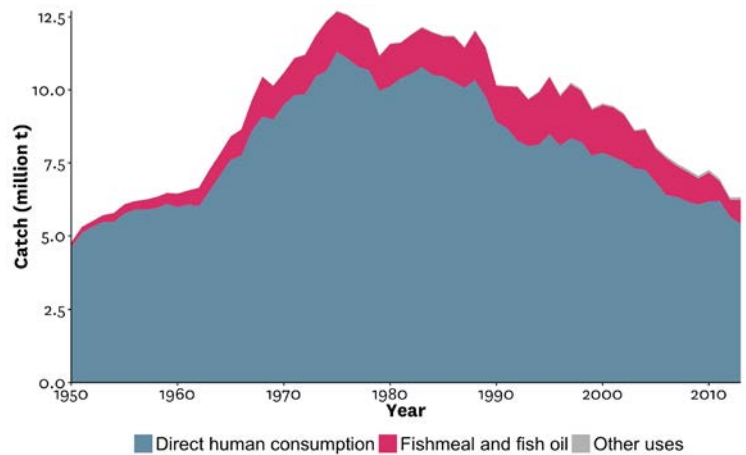


Figure 7: End use of EU industrial and artisanal marine landings (i.e. excluding discarded catch and recreational fisheries), 1950–2013.<sup>[17]</sup>

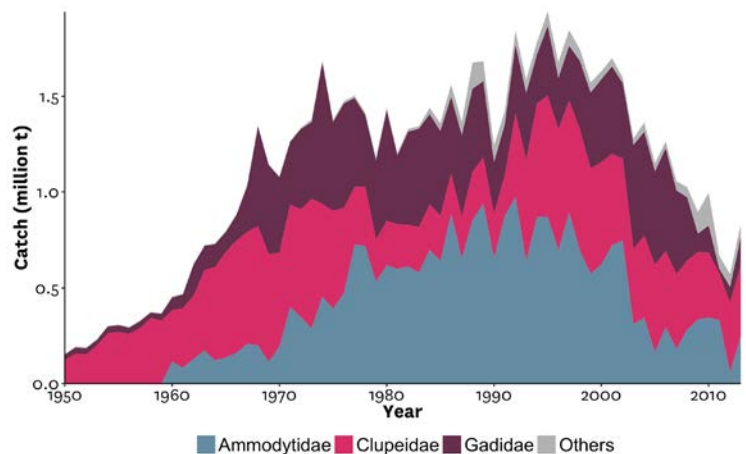


Figure 8: EU reduction fisheries by family, 1950–2013.<sup>[17]</sup>

<sup>4</sup> Non-EU countries such as Norway, Iceland and Russia are very important reduction fisheries nations, with a catch since 1950 reaching almost twice that of EU countries.

# FISHING DOWN EUROPEAN FISH (STOCKS)

## FISHING DOWN

Historically, the most productive fishing area in Europe has been the North Sea. However, both the North Sea and the Barents Sea have experienced major declines in landings in the past half-century,<sup>[22]</sup> and **a rise in reduction fisheries occurred when fleets started turning their attention from collapsing stocks fished for human consumption to species that could be reduced to fishmeal and fish oil.**

New fisheries targeting species such as boarfish and capelin have also been developing as historical fisheries have declined. **Yet again, we see the pattern of exploiting least desirable species lower on the food chain as a result of a complete failure to manage fisheries of other stocks sustainably** (see Annex and sidebox ‘Sequential exploitation and depletion of the ocean’).

## FISHING FURTHER (INTO OTHER WATERS)

European vessels also target species for reduction outside the Northeast Atlantic, essentially in the Eastern Central Atlantic and in the Northwest Pacific.<sup>[9]</sup> The case of European reduction fisheries in the Eastern Central Atlantic is particularly interesting and worrisome, since they occur in the western part of Africa, i.e., an area **where coastal populations strongly depend on fish, including a few species of forage fish, for their daily protein needs.**<sup>[63]</sup>

In order to target various species such as jack and horse mackerels, European pilchard, and sardinellas, **the European Union has secured two fishing access agreements with Morocco and Mauritania since 1988.**<sup>[64-77]</sup> Since 2000, the EU countries that took most of the licenses attributed via these publicly-funded agreements are the Netherlands (30.5%), Ireland (26.6%), Lithuania (17.8%) and Latvia (10.2%).<sup>[78-85]</sup> In Mauritania, quotas have fluctuated between 250 000 and 450 000 tonnes per year (for 15-25 vessels), whereas they were of 60-80 000 tonnes per year in Morocco (for 18 vessels).

## SEQUENTIAL EXPLOITATION AND DEPLETION OF THE OCEAN

Historically when one species or stock of fish is fully exploited, fleets just start fishing new species altogether. There is evidence that a new reduction fishery targeting boarfish (*Capros aper*) has recently begun in Europe,<sup>[86]</sup> and industry representatives even declared it one of the main target species ([www.eufishmeal.org/resources](http://www.eufishmeal.org/resources)). Although boarfish used to be considered a ‘nuisance’ bycatch species in mackerel, horse mackerel and crustacean trawl fisheries, large spawning aggregations of this small mesopelagic fish are now being targeted by Irish and Danish fleets.<sup>[87]</sup> Catches of boarfish now replace scarcer sandeels in Danish fishmeal plants.<sup>[87]</sup>

## FISHING DOWN, AND DOWN, AND DOWN...

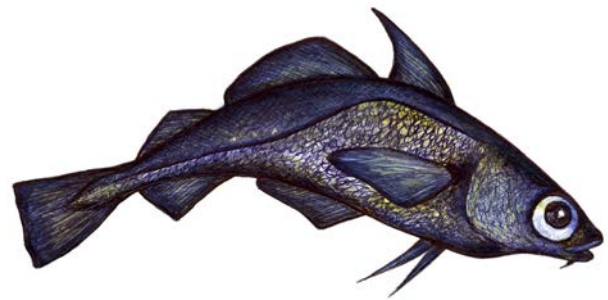
Recently, it has been suggested that targeting deeper-dwelling mesopelagic species (those living at depths of about 200-1,000 m) may be a possible future direction for reduction fisheries.<sup>[22; 88]</sup> Mesopelagic fishes may be — by far — the most abundant in the ocean.<sup>[89]</sup> One such group of species, the lantern fishes (family Myctophids) is the most abundant mesopelagic fish group,<sup>[90]</sup> spending the day at about 400-1,000 m depth, and migrating closer to the surface at night to feed on plankton. Lantern fishes were tested as a possible fishmeal and fish oil input as early as the 1980s.<sup>[91]</sup> South Africa is already using lantern fish (*Lampanyctodes hectoris*) in their production of fishmeal and fish oil.<sup>[92]</sup>

### HEALTH CHECK OF EUROPEAN 'FORAGE FISH'

Regarding the overall situation in the world, an early initiative by the NGO 'Sustainable Fisheries Partnership' was undertaken to assess the sustainability of the fisheries used for reduction into fishmeal and fish oil. Their first findings were less than encouraging: none of the principal reduction fisheries in the world used ecosystem-based management approaches and only 14% of the fish stocks used for reduction had biomass levels larger than sustainable target levels estimated by biologists.<sup>[93]</sup> Their most recent report is still alarming: **over a third of the total catch destined to be reduced comes from poorly managed fisheries.**<sup>[94]</sup>

In Europe, five species account for over 90% of the catch reduced into fishmeal and fish oil:<sup>[17]</sup> sandeels (*Ammodytes*

sp.), herring (*Clupea harengus*), Norway pout (*Trisopterus esmarkii*), blue whiting (*Micromesistius poutassou*), and sprat (*Sprattus sprattus*). The EU sets quotas for all these species (see **Annex**),<sup>[95-100]</sup> and in 2016, the International Council for the Exploration of the Sea (ICES) published an exploitation status for 27 of their stocks (see **Table**).<sup>5</sup>



Norway pout (*Trisopterus esmarkii*). © A. Fraikin

### STATUS OF THE MAIN EUROPEAN FORAGE FISH STOCKS

Species	Area	Indicator		Ref.
		Fishing effort	Biomass	
Norway pout	North Sea, Skagerrak, and Kattegat	No status	Not in good shape*	[101]
Blue whiting	-	Overfished	In correct shape**	[102]
Sprat	North Sea	Overfished	In correct shape**	[103]
	Baltic Sea	Overfished	In correct shape**	[104]
Sandeel	North Sea, Skagerrak and Kattegat	No status	In correct shape**	[105]
	Central and South North Sea, Dogger Bank	No status	In correct shape**	[106]
	Central and South North Sea	No status	In bad shape***	[107]
Herring	Eight different stocks	Appropriate	In correct shape**	[108-115]
	Gulf of Riga	Overfished	In correct shape**	[116]
	West of Scotland and Ireland	Appropriate	In bad shape***	[117]
Other stocks (10)		No status	No status	

\* 'Not in good shape' means that the biomass is above the limit reference point, but below the threshold that triggers a specific management action.

\*\* 'In correct shape' here means that the biomass is above the threshold that triggers a specific management action. It does not mean that the biomass is at its optimum ( $B_{MSY}$ ).

\*\*\* 'In bad shape' means that the biomass is below the threshold that triggers a specific management action.



## WHY ARE REDUCTION FISHERIES A PROBLEM?

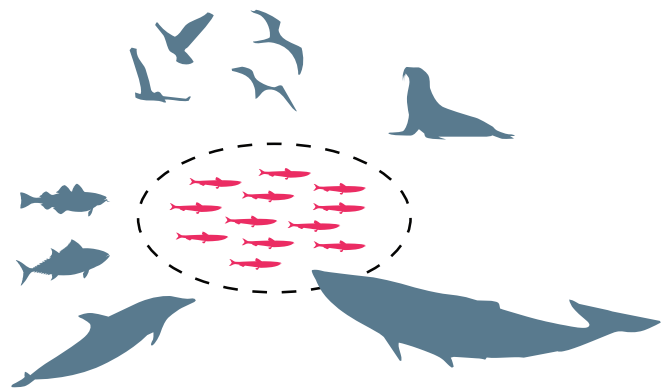
As demand for animal protein grows around the world (in response to countries moving from the ‘least developed’ to ‘developing’ or ‘developed’ category), the use of reduction fisheries for fish/pork/chicken feeds is, in reality, **not alleviating pressure on wild fish stocks and marine habitats, but in fact, it is worsening the situation.**<sup>[118]</sup> The removals of marine biomass associated with reduction fisheries lead to three main issues, namely i) ecosystem effects, ii) food security, and iii) energy efficiency.<sup>[16; 119]</sup> **As the demand for fishmeal and fish oil is global, so are these problems.**<sup>[120]</sup>

### ECOSYSTEM EFFECTS

Because the species targeted for reduction are generally short-lived, fast-growing fish, it is often suggested that they are capable of high catch rates.<sup>[21]</sup> However, as for all fisheries but especially true of those targeting forage species, **an ecosystem approach needs to be implemented** because forage fish and krill form an essential component of the trophic chain.

Krill, for example, which mainly feeds on phytoplankton, is considered a core second link in the food chain. Forage fish species generally represent the third link in the food chain. **Altogether, these forage species play a crucial role in the**

**food web, converting energy from phytoplankton and zooplankton into a useable form for predatory fish,** such as marlin, tuna, cod etc.,<sup>[22; 121-122]</sup> as well as seabirds<sup>[22; 59; 122-124]</sup> and marine mammals.<sup>[13; 125]</sup>



Forage fish are key in the functioning of marine ecosystems because are a crucial food item for many species such as predatory fish, seabirds, and marine mammals

Despite the importance of forage fish for the integrity of the ecosystem, studies on the lateral effects of large removals of small pelagic species are not abundant. Given their high natural variability of biomass (due to phenomena such as El Niño and La Niña), large removals of forage fish stocks may have catastrophic ecological consequences for other species (some commercially exploited) at times of low abundance. Anecdotal events have been described, such as the fact that large numbers of seabirds starved to death in the Barents Sea when capelin stocks declined in the 1980s, and similarly, a sharp decrease in numbers of puffins coincided with the collapse of the Atlantic herring stocks in the North Sea (see **Annex**).<sup>[126]</sup>



More recently, it appeared that diminished forage fish populations resulted in thousands of sea lion pups starving to death.<sup>6</sup>



One notable quantitative study concluded that, although consumption of **small pelagic fishes by marine mammals and sea birds does not interfere with fisheries exploitation**, the reverse is not always true.<sup>[127]</sup> The authors found that reduced biomass of pelagic fishes can be a challenge for many marine mammal and seabird species when considering local or regional populations whose distributional ranges may be limited.<sup>[127]</sup>

Furthermore, we have limited knowledge about how global changes in the future climate will affect forage fish stocks.<sup>[16]</sup> More ecosystem studies on the interaction of reduction fisheries and ecological processes are needed to help quantify how and where such interactions may have negative conse-

### LEAVE A THIRD FOR THE BIRDS<sup>[124]</sup>

In 2011, the first global analysis of the impact that removals of forage fish species can have on seabirds breeding success concluded that **forage fish populations needed to be kept at a minimum of about a third of their historic maxima to promote the breeding success of seabirds.**

quences on other animal populations. Forecasting models to predict these changes have been developed in the past decade, several of which refer to fish and fisheries in the North Sea. Scientists agree that changes in the distributions of forage fish species will impact ecosystems and fisheries, although to what extent is not fully understood.<sup>[128-129]</sup> It has been predicted that future climate change outcomes could result in regional species extinctions in the Mediterranean Sea, and an invasion of new species into the North Atlantic, north of 40°.



Seabird. © P. Beneton

<sup>6</sup> <http://news.nationalgeographic.com/2015/06/150605-sea-lion-deaths-stranding-california-ocean-animal-science>.



Picture of an Atlantic cod (*Gadus morhua*) with a capelin (*Mallotus villosus*) in its mouth. © H. Mokhenache / Sailing Explorers.

<sup>[129]</sup> Given the range of possible futures, it seems pertinent to be cautious in removing large amounts of biomass from the oceans, especially of species known to be particularly important in the diets of finfish, marine mammals and seabirds.<sup>[129]</sup>

### FOOD SECURITY AND HUMAN HEALTH

Given that most fish destined to be reduced into fishmeal and fish oil are fit for direct human consumption,<sup>[17]</sup> many questions pertaining to the sustainability of this inefficient and unethical process have been raised.<sup>[118; 130]</sup>

Many forage fish species, due to their low harvesting costs and lower market prices, often form the only viable economic option for fish consumption by low-income groups. At the same time, they are highly valuable as export to fishmeal-producing countries.<sup>[16]</sup> The major issue with this is that **it is precisely the exporting populations that are most dependent on forage fish**. Fish consumption currently contributes about 21% and 18% of the total animal protein supply for Asian and

African countries, respectively, compared to contributing only about 12% to the protein supply of developed countries.<sup>[15]</sup> While reduction species are not appreciated by the European palate, African countries imported about 1 million tonnes of processed pelagic fish products (mostly frozen) in 2006 for human consumption.<sup>[15]</sup> In Indonesia, the Philippines, and other Southeast Asian countries, there is also consumer demand for small pelagic fish such as anchovy that are brine-salted or dried.<sup>[131; 132]</sup>

In Peru, the anchoveta was traditionally considered a 'poor man's food', and thus demand for it was low in more affluent communities.<sup>[48]</sup> With the advent of reduction fisheries and aquaculture, most anchoveta became reduced and exported to farms in other countries. Recently, however, an anchoveta revolution has occurred thanks to the determination of Patricia Majluf, with local chefs in leading restaurants serving anchoveta dishes for sophisticated palates. The goal: if local demand for anchoveta could be increased, perhaps less would

be reduced to fishmeal. Instead of satiating the appetites of consumers in the developed world through farmed fish, pigs and poultry, local consumption of anchoveta could contribute to food security in Peru.<sup>[133]</sup> It has even been estimated that the possible economic returns from the landed fish could be increased ten times if more of the anchoveta catch were destined for direct consumption.<sup>[48; 133]</sup>

The problem is the same in East Africa, and coastal populations who once relied on their small pelagics now see them exported as fishmeal to and for China or developed countries to farm salmon, pig and poultry.<sup>[63]</sup>

**Pelagic fish are an essential component of the developing world's diet but the demand for these fish by the fishmeal sector directly threatens the food security of local populations.** Market economics dictates that the supply of small pelagic fish will be destined for whoever is demanding it, and currently, it is the aquaculture sector that is willing to pay the highest prices.<sup>[15; 51]</sup> The entire cycle of reduction, fisheries from initial targeting of food-grade fish to the end use of fishmeal in aquaculture, pig and poultry farming is contrary to the FAO Code of Conduct for Responsible Fisheries,<sup>[134]</sup> which specifically states that **fisheries should contribute to food security, and that the use of food-grade small pelagic fish for fishmeal and fish oil production should be limited where it can otherwise be consumed.**

This begs the following question: **is it ethical to remove fish from one place where they are necessary, to create less but more desired protein in a place that is already largely overfed?**

#### WHAT IS THE FUTURE OF REDUCTION FISHERIES?

When we consider the end users of fishmeal and fish oil, it seems that the pig, poultry and pet sectors<sup>7</sup> are the odd-men out. Pigs and poultry, in the wild and in captivity, have never eaten fish as a natural part of their diet. The use of fishmeal in their diets is therefore absolutely not essential, and **certain-**

#### COMPLICATED CONVERSION RATIOS

There has been much confusion in the literature over conversion ratios, i.e. the amount of farmed fish that is produced from a given amount of wild-caught fish. For example, if every tonne of a given species required 5 tonnes of wild fish reduced into fishmeal, then the ratio would be 5:1. By considering the production of all farmed marine species (including carnivorous, omnivorous and herbivorous species), the International Fishmeal and Fish Oil Organisation (IFFO) fallaciously reports a ratio of 0.7:1, i.e. for every tonne of wild fish, the aquaculture industry produces almost 1.5t of output.<sup>[29]</sup> **However, when single species conversion ratios are used, the conversion efficiency changes drastically and is clearly greater than 1:1.**<sup>[135]</sup> Overall, it was estimated in the late 2000s that almost five kilos of forage fish were needed to produce one kilo of carnivorous fish in the late 2000s,<sup>[14]</sup> with ratios as high as 10:1 for salmon in Chile.<sup>[136]</sup> Since then, however, this ration has decreased thanks to improvements in feed's composition and has even been inferior to one in a few cases.<sup>[137-139]</sup>

**ly does not contribute to the sustainable use of fisheries resources.** The agriculture industry can and should eliminate the use of fishmeal and fish oil. The EU has enacted a first step in banning the use of fishmeal in ruminant diets in 2001, with an exception made for young animals.<sup>[51; 140]</sup>

Regarding aquaculture, the issue is more complex. In order to become a viable fish and seafood producer in the future, **the aquaculture sector must radically improve conversion ratios and seek alternative sources of essential protein.**<sup>[29-30; 55]</sup>

The proportion of fishmeal used in salmon feeds has, in fact, already decreased substantially in the past 20 years, from about 60% in 1985 to 30% today,<sup>[30]</sup> with some companies even reaching as low as 20%.<sup>[139]</sup>

<sup>7</sup> In 2010, Sheba and Whiskas released the first MSC-certified pet food: [www.mars.com/global/press-center/press-list/news-releases.aspx?SiteId=94&Id=2877](http://www.mars.com/global/press-center/press-list/news-releases.aspx?SiteId=94&Id=2877). Although not always made with forage fish, one can wonder whether feeding pets with wild animals, even indirectly via aquaculture, is a smart move.

In the meantime, **an obvious recommendation is that consumer's demand for carnivorous fish species, pigs and poultry decreases** (particularly in developed countries) so that pressure on wild fish stocks does not increase. However, the aquaculture industry must tackle questions surrounding the current increase in demand. To decrease its reliance on fishmeal without replacing it with other problematic sources (e.g. soybean), other alternatives must be widely encouraged and developed. These bioconversion initiatives set forth a fully beneficial cradle-to-cradle recycling scheme. For example, blood collected from slaughterhouses or organic waste are used to feed insect larvae, which are then turned into feeds.

<sup>[141-142]</sup> **Such projects are multiplying and could well be the future of aquaculture.**

## THE FUTURE OF AQUACULTURE MAY COME FROM THE PAST!

The aquaculture that first developed in China thousands of years ago is what we **today call 'integrated multi-trophic' aquaculture**,<sup>[143-145]</sup> i.e., a farming scheme by which fish grow on waste in ponds or rice paddies, themselves fertilizing plants by releasing nutrients.<sup>[10]</sup>

### THE MSC-ASC-WWF BUSINESS-TO-BUSINESS TRILOGY

The Marine Stewardship Council (MSC) is the most widely available seafood label. In 2016, it reported certifying 10% of global wild-caught seafood by volume, with higher statistics in key regions such as the Northeast Atlantic (40%) and the Northeast Pacific (83%).<sup>[146]</sup> The MSC claims to offer sustainable fisheries, although this assertion is largely disputed by scientists and NGOs, which also voice concerns about the tremendous growth of this problematic certifying scheme.<sup>[147-151]</sup>

**Overall, the MSC reports to certify 7% of global reduction fisheries**,<sup>[152]</sup> including ones targeting krill,<sup>[153]</sup> blue whiting,<sup>[154]</sup> mackerel,<sup>[155]</sup> and herring.<sup>[156]</sup> This percentage will grow drastically if the Peruvian anchovy fishery were to become certified.

This fishery has been interested in obtaining the MSC label since 2008,<sup>[157]</sup> and although as of January 2017 the fishery has still not entered a full assessment, it is about to start a 'fisheries improvement program' in order to achieve the MSC certification within a few years.<sup>[158]</sup>

Certifying fisheries that, as seen in this report, reduce fish to produce fish and pose stark food security problems **is in total contradiction with the FAO Code of conduct for responsible fisheries and elementary ethics.**

**Why would a seafood label that is already harshly criticized would expose itself by certifying such controversial fisheries?** In order to give a stamp of 'sustainability' approval to controversial yet certified aquaculture schemes. Indeed, the MSC label was launched by the WWF in 1997 and the panda NGO also launched the Aquaculture Stewardship Council (ASC) in 2010. Because the fastest growing aquaculture is the one farming predatory fish and using large amounts of fishmeal, the WWF certified-aquaculture scheme, ASC, depends on the MSC to greenwash its certifications. As the director of aquaculture for the WWF's sustainable food program explains: *"By requiring reduction fisheries to be MSC certified, ASC can most effectively protect biodiversity in our oceans"*.<sup>[159]</sup>



## CONCLUSION

The issues associated with aquaculture sustainability need to be tackled sooner rather than later. **Instead of rolling over by default a pattern of serial depletion of fish stocks (i.e. overfishing one stock and moving on to the next),<sup>[160]</sup> it is imperative to take a step back and reflect on how to make current fisheries sustainable instead of blindly encouraging the development of unsustainable aquaculture schemes.** The recent boom of the aquaculture sector is the result of the sequential depletion of marine species, which were fished down from the top of the food chain until reaching the first links of food webs (excluding algae), i.e. forage fish and krill.<sup>[161]</sup> Aquaculture that reduces small pelagic species to produce large predatory fish should be seen as the ultimate proof that managing fisheries sustainably has failed. This unsustainable pattern is ongoing: **even forage fish species are now being fished down to the extent that fleets need to seek new possibilities.** Fisheries for species that were disregarded until very recently, such as krill, boarfish and lantern fish (Myctophids) are now being developed. This is extremely worrisome, as **we are mining the foundations of oceanic ecosystems.** Fishing fleets and governments should steer clear from forage fisheries.

Issues surrounding food security and even ecosystem implications are often ignored, and in particular, the end use of a fishery is not a factor in determining sustainability.<sup>[162]</sup> **It seems fair to question whether the consumption side of the equation, that is the final consumers of a given fishery, contributes to an ethical and sustainable use of natural resources.<sup>[15]</sup>** Our concept of sustainability needs to be broadened to encompass food security considerations. Therefore, adoption of and adherence to the FAO Code of Conduct, which explicitly states that **fish should be used for direct consumption (and not, for ex-**

**ample, for reduction)** when possible,<sup>[134]</sup> should be one goal all nations strive for in their quest for sustainable fisheries.<sup>[13]</sup> Because food security is stated as a global priority, **legislation prohibiting the use of fishmeal in animal feed should be enacted.<sup>[15]</sup>** It has also been suggested that **reduction fisheries should not be eligible for sustainable certification.<sup>[130; 163]</sup>**

In Europe, scientists are calling for better management of fisheries in an effort to foster sector sustainability from ecological, economic and social perspectives.<sup>[164]</sup> European countries, particularly Denmark, but also Sweden, the UK, and other countries, participate at all levels in the fishmeal and fish oil supply chain, from the fishing of forage fish species, and the production of fishmeal and fish oil to using them in aquaculture and agricultural industries. The EU committed to improve fisheries management, therefore, Europe should aim to be a leader in promoting sustainable global fisheries.<sup>[165]</sup>

**Unsustainable aquaculture and associated reduction fisheries are by no means a fatality.** The EU can decide to reverse the current trend by setting high standards on industrial and fishing practices. It is not too late for Europe, which is just beginning to develop its own aquaculture sector, to pave the way towards a truly socially and environmentally sustainable fish farming. **This would encompass setting ambitious standards by refusing to reduce fish to produce fish, and by adopting on the contrary cradle-to-cradle solutions such as insect farming, resulting in waste problem management and protein production.** Europe could thus serve as a role model to show other nations such as Iceland, Norway and Russia, how governments can make choices today that will shape a sustainable future.



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## REFERENCES

- [1] Naylor *et al.* (1998) Nature's subsidies to shrimp and salmon farming. *Science* 282(5390): 883-884.
- [2] FAO (2010) The state of world fisheries and aquaculture. Food and Agriculture Organization of the United Nations (FAO), Rome (Italy). 197 p.
- [3] World Bank (2013) Fish to 2030 — Prospects for fisheries and aquaculture. World Bank Report Number 83177-GLB, Agriculture and Environmental Services Discussion Paper 03, The World Bank, Washington, DC (USA). xx + 80 p.
- [4] Africa Progress Panel (2014) Grain, fish, money — Financing Africa's green and blue revolutions. Africa Progress Panel, Geneva (Switzerland). 183 p.
- [5] European Commission (2015) Aquaculture — Facts and figures. Available at: [http://ec.europa.eu/fisheries/documentation/publications/2015-aquaculture-facts\\_en.pdf](http://ec.europa.eu/fisheries/documentation/publications/2015-aquaculture-facts_en.pdf).
- [6] European Commission (2013) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions — Strategic guidelines for the sustainable development of EU aquaculture. COM(2013) 229 final, European Commission, Brussels (Belgium). 12 p.
- [7] European Union (2013) Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC. Official Journal L 354: 22-61.
- [8] Duarte *et al.* (2007) Rapid domestication of marine species. *Science* 316: 382-383.
- [9] FAO (2015) FishStatJ — Software for fishery statistical time series. V2.12.2. Food and Agriculture Organization of the United Nations (FAO), Rome (Italy).
- [10] Halweil (2008) Farming fish for the future. Worldwatch Report 76, Worldwatch Institute, Washington, DC (USA). 43 p.
- [11] Rabanal (1988) History of aquaculture. ASEAN/SF/88/Tech. 7, ASEAN/UNDP/FAO Regional Small-Scale Coastal Fisheries Development Project, Manila (Philippines). 15 p.
- [12] FAO (2014) The state of world fisheries and aquaculture. Food and Agriculture Organization of the United Nations (FAO), Rome (Italy). xvi + 223 p.
- [13] Tacon and Métian (2009) Fishing for aquaculture: non-food use of small pelagic forage fish—A global perspective. *Reviews in Fisheries Science* 17(3): 305-317.
- [14] Tacon and Métian (2008) Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: trends and future prospects. *Aquaculture* 285(1-4): 146-158.
- [15] Tacon and Métian (2009) Fishing for feed or fishing for food: increasing global competition for small pelagic forage fish. *AMBIO: A Journal of the Human Environment* 38(6): 294-302.
- [16] Alder *et al.* (2008) Forage fish: from ecosystems to markets. *Annual Review of Environment and Resources* 33: 153-166.

- [17] Cashion *et al.* (2017) Most fish destined for fishmeal production are food-grade fish. *Fish and Fisheries*.
- [18] Barlow and Windsor (1984) *Fishery by-products*. Technical Bulletin 19, International Association of Fish Meal Manufacturers (IAFMM), London (UK). 23 p.
- [19] FAO (1986) *The production of fish meal and oil*. FAO Fisheries Technical Paper 142, Food and Agriculture Organization of the United Nations (FAO), Rome (Italy).
- [20] Windsor (2001) *Fish meal*. Torry Advisory Note No. 49, Department of Trade and Industry, Torry Research Station. 14 p.
- [21] Anon. (2012) *Annual Review of the status of the feed grade fish stocks used to produce fishmeal and fish oil for the UK market*. Seafish, Edinburgh (UK). 50 p.
- [22] Matthiessen (2007) *Forage fish and the industrial fisheries*. Quebec-Labrador Foundation, Montreal (Canada). 94 p.
- [23] Anon. (2008) *Fishmeal and other aquatic products*. Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), Issy les Moulineaux (France). 4 p.
- [24] Anon. (2000) *Fishmeal update — August/September 2000*. Fishmeal Information Network Issue 4.
- [25] *Fishmeal Information Network (2001) Fishmeal for dairy cows — A feed with a very healthy future*. Fishmeal Information Network (FIN), Peterborough (UK). 8 p.
- [26] *Fishmeal Information Network (2001) Fishmeal for pigs — A feed with a very healthy future*. Fishmeal Information Network (FIN), Peterborough (UK). 6 p.
- [27] *Fishmeal Information Network (2001) Fishmeal for sheep — A feed with a very healthy future*. Fishmeal Information Network (FIN), Peterborough (UK). 6 p.
- [28] Miles and Chapman (2006) *The benefits of fish meal in aquaculture diets*. IFAS Extension — FA 122, University of Florida. 6 p.
- [29] Jackson (2009) *Fish In — Fish Out (FIFO) ratios explained*. International Fishmeal and Fish Oil Organisation. 6 p.
- [30] Schipp (2008) *Is the use of fishmeal and fish oil in aquaculture diets sustainable?* Technote 124: 15.
- [31] Tou *et al.* (2007) *Krill for human consumption: nutritional value and potential health benefits*. 63-77 p.
- [32] SumOfUs (2015) *Vacuuming Antarctica for krill — The corporations plunderings the Earth's last frontier*. SumOfUs, New York, NY (USA). 9 p.
- [33] ICES (2015) *Report of the Working Group on North Atlantic Salmon (WGNAS)*, March 17-26, Moncton (Canada). ICES CM 2015/ACOM:09, International Council for the Exploration of the Sea (ICES), Advisory Committee, Copenhagen (Denmark). 332 p.
- [34] Gross (1998) *One species with two biologies: Atlantic salmon (*Salmo salar*) in the wild and in aquaculture*. Canadian Journal of Fisheries and Aquatic Sciences 55(S1): 131-144.
- [35] Cabello (2006) *Heavy use of prophylactic antibiotics in aquaculture: a growing problem for human and animal health and for the environment*. Environmental Microbiology 8(7): 1137-1144.
- [36] Buschmann *et al.* (2012) *Salmon aquaculture and antimicrobial resistance in the marine environment*. PLOS ONE 7(8): e42724.
- [37] Krkošek *et al.* (2007) *Declining wild salmon populations in relation to parasites from farm salmon*. Science 318(5857): 1772-1775.
- [38] Costello (2009) *The global economic cost of sea lice to the salmonid farming industry*. Journal of Fish Diseases 32(1): 115-118.
- [39] Torrissen *et al.* (2013) *Salmon lice — Impact on wild salmonids and salmon aquaculture*. Journal of Fish Diseases 36(3): 171-194.
- [40] Volpe *et al.* (2000) *Evidence of natural reproduction of aquaculture-escaped Atlantic salmon in a coastal British Columbia river*. Conservation Biology 14(3): 899-903.
- [41] Naylor *et al.* (2005) *Fugitive salmon: assessing the risks of escaped fish from net-pen aquaculture*. Bioscience 55(5): 427-437.
- [42] Kutti *et al.* (2008) *Effects of organic effluents from a salmon farm on a fjord system. III. Linking deposition rates of organic matter and benthic productivity*. Aquaculture 282(1-4): 47-53.
- [43] FAO (2016) *The state of world fisheries and aquaculture — Contributing to food security and nutrition for all*. Food and Agriculture Organization of the United Nations (FAO), Rome (Italy). x + 190 p.
- [44] Pike and Jackson (2010) *Fish oil: production and use now and in the future*. Lipid Technology 22(3): 59-61.
- [45] IFFO (2011) *Responding to our critics — Does production of fishmeal and fish oil reduce the amount of fish available for human consumption?*, International Fishmeal and Fish Oil Organisation (IFFO), London (UK). 3 p.
- [46] Jacquet (2011) *Forage fish and the conservation landscape*. Seafood Summit, January 31, 2011, Vancouver



- (Canada).
- [47] Jackson (2012) Fishmeal & fish oil and its role in sustainable aquaculture. *International Aquafeed*: 18-21.
- [48] Christensen *et al.* (2014) Valuing seafood: the Peruvian fisheries sector. *Marine Policy* 44: 302-311.
- [49] De Silva and Turchini (2008) Towards understanding the impacts of the pet food industry on world fish and seafood supplies. *Journal of Agricultural and Environmental Ethics* 21(5): 459-467.
- [50] Pike (1996) What raw materials will be available in the future — Fishmeal and oil. *Aquavision*, Seattle, WA (USA).
- [51] Jackson (2007) Challenges and opportunities for the fishmeal and fish oil industry. *Feed Technology Update* 2(1): 3-11.
- [52] Anon. (2003) The fish meal and fish oil industry — Its role in the Common Fisheries Policy. *Fisheries Series — Working Paper FISH 113 EN*, European Parliament, Directorate-General for Research, Strasbourg (France). xxiv + 148 p.
- [53] Brunner *et al.* (2009) Fish, human health and marine ecosystem health: policies in collision. *International Journal of Epidemiology* 38(1): 93-100.
- [54] FAO (2015) Fish meal and fish oil, July 2015. *Globefish Market Reports*, Food and Agriculture Organization of the United Nations (FAO), Rome (Italy). Available at: [www.globefish.org/fishmeal-and-fish-oil-may-2015.html](http://www.globefish.org/fishmeal-and-fish-oil-may-2015.html).
- [55] Rust *et al.* (2011) The future of aquafeeds. *NOAA Technical Memorandum NMFS F/SPO-124*, National Oceanic and Atmospheric Administration (NOAA) and the U.S. Department of Agriculture (USDA), Washington, DC (USA). vii + 93 p.
- [56] Smith *et al.* (2010) Genetically modified salmon and full impact assessment. *Science* 330(6007): 1052-1053.
- [57] Brown and Mahfuzuddin (2004) Consumption and trade of fish. pp. 47-58 In Sporrang N, Coffey C, Brown J and Reyntjens D (eds.), *Sustainable EU fisheries: facing the environmental challenges*, European Parliament, November 8-9, 2004, Conference Report. Institute for European Environmental Policy (IEEP) and Fisheries Secretariat (FISH), Brussels (Belgium).
- [58] SeaFish (2011) Fish meal and fish oil figures. 30 p.
- [59] Huntington *et al.* (2004) Assessment of the sustainability of industrial fisheries producing fish meal and fish oil — Final report to the Royal Society for the Protection of Birds prepared by Poseidon Aquatic Resource Management Ltd and The University of Newcastle-upon-Tyne. *Royal Society for the Protection of Birds (RSPB)*, Edinburgh (UK). xii + 105 p.
- [60] Fréon and Misund (1998) Dynamics of pelagic fish distribution and behaviour: effects on fisheries and stock assessment. *Fishing News Books*, Oxford (UK).
- [61] Anon. (2005) *Convention Spécifique n°20 : Mauritanie — Evaluation ex-post du protocole d'accord de pêche entre la Mauritanie et la Communauté européenne, et analyse de l'impact du futur protocole sur la durabilité, incluant une évaluation ex-ante. Contrat-cadre pour la réalisation d'évaluations, d'études d'impact et de suivi concernant les Accords de Partenariat dans le domaine de la Pêche conclus entre la Communauté et les Pays Tiers — Projet FISH/2003/02*, Oceanic Développement, Poseidon Aquatic Resource Management Ltd, and MegaPesca Lda, Brussels (Belgium). 245 p.
- [62] Ulrich and Andersen (2004) Dynamics of fisheries, and the flexibility of vessel activity in Denmark between 1989 and 2001. *ICES Journal of Marine Science* 61(3): 308-322.
- [63] Neiland (2006) Contribution of fish trade to development, livelihoods and food security in West Africa: key issues for future policy debate. 23 p.
- [64] European Economic Community (1987) Protocol setting out fishing opportunities and financial compensation for the period 1 July 1987 to 30 June 1990. *Official Journal L* 302: 34-35.
- [65] European Economic Community (1988) Protocol 1 setting out fishing opportunities accorded by Morocco and the compensation accorded by the Community for the period from 1 March 1988 to 29 February 1992. *Official Journal L* 99: 14-16.
- [66] European Economic Community (1990) Protocol setting out the fishing opportunities and financial contribution provided for in the Agreement between the European Economic Community and the Islamic Republic of Mauritania on fishing off the coast of Mauritania for the period 1 August 1990 to 31 July 1993. *Official Journal L* 334: 12-22.
- [67] European Economic Community (1992) Protocol setting out fishing opportunities and the financial compensation and financial contributions accorded by the Community. *Official Journal L* 407: 15-28.
- [68] European Economic Community (1993) Protocol setting

out the fishing opportunities and financial contribution provided for in the Agreement between the European Community and the Islamic Republic of Mauritania on fishing off the coast of Mauritania for the period 1 August 1993 to 31 July 1996. Official Journal L 290: 20-31.

- [69] European Community (1995) Protocole fixant les possibilités de pêche et les montants de la compensation financière et des appuis financiers. Official Journal L 306: 32-43.
- [70] European Community (1996) Protocol setting out fishing opportunities and the financial compensation and financial contributions for the period 1 August 1996 to 31 July 2001. Official Journal L 334: 24-54.
- [71] European Community (2001) Protocol setting out the fishing opportunities and financial compensation provided for in the Agreement on cooperation in the sea fisheries sector between the European Community and the Islamic Republic of Mauritania for the period 1 August 2001 to 31 July 2006. Official Journal L 341: 128-159.
- [72] European Community (2006) Protocol setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Community and the Islamic Republic of Mauritania. Official Journal L 343: 9-60.
- [73] European Community (2006) Protocol setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Community and the Kingdom of Morocco. Official Journal L 141: 9-37.
- [74] European Community (2008) Protocol setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Community and the Islamic Republic of Mauritania for the period 1 August 2008 to 31 July 2012. Official Journal L 203: 4-59.
- [75] European Union (2011) Protocol between the European Union and the Kingdom of Morocco setting out the fishing opportunities and financial compensation provided for in the Fisheries Partnership Agreement between the European Community and the Kingdom of Morocco. Official Journal L 202: 3-30.
- [76] European Union (2012) Protocol setting out the fishing opportunities and financial contribution provided for in the fisheries partnership Agreement between the European Union and the Islamic Republic of Mauritania for a period of two years. Official Journal L 361: 44-84.
- [77] European Union (2013) Protocol between the European Union and the Kingdom of Morocco setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Union and the Kingdom of Morocco. Official Journal L 328: 2-21.
- [78] European Community (1996) Council Decision of 26 November 1996 on the conclusion of an Agreement in the form of an Exchange of Letters concerning the provisional application of the Agreement on cooperation in the sea fisheries sector between the European Community and the Islamic Republic of Mauritania. Official Journal L 334: 16-18.
- [79] European Community (2001) Council Regulation (EC) No 2528/2001 of 17 December 2001 on the conclusion of the Protocol setting out the fishing opportunities and the financial contribution provided for in the Agreement on cooperation in the sea fisheries sector between the European Community and the Islamic Republic of Mauritania for the period 1 August 2001 to 31 July 2006. Official Journal L 341: 1-2.
- [80] European Community (2006) Council Regulation (EC) No 764/2006 of 22 May 2006 on the conclusion of the Fisheries Partnership Agreement between the European Community and the Kingdom of Morocco. Official Journal L 141: 1-3.
- [81] European Community (2006) Council Regulation (EC) No 1801/2006 of 30 November 2006 on the conclusion of the Fisheries Partnership Agreement between the European Community and the Islamic Republic of Mauritania — Fisheries Partnership Agreement between the European Community and the Islamic Republic of Mauritania. Official Journal L 343: 1-3.
- [82] European Community (2008) Council Regulation (EC) No 704/2008 of 15 July 2008 on the conclusion of the Protocol setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Community and the Islamic Republic of Mauritania for the period 1 August 2008 to 31 July 2012. Official Journal L 203: 1-3.
- [83] European Union (2011) Council Regulation (EU) No 779/2011 of 12 July 2011 concerning the allocation of the fishing opportunities under the Protocol between the European Union and the Kingdom of Morocco setting out the fishing opportunities and financial compensation provided for in the Fisheries Partnership Agreement

between the European Community and the Kingdom of Morocco. Official Journal L 202: 31-33.

- [84] European Union (2013) Council Regulation (EU) No 680/2013 of 15 July 2013 amending Regulation (EU) No 1259/2012 on the allocation of the fishing opportunities under the Protocol setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Union and the Islamic Republic of Mauritania for a period of two years. Official Journal L 195: 15-15.
- [85] European Union (2013) Council Regulation (EU) No 1270/2013 of 15 November 2013 on the allocation of fishing opportunities under the Protocol between the European Union and the Kingdom of Morocco setting out the fishing opportunities and financial contribution provided for in the Fisheries Partnership Agreement between the European Union and the Kingdom of Morocco Official Journal L 328: 40-41.
- [86] IFFO (2015) TACs and quotas for the EEA, Peru, Chile and Southern Africa — Version 2.1 issued 13th May 2015. IFFO — The Marine Ingredients Organisation, London (UK). 39 p.
- [87] White *et al.* (2011) First estimates of age, growth, and maturity of boarfish (*Capros aper*): a species newly exploited in the Northeast Atlantic. ICES Journal of Marine Science 68(1): 61-66.
- [88] Cox (2017) The race to fish the larder living in the 'twilight zone'. BBC, edition of January 16 2017. Available at: [www.bbc.com/earth/story/20170113-the-race-to-fish-the-larder-living-in-the-twilight-zone](http://www.bbc.com/earth/story/20170113-the-race-to-fish-the-larder-living-in-the-twilight-zone).
- [89] Irigoien *et al.* (2014) Large mesopelagic fishes biomass and trophic efficiency in the open ocean. Nature Communications 5.
- [90] Valinassab *et al.* (2007) Lantern fish (*Benthosema pterotum*) resources as a target for commercial exploitation in the Oman Sea. Journal of Applied Ichthyology 23(5): 573-577.
- [91] Haque *et al.* (1981) Fishmeal and oil from lantern fish (Myctophidae) with special emphasis on protein quality. Journal of the Science of Food and Agriculture 32(1): 61-70.
- [92] Jan de Koning (2005) Properties of South African fish meal: a review. South African Journal of Science 101: 21-25.
- [93] Anon. (2010) FishSource, reduction fisheries and aquaculture. Sustainable Fisheries Partnership Briefing, March 2010. 10 p.
- [94] Veiga *et al.* (2015) Reduction fisheries: SFP fisheries sustainability overview 2015. Sustainable Fisheries Partnership Foundation. 35 p.
- [95] European Union (2010) Fishing TACs and quotas 2010 — As agreed by Council Regulations (EC) No 1359/2008 of 28 November 2008, (EC) No 1226/2009 of 20 November 2009, (EC) No 1287/2009 of 27 November 2009, (EU) No 53/2010 of 14 January 2010 and (EU) No 219/2010 of 15 March 2010. Changes may be made during 2010. European Commission, Directorate-General for Maritime Affairs and Fisheries (DG MARE), Brussels (Belgium).
- [96] European Union (2011) Fishing TACs and quotas 2011 — As fixed by Council Regulations (EU) No 685/2010 of 26 July 2010, No 1124/2010 of 29 November 2010, No 1225/2010 of 13 December 2010, No 1256/2010 of 17 December 2010, and No 57/2011 of 18 January 2011. Changes may be made during 2011. European Commission, Directorate-General for Maritime Affairs and Fisheries (DG MARE), Brussels (Belgium).
- [97] European Union (2012) Fishing TACs and quotas 2012 — As fixed by Council Regulations No 1225/2010 of 13 December 2010, No 716/2011 of 19 July 2011, No 1256/2011 of 30 November 2011, No 5/2012 of 19 December 2011, No 43/2012 of 17 January 2012 and No 44/2012 of 17 January 2012. Changes may be made during 2012. European Commission, Directorate-General for Maritime Affairs and Fisheries (DG MARE), Brussels (Belgium).
- [98] European Union (2013) Fishing TACs and quotas 2013 — As fixed by Council Regulations (UE) No 694/2012 of 27 July 2012, No 1088/2012 of 20 November 2012, No 1261/2012 of 20 December 2012, No 1262/2012 of 20 December 2012, No 39/2013 of 21 January 2013, No 40 of 21 January 2013 and No 297/2013 of 27 March 2013. Changes may be made during 2013. European Commission, Directorate-General for Maritime Affairs and Fisheries (DG MARE), Brussels (Belgium).
- [99] European Union (2014) Fishing TACs and quotas 2014 — As fixed by Council Regulations (EU) No 1262/2012 of 20 December 2012, No 713/2013 of 23 July 2013, No 1180/2013 of 19 November 2013, No 24/2014 of 10 January 2014, No 43/2014 of 20 January 2014, No 315/2014 of 24 March 2014 and No 432/2014 of 22 April 2014. Changes may be made during 2014. European Commission, Directorate-General for Maritime Affairs and Fisheries (DG MARE), Brussels (Belgium).

- [100] European Union (2015) Fishing TACs and quotas 2015 as fixed by Council Regulations (EU) No 1221/2014 of 10 November 2014, No 1367/2014 of 15 December 2014, No 2015/104 of 19 January 2015, and No 2015/106 of 19 January 2015. European Commission, Directorate-General for Maritime Affairs and Fisheries (DG MARE), Brussels (Belgium).
- [101] ICES (2016) 6.3.34 — Norway pout (*Trisopterus esmarkii*) in Subarea 4 and Division 3.a (North Sea, Skagerrak, and Kattegat). ICES Advice on fishing opportunities, catch, and effort — Greater North Sea and Celtic Seas Ecoregions. ICES Advice 2016, Book 6, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 9 p.
- [102] ICES (2016) 9.3.6 — Blue whiting (*Micromesistius pou-tassou*) in subareas 1–9, 12, and 14 (Northeast Atlantic). ICES Advice on fishing opportunities, catch, and effort — Northeast Atlantic. ICES Advice 2016, Book 9, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 9 p.
- [103] ICES (2016) 6.3.51 — Sprat (*Sprattus sprattus*) in Subarea 4 (North Sea). ICES Advice on fishing opportunities, catch, and effort — Greater North Sea Ecoregion. ICES Advice 2016, Book 6, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 8 p.
- [104] ICES (2016) 8.3.18 — Sprat (*Sprattus sprattus*) in subdivisions 22–32 (Baltic Sea). ICES Advice on fishing opportunities, catch, and effort — Baltic Sea Ecoregion. ICES Advice 2016, Book 8, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 8 p.
- [105] ICES (2016) 6.3.39 — Sandeel (*Ammodytes* spp.) in Divisions 3a, 4a, and 4b, SA 3 (Skagerrak and Kattegat, North and Central North Sea). ICES Advice on fishing opportunities, catch, and effort — Greater North Sea Ecoregion. ICES Advice 2016, Book 6, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 7 p.
- [106] ICES (2016) 6.3.41 — Sandeel (*Ammodytes* spp.) in Divisions 4b and 4c, SA 1 (Central and South North Sea, Dogger Bank). ICES Advice on fishing opportunities, catch, and effort — Greater North Sea Ecoregion. ICES Advice 2016, Book 6, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 8 p.
- [107] ICES (2016) 6.3.42 — Sandeel (*Ammodytes* spp.) in Divisions 4b and 4c, SA 2 (Central and South North Sea). ICES Advice on fishing opportunities, catch, and effort — Greater North Sea Ecoregion. ICES Advice 2016, Book 6, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 7 p.
- [108] ICES (2016) 2.3.8 — Herring (*Clupea harengus*) in Division 5.a, summer-spawning herring (Iceland grounds). ICES Advice on fishing opportunities, catch, and effort — Iceland Sea and Greenland Sea ecoregions. ICES Advice 2016, Book 2, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 6 p.
- [109] ICES (2016) 5.3.31 — Herring (*Clupea harengus*) in Division 7.a North of 52°30'N (Irish Sea). ICES Advice on fishing opportunities, catch, and effort — Celtic Seas Ecoregion. ICES Advice 2016, Book 5, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 7 p.
- [110] ICES (2016) 5.3.32 — Herring (*Clupea harengus*) in divisions 7.a South of 52°30' North, 7.g–h, and 7.j–k (Irish Sea, Celtic Sea, and southwest of Ireland). ICES Advice on fishing opportunities, catch, and effort — Celtic Seas Ecoregion. ICES Advice 2016, Book 6, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 8 p.
- [111] ICES (2016) 6.3.17 — Herring (*Clupea harengus*) in subdivisions 20–24, spring spawners (Skagerrak, Kattegat, and western Baltic). ICES Advice on fishing opportunities, catch, and effort — Baltic Sea and Greater North Sea Ecoregions. ICES Advice 2016, Book 6, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 11 p.
- [112] ICES (2016) 6.3.18 — Herring (*Clupea harengus*) in Subarea 4 and divisions 3.a and 7.d, autumn spawners (North Sea, Skagerrak, Kattegat, and eastern English Channel). ICES Advice on fishing opportunities, catch, and effort — Greater North Sea Ecoregion. ICES Advice 2016, Book 6, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 17 p.
- [113] ICES (2016) 8.3.12 — Herring (*Clupea harengus*) in Subdivision 30 (Bothnian Sea). ICES Advice on fishing opportunities, catch, and effort — Baltic Sea Ecoregion. ICES Advice 2016, Book 6, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 7 p.
- [114] ICES (2016) 8.3.14 — Herring (*Clupea harengus*) in subdivisions 25–29 and 32 (central Baltic Sea, excluding Gulf of Riga). ICES Advice on fishing opportunities, catch,

and effort — Baltic Sea Ecoregion. ICES Advice 2016, Book 8, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 9 p.

- [115] ICES (2016) 9.3.33 — Herring (*Clupea harengus*) in subareas 1, 2, and 5, and in divisions 4.a and 14.a, Norwegian spring-spawning herring (Northeast Atlantic). ICES Advice on fishing opportunities, catch, and effort — Northeast Atlantic. ICES Advice 2016, Book 9, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 8 p.
- [116] ICES (2016) 8.3.11 — Herring (*Clupea harengus*) in Subdivision 28.1 (Gulf of Riga). ICES Advice on fishing opportunities, catch, and effort — Baltic Sea Ecoregion. ICES Advice 2016, Book 8, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 10 p.
- [117] ICES (2016) 5.3.33 — Herring (*Clupea harengus*) in divisions 6.a and 7.b-c (west of Scotland, west of Ireland). ICES Advice on fishing opportunities, catch, and effort — Celtic Seas Ecoregion. ICES Advice 2016, Book 5, International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 10 p.
- [118] Naylor *et al.* (2000) Effect of aquaculture on world fish supplies. *Nature* 405(6790): 1017-1024.
- [119] Deutsch *et al.* (2007) Feeding aquaculture growth through globalization: exploitation of marine ecosystems for fishmeal. *Global Environmental Change* 17: 238-249.
- [120] Asche and Tveteras (2004) On the relationship between aquaculture and reduction fisheries. *Journal of Agricultural Economics* 55(2): 245-265.
- [121] Carscadden and Vilhjálmsson (2002) Capelin — What are they good for? Introduction. *ICES Journal of Marine Science* 59: 863-869.
- [122] Pikitch *et al.* (2012) Little fish, big impact: managing a crucial link in ocean food webs. Lenfest Ocean Program, Washington, DC (USA). 108 p.
- [123] Furness and Tasker (2000) Seabird-fishery interactions: quantifying the sensitivity of seabirds to reduction in sandeel abundance, and identification of key areas for sensitive seabirds in the North Sea. *Marine Ecology Progress Series* 202: 253-264.
- [124] Cury *et al.* (2011) Global seabird response to forage fish depletion — one-third for the birds. *Science* 334: 1703-1706.
- [125] Enticknap *et al.* (2011) Marine forage species management off the U.S. west coast. Oceana, Washington, DC (USA). 43 p.
- [126] Gislason (2003) The effects of fishing on non-target species and ecosystem structure and function. pp. 255-274 In Sinclair M and Valdimarsson G (eds.), *Responsible fisheries in the marine ecosystem*. FAO/CABI Publishing, Wsallingford (UK).
- [127] Kaschner *et al.* (2006) Forage fish consumption by marine mammals and seabirds. pp. 33-46 In Alder J and Pauly D (eds.), *On the multiple uses of forage fish: from ecosystems to markets*. Fisheries Centre Research Reports 14 (3). University of British Columbia, Vancouver (Canada).
- [128] Worm *et al.* (2006) Impacts of biodiversity loss on ocean ecosystem services. *Science* 314(5800): 787-790.
- [129] Cheung *et al.* (2009) Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries* 10(3): 235-251.
- [130] Jacquet *et al.* (2009) Conserving wild fish in a sea of market-based efforts. *Oryx* 44(1): 45-56.
- [131] Pizalli (2001) Low-cost fish retailing equipment and facilities in large urban areas of Southeast Asia. FAO Fisheries Technical Paper 405, Food and Agriculture Organization of the United Nations (FAO), Rome (Italy). 142 p.
- [132] Bailey *et al.* (2008) The migrant anchovy fishery in Kabui Bay Raja Ampat, Indonesia: catch profitability and income distribution. *Marine Policy* 32(3): 483-488.
- [133] Pauly (2006) Babette's feast in Lima. *Sea Around Us Newsletter* 38: 1-2.
- [134] FAO (1995) Code of conduct for responsible fisheries. Food and Agriculture Organization of the United Nations (FAO), Rome (Italy). 41 p.
- [135] Regnier and Schubert (2015) Opinion paper: prospects for the fed-aquaculture sector. *Animal* 9(6): 917-918.
- [136] Pinto and Furci (2006) Salmon piranha style: feed conversion efficiency in the Chilean salmon farming industry. *Terram APP* 34: 21 p.
- [137] Ytrestøyl *et al.* (2014) Resource utilisation of Norwegian salmon farming in 2012. Nofima, Tromsø (Norway). 34 p.
- [138] Ytrestøyl *et al.* (2015) Utilisation of feed resources in production of Atlantic salmon (*Salmo salar*) in Norway. *Aquaculture* 448: 365-374.
- [139] Cashion *et al.* (2016) Review and advancement of the marine biotic resource use metric in seafood LCAs: a case study of Norwegian salmon feed. *The International Journal of Life Cycle Assessment* 21(8): 1106-1120.



- [140] European Community (2001) Regulation (EC) No 999/2001 of the European Parliament and of the Council of 22 May 2001 laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies. Official Journal L 147: 1-40.
- [141] Barclay (2012) How fly farming may help more fish stay in the sea. NPR, edition of October 23 2012. Available at: [www.npr.org/sections/thesalt/2012/10/15/162961073/how-fly-farming-may-help-more-fish-stay-in-the-sea](http://www.npr.org/sections/thesalt/2012/10/15/162961073/how-fly-farming-may-help-more-fish-stay-in-the-sea).
- [142] Fleming (2014) How insects could feed the food industry of tomorrow. BBC, edition of June 4, 2014. Available at: [www.bbc.com/future/story/20140603-are-maggots-the-future-of-food](http://www.bbc.com/future/story/20140603-are-maggots-the-future-of-food).
- [143] White *et al.* (2004) At a crossroads: will aquaculture fulfill the promise of the blue revolution? Seaweb Aquaculture Clearinghouse. 17 p.
- [144] Troell *et al.* (2009) Ecological engineering in aquaculture — Potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. *Aquaculture* 297(1-4): 1-9.
- [145] Chopin (2010) Integrated multi-trophic aquaculture — Part II. Increasing IMTA adoption. *Global Aquaculture Advocate*: 17-20.
- [146] MSC (2016) From sustainable fishers to seafood lovers — Annual report 2015-16. Marine Stewardship Council (MSC), London (UK). 47 p.
- [147] Jacquet and Pauly (2010) Seafood stewardship in crisis. *Nature* 467(2): 28-29.
- [148] Froese and Proelss (2012) Evaluation and legal assessment of certified seafood. *Marine Policy* 36: 1284-1289.
- [149] Christian *et al.* (2013) A review of formal objections to Marine Stewardship Council fisheries certifications. *Biological Conservation* 161: 10-17.
- [150] Moreno *et al.* (2016) To FAD or not to FAD: A challenge to the marine stewardship council and its conformity assessment bodies on the use of units of assessment and units of certification for industrial purse seine tuna fisheries. *Marine Policy* 73: 100-107.
- [151] Opitz *et al.* (2016) Assessment of MSC-certified fish stocks in the Northeast Atlantic. *Marine Policy* 71: 10-14.
- [152] MSC (2016) Global impacts report 2016. Marine Stewardship Council (MSC), London (UK). 64 p.
- [153] Hønneland *et al.* (2015) Aker Biomarine Antarctic krill fishery. Marine Stewardship Council (MSC), Public Certification Report (PCR), Food Certification International Ltd, Inverness (UK). 166 p.
- [154] des Clers *et al.* (2016) The SPSG, DPPO, PFA, KFO & Compagnie des Pêches St Malo Northeast Atlantic Blue Whiting pelagic trawl fishery. Marine Stewardship Council (MSC), Public Certification Report (PCR), ME Certification Ltd, Lymington (UK). 238 p.
- [155] Kiseleva *et al.* (2016) Faroese Pelagic Organization North East Atlantic mackerel fishery. Marine Stewardship Council (MSC), Full assessment report, DNV GL Business Assurance Høvik (Norway). 223 p.
- [156] Gascoigne *et al.* (2015) The SPSG, DPPO, PFA, SPFPO & KFO Atlanto-Scandian purse seine and pelagic trawl herring fishery. Marine Stewardship Council (MSC), Public Certification Report (PCR), ME Certification Ltd, Lymington (UK). 252 p.
- [157] Anon. (2009) Association of Peruvian anchovy producers pursues MSC certification. PR Newswire, edition of July 21 2009. Available at: [www.prnewswire.com/news-releases/association-of-peruvian-anchovy-producers-pursues-msc-certification-62238602.html](http://www.prnewswire.com/news-releases/association-of-peruvian-anchovy-producers-pursues-msc-certification-62238602.html).
- [158] Schultz (2016) Despite generally good reputation, Peruvian anchovy fishery still not MSC certified. NUTRA ingredients-usa.com, edition of November 28 2016. Available at: [www.nutraingredients-usa.com/Suppliers2/Despite-generally-good-reputation-Peruvian-anchovy-fishery-still-not-MSC-certified](http://www.nutraingredients-usa.com/Suppliers2/Despite-generally-good-reputation-Peruvian-anchovy-fishery-still-not-MSC-certified).
- [159] Murphy (2015) NGO calls for ASC to require certified feed in fish farms. SeafoodSource, edition of September 22 2015. Available at: [www.seafoodsource.com/news/environment-sustainability/ngo-calls-for-asc-to-require-certified-feed-in-fish-farms](http://www.seafoodsource.com/news/environment-sustainability/ngo-calls-for-asc-to-require-certified-feed-in-fish-farms).
- [160] Berkes *et al.* (2006) Globalization, roving bandits, and marine resources. *Science* 311(5767): 1557-1558.
- [161] Pauly *et al.* (1998) Fishing down marine food webs. *Science* 279: 860-863.
- [162] Christian *et al.* (2013) A review of formal objections to Marine Stewardship Council fisheries certifications. *Biological Conservation* 161: 10-17.
- [163] Jacquet *et al.* (2010) Seafood stewardship in crisis. *Nature* 467(7311): 28-29.
- [164] Gascuel *et al.* (2011) A future for marine fisheries in Europe (Manifesto of the Association Française d'Halieumétrie). *Fisheries Research* 109(1): 1-6.
- [165] European Commission (2009) Green paper — Reform of the Common Fisheries Policy. European Commission, Brussels (Belgium). 27 p.

# ANNEX

## SPECIES TARGETED BY EUROPEAN REDUCTION FISHERIES

### SANDEELS (*AMMODYTES* SPP.)



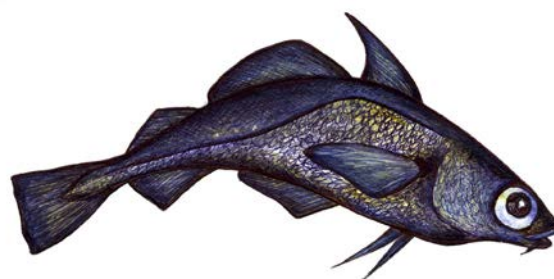
- Found from Russia and Iceland south to Portugal, and the Baltic Sea
- Prey for cod, haddock and seabirds
- Targeted by trawlers
- Stock suffering from reduced reproductive capacity
- No market for direct human consumption

There are several species of sandeels found in the North-east Atlantic,<sup>[1]</sup> but it is mostly the small sandeel (*Ammodytes tobianus*) that is targeted by reduction fisheries.<sup>[2]</sup> Small sandeels, are a bottom-dwelling species, preferring sandy seabed and brackish water estuaries. They are primarily captured in the North Sea by trawlers. As stocks of Norway pout and European sprat declined in the 1970s, the sandeel fishery intensified.<sup>[1]</sup> Annual catches of about a million tonnes were reported in the mid-nineties, but these catches have decreased since. Sandeel are usually harvested in the spring and summer.<sup>[2]</sup>

Sandeels are high in lipid content, and have been identified as an important prey species for seabirds in the North Sea.<sup>[3-6]</sup> Overlap between reduction fisheries in these areas and seabird distribution shows that fisheries may in fact contribute to decreased breeding success in some areas.<sup>[3: 6]</sup> Poor breeding success of kittiwakes has been observed in an area where a local sandeel fishery is present.<sup>[7]</sup> The EU thus prohibited the fishing of sandeels in a 20,000 km<sup>2</sup> area in the North Sea between April and August, when kittiwakes, along with puffins and gannets, use sandeel as feed for their young.<sup>[2: 8]</sup> The sandeel fishery is also regulated with quotas, minimum mesh size,

vessel registration and vessel satellite tracking.<sup>[8]</sup> It is thought that the stock is suffering from reduced reproductive capacity, and the 2010, 2012 and 2014 EU quotas were placed at between 177,500 and 264,000 tonnes.<sup>[9-13]</sup>

### NORWAY POUT (*TRISOPTERUS ESMARKII*)



- Distributed from Iceland and Norway to the Barents Sea
- Targeted by bottom trawlers
- Bycatch of juvenile haddock and whiting, and of adult blue whiting is of concern
- Stock suffering from reduced reproductive capacity.
- No market for direct consumption

Norway pout are in the Gadidae family, which also includes cod and haddock. They are short-lived, maturing at about two years of age, and reaching a maximum age of five years ([www.fishbase.org](http://www.fishbase.org)). Currently, Norway pout are not targeted for human consumption because of their small size, according to the International Council for the Exploration of the Sea.<sup>[14]</sup> Norway pout are considered benthopelagic fish: dense schools can be found near the muddy bottom of the ocean, where they are targeted by small-mesh bottom trawls.<sup>[1]</sup> Generally, they are found between 100 and 200 m in depth.<sup>[14]</sup> All of the catch is destined to be reduced into fishmeal or fish oil. Record high catches of almost 880,000 tonnes of Norway pout were reported in 1974, but the annual harvest has steadily declined since then.



ICES reports that the stock has suffered from reduced reproductive capacity in recent years, with biomass reaching the lower limits of what is considered acceptable.<sup>[14]</sup> In 2005 the fishery was closed for the year, however, catch limits (total allowable catches or TACs) have been set in subsequent years. Regulations have been initiated, including a minimum mesh size, and a closed area in the North Sea to limit bycatch of haddock and whiting.<sup>[14]</sup> ICES explicitly recognizes that Norway pout is an important prey item for many predatory species in the ecosystem.<sup>[14]</sup> Furthermore, scientists have also highlighted the role that Norway pout plays in regulating euphausiid and copepod dynamics in the North Sea.<sup>[15]</sup> The EU quota for 2010 was recommended at 76,000 tonnes.<sup>[9]</sup> In subsequent years, it fluctuated between zero and 167,500 tonnes.<sup>[10-13]</sup>

### BLUE WHITING (*MICROMESISTIUS POUTASSOU*)



- Found in Bering Sea, western parts of the Mediterranean Sea, and south to Africa
- Important component of diets of cod, haddock, monkfish, mackerel, pilot whales, common dolphin
- Targeted by mid-water trawls
- Small proportion of catch supplies sashimi market, majority for reduction and surimi

Also a member of the Gadidae family, blue whiting reaches sizes of about 50 cm.<sup>[1]</sup> Most blue whiting catch is destined for fishmeal, but there are efforts to increase the amount contributing to the supply of fish for human consumption.<sup>[16]</sup>

Little is known of the biology and ecology of blue whiting. The high volume catches common in this fishery are therefore a cause for concern.<sup>[17]</sup> ICES reported that the 2003 exploitation rate of blue whiting was not ecologically sustainable,<sup>[18]</sup> and catches in subsequent years have decreased. A quota system is in place for the blue whiting fishery and steeply increased in recent years, from 11,000 tonnes in 2011 to over 218,000 tonnes in 2014.<sup>[10-13]</sup>

Blue whiting is a component in the diets of several fish species, including cod, haddock and hake, and it is also an important prey item for marine mammals.<sup>[1]</sup> The ecosystem effects of large biomass removals of this important prey species have not been studied.

### EUROPEAN SPRAT (*SPRATTUS SPRATTUS*)



- Distributed from the North Sea to Morocco, and in the Mediterranean, Adriatic and Black Seas
- Majority of catch reduced to fishmeal and fish oil
- Market for canned sprat (sold as anchovy) also exists
- Highest catches during the 1970s
- Bycatch of herring is an issue

Sprat are Clupeidae (i.e., the same family as herring) and reach about 16 cm in length. As much as 20% of their total weight can be composed of fat.<sup>[1]</sup> They are thus highly desirable for reduction fisheries, particularly for fish oil production, and this is where the majority of the European catch ends up.<sup>[2]</sup> There is potential for human consumption through canning (labelled as 'anchovy') and smoking, and they are also used as food for mink.<sup>[1]</sup>

Sprat are primarily caught in the Baltic and North Seas, and the Kattergat/Skagerrak area.<sup>[17]</sup> They are captured with fine-mesh trawls<sup>[1]</sup> and purse seines.<sup>[2]</sup> According to the FAO, catches of sprat peaked in the mid-1970s, at about 900,000 tonnes, and dropped substantially in the late 1990s.<sup>[19]</sup> Catches of sprat over the past decade have averaged about 600,000 tonnes per year.<sup>[19]</sup>

The state of the stock is unknown, with available research suggesting that the drop in catches is due to factors other than stock abundance.<sup>[2]</sup> It is generally thought that the stock is in good condition, however, the spawning stock biomass in the Baltic Sea has decreased.<sup>[2]</sup> Herring bycatch is an issue in this fishery, and consequently, restrictions have been implemented.<sup>[20]</sup> The EU quotas have steadily declined from almost 585,000 t in 2010 to just over 420,000 tonnes in 2014.<sup>[9-13]</sup>

## ATLANTIC HERRING (*CLUPEA HARENGUS*)



- Distributed along the entire European coast
- Food source for cod, pollock, mackerel, tuna, squid, whales, seabirds
- Valued food fish in Europe, smoked, salted or pickled
- About half of the catch is reduced

Atlantic herring are distributed along the entire European coast, with the same species also found in the Northwest Atlantic. They grow to be about 20-25 cm in length, and reach maturity between three and nine years of age.<sup>[20]</sup> Catches of herring peaked in the 1960s, reached lows in the early 1980s, and have increased consistently to the present day. Different stocks are fished for both direct human consumption and for reduction. Overall, EU quotas have increased from around 600,000 tonnes in 2010 to over 780,000 tonnes in 2014.<sup>[9-13]</sup>

About half of the annual European herring catch is destined for reduction.<sup>[1]</sup> The EU, however, has banned the landing of herring for fishmeal and fish oil reduction,<sup>[20]</sup> except from catches originating in the Baltic Sea. The small size of Baltic Sea herring reportedly makes them unmarketable for human consumption.<sup>[17]</sup> However, Baltic Sea herring are reported to have high dioxin levels.<sup>[20]</sup> Dioxins are persistent organic pollutants that can have negative impact on humans, wildlife and ecosystems.<sup>[21]</sup>

Herring are an important prey species for cod, pollock, mackerel, tuna, squid, whales and seabirds.<sup>[1]</sup> Killer whales (*Orcinus orca*), in particular, feed on Atlantic herring, often following migrating herring into the fjords of northern Norway.<sup>[20]</sup>

When catches of Norwegian spring-spawning herring declined drastically in the mid-1960s, capelin (*Mallotus villosus*) started to be targeted for reduction fisheries in Europe, in order to supplement fishmeal plants in needed raw material.<sup>[22]</sup> Capelin is a key target species for reduction fisheries in Europe, but its ecosystem importance

was recognized in an ICES Symposium dedicated solely to discussing this species.<sup>[22]</sup> Capelin have been identified as an important component of the diets of finfish, marine mammals and seabirds<sup>[22]</sup>, including the great cormorant off Greenland<sup>[23]</sup>. It is believed that millions of tonnes of capelin are consumed as prey species annually<sup>[22]</sup>. Most of the European catch of capelin takes place in the Barents Sea, and a significant proportion of that is reduced to fishmeal.<sup>[1]</sup>

## REFERENCES

- [1] Matthiessen (2007) Forage fish and the industrial fisheries. Quebec-Labrador Foundation, Montreal (Canada). 94 p.
- [2] Anon. (2012) Annual Review of the status of the feed grade fish stocks used to produce fishmeal and fish oil for the UK market. Seafish, Edinburgh (UK). 50 p.
- [3] Furness and Tasker (2000) Seabird-fishery interactions: quantifying the sensitivity of seabirds to reduction in sandeel abundance, and identification of key areas for sensitive seabirds in the North Sea. Marine Ecology Progress Series 202: 253-264.
- [4] Rindorf *et al.* (2000) Effects of changes in sandeel availability on the reproductive output of seabirds. Marine Ecology Progress Series 202: 241-252.
- [5] Huntington *et al.* (2004) Assessment of the sustainability of industrial fisheries producing fish meal and fish oil — Final report to the Royal Society for the Protection of Birds prepared by Poseidon Aquatic Resource Management Ltd and The University of Newcastle-upon-Tyne. Royal Society for the Protection of Birds (RSPB), Edinburgh (UK). xii + 105 p.
- [6] Cury *et al.* (2011) Global seabird response to forage fish depletion — one-third for the birds. Science 334: 1703-1706.
- [7] Frederiksen *et al.* (2004) The role of industrial fisheries and oceanographic change in the decline of North Sea black-legged kittiwakes. 41 6(1129-1139).
- [8] Schipp (2008) Is the use of fishmeal and fish oil in aquaculture diets sustainable? Technote 124: 15.
- [9] European Union (2010) Fishing TACs and quotas 2010 — As agreed by Council Regulations (EC) No 1359/2008 of 28 November 2008, (EC) No 1226/2009 of 20 November 2009, (EC) No 1287/2009 of 27 November 2009, (EU) No 53/2010 of 14 January 2010 and (EU) No 219/2010 of 15 March 2010. Changes may be made during 2010. European Commission,

Directorate-General for Maritime Affairs and Fisheries (DG MARE), Brussels (Belgium).

- [10] European Union (2011) Fishing TACs and quotas 2011 — As fixed by Council Regulations (EU) No 685/2010 of 26 July 2010, No 1124/2010 of 29 November 2010, No 1225/2010 of 13 December 2010, No 1256/2010 of 17 December 2010, and No 57/2011 of 18 January 2011. Changes may be made during 2011. European Commission, Directorate-General for Maritime Affairs and Fisheries (DG MARE), Brussels (Belgium).
- [11] European Union (2012) Fishing TACs and quotas 2012 — As fixed by Council Regulations No 1225/2010 of 13 December 2010, No 716/2011 of 19 July 2011, No 1256/2011 of 30 November 2011, No 5/2012 of 19 December 2011, No 43/2012 of 17 January 2012 and No 44/2012 of 17 January 2012. Changes may be made during 2012. European Commission, Directorate-General for Maritime Affairs and Fisheries (DG MARE), Brussels (Belgium).
- [12] European Union (2013) Fishing TACs and quotas 2013 — As fixed by Council Regulations (UE) No 694/2012 of 27 July 2012, No 1088/2012 of 20 November 2012, No 1261/2012 of 20 December 2012, No 1262/2012 of 20 December 2012, No 39/2013 of 21 January 2013, No 40 of 21 January 2013 and No 297/2013 of 27 March 2013. Changes may be made during 2013. European Commission, Directorate-General for Maritime Affairs and Fisheries (DG MARE), Brussels (Belgium).
- [13] European Union (2014) Fishing TACs and quotas 2014 — As fixed by Council Regulations (EU) No 1262/2012 of 20 December 2012, No 713/2013 of 23 July 2013, No 1180/2013 of 19 November 2013, No 24/2014 of 10 January 2014, No 43/2014 of 20 January 2014, No 315/2014 of 24 March 2014 and No 432/2014 of 22 April 2014. Changes may be made during 2014. European Commission, Directorate-General for Maritime Affairs and Fisheries (DG MARE), Brussels (Belgium).
- [14] ICES (2006) ICES FishMap — Norway Pout. International Council for the Exploration of the Sea (ICES), Copenhagen (Denmark). 6 p.
- [15] Pauly *et al.* (1998) Fishing down marine food webs. *Science* 279: 860-863.
- [16] Was *et al.* (2008) Evidence for population structuring of blue whiting (*Micromesistius poutassou*) in the Northeast Atlantic. *ICES Journal of Marine Science: Journal du Conseil* 65(2): 216-225.
- [17] Anon. (2003) The fish meal and fish oil industry — Its role in the Common Fisheries Policy. Fisheries Series — Working Paper FISH 113 EN, European Parliament, Directorate-General for Research, Strasbourg (France). xxiv + 148 p.
- [18] ICES (2007) Report of the working group on northern pelagic and blue whiting fisheries (WGNPBW), August 27-September 1, 2007, Vigo (Spain). ICES CM 2007/ACFM:29, International Council for the Exploration of the Sea (ICES), Advisory Committee on Fishery Management, Copenhagen (Denmark). 229 p.
- [19] FAO (2013) FishStatJ — Software for fishery statistical time series. V2.1.1. Food and Agriculture Organization of the United Nations (FAO), Rome (Italy).
- [20] Tuominen and Esmark (2003) Food for thought: the use of marine resources in feed fish. Report 2/03, WWF-Norway, Oslo (Norway). 53 p.
- [21] Anon. (2004) Dioxins in the Baltic Sea. Helsinki Commission, Baltic Marine Environment Protection Commission, Helsinki (Finland). 20 p.
- [22] Carscadden and Vilhjálmsson (2002) Capelin — What are they good for? Introduction. *ICES Journal of Marine Science* 59: 863-869.
- [23] Gremillet *et al.* (2004) Linking the foraging performance of a marine predator to local prey abundance. *Functional Ecology* 18: 793-801.