Lecture 21: Fisheries & Aquaculture

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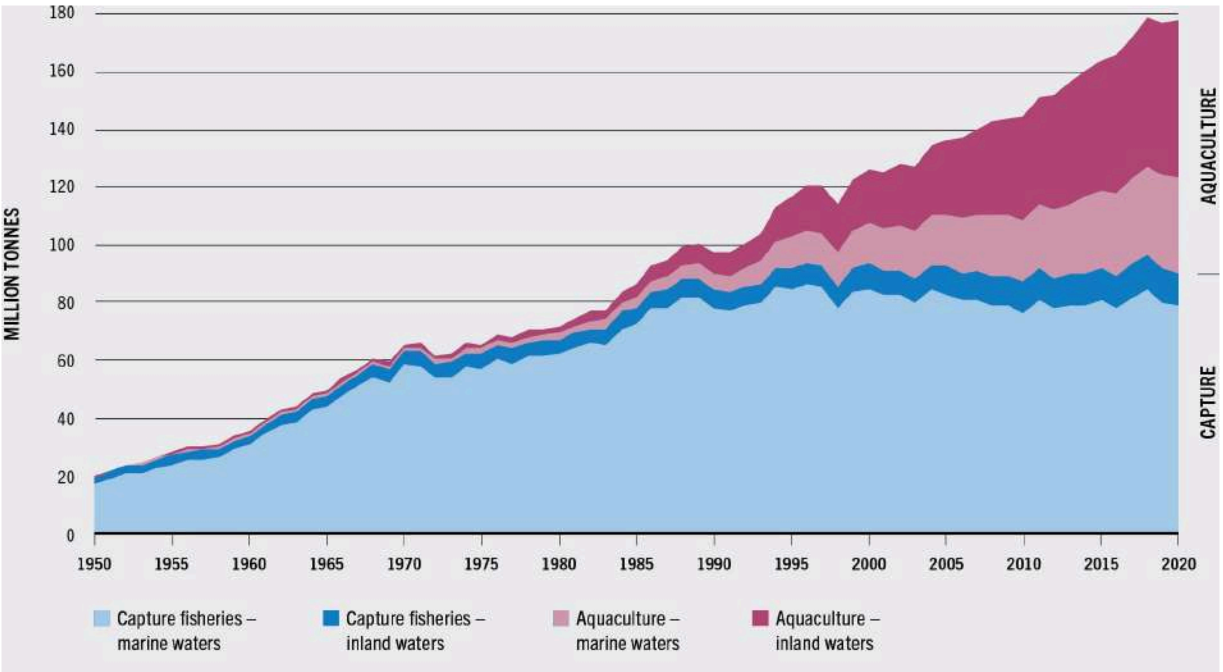
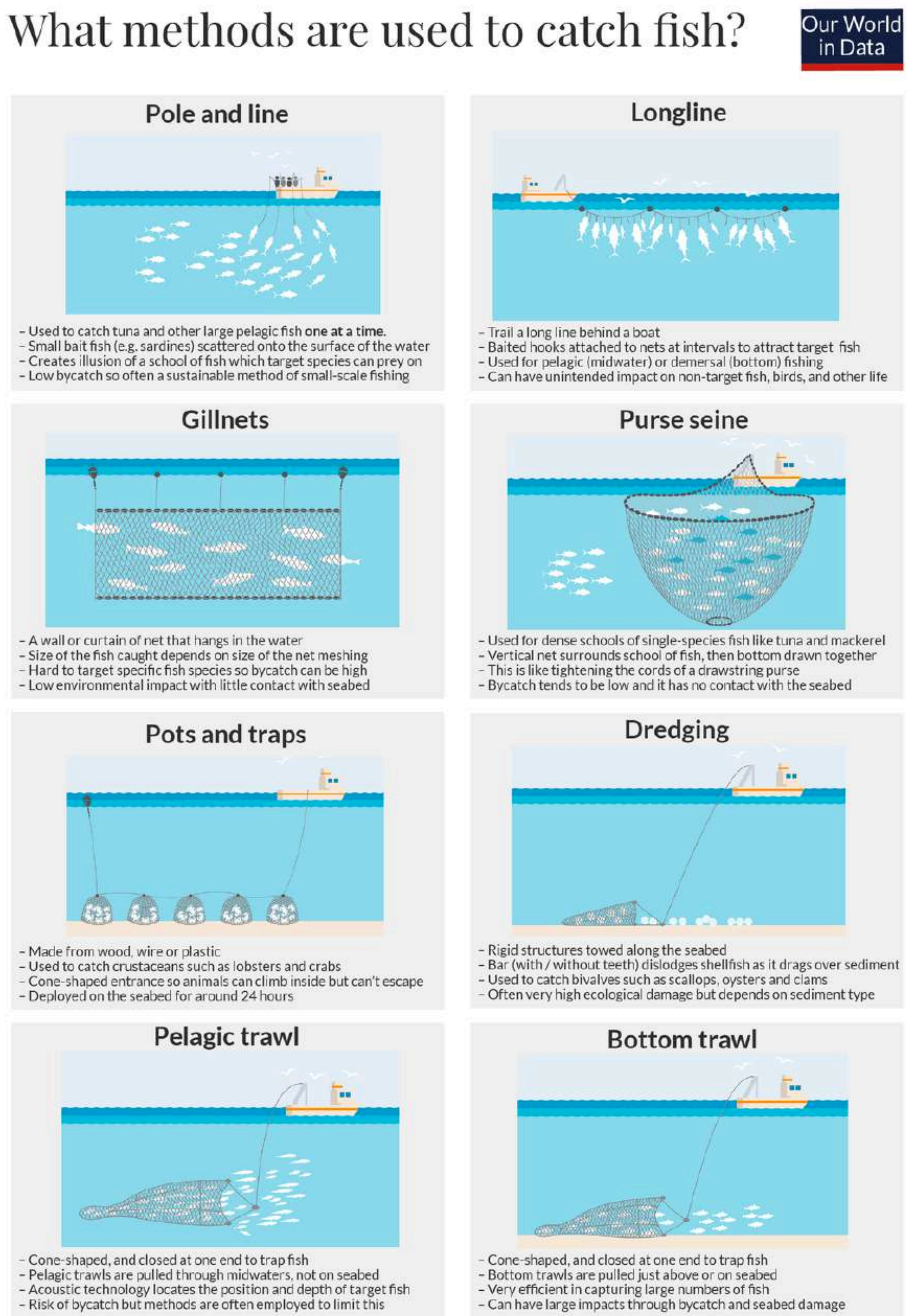
With a global human population over 7.8 billion (around 800 million of whom are undernourished), demand for food is putting pressure on human food resources worldwide. The decisions we make about how to feed people will become increasingly important to the maintenance and stability of the ecosystems that we rely on to produce this food. There is no way around this problem, and the way that we are meeting that demand using marine food production looks very different today than it did a couple of decades ago. Take a close look at the graph below of fish food production. Global food fish supply grew by 62% from 1960 through 2010. This increase was initially (from 1960–1980) because of increases in fishery landings. Since the mid-1980's, expansion of aquaculture has driven the increase in global fish supply.



In this lecture I will give a brief introduction to marine fisheries and aquaculture as human food production systems. These fishery and aquaculture industries also exist in freshwater (streams, rivers and lakes), but for the purposes here we will focus solely on the marine industries. The great challenge of managing these marine food production systems is balancing the global need for marine food resources with the long-term sustainability and stability of the populations being fished and the ecosystems that support them. Sound complicated? It can be, but let's start with an introduction of what these things are.

Marine Fisheries

If you who have seen Deadliest Catch, you probably have a sense of how exciting and dangerous open ocean fishing can be. There are a number of types of capture fisheries including recreational and commercial, small-scale artisanal and industrial, and not all fisheries are as wild or made for prime time TV as the King Crab fishery in the Pacific. A fishery is any undertaking that seeks to harvest fish. We can think of the fishery as being inclusive of all of the people, products and operations involved. It includes the fish caught, the people doing the fishing, the ecosystem the fishery operates in, the markets that the fish are sold to, the boats, docks, transportation of the fish, the processors that turn the whole fish into other things (canneries for example), and often more. Some of the more common types of fishing methods that you may already be familiar with are hook and line, longline, gillnet or driftnet, trap, trawl, and dredge.



Source: Adapted from the Marine Stewardship Council (MSC). Image credits: Marine Stewardship Council.
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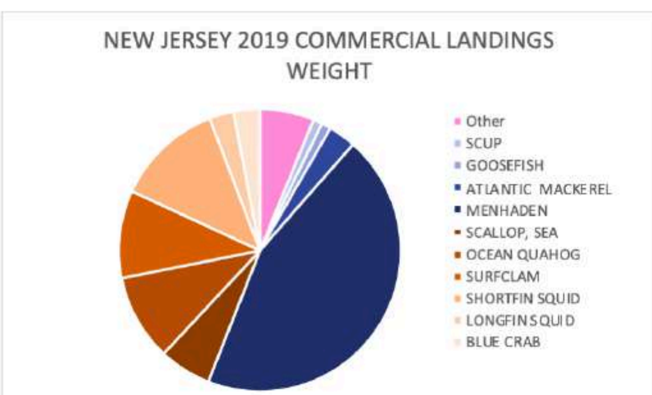
Fishers typically target one species when they are fishing, but depending on the way that they are fishing, they will sometimes catch other species unintentionally. We call the other fish that are caught accidentally bycatch. The amount of bycatch will vary depending on the fishery and the methods used to fish. Bycatch is an issue that brings heavy criticism for the fisheries that have high rates of bycatch. The shrimp fishery is one fishery that tends to have high rates of bycatch, but recently researchers and the fishing industry have made advances in gear innovation that has allowed them to reduce bycatch. The photo below shows an example *of innovations to reduce bycatch in the Northern shrimp fishery. The pink things are shrimp, silver things are bycatch (fish). Old gear catch on left, bycatch reduction gear catch on right.*

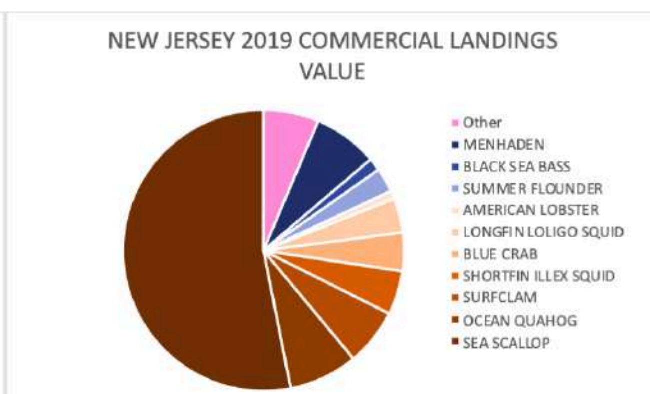
The fish that are being targeted are from what is called a stock. Managers who make decisions about how many fish can be harvested will consider the status of the stock when setting limits. The number of fish in a stock fluctuates over time. This is true whether fishing is present or not, but a fishery can also affect how many fish are there. The challenge for fishery management is to try to predict these fluctuations and to set sustainable levels of harvest that will not cause problems for these stocks over time. Not an easy job, and one that is often highly criticized when managers are off in their predictions. It is a big enough problem to simply try to sample and make estimates of how many fish exist now, let alone predict what will come in the future. This uncertainty in assessment and prediction leads to much of the controversy about fishing and it's impact on global ocean ecosystems.

Some other important jargon to know when you are reading about fisheries, are the terms underexploited, fully exploited, overexploited. These are words that relate to the status of the fishery. When a manager is making decisions about a fishery, the aim is to maximize/optimize the gains from the fishery (catch, profit, productivity) while maintaining a biologically sustainable stock. A delicate balance. If a fishery has room for expansion (meaning that it is not yet harvesting at a level that achieves the optimal production), it is considered 'underexploited'. When a fishery is at that maximal point, it is considered 'fully exploited'. An exploited stock, therefore, has no room for additional harvest beyond the levels it is already at. An 'overexploited stock', as the name suggests, is being harvested at a higher rate than that optimal rate and a manager should look to impose measures to reduce the catch. The graph below shows that the majority of the world fish stocks are fully exploited, and that since the mid-1970's the underexploited stocks have been declining, while the number of overexploited stocks have been increasing. Fisheries management is a complex science and unfortunately we won't have time here to get into the details of how it is done. Instead, we will take a look at the status of some fisheries locally and globally.

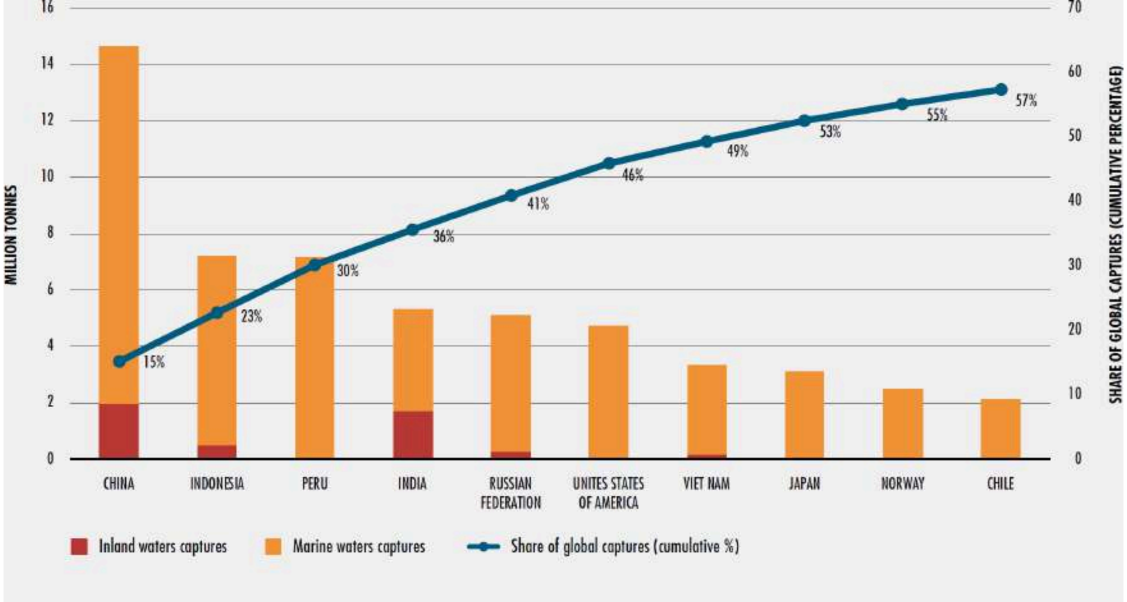
Now that we have an idea of what a fishery is, let's discuss the local fishery, then take a broader look at global fisheries. New Jersey has a large and active federal commercial fishery. Although most people think of fisheries as catching finfish (these are the bony fishes – return to the lecture on marine fish if you don't recall what these are), in New Jersey, over 85% of the value in commercial fishery landings are from invertebrate fisheries. The vast clam populations living in the sandy bottom along the Mid-Atlantic continental shelf are the basis of a major fishing industry. The clam fishery in New Jersey lands nearly $20 million of clam meat each year that is processed and made into soups and stews (among other things) locally. The sea scallop fishery is currently the second most valuable fishery in the U.S.; its ex-vessel value in New Jersey alone in 2018 was over $83 million (it is worth $523 million federally). The squid fishery in New Jersey landed the second most fish (over 30 million pounds) for a landed value over $15.5 million. The menhaden fishery is the highest landings fishery in New Jersey with 85 million pounds landed in 2018, but the value for menhaden is low. So, although it landed the most overall weight of all fish landed in New Jersey in 2018, it was only worth 7% of the landed value ($13 million).

In the charts below you can see that the weight of landings (the left graph) shows you a very different picture of New Jersey landings in the federal fisheries than is shown by the value landings (the right graph). Why is that? The landing weight is a reflection of the amount of fish caught, while the value is what is paid at the dock for that catch. The discrepancy between these two metrics tells us that fish like menhaden are low value, while scallops are very valuable. Also evident in these graphs are the balance between finfish fisheries (shown in purples) and invertebrate fisheries (shown in oranges) – the 'other' category (pink) contains both finfish and invertebrates. By weight, there is a pretty even split between invertebrate and vertebrate fisheries; however, by value, invertebrate fisheries are much more valuable, at least in New Jersey.





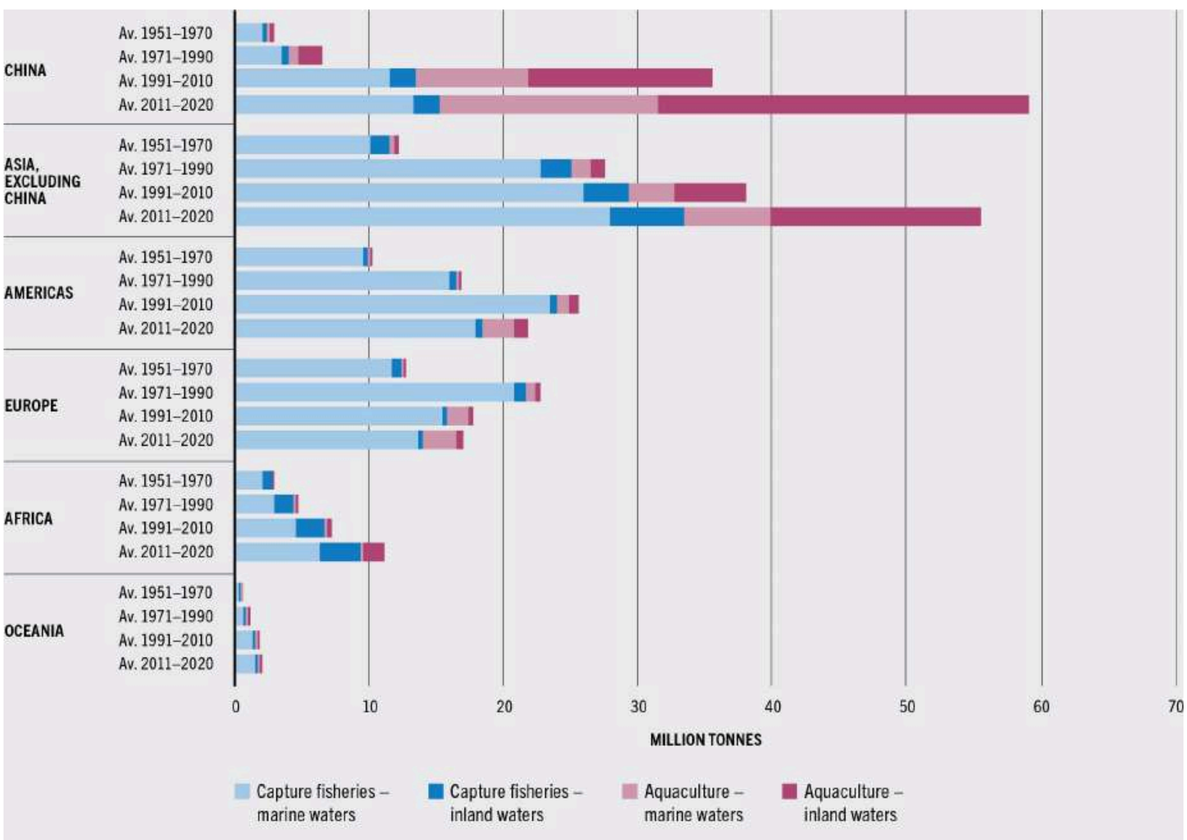
Globally, fisheries catch has remained relatively stable at 85 million tons over the past 15 to 20 years. The majority of the world's catch comes from the Northern Pacific Ocean. The chart below shows the breakdown of global catch (by weight) over the major ocean regions. It is estimated that in 2018 about 4.6 million fishing vessels operate on the world's ocean. A whopping 68% of those boats are from Asian countries. This is in part because fisheries in developed countries tend to be highly mechanized and industrial, whereas those in developing nations tend to be smaller and more artisanal.



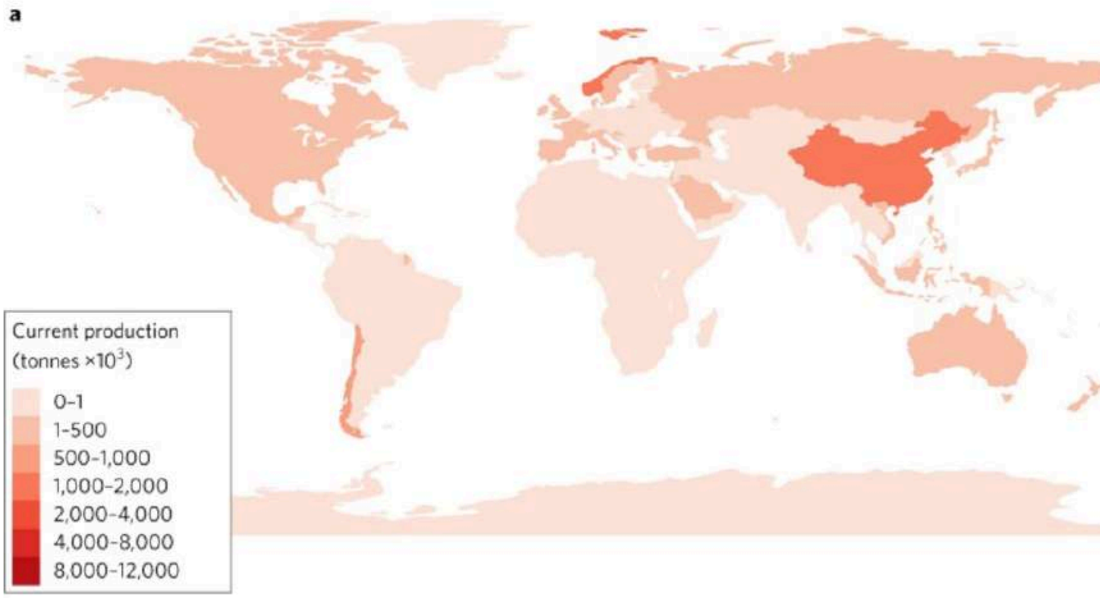
SOURCE: FAO.

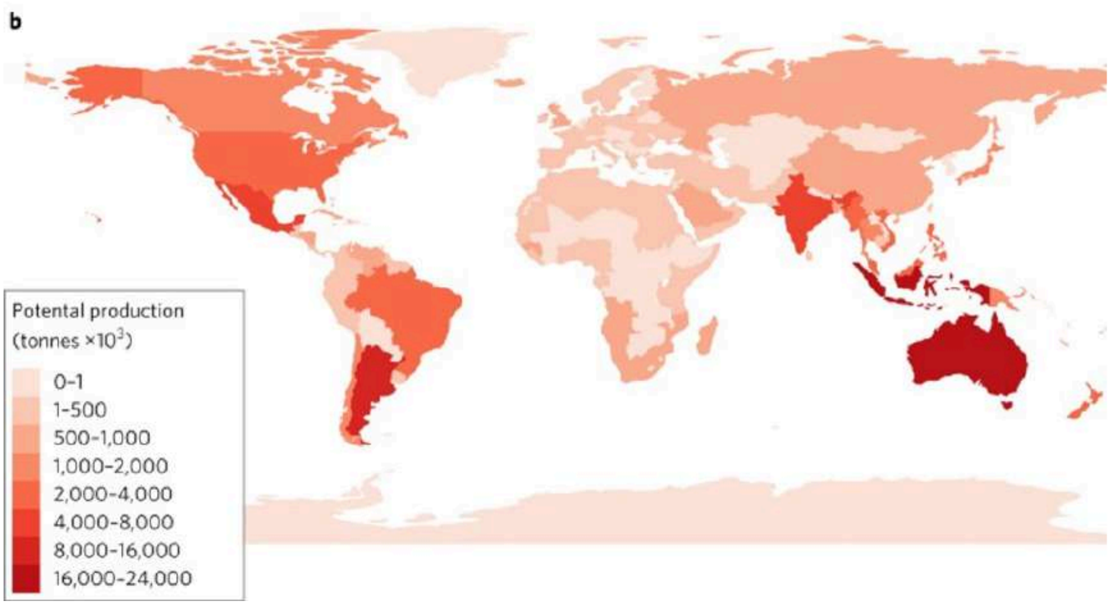
Aquaculture

Global aquaculture production has been expanding and now accounts for over half of the world food fish production, up from only 6% in 1970. Marine aquaculture has the potential to fill the demand for marine and coastal fish resources, whilst helping to protect stocks that are fully exploited or under pressure from capture fisheries. Take another look at the very first figure in this lecture. You can see how rapidly aquaculture is expanding, while wild capture fisheries are remaining stable. The majority of the expansion in world aquaculture is being driven by growth of this sector in China. Below is a graph showing the relative contributions of fisheries (blue bars) and aquaculture (purple bars) to fish for human food broken down by regions of the world. The top series are the production over time in China alone, clearly showing how much more it produces than other places.



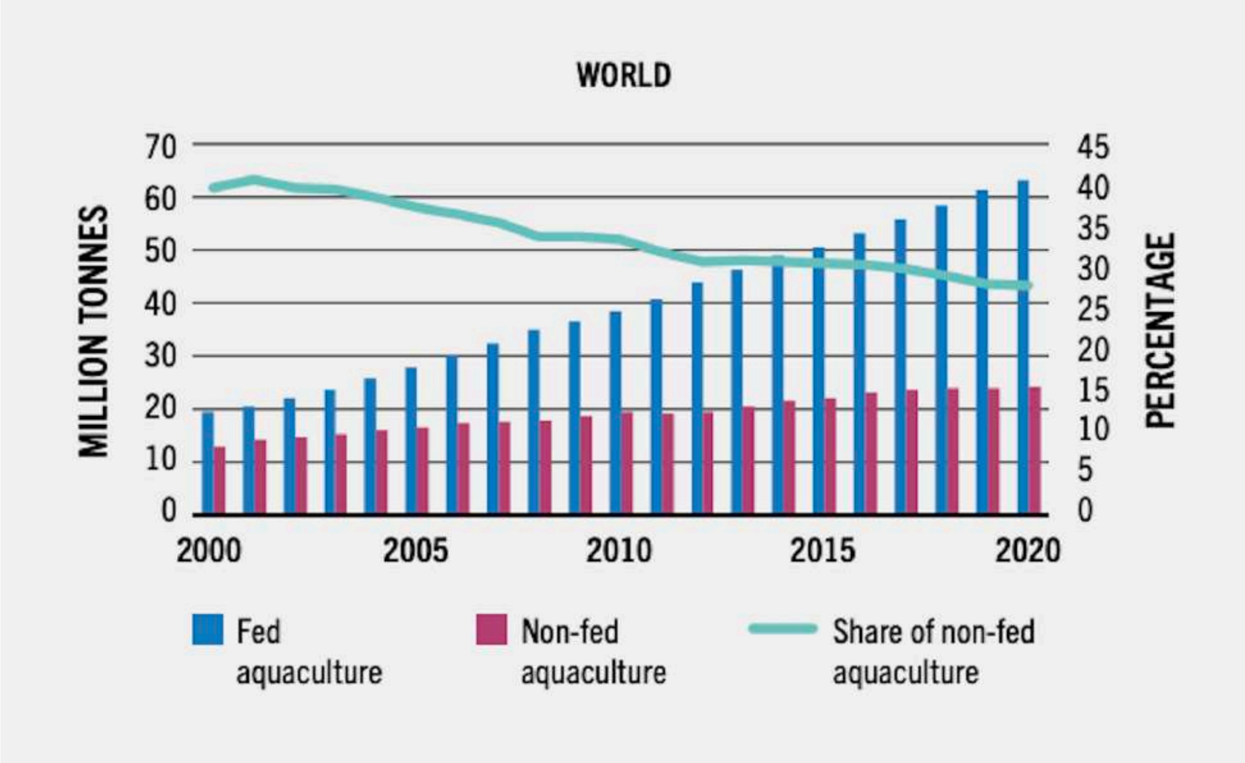
The top map below shows the world distribution (by country) of aquaculture production in 2017. You can see the dominance of this industry by China. Other areas of high aquaculture production India and the countries of the central Pacific (Thailand, Indonesia, the Philippines, Japan), North America (US and Canada), and parts of South America (Chile, Peru and Equador). The lower map shows the potential for expansion, in the future. The authors of the study that produced these maps estimate that today's total landings of all wild-capture fisheries could be produced using less than 0.015% of the global ocean area via aquaculture.





This map is from Gentry, *et al.* (2017). https://doi.org/10.1038/s41559-017-0257-9

Aquaculture is farming in the sea. Possibly the most familiar example is salmon farming, but there are farms that raise all kinds of species including shellfish, kelp, fish, and shrimp. Broadly, aquaculture can be split into two groups – fed farms and extractive farms. Fed farms are farms where the animals being raised need to be fed. These are things like salmon where food is provided for the animals in the pens. Some species don't need additional food beyond the food available naturally in the ocean – these are called extractive forms of aquaculture. An example of an extractive farm is a clam or an oyster farm where the animals are put in the ocean and they feed on their own from phytoplankton that is in the water naturally – no additional food or nutrients are added. The graph below shows a breakdown of global aquaculture production by groups of fed and unfed farmed species. Although the amount of non-fed species has been relatively steady over time world-wide, that proportion has been increasing slightly in the Americas.



Bivalves are particularly attractive for aquaculture because they feed on wild algae and need very little husbandry once they are ‘planted’ on beaches or in cages or nets. As a result, shellfish aquaculture has been expanding rapidly worldwide. The increase in shellfish (molluscan) aquaculture worldwide is due to both innovations allowing the methods (husbandry) for new species to be developed, plus advances in technology allowing farms to be more efficient and animal growth to be maximized which is reflected in the increases in production. Shellfish aquaculture has also been expanding in the US, and today oysters and clams are the most valued aquaculture crop at over $300 million – the infographic below is from 2017 - the value of farmed oysters and clams in the US in 2019 was about $340 million.

Clams and oysters that are raised on farms are mostly born in hatcheries. A hatchery is a facility where broodstock (these are the parents) are used to get the eggs and sperm to make new generations of shellfish babies.

[Here is a video (https://youtu.be/2lvQjekx7dY)](https://youtu.be/2lvQjekx7dY)

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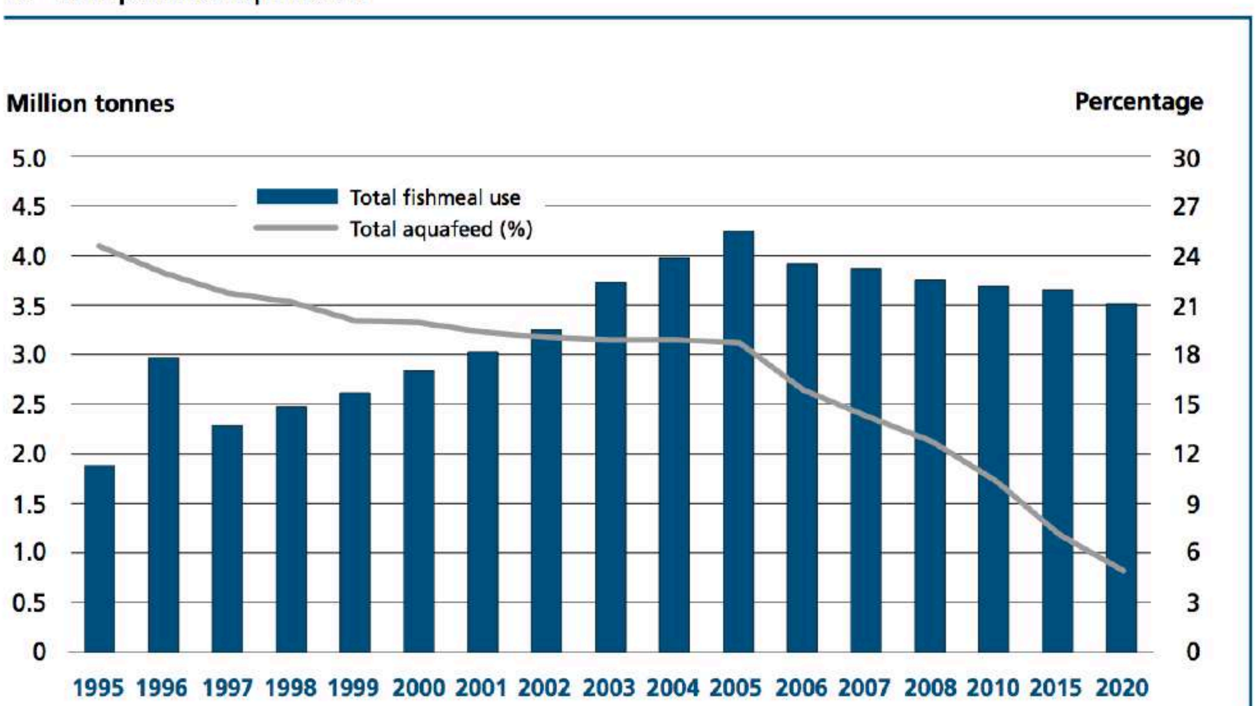
of an oyster hatchery at work.

These babies start out as swimming zooplankton (larvae) and need specialized food (microalgae that is also grown in the hatchery). You have already learned about zooplankton and invertebrates, so this is already familiar! The planktonic babies are delicate and need special care to get them to a size that can be safely put out into the ocean to be grown up to a size that can be sold at a market. Scallops and mussels are sometimes raised in a hatchery, but in many places in the world the animals that end up on the farms are collected from wild populations as small shellfish and then put on farms. Once they are ready to be grown, clams are generally ‘planted’ into intertidal or subtidal muddy habitats, sometimes with nets over them to keep predators out. Oysters, scallops and mussels tend to be grown in structures like mesh bags or cages that are either hung in the water column, or sitting on the bottom.

Salmon are raised in a similar way to shellfish. Baby salmon are raised in hatcheries from eggs through to smolts (smolts are the stage that can live in the ocean – recall the marine fish lecture). These smolts are put in floating cages in the ocean to contain and protect the fish while they grow to sizes that can be harvested and marketed. Atlantic salmon are a species that survive very well in the hatchery and farm pens. Salmon in general have very large eggs, making them easy to handle in the hatchery. Atlantic salmon have high growth rates and aren’t aggressive with one another when they are in high density in pens, making them well suited to farm conditions. Salmon farms are one form of aquaculture that is often criticized because the feeds used on these farms are derived from other fish species. To make salmon feed, you need to fish for other smaller fish species (things like menhaden) and use the fishmeal (this is the ground up fish that goes into the feed pellets) to make salmon food pellets (recall above the difference between fed and non-fed aquaculture). Critics claim that this is unsustainable and inappropriate use of fishery resources. In response to this criticism and declining quotas for fish stocks used for fishmeal, the salmon farming industry have made big improvements and changes in salmon feed technology. Researchers are working towards identifying alternatives for fish oils using sources like marine algae, yeasts and soymeal that can be substituted in without compromising the health of the fish or quality of the flesh. These advances have not only reduced the amount of wild fish needed for feeding salmon, but have also helped in allowing the fish to use their food more efficiently (called food conversion ratios). The graph below shows the trend over time in the proportion of fishmeal that goes into fish food (the grey line).

Actual and predicted reduction in fishmeal use relative to the global production of compound aquafeed



The majority of aquaculture farms today grow only one or two species on the farm at a time. There is a shift in this approach and some farmers are taking a more ecological approach to farm design with attempts to include multiple species from different and complimentary trophic levels on one farm. These systems are sometimes called Integrated Multi-Trophic Aquaculture (IMTA) or Polyculture systems. This approach is intended to blend fed and extractive (non-fed) farm approaches into a single farm as a way to minimize the waste being put into the environment. The additional nutrients that come from adding feed in the water can be taken up by algae grown near fish farms (the algae use the nutrients for their own growth, as you are already well aware) and can help enhance natural algae growth, providing even more natural food for species like mussels, oysters and scallops. There are challenges to making these systems work together – not the least of which is how to structure the legislative and policy regulations that the farmers have to adhere to – but exciting scientific advances are being made.

If any of these topics have been interesting and you find yourself looking to learn more, you might pick up one of the three books shown here. They are all really interesting, and easy reading (and also not required for this course – I am just offering up some good holiday reading if you are interested). Enjoy!