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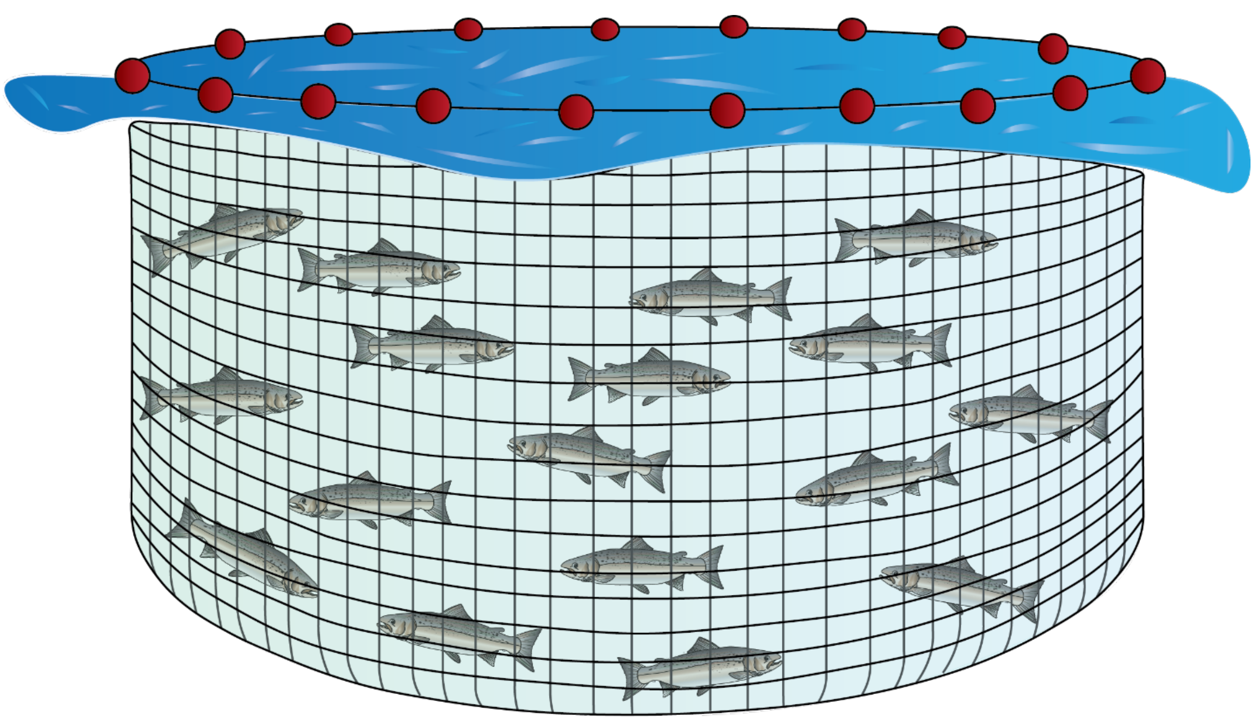
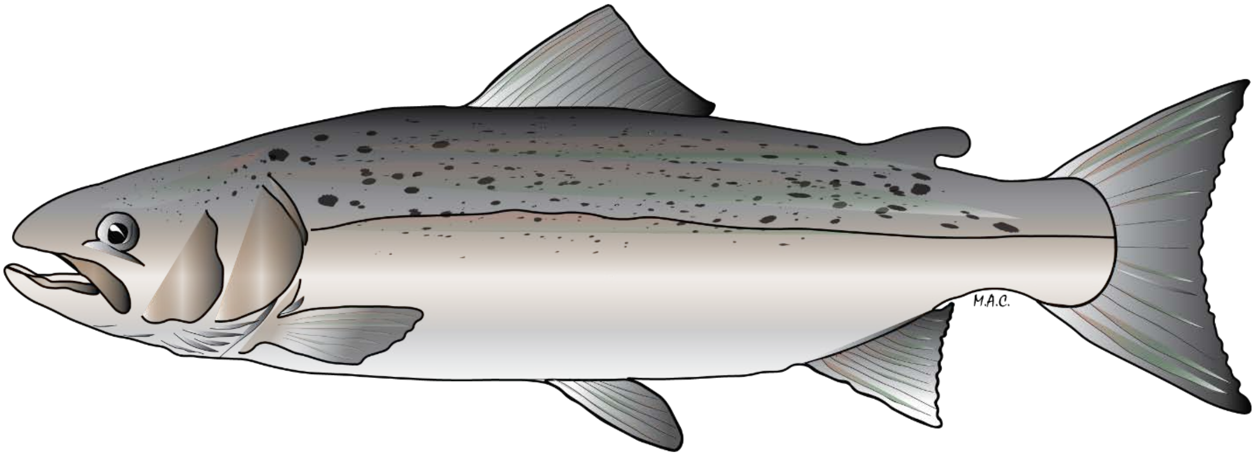
New York Sea Grant

SEAFOOD EAT FOOD

Local Fresh Safe

Aquaculture Curriculum





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The Need for Aquaculture in Modern Seafood Production

Seafood Security

- Global fisheries have declined or leveled off in the last two decades.
  - Most of the world's targeted fisheries have been identified and are commercially fished.
  - Overfishing led to the decline of some fisheries.
  - 85-90% of targeted fisheries are either fished to maximum capacity or overfished (Figure 1).
  - Even accounting for potential recovery of fisheries in decline, the maximum sustainable yield cannot meet the current, nor growing demand for seafood.
    - Maximum sustainable yield refers to the most fish that can be harvested without exceeding the natural restocking rate of a population.

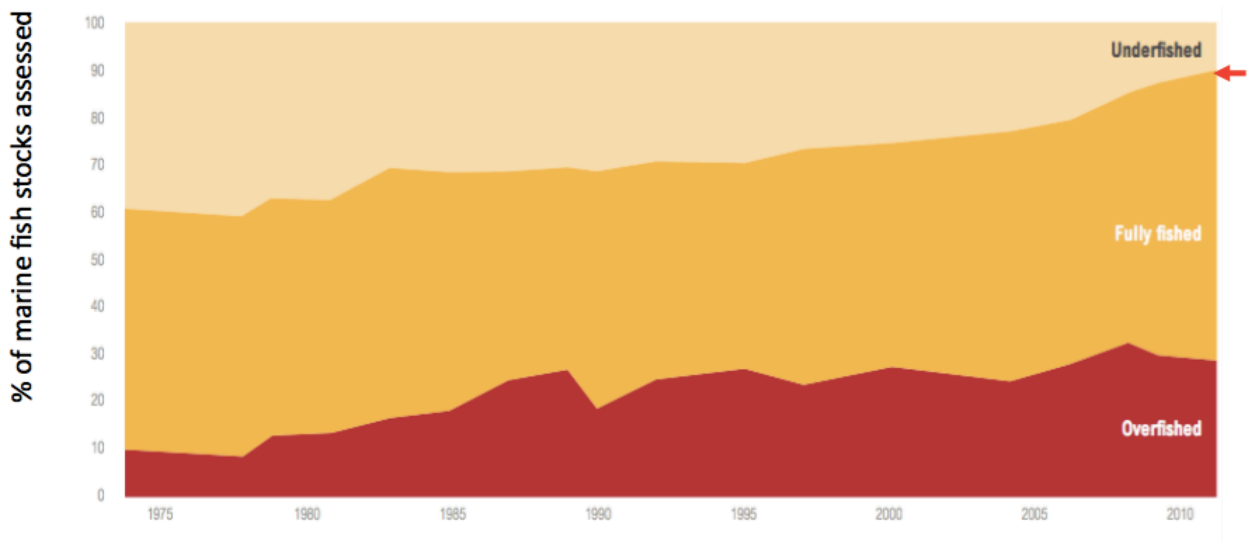

Figure 1. This figure represents the proportion of wild caught marine (saltwater) fisheries under, at, or exceeding maximum capacity throughout the world. Source: FAO 2014b.

- Demand will continue to increase as the population increases and the middle class expands in developing regions and countries. There is also a push for increased consumption in the U.S. on account of the many nutritional and health benefits that come from consuming seafood.
- Since most wild fisheries are already being fished at or above capacity, virtually all increases in seafood production must come from aquaculture.
- In 2014, "the farmed sector's contribution to the supply of fish for human consumption surpassed that of wild-caught fish for the first time." [1]

[1] The State of World Fisheries and Aquaculture, FAO 2016 http://www.fao.org/3/a-i5555e.pdf

- Constant advances in technology and fishing/farming practices are leading to more efficient and sustainable seafood production.
    - Because seafood is so diverse and can be produced in many different ways and many different locations around the world it is important to understand the important safety and sustainability concerns associated with the various production methods and regions.

General Aquaculture Information

- Sometimes referred to as fish farming, aquaculture is the rearing of animals and the cultivation of plants in any aquatic (water) environment. Aquaculture has the fastest growth rate of any sector of agriculture.
- Aquaculture species can be raised for many different purposes, including food, as ornamental species, for medical research or for ecosystem restoration and conservation efforts. For the purpose of this curriculum we will focus of aquaculture of food fish, shellfish and seaweeds.
    - The term "Fish" will be used throughout the rest of this outline as any finfish, shellfish or seaweed.
- Fish farms can vary in size from small and often family-run to large commercial operations.

Aquaculture Practices

- Hatchery
    - Spawning occurs when eggs are released and fertilized and takes place in a hatchery.
    - Spawning can occur naturally during spawning season, which will vary by species and location, or it can be induced in hatcheries.
    - Broodstock are mature individuals used for breeding in aquaculture operations.
    - When breeding eggs and sperm are collected from the parent fish (broodstock) and mixed to fertilize.
        - Fertilized eggs are held under optimal conditions for growth and maturation until they hatch and are further reared in the nursery.
- Nursery
    - A place where juvenile fish are raised before being transferred to a fish farm or a larger facility to grow-out (grow to market size).
    - Nurseries are used to increase survival of the fish. If released too young/small into a large grow-out operation the juveniles will be more susceptible to stress, escape and predation. The age or size that a fish will be released depends on what type of grow-out system is being used and the species.
    - Fish in a nursery can come from hatcheries or be collected from the wild, as is the case with some species of farmed tuna.

- Grow-out operations
  - This is the final and most expensive stage, in which fish are transferred to a larger facility where they are fed and cared for to allow them to develop to market size.
  - Juveniles are stocked in tanks at high densities to allow easier care, feeding and maintenance and are sorted as they grow to separate fish based on size to reduce the density and allow further growth while limiting the chances of stress and disease outbreaks.

Production Cycle Examples:

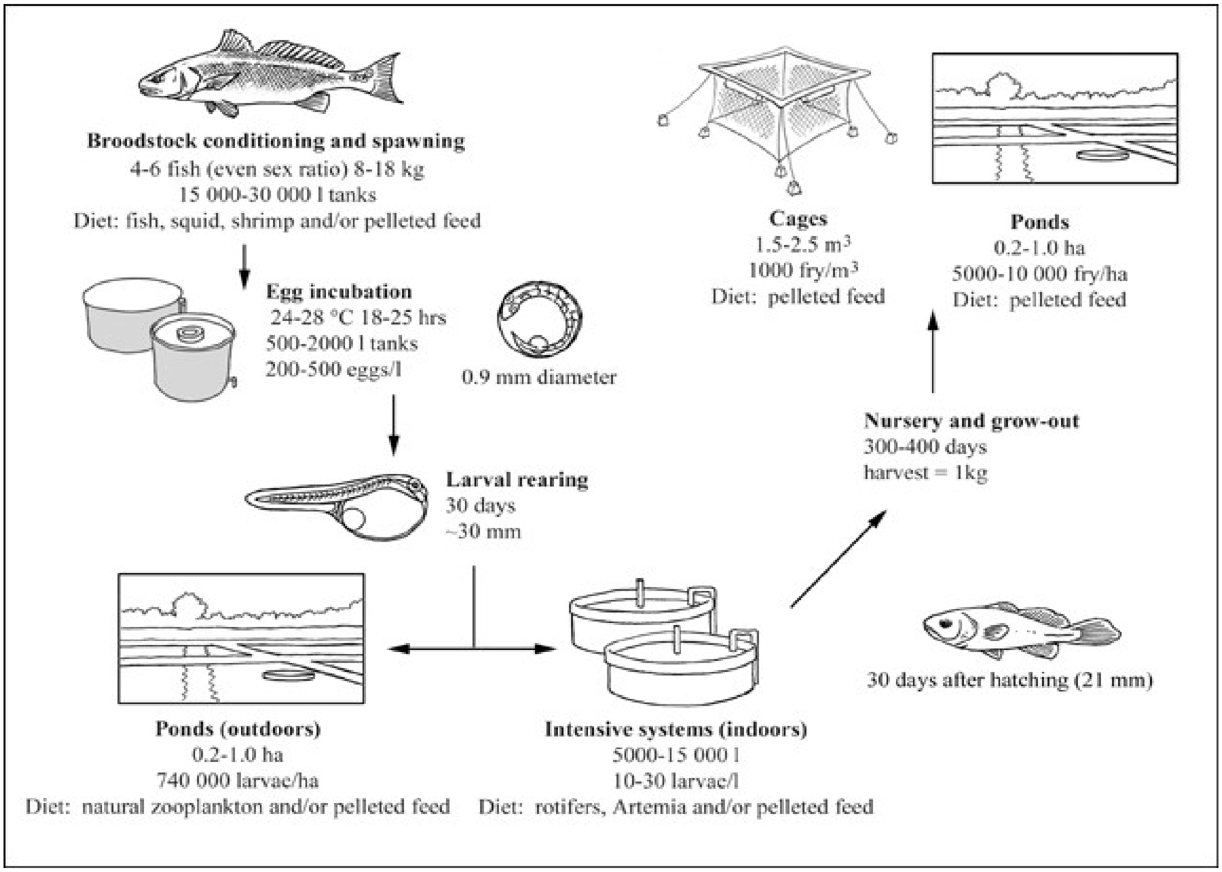

Figure 2. The Production Cycle of Channel Bass (red drum) from the Food and Aquaculture Organization of the United Nations (FAO).[2]

- Harvest
  - After fish have grown to a size that is marketable, or can be sold for food, they are harvested, or removed from the system and sent for processing/sale. There are many different methods that can be utilized when harvesting a system. Some of the most common include:

[2] More information can be accessed at http://www.fao.org/fishery/culturedspecies/Sciaenops_ocellatus/en

- Complete harvest of all fish in a system. Following a complete harvest a system can often be drained to clean and eliminate potential disease-causing bacteria, viruses and parasites before starting the next population.
- Harvest of only market size fish that can be sold as food. In this case undersized fish might be left to continue to grow, transferred to a new system or diverted to another use.
- Intermittent partial harvesting involves harvesting market size individuals followed by the addition of juveniles; usually the restocking rate equals that of the harvest rate in addition to mortalities between partial harvests.[3]
    - In this type of system, you can maintain a system without ever draining. It will always be in operation with fish growing.
- At harvest fish can be shipped live for sale in live markets, transported live to facilities for processing or killed and chilled before transport to the processing facility/market.

Key considerations for a fish farmer:

Species:

- Which species to grow? Choosing what species a farmer will grow is an important first step in starting an aquaculture venture because what species you choose to farm will dictate what systems can be used and will change what you decide for the rest of the key considerations outlined below.
    - A farmer may grow one species, a group of related species, or multiple species from different levels of the food chain.

System:

- Once a species is chosen a farmer must identify the farming system/method that is best suited for growing them. Different species grow best under different conditions. Geographic location will also dictate the types of systems that are necessary to grow a certain species.
    - The next section will review some of the many different types of aquaculture systems there are.

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[3] Stickney, Robert R. *Aquaculture: an introductory text*. Wallingford, Oxfordshire: CABI, 2009. Print.

Density:

- A farmer will also need to determine the number of fish they will place in a given system, this is known as the stocking density (fish/volume).[4]
    - Species, system, facility needs/capability, and water quality are some of the factors that will affect how many fish can be stocked in a system.

Diet:

- Every species has an optimal diet that will promote quick and efficient growth.
    - Mimicking the fishes natural diet will create a nutritionally similar product to the wild fish.
    - A farmer may also consider different feeds to create a nutritionally enhanced product.
        - For example, fish that absorb more omega 3 fatty acids from feed will translate to more omega-3's in the final marketed product.
        - Many salmon farmers will add pigments such as astaxanthin to their feeds to enhance the coloration of the fillets produced. Fish with this pigment in the feed must be labeled "color added," which many consumers misinterpret as dyes added to the fillets themselves.

Water Quality:

- Living in water, fish have an intimate relationship with it. The quality of the water is very important in ensuring high quality and healthy fish are grown efficiently. There are many physical and chemical characteristics of the water that must be monitored and maintained, often within narrow ranges. Some of the quality parameters that might be considered include:
    - pH: a measurement of the acidity or alkalinity of the water
    - Nitrogen: necessary for plant growth, but excess can be harmful to finfish and shellfish.
    - Temperature: different species of fish can only survive in limited water temperature ranges.
    - Dissolved oxygen: the content of oxygen in the water is important, as fish need oxygen to breathe.
- While these represent some of the more common water quality parameters measured there are many others a facility may need to monitor (i.e. iron, turbidity, and other contaminants) depending on the water source, system and species. The optimal range for each characteristic will vary by species being grown.

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[4] Stickney, 2009.

- For more information on water quality management visit http://www.aces.edu/dept/fisheries/aquaculture/waterquality.php

Disease:

- Fish, like humans, are susceptible to bacterial and viral infections that cause illness and even death in severe cases. Managing the introduction and spread of disease is important to maintain a healthy population.
  - While drugs are one way to manage and control disease, they are expensive for farmers to use and highly regulated in the US. Thus, most farmers try to control outbreaks through Good Aquaculture Practices (GAPs).
  - Farms practicing GAPs will have biosecurity measures and safety protocols in place to limit fish exposure and susceptibility to potentially harmful bacteria and viruses, which can result in disease.
  - Examples of GAPs include:
    - Sourcing "disease free" eggs or larvae, for example, those certified by genetic testing, should prevent the introduction of diseases into a facility as long as other GAPs are followed.
    - Clean and sanitary hatchery, nursery and grow-out facilities.
    - Regular sanitation and separation of equipment and materials.
    - Controlled exposure of facilities to outsiders.
    - Reduction of stress.
      - Stressors, like overcrowding, make fish more susceptible to disease; thus, they are usually limited.
      - Stressors include changes in the environment, like sudden changes in temperature, salinity or density.

Types of Aquaculture

- Marine aquaculture refers to production of species native to saltwater environments (i.e. oceans)
- Freshwater aquaculture refers to species native to "rivers, lakes, and streams."[5]
- Single species aquaculture systems grow only one species.
- Multi-species aquaculture systems involve raising a group of related species or raising species from multiple levels of the food chain (trophic levels).
  - Some examples of systems that utilize multiple trophic levels are:
    - Aquaponics, which combines terrestrial plants and freshwater fish. In this system, the waste produced by the fish is broken down into micronutrients

[5] More information about marine and freshwater aquaculture can be accessed at http://www.nmfs.noaa.gov/stories/2012/10/docs/fish_farming_what_would_you_decide.pdf

by bacteria in the water/filter that the plants can then use to grow. The plants act as a filtration system for the fish.

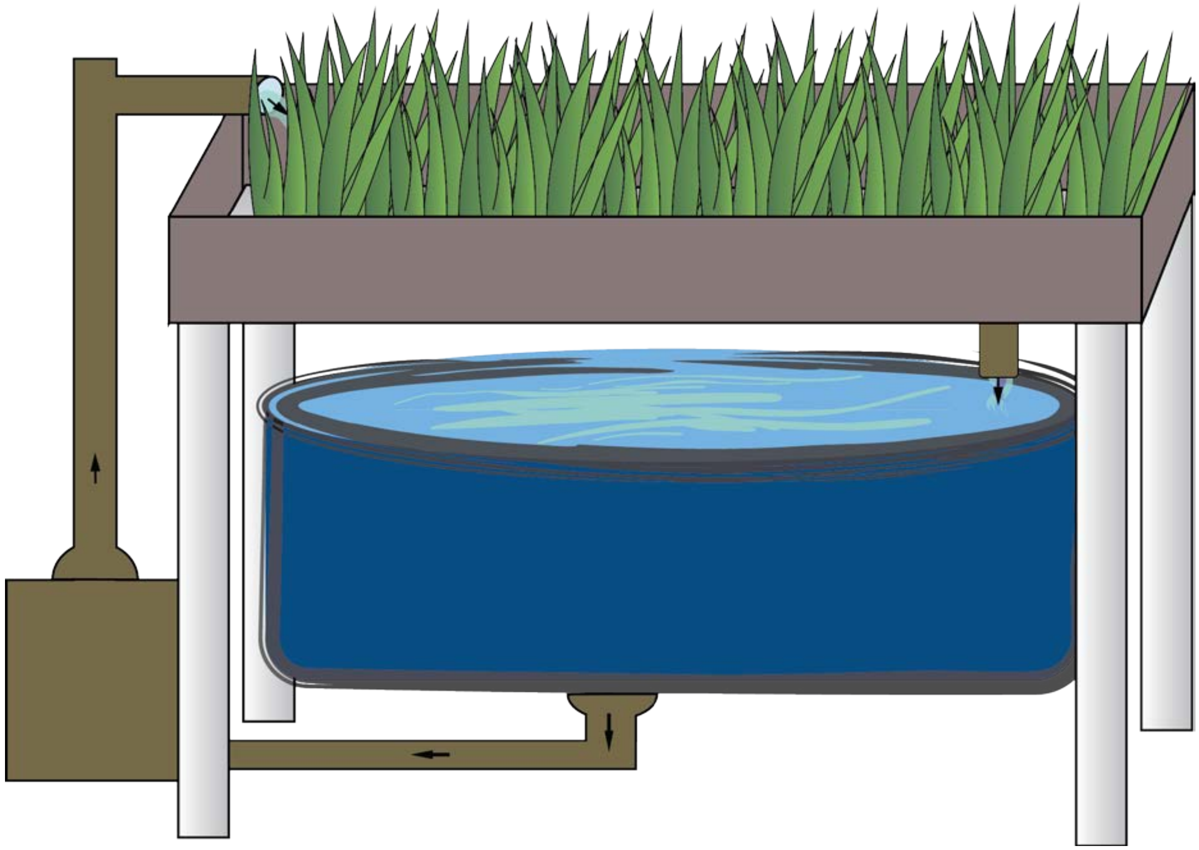

Figure 3. Example of a simple aquaponics system, where nutrients cycle within a culture system of fish and aquatic plants.

- Integrated multitrophic aquaculture (IMTA) is a system that combines finfish, filter feeding shellfish and photosynthesizing seaweeds to effectively use all nutrients input into the system.
  - The fish are fed and generate waste full of macronutrients.
  - The shellfish filter out the macronutrients and produce waste full of dissolved micronutrients.
  - The seaweeds remove the micronutrients from the system and use the energy of the sun to grow.

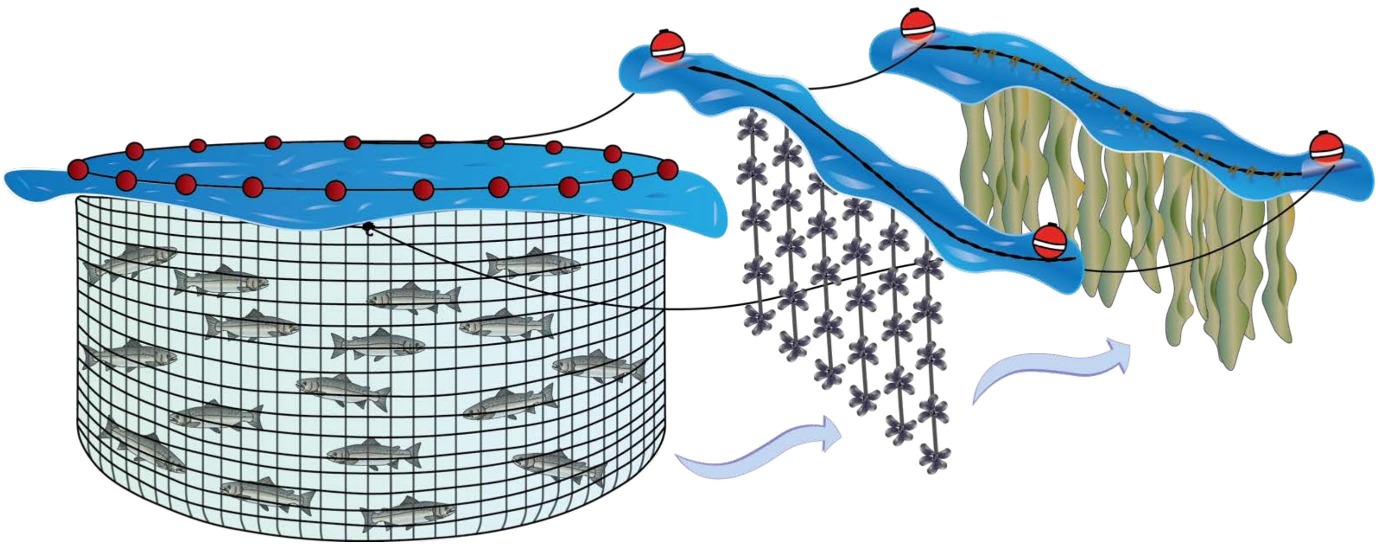

Figure 4. Example of an IMTA system, where waste from one species is utilized by the other species down current.

- In-land cultivation types for finfish and shellfish:
    - Finfish
        - Ponds: Earthen ponds can be used for fish spawning and grow-out.
            - The ponds used can either be natural or man-made but tend to be shallow with muddy bottoms to make fish harvest easy.
            - Pond systems tend to be less intensive because there are not as many technical requirements (i.e. tanks, filtration, etc.)
            - A farmer will have less control over the environment in a pond system, especially of physical characteristics such as temperature, than they will in one of the more enclosed systems discussed later.
                - This feature makes these systems more commonly used in warmer climates in the southern U.S. and tropics. The further north, the shorter the grow-out season will be, limiting growth potential and the species suitable for this type of system.
            - Harvesting from ponds typically takes place with seine nets, which are long nets that often span the whole pond, with floatation on the top and weights on the bottom. By starting on one end and moving to the other the fish can be condensed in one side of the pond at high densities making netting them out easier.

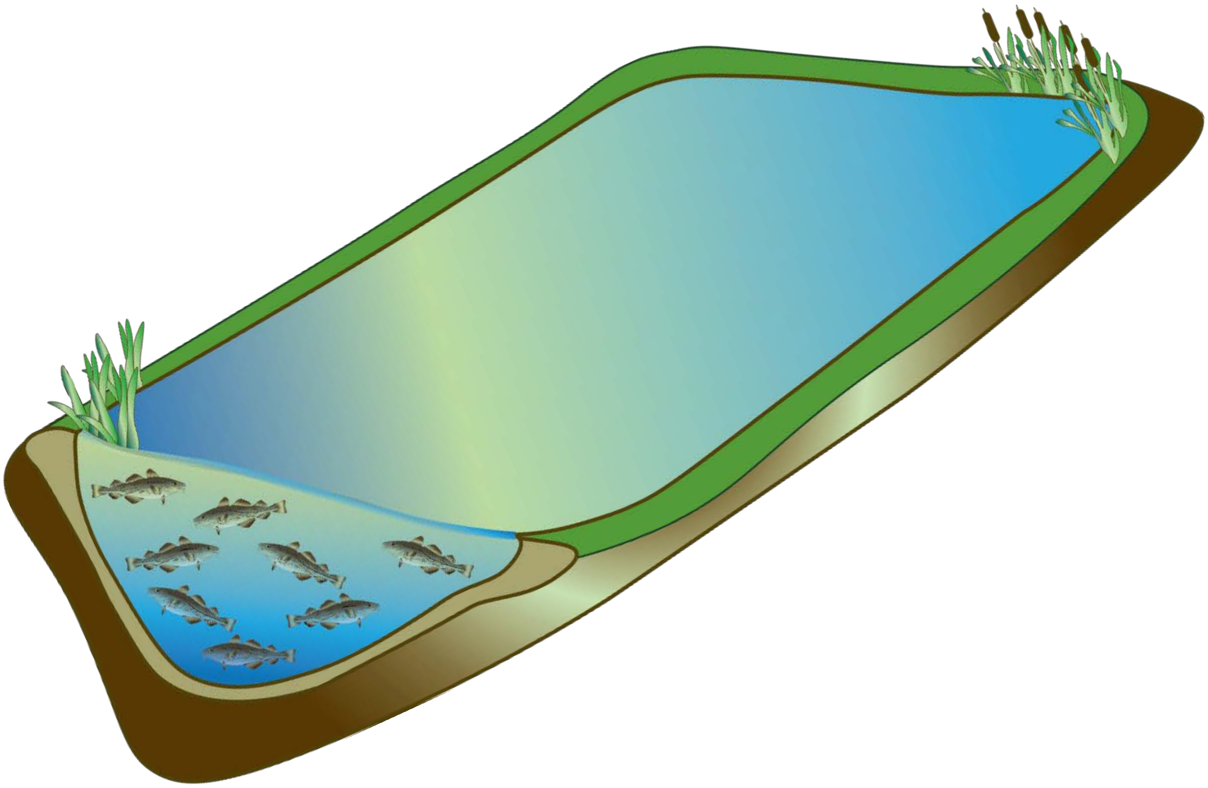

Figure 5. Example of an earthen pond system.

- Recirculating systems recycle water within a tank by filtering and cleaning the water through physical, chemical and biological means before returning it back to the original system.
  - There is minimal waste water produced in a recirculating system and it is a great way to limit water use with 95% of water being retained daily.
  - These systems tend to be more technologically advanced requiring more energy and expertise to operate.
  - The types of filtration and frequency will depend on the species, density and initial quality of the water used in the system.
  - Most in home aquaria are recirculating systems.

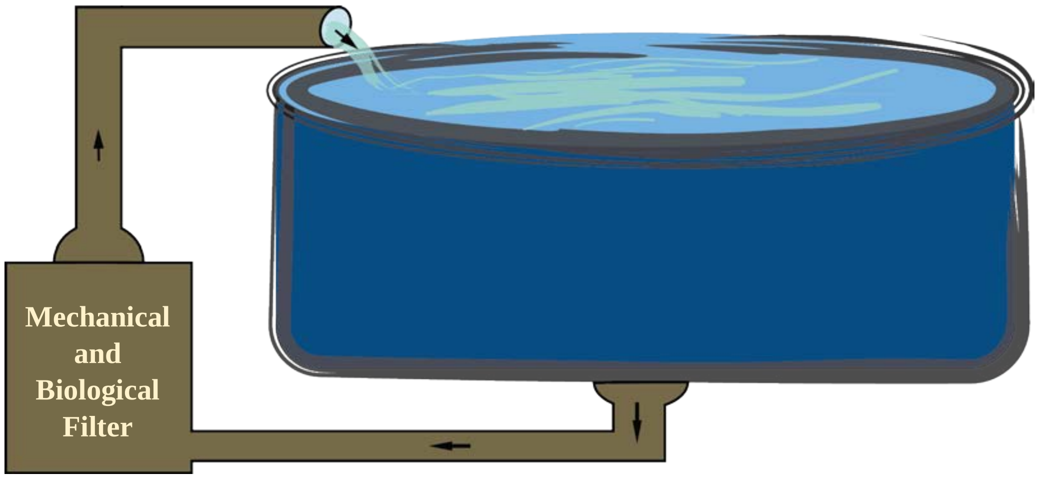

Figure 6. Example of recirculating system, which recycles its water by passing it through a series of biological, mechanical and sometimes chemical filters to remove waste and excess nutrients.

- Flow-through simply refers to a system where water is constantly flowing into and out of a system. The water exiting the system is disposed of and not reused.
  - The structure and design of a flow-through system will vary depending on the species being farmed and the operation.
  - Raceways are a type of flow-through system with "culture units through which water continuously flows."[6]
    - They have a river-like feel with a structure resembling tiered channels.
    - Freshwater species that live in flowing water systems, like rivers and streams, are usually grown in raceway systems.
    - In open raceway systems, the water is diverted from a natural spring, river, or stream through the raceway before it is sent back to its source.
      - There are strict regulations controlling the quality of the water released back into the natural source. In some cases, farms will have to treat the water before it is discharged.

- Shellfish may include mollusks and crustaceans.
  - Ponds can be used to spawn and rear crustaceans, such as crawfish and shrimp.

[6] Stickney, 2009.

        - Crustacean shellfish can also be grown in indoor tank systems either recirculating or flow-through. In fact, a couple farms have small pilot systems in New York for shrimp.

- Coastal aquaculture or nearshore aquaculture:
    - Finfish
        - Cage and Net Pen Systems
            - Cages and net pens are designed to confine aquatic life in larger bodies of water.
            - Confining the fish to a cage within a larger system can protect from predation and allow better control over the diet and water quality surrounding the fish.
            - Saltwater designs tend to be much larger than freshwater counterparts and are typically subject to more intense currents and storm events.
                - Aquaculture engineers must build their systems to withstand the natural environment while promoting efficient growth and easy maintenance and harvest.

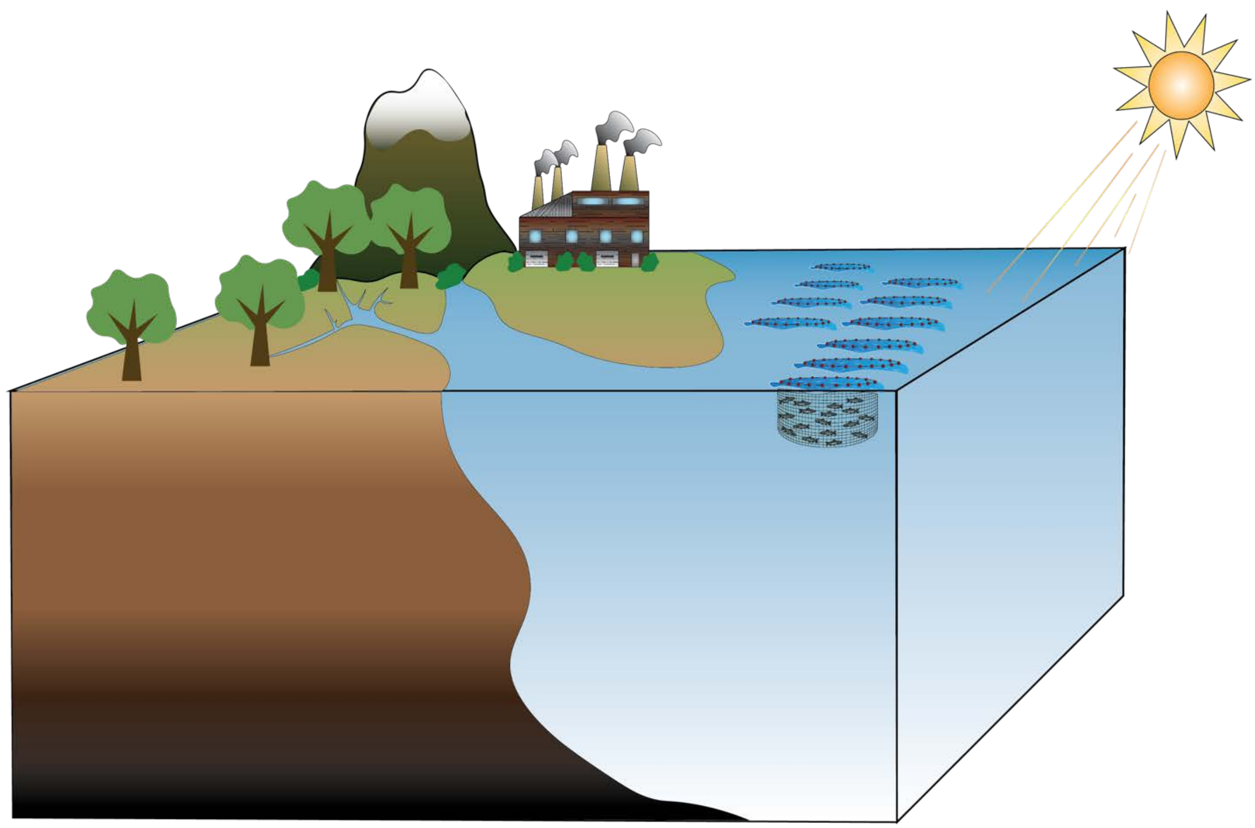

Figure 7. Example of coastal aquaculture net pen systems.

- Shellfish
  - Bottom culture of shellfish takes place on the sea floor. In some cases they can be in shallow coastal areas where they are regularly exposed to air during low tides. In other cases, they are placed in deeper waters where they are always submerged. This system typically employs some type of cage or bag that sits on the sea floor.
    - Rack and bag culture involves placing oysters in grow-out mesh bags tied to racks, which can be placed on the sea floor.
    - Tray culture is similar to rack and bag except oysters are placed in grow-out trays which can be stacked on the sea floor to maximize space.

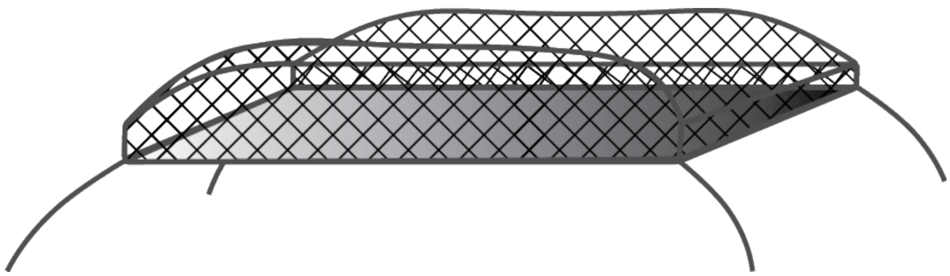

Figure 8. Illustration of a rack and bag culture.

  - Surface culture of shellfish takes place at the surface of the water column. There are many different systems and practices for grow-out that vary based on species, location and farm. Some examples are described below:
    - Mesh bags can be filled with shellfish and maintained at the surface with floatation or lines attached to posts.
    - Shellfish are placed in "socks" (long narrow bags) or lantern nets that are suspended from lines between two floats, poles or some other structure.[7] The shellfish in the socks or nets hang down in the water column and feed on macronutrients and plankton that pass by with the currents.
    - Top culture has the added benefit of keeping the shellfish out of reach for most predators (crabs, snails, starfish etc.).

[7] Stickney, 2009.

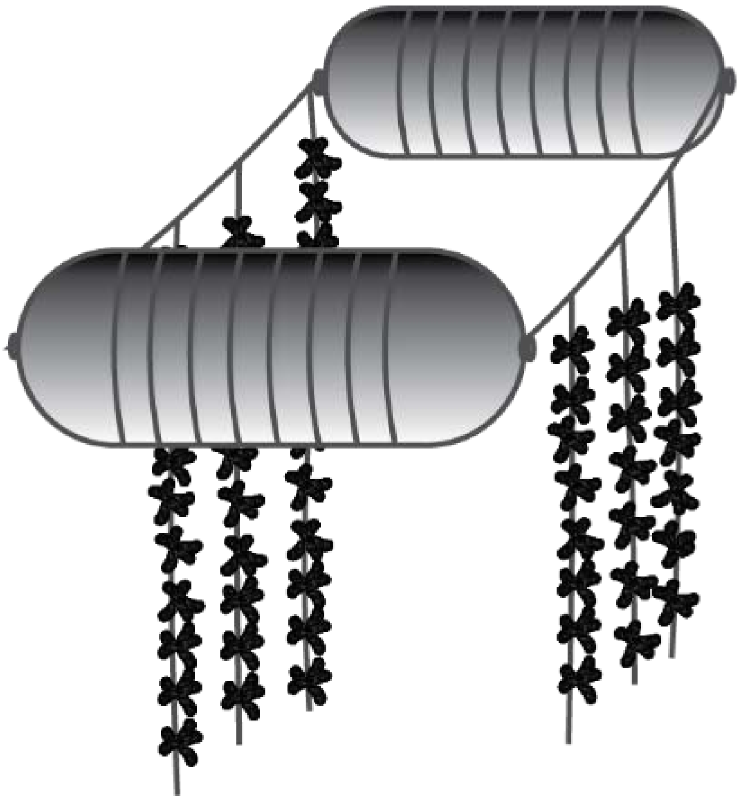

Figure 9. Illustrates one type of suspension top culture that is typically employed for mussels. The mussels are placed in socks that suspend from the surface down into the water column.

- Seaweeds
  - Seaweed culture is typically done on long floating lines that the seaweeds have cemented to. This must be done at the surface so the seaweed has access to sunlight to photosynthesize.

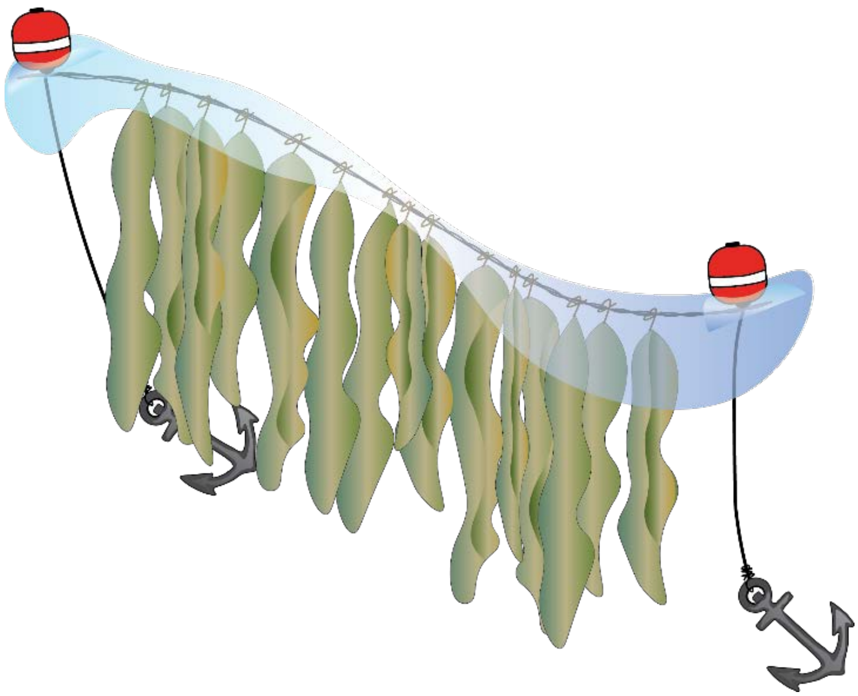

Figure 10. Illustrations of the top culture of seaweeds.

- Open water
  - Finfish
    - Net Pen/cages
      - Similar to coastal net pen systems, except that open ocean systems are built to withstand strong currents and heavy storm activity.
      - Unlike coastal net pens some of these off-shore systems are submersible and require more technical skills and equipment to maintain, feed and monitor the fish.
      - Automatic feeders and regular dive activity is typically an integral part of these types of facilities.

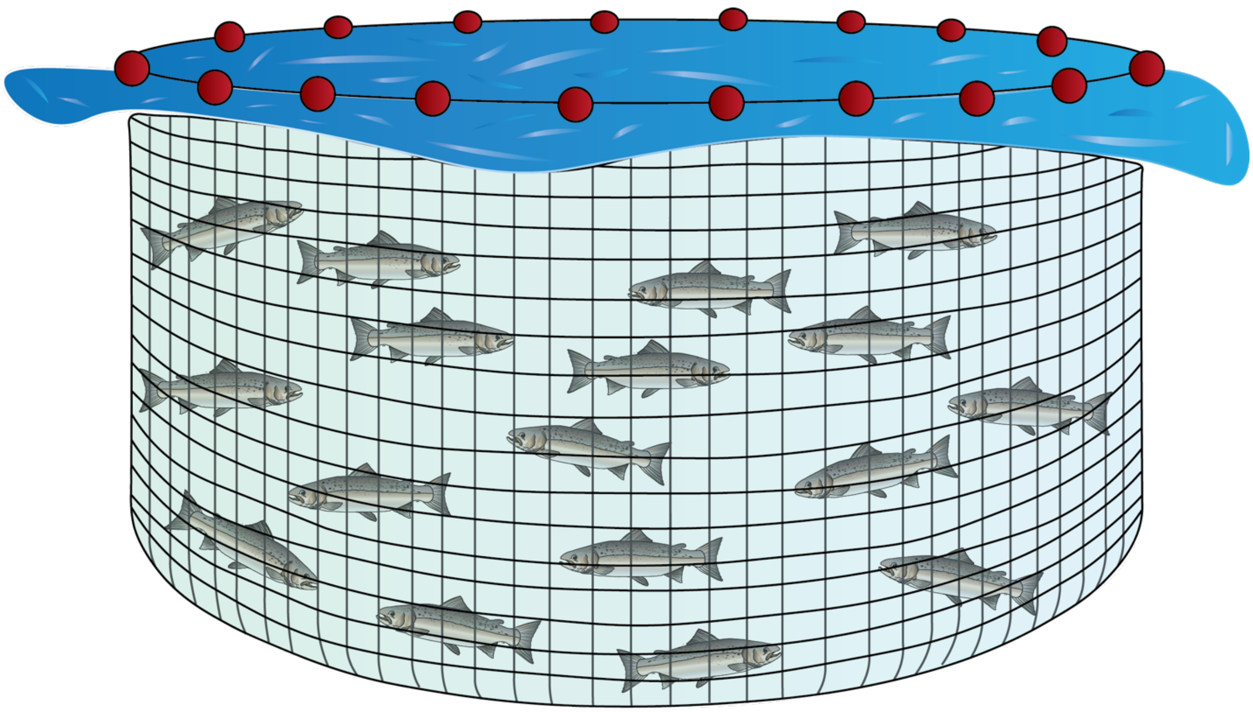

Figure 11. Close up view of one type of net pen system, where the fish are confined within a larger body of water. There are many different structures and models that can be used for coastal aquaculture operations. This is just one example of a common form.

- Ocean Ranching
  - The practice of capturing small, often juvenile, fish like tuna to grow out in some variation of a sea pen, before harvesting them.
  - These fish never have a chance to spawn and are not accounted for in management plans, which can be detrimental to management efforts.
- A form of stock enhancement used to supplement wild stocks and ensure a more stable harvest involves the practice of releasing juvenile individuals of a species into waterways and open-ocean to grow-out naturally for future harvest.[8]
  - This method is very common with anadromous species, those that spawn in freshwater but migrate to the ocean to live and feed, such as salmon.
  - This practice is very common on the west coast to support the Salmon industry.

o Shellfish
- Shellfish culture in open water must be done at the surface and typically consists of lines suspended from floats to keep the shellfish near the

[8] More information can be accessed at http://www.fao.org/docrep/005/Y1805E/y1805e06.htm

surface where currents bring macronutrients and plankton for them to feed on. Open ocean shellfish culture is typically performed as part of an IMTA system and not on its own.

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Authors:

Jack Novak
CALS CCE Summer Intern

Contact: **Michael Ciaramella, MSc, PhD**
NY Sea Grant Seafood Specialist
mc2544@cornell.edu
631-632-8730