Updated August 2017

New York Sea Grant

SEAFOOD EAT FOOD

Local Fresh Safe

Seafood Science Curriculum

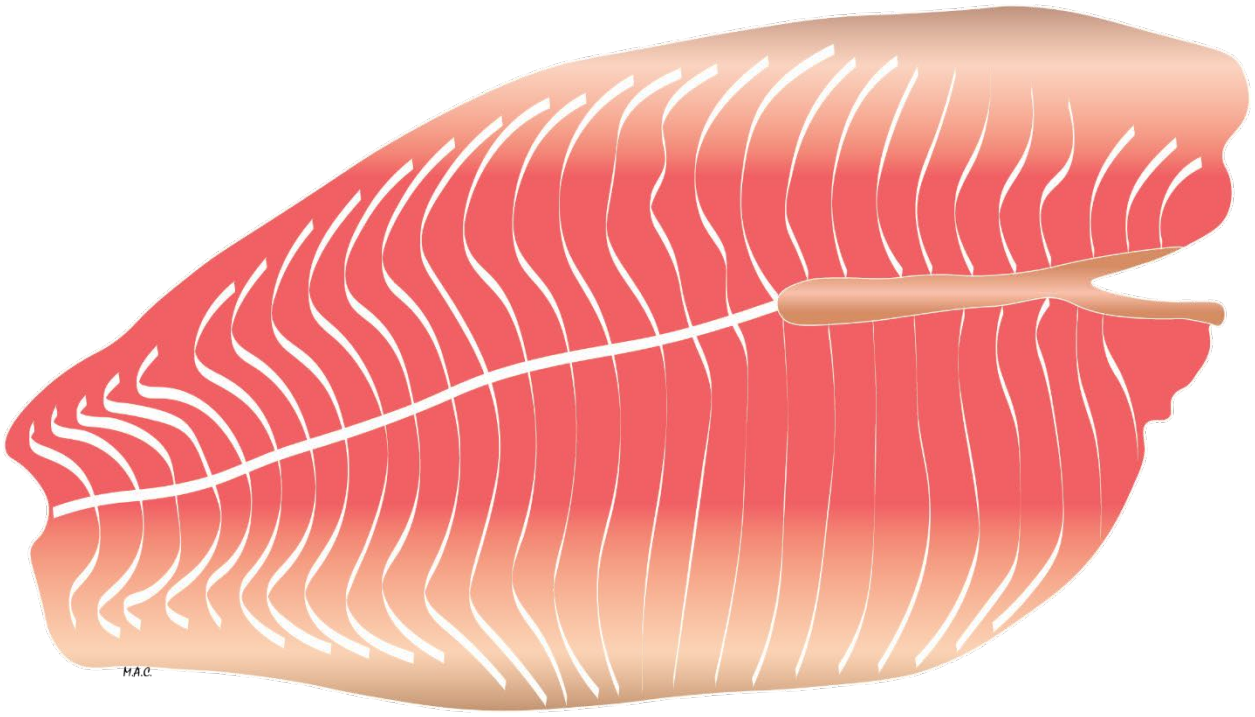


Table of Contents

Introduction

Food Science: The multidisciplinary study of the physical, chemical and biological makeup of foods including nutrition, food processing, and food safety. The physical, chemical and biological properties of a food will change how one perceives that food when eaten. In other words, the chemical and physical properties affect the look, taste, smell, texture and mouthfeel of foods. These properties can also affect how the food is prepared and how long it lasts (shelf-life). Seafood science is the branch of food science that deals with foods that are primarily sourced from the water, such as fish, shellfish and seaweeds. A seafood scientist works to produce and process seafood that meets the four P's of seafood science:

- Produce seafood efficiently, while maintaining high quality.
- Preserve seafood to extend its shelf-life.
- Protect seafood from hazards like bacteria, viruses, parasites and chemical contaminants.
- Perfect the consumer's sensory perception of the seafood.

General Food Science

Before exploring the world of seafood science, it is important to understand the basic components of all foods and how they relate to seafood. All foods are made of varying amounts of water, micronutrients and macronutrients:

- Water
  - 55-60% of the human body is made up of water.
  - Water is crucial for many bodily functions: [1]
    - Regulating body temperature
    - The makeup of body structures, like organs, muscles, and even bones
    - The survival, growth and reproduction of cells
    - Flushing waste
    - The manufacture of hormones and neurotransmitters in the brain
  - Water is the major component of fish flesh, usually making up 80% of fresh white fish fillets and 70% of fatty fish fillets, with extremes in water content ranging from 30% to 90% for some species.[2]
- Micronutrients are nutrients required in trace amounts in order to maintain health.
  - Minerals are inorganic compounds that come from your diet and are necessary for maintaining a normal healthy state.

[1] More information of water's role in bodily functions can be accessed at https://water.usgs.gov/edu/propertyyou.html

[2] Information accessed at http://www.fao.org/wairdocs/tan/x5916e/x5916e01.htm

- No single nutrient can promote good health on its own; a balance of many different nutrients is best and typically necessary to maintain a healthy mind and body.
- Seafood contains a variety of minerals important for human health. Some of these minerals include:[3]
  - Selenium
  - Zinc
  - Iodine
  - Iron
  - Phosphorous
  - Potassium
  - Calcium
- The minerals and concentrations of them present in seafood vary by the type of seafood and the season and location where the seafood is caught or grown.

o Vitamins are organic compounds necessary to your health; some of which must be obtained through diet as the body cannot synthesize them.

- Fish are an important source of vitamin B, which is essential for metabolic function.
- Vitamin D and Vitamin A can be found in fattier fish like mackerel and herring.[4]
  - Vitamin D is important for "blood pressure regulation, bone growth, calcium balance, hormone production, immune function, and nervous system function."[5]
  - Vitamin A is important to vision and normal skin and membrane development.[6]

[3] For information on the function of these minerals visit: https://www.accessdata.fda.gov/scripts/InteractiveNutritionFactsLabel/factsheets/Vitamin_and_Mineral_Chart.pdf

[4] More information can be accessed at http://www.seafoodhealthfacts.org/seafood-nutrition/patients-and-consumers/seafood-nutrition-overview

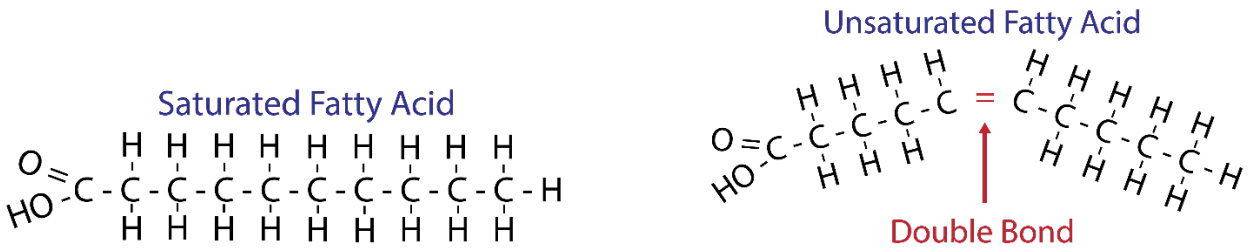
[5] More information can be accessed at https://www.accessdata.fda.gov/scripts/InteractiveNutritionFactsLabel/factsheets/Vitamin_and_Mineral_Chart.pdf

[6] Potter, Norman & Hotchkiss, Joseph. *Food Science*. 5th ed. New York: Chapman & Hall, 1995. Print.

- Macronutrients
  - Proteins are made up of amino acids. There are 20 different amino acids that join together in different combinations to create proteins with different functions.
    - They play an important role in nearly every process in your whole body, including:[7]
      - Cell Structure
      - Enzymes
      - Muscle tissue
      - Hormones
      - Transferring other molecules
      - Antibodies
      - Storage
      - Protection
    - Fish have a high protein content, which is easily digestible and includes all essential amino acids.
    - Essential amino acids are those which we cannot make on our own and thus, need to obtain in our diet.
  - Lipids
    - A typical fat molecule is composed of a glycerol (molecules made up of carbon, hydrogen, and oxygen) attached to three fatty acids.
    - Some important lipids are fats and oils.
      - Fats are solid at room temperature.
      - Oils are liquid at room temperature.
      - Whether lipids are considered fats or oils typically depends on how saturated they are with hydrogen atoms.
      - Saturated fats have fatty acid chains with only single bonds between C atoms so they become saturated with H atoms.
      - Unsaturated fats have at least one double bond leaving less room for H atoms to bond.

[7] Fellows, Peter. *Food Processing Technology: Principles and Practice.* 3rd ed. Cambridge: Woodhead, 2009. Print.

Figure 1: Visual illustration of saturated and unsaturated fatty acids.



- Unsaturated fats are commonly referred to as "good" fats as they do not tend to increase cholesterol levels, unlike saturated fats, while providing molecules that our bodies' need.
- Hydrogenation is used in food processing to make unsaturated fats more stable by adding hydrogens to replace double bonds between carbon atoms with single bonds to hydrogen atoms.

- Some important functions of fats are:
  - Membranes
  - Energy storage
  - Hormones
- Fish generally contain more of the healthy unsaturated fats than saturated fats, although the exact amounts vary among different species.
  - The most important unsaturated fats in fish are omega-3 fatty acids, which are essential fats- fats that your body needs, but cannot synthesize on its own and, thus, must be included in your diet.
  - Higher intake of omega-3 fatty acids "are likely to contribute towards lower risk for cardiovascular disease" [8] (heart disease), and are important for brain[9] and eye health[10].

[8] Bowen, K. J., Harris, W. S., & Kris-Etherton, P. M. (2016). Omega-3 Fatty Acids and Cardiovascular Disease: Are There Benefits? *Current Treatment Options in Cardiovascular Medicine*, *18*(11), 69. http://doi.org/10.1007/s11936-016-0487-1

[9] Tan, ZS; Harris, WS; Beiser, AS; Au, R; Himali, JJ; Debette, S; Pikula, A; DeCarli, C; Wolf, PA; Vasan, RS; Robins, SJ; Seshadri, MD. 2012. Red blood cell omega-3 fatty acid levels and markers of accelerated brain aging.

[10] More information from the American Optometric Association can be accessed at https://www.aoa.org/patients-and-public/caring-for-your-vision/diet-and-nutrition/essential-fatty-acids?sso=y

- Carbohydrates
  - Carbohydrates, also called saccharides, are made of chains of monosaccharides – a compound made of a single ring of carbon, hydrogen, and oxygen.
  - Sugars are oligosaccharides, which are made of 2-20 monosaccharides.
  - Sugars are often broken down to generate ATP as a source of energy that all cells in the body need and use; ATP is the main source of energy for our bodies.
  - Polysaccharides are made of 20 or more monosaccharides and include, starch, pectin, cellulose, and gums.
    - Starch is commonly found in plants to store energy produced during photosynthesis. When consumed our bodies can break it down into simpler forms (monosaccharides) and use it to generate more energy.
    - Pectin and cellulose are found in the cell walls of plants.
    - Gums can be extracted from seaweeds.[11]
  - Carbohydrates are minimal in most seafood, but there are more present in some shellfish, especially those eaten raw.

Seafood Science

Now that we have looked deeper into the main components of a food, we can take a closer look at the roles of a Seafood Scientist. Below we will explore the 4 P's of Seafood Science.

Produce seafood efficiently, while maintaining high quality.

Fish is highly perishable and must be processed, stored and cooked properly to maintain safety, quality and nutritional composition.

- Once fish are harvested, either from the wild or on a farm, they are transferred to a processing facility that will process the seafood into the form it will be sold. There are many different processes that can be used, which are outlined below.
  - Gutting will occur in most cases to remove inedible parts of the fish, concentrated in the belly cavity, from the flesh. The liver can be separated from the rest to be processed for fish oil.[12] This can be done by hand or by machine.

[11] More information can be accessed at http://www.seaweed.ie/uses_general/industrialgums.php

[12] Mackie, I. M.; Merritt, J. H.; Windsor, J. H. and Aitken, A. *Fish Handling & Processing.* 2nd ed. New York: Crown, 1982. Print.

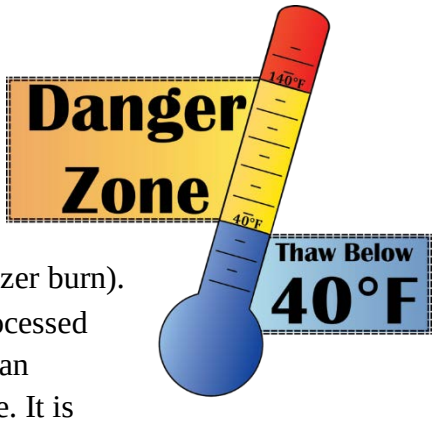
- Fish are generally washed down to remove any remaining guts, feces, or slime, before being chilled to slow bacterial growth.[13]
- Scaling, or removing scales, may need to be performed before filleting, although for many species of finfish, skinning will suffice.[14] Skinning can occur during the fillet process by simply cutting away the skin layer.[15]
- Cutting will depend on the size and use of the seafood.
  - Fillets are cut parallel to the backbone and may or may not contain smaller bones, or pins.
  - Steaks are cut perpendicular to the backbone, like a cross-section of the fish. They usually contain larger bones and the skin may still be attached.
- Value added products are those that are processed beyond what is discussed above. In these cases, you are adding value to the product by enhancing the shelf-life, flavor, taste, texture etc.
- Examples include:
  - Marinating
  - Soups, stews, meals etc.
  - Fish Oil
  - Pre-Cooked
  - Ready-to-Eat (will not be cooked by consumer before eating)
    - Canned
    - Smoked
    - Surimi

- How seafood is handled is very important because it will affect the quality and safety of the food.
  - Seafood will begin to deteriorate as soon as it is harvested.
    - Deterioration will be caused primarily by bacterial growth and enzyme activity (enzymes in the meat will continue to work and can slowly break down the muscle).
    - Unsaturated fats easily oxidize, or breakdown, producing off-odors and off-flavors.
    - Seafood scientists are constantly researching the best methods to slow this process and maintain quality and safety.
    - One of the best ways to slow this process down is temperature control.
- There is a growing use of factory ships that can process fish on board, this can help preserve the quality and safety of the fish.

[13] Mackie et al., 1982.
[14] Regenstein, J. M., and Carrie E. Regenstein. *An Introduction to Fish Technology.* New York: Van Nostrand Reinhold, 1991. Print.
[15] Regenstein & Regenstein, 1991.

Preserve seafood to extend its shelf-life.[16]

- Shelf-life represents how long a food product lasts before spoiling.
    - There are many factors that can affect the shelf-life of seafood but the most important is temperature.
        - The colder the fish is kept, the slower bacteria will grow. Enzyme activity will be slowed as well, both working to extend the shelf-life.
- A general rule is the cooler the fish, the longer the shelf-life.
    - Fish can be refrigerated or left on ice to be sold fresh at markets.
    - Fish can be frozen to be preserved for longer periods of time.
        - Spoilage in frozen fish is more often due to oxidation of fats and drying of the fish (i.e. freezer burn).



- "Fresh" fish at your local supermarket is simply minimally processed fish held at refrigerated temperatures. The word "fresh" is not an indication of quality, as many consumers may be led to assume. It is important to understand how to identify good quality seafood when purchasing. Purchasing from a reputable and reliable source is recommended as they will often ensure quality for you.
    - Just because fish is frozen does not mean it is not fresh either. In many cases the quality of frozen fish can be better than what is marketed as "Fresh" at your local grocery store. Consider where your seafood is coming from when making "Fresh" selections. "Fresh" fish from oversees will have been maintained in a thawed (unfrozen) state for days or weeks before it ends up at your local grocer.
- Here are some other ways that seafood scientists work to preserve and extend the shelf-life of seafood.
    - Smoking is the process by which fish is preserved with salt, smoke and dehydration. It involves brining (submerging in a liquid with high salt) the fish, and applying low heat and smoke to dry the fish out and allow smoke to penetrate. Certain characteristics of the smoke have a preservative effect.
        - There is also a cold smoking process, which does not involve heat. During cold smoking the fish is cured in a liquid smoke and salt solution to allow the salt and smoke to penetrate the fish flesh.
    - Salting, with dry salt or a brine (saltwater) solution, limits spoilage by increasing the salt content and restricting water activity (water activity is the amount of water available for growth) within the fish.

[16] Regenstein & Regenstein, 1991.

- Pickling is submerging the seafood in a vinegar and salt solution to decrease the pH of the fish. The lower pH not only adds to the flavor of the fish but is important for limiting or stopping bacteria from growing.
- Fermenting is the preservation of fish by certain non-pathogenic (do not cause disease or illness) microbes, which produce acid when they grow and decrease the pH, similar to pickling. This is less common in the present-day but it is still an important part of some cultures, such as those in Korea.[17]
- Packaging can extend shelf life through a variety of techniques, such as:
    - Modified Atmosphere Packaging (MAP) uses different gases or combinations of gases, including nitrogen and carbon dioxide, to create environments that will slow or inhibit the growth of bacteria.
    - Aseptic packaging is packaging products in sterile environments, which are typically achieved by heating. Canned foods are a good example of this.
    - Time Temperature Indicators can be displayed on products to show that raw seafood, for example, never exceeded a certain temperature range for an amount of time, ensuring consumers that the product was not exposed to a time or temperature in which significant bacteria growth can occur.
    - Antimicrobial packaging can release antimicrobial compounds over a period of time to slow or inhibit bacteria from growing over time.

Protect seafood from hazards like bacteria, viruses, parasites and chemical contaminants.

Food Safety Hazards

- Biological hazards
    - Bacteria
        - Background: Bacteria are microscopic single celled organisms that are present everywhere.
        - Examples: Depending on water quality and hygienic practices, *E. coli* can be transferred from raw or undercooked seafood to consumers, causing illness.[18] *Vibrio* bacteria are a particular concern in shellfish eaten raw. They can grow to high levels in the environment and accumulate in the shellfish during feeding.
        - Concerns: Some can cause illness when consumed or produce toxins that will get humans sick when eaten. Bacteria that cause illness are called pathogens.

[17] More information can be accessed at http://www.sciencedirect.com/science/article/pii/S2352618116300506
[18] An overview of *E. coli* and seafood can be accessed at: https://file.scirp.org/pdf/ABB_2013032910234305.pdf

- Bacterial pathogens require nutrients and water to grow, which makes many foods, especially seafood, an ideal environment for microbial growth.
- Controls: Temperature, pH, salt, water activity (to limit the amount of water available to bacteria.)

- Viruses
  - Background: Viruses are non-living microscopic pathogens that can be found throughout the environment.
  - Examples: Noroviruses can outbreak in sewage-contaminated waters and transfer from raw or undercooked seafood to humans.[19]
  - Concerns: Although viruses will not grow on the food itself if present they can cause serious foodborne illnesses.
  - Controls: The best control for viral pathogens is to source the seafood products from reliable sources and clean open waters. It is also important that processing facilities practice good manufacturing practices, which outline proper sanitation and hygiene, to ensure their employees do not contaminate the foods they are handling.[20]
- Parasites
  - Background: Parasites are living organisms that require a host to survive.
  - Examples: Certain worms and protozoa.
  - Concerns: Parasites can be a concern in undercooked or raw foods in which they are living; if consumed alive some parasites can use humans as a host.
  - Controls: Parasites can be controlled by properly freezing seafood to kill those present, physical removal (some worms) and properly cooking the seafood to ensure the parasites are killed.

- Chemical hazards
  - Natural toxins
    - Background: Some chemicals that occur naturally in the environment or in the seafood itself can be toxic.
    - Examples: Some species produce toxins for defense, such as pufferfish. Some algae produce toxins when growing; when these algae grow rapidly and to high numbers the levels of toxins in the water can be high.
    - Concerns: During large algae blooms (growth) some seafood, like filter feeding shellfish, which consume particulate matter suspended in the water, can accumulate toxins that build-up in the water during feeding.

[19] More information can be accessed at http://cmr.asm.org/content/23/2/399.full
[20] More information of good manufacturing practices can be accessed at https://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/Seafood/ucm176892.htm#ii

- Controls: Species like the pufferfish that produce toxins for defense must be prepared properly to remove or avoid the hazardous toxins before eating. Build-up of toxins in shellfish can be controlled through proper sourcing. They should never be harvested from waters with high levels of toxin-producing algae.
    - State and local government agencies regularly monitor coastal areas for potential toxins and chemicals. They will make the final determination on whether or not a water body is open for harvest.

o Environmental Chemicals[21]
- Background: Chemical toxins can be present anywhere and some naturally occur at low levels, while others are a result of human activity.
- Examples: Some of the most common are mercury and PCBs, but there are many other pollutants that can make their way into local waterways.
- Concerns: If chemical toxins are allowed to build up in the human body to unsafe levels there can be significant effects on one's health. Fish that are high up on food chain can accumulate higher levels of these contaminants through a process known as bioaccumulation.
    - Bioaccumulation occurs because fish higher up on the food chain have to eat increasingly more individuals from lower in the food chain, thus concentrating the toxins from the food they eat. While toxin concentrations in the lower trophic levels may be minimal, as you go up the food chain the levels increase.[22]
- Controls: Sourcing fish from approved waters with low levels of chemical contaminants is the best control. Choosing to consume fish lower down in the food chain can limit exposure to high levels of contaminants that build up in these species due to bioaccumulation. Many of these environmental chemicals will be more concentrated in fat and skin, removing the skin and trimming the fat can help limit exposure.

o Aquaculture Drugs
- Background: In order to prevent an entire crop of fish from being lost in the case of an outbreak of disease, antibiotics can be applied to feed.
- Example: An aquaculturist notices a few fish appear to have fallen ill to a disease and seeks approval by an aquatic veterinarian to quickly order a feed treated with an approved antibiotic before the disease can spread and harm additional fish.

[21] More information on environmental contaminants can be accessed at http://seafood.oregonstate.edu/.pdf%20Links/Contaminants%20in%20Fish%20and%20Seafood%20-%20A%20Guide%20to%20Safe%20Consumption%20-%20PowerPoint.pdf

[22] A classroom activity on bioaccumulation can be accessed at http://www.dec.ny.gov/docs/administration_pdf/ifnyfdwebbioacclp.pdf

- Controls: Regulations are in place to limit the antibiotics and instances in which they can be used in aquaculture operations; these apply to imports as well. There are only a few drugs in the US approved for use in farmed fish. Vaccines have almost completely displaced this need for antibiotics in US aquaculture.[23]
    - Antibiotics are very expensive and most farms will try to maintain healthy fish populations through extensive biosecurity plans and control of stress on the farm instead of with antibiotics.
    - If antibiotics must be used farmers are required to hold the fish for a certain amount of time before harvesting and selling. This allows antibiotic residues to leave the fish and limits human exposure.

o Allergies

- Background: Most food allergens are proteins that cause a reaction from the immune system when consumed.
- Examples: Fish and crustacean shellfish are on the list of top 8 food allergens for Americans.
- Concerns: When eaten by susceptible individuals it can cause a severe allergic reaction. Symptoms may include hives, swollen airways, or digestion issues.
- Controls: The proteins that cause allergic reactions are inherent in fish and shellfish. They cannot be removed so the foods must be properly labeled to make sure those who are allergic can safely avoid these foods.

Seafood Safety Regulations

There are strict regulations in place that seafood processors (foreign and domestic) must follow to ensure that the food they produce remains safe.

- The National Oceanic and Atmospheric Administration (NOAA) runs the Seafood Inspection Program, which regulates imported seafoods.
- All processors must follow good manufacturing practices (GMP), which outlines how a facility should be built, organized, cleaned and operated. These regulations also outline employee hygiene guidelines.
- The FDA hazard analysis critical control point (HAACP) regulation has been enforced since 1997. This regulation requires processors to identify potential food safety hazards associated with their product and process and put in place controls to ensure the foods remain safe.
- The U.S. Seafood Import Monitoring program "establishes, for imports of certain seafood products, the reporting and recordkeeping requirements needed to prevent

[23] More information on antibiotic use in U.S. aquaculture can be accessed at http://www.nmfs.noaa.gov/aquaculture/faqs/faq_feeds.html#14are

illegal, unreported and unregulated (IUU)-caught and/or misrepresented seafood from entering U.S. commerce."[24]

- In addition, state and local health agencies have rules and regulations in place to maintain safe and wholesome seafood production.

Perfect the consumer's sensory perception of the seafood.

Understanding consumer expectations of different fish and meeting them is crucial to an operation's success in the market. Seafood scientists that specialize in sensory science often play an important role in achieving this goal. Sensory scientists evaluate foods based on how they are perceived by the five senses when consumed. The following categories are especially prominent in a consumer's perception of nutritious and delicious seafood:

- Taste
  - Different species of fish have different flavors.
    - These can be described for the most common seafood as mild, moderate, or full flavored. This is a sliding scale with mild fish having little flavor of its own, taking on the flavors of the seasonings you choose to cook with. The fuller flavored species have a more distinct flavor that can be love or hate for many consumers.
  - Off-flavors can be produced during fish development, from blue-green algae and other components of the diet. Off-flavors can also develop during storage due to different chemical interactions in packaging and chemical changes in the foods themselves, such as oxidation of fats. These changes will be affected by how the products are handled and stored and can turn consumers off to certain species or products.
- Smell
  - Sense of smell can play an important role in how one perceives their food.
  - High-quality fish and shellfish tend to have a subtle odor, likened to a sea breeze, while lower quality or poor sanitation is indicated by a strong "fishy" or an unusual odor.[25]
  - When creating value-added seafood products and other processed foods containing seafood ingredients, smell can be an important characteristic that sensory scientists consider.
  - The goal is to produce and/or create foods with pleasing aroma's that entice the consumer.

[24] More information can be accessed at http://www.iuufishing.noaa.gov/Portals/33/NMFS_SIMP%20FR_%20Fact%20Sheet.pdf

[25] Gall, Ken. *Seafood Savvy: A Consumer's Guide to Seafood Nutrition, Safety, Handling and Preparation*. New York Sea Grant, 1992. Accessed at http://www.seagrant.sunysb.edu/seafood/pdfs/SeafoodSavvy.pdf

- Texture
  - Like taste, different species have varying textures: delicate, moderate, and firm.
    - Table 1 below will show you a variety of different species grouped by flavor intensity and texture characteristics. This can be a guide to identifying other great seafood options similar to those you like and eat regularly.
  - Unlike most terrestrial proteins (beef, pork, chicken etc.) the muscle of fish is structurally different.
  - The difference in structure causes the fish to be a much tenderer product with layers of protein that will flake apart when cooked.
  - Some processes like salting, pickling, smoking and cooking can affect the texture of seafood. Seafood scientists will work to determine the best procedures for processing the seafood to ensure consistent texture ideal for the consumer's preference.

Table 1. Examples of Common Seafoods Grouped by Flavor and Texture.

Texture	Flavor Mild	Moderate	Full
Delicate			
	Cod	Butterfish	Mussels
	Crab	Lake perch	Oysters
	Flounder	Whitefish	
	Haddock	Whiting	
	Hake		
	Pollock		
	Scallops		
	Sole		
Moderate			
	Crayfish	Mullet	Bluefish
	Lobster	Ocean perch	Mackerel
	Pike (walleye)	Shad	Salmon (canned)
	Orange roughy	Smelt	Sardines (canned)
	Shrimp	Surimi products	
	Tilapia	Trout	
		Sea trout (weakfish)	
		Tuna (canned)	
Firm			
	Grouper	Catfish	Clams
	Halibut	Mahi-mahi	Marlin
	Monkfish	Octopus	Salmon (canned)
	Sea bass	Pompano	Swordfish
	Snapper	Shark	Tuna
	Squid	Sturgeon	
	Tautog (blackfish)		
	Tilefish		
	Wolffish		

Adapted from: "Seafood Alternatives" in *Seafood Savvy*, New York Sea Grant, 1992; "Fish and Seafood Chart" in *Fish and Seafood Made Easy*, National Fish and Seafood Promotional Council, 1989.

- Mouthfeel
    - Mouthfeel is similar to our sense of touch. It has to do with the feeling left in one's mouth during or after eating a certain seafood product.
        - For example; fattier fish might leave a greasy feel in your mouth after eating. This is commonly felt after eating greasy, fried foods.
    - Just like the other sensory characteristics, how the seafood makes your mouth feel during or after consumption can affect the consumer's opinion or preference for a particular food.

When a food product is not meeting the needs of the consumer, a sensory scientist will work to change the ingredients and/or the process of preparing the product to alter the sensory characteristics to better suit the consumer's preferences.

This Seafood Science curriculum was produced by NY Sea Grant with funds supporting the project and associated workshops and trainings from NOAA Sea Grant project number NA16OAR4170251 and the CALS CCE Summer Internship Program.

Authors:

Jack Novak
CALS CCE Summer Intern

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