Lecture 17: Plankton & Nekton

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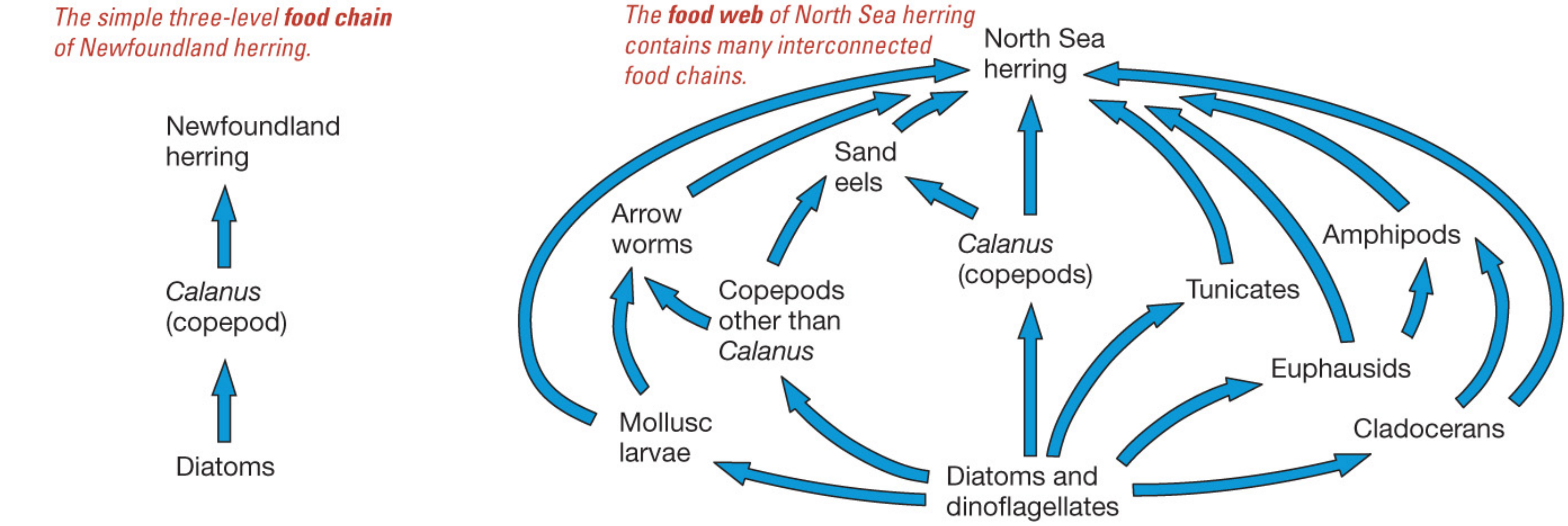
Zooplankton – as the first syllable of the word suggests, we are starting into the world of animals in the ocean. I will end each of the lectures about marine animals with a cool story about an amazing marine critter that will be a sure hit at your next dorm party. You will be amazed by how weird marine animals can be. But first, what are these zooplankton things?

Let's start with defining the word. First, the 'ZOO' part means pretty much what you would think it means - animal. The animals in the ocean can be broken down into three classes according to where and how they hang out; either in the benthos (in or on the bottom), the nekton (swim actively in the water - things like fish) or the plankton (float mostly passively in the water). The second part of the word, 'PLANKTON', tells you that these animals float around in the water. You learned in the last couple of lectures about the plants that float around passively in the water, phytoplankton. Now we will learn about the tiny animals that float around in the same environment.

Food webs are the way that food energy moves through ecosystems. As an example, we might think of this in terms of the African Savannah. In this example, you might think of grass being the base of the food chain. The grass is fed on by grazers like antelope, which are in turn fed on by lions. This series of one group feeding on another is the way that the energy from the sun, that was converted into matter by the plants, moves through the ecosystem all the way up to lions. In the ocean system, the zooplankton are often the major group of animals feeding on the abundant phytoplankton, and in doing so, transfer that energy along the food web to higher animals and mammals. Here is a conceptual example of a marine food chain. Obviously, they can get complex because so many of the animals in the chain can feed on a variety of things – because of that complexity, we often call them food webs rather than food chains. Note in the figure below the food chain on the left, versus the food web on the right.



(a) An example of a food chain, showing the passage of energy along a single path, such as from diatoms to copepods to Newfoundland herring in three trophic levels.

(b) An example of a food web for a similar herring species, showing the multiple paths for food sources of the North Sea herring, which may be at the third or fourth trophic level.

The role of zooplankton in linking the production of phytoplankton with higher levels of animals in the marine food web is a critical element in supporting marine fisheries and other important species that we rely on for healthy marine ecosystems. As the energy from the base of the food chain is transferred from one level to another, some of it is lost to things like respiration, growth, loss (feces etc). This loss along the way means that there are more of the base animals than there are of the higher trophic level animals like fish. In turn, this means that even though zooplankton are mostly tiny microscopic animals, when taken all together they make up the most abundant animals in the ocean.

There is an amazing diversity of body types in the zooplankton. They are often the juvenile or larval (this basically means baby) life stages of many marine animals. The image below shows some of the strange and amazing shapes of marine zooplankton forms.

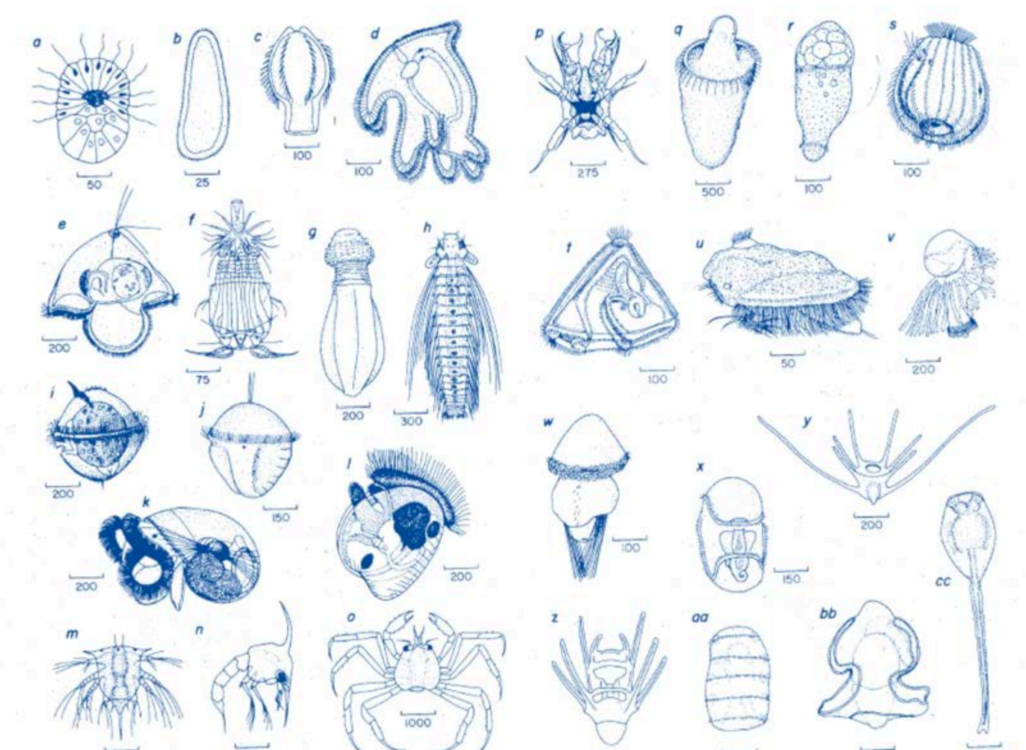


Image from: Levin and Bridges, 1995 in "Ecology of Marine Invertebrate Larvae"

This diversity comes in part from the fact that the zooplankton includes representatives of nearly all animal groups that exist today. To understand the diversity of the zooplankton, we must take a step back and consider the diversity of animals, and to do that, we first have to clarify what an animal is.

Many of us think we know what an animal is – we typically think of things like dogs, cats, maybe even whales and dolphins. In total, there are five kingdoms of living things on our little planet. There are Monerans (bacteria), Protists (weird single-celled organisms), Fungi (mushrooms etc.), Plants, and Animals. In reality, the things that typically come to mind when we think of animals (cats, dogs, aligators, fish) are only a small subset of the animals that live on the planet. The animals we normally think of all belong to a group called Vertbrates. The Vertebrates are only one small Phyla of many that make up the Animalia (the Kingdom of Animals). In fact, of all of the different animals that we know about, the Vertebrates only account for a measly 3%. There are over 35 other Phyla that are part of the Animal Kingdom – that is a **lot** more animals. Each phyla has its own unique body plan and that is where we get such a diversity of forms in the zooplankton. The graph below shows a list of some of the more common Phyla within the Animal Kingdom and the bar graph on the right shows the number of known species in each group. The point of the figure is to demonstrate that there are literally millions more types of animals than the ones that we commonly picture when we think 'animal'.

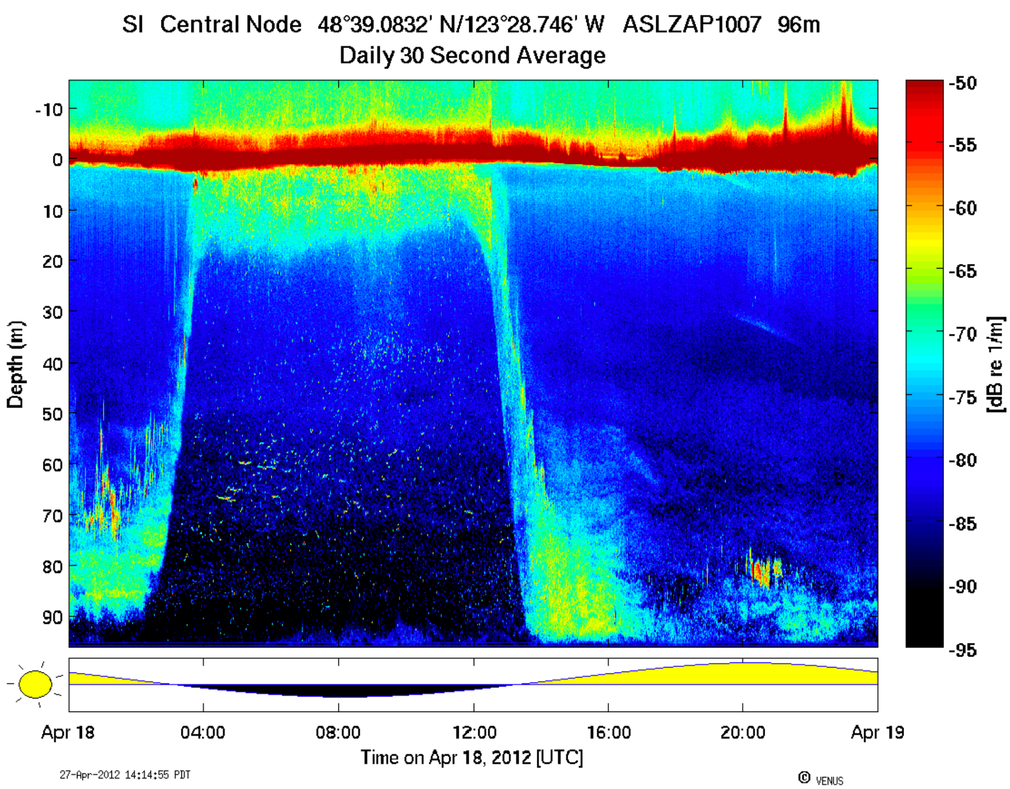
This video shows (https://youtu.be/nC9yif-SCs8)

(https://youtu.be/nC9yif-SCs8)
some of the amazing diversity of body forms in the zooplankton. Stunning!

In addition to the amazing diversity, the zooplankton also exist in staggering abundance. In just one spoonful of ocean water, you could find up to a million of these tiny animals (note – if this doesn't sound familiar to you, click on the link above and watch the video). Two of the most common zooplankton groups are copepods and krill. Copepods are relatively large planktonic animals and are among the most common, found throughout the world oceans. Most species of copepod spend their entire life in the plankton, and for that we call them holoplankton. They are part of a large and diverse group called crustaceans, which includes other (delicious) animals like lobster, crab and shrimp. Copepods use long tentacles that stick out from the sides of their heads that they use to catch small algae. They are highly abundant in the ocean and they provide an important food source for fish and whales. Even their waste is important; their fecal pellets drop to the bottom of the ocean providing organic biomass to the benthos (the benthos are the animals that live in or on the bottom of the ocean). By providing organic matter to the bottom of the ocean, they are helping nutrients move from the upper ocean to the bottom – a process called nutrient cycling. There are many species of copepods (about 9000 or so), many of which are parasitic in their adult phase and attach to fish (ever heard of sea lice?).

Krill are another highly abundant and important species of zooplankton found in the ocean. Like copepods, they are a critical link in many marine food webs, converting algal resources into food for fish and marine mammals. Krill are a vital component (keystone species) of Antarctic (Southern Ocean) food webs, and are a primary food source for baleen whales. Krill rely heavily on Antarctic sea ice. Phytoplankton beneath the sea ice provides food, and the ice provides shelter for juvenile krill. Like many other marine zooplankton, krill perform a behaviour called diel vertical migration. This means that each day (diel) they move (migration) up and down (vertical) in the water column. During the day, they spend time lower in the water column, below the depths where there is sufficient light for photosynthesis. They hang out down there during the day to hide out in darker water and avoid predators that might eat them. At night, under a cover of darkness, they swim upward into that zone to feed on phytoplankton. This daily migration up and down is one of the biggest regular movements of biomass that we know of on the planet.

The image below shows this migration of zooplankton from an ocean observatory in Saanich Inlet, British Columbia, Canada . These data come from an acoustic signal that is sent up into the water column from the bottom. If that signal hits something in the water, it is rebounded back to the receiver at the bottom. The time it takes for the signal to go out and come back allows calculation of how deep in the water the particles that are rebounding the signal are. In the example image below, the zooplankton particles are the things that are bouncing back the signal (the green/yellow band). The axis on the left shows the depth (the bottom of the ocean is the bottom of the graph). The axis across the bottom is the time of day – you can see the sunlight hours shown in the panel just below the axis. The dark red line at the top is the surface of the water, and the green/yellow colors are the signal that is being rebounded. You can see that the zooplankton hang out at the bottom until the sun sets, then they hear the dinner bell. When it is dark, they go streaking for the surface, an amazing migration of about 80 meters in a couple of hours (remember that most of them are microscopic, so that is a pretty impressive pace for such tiny critters).



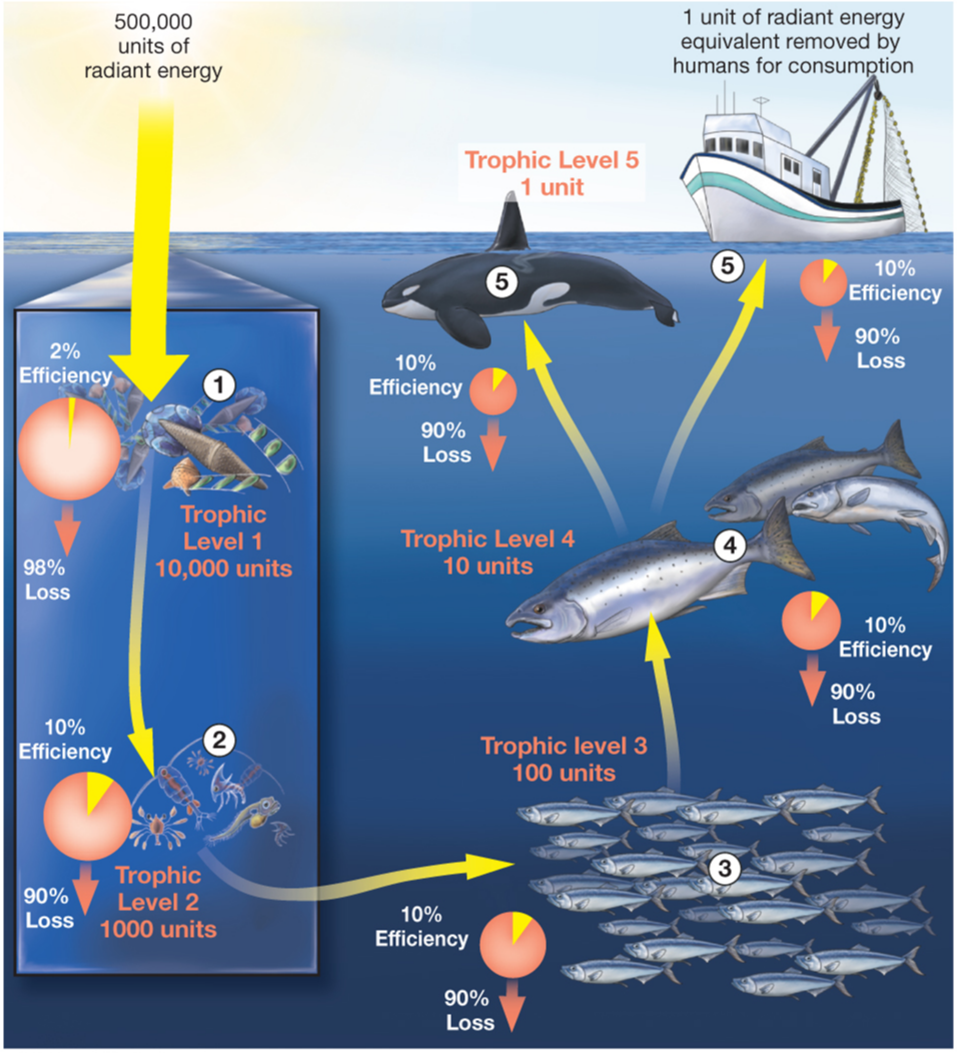
Many zooplankton spend only part of their life in the water column. These animals are called meroplankton, and they are often the larval or juvenile stages of species that live in other parts of the ocean as adults. Ocean animals that you might find on your dinner plate, like clams, crabs, lobster or herring, are born into a stage that is planktonic. In those early parts of their life, called the larval phase, these animals often don't look anything like their adult body form. There are laval stages of fish and invertebrates – the larvae stages of fish are called ichthyoplankton. Some ichthyoplankton make amazing journeys in the ocean –
watch this video about American eels (https://youtu.be/BR1enXROmgA)

(https://youtu.be/BR1enXROmgA)

to learn about one of those amazing journeys. The images below show a crab larvae (left) at this stage called a zoea, and an adult crab (right). Recall that this animal is in the same group as the copepods we talked about earlier, the Crustacea.

Larvae are so tiny, and they are floating around in the big wild ocean, but the adults for these species are often only able to survive in very specific habitats. This presents a problem for these tiny larvae that are easily carried around on ocean currents. Recall from the previous lecture on tides and currents, that this could mean that the little larvae get whisked far far away from a place that they could call home, which would mean they die before they get to mature into adults. How do they deal with this? Many adults and larvae have specific behaviours that allow them to stay close or return to home, even in the face of strong ocean currents. They can move up and down in the water column in response to environmental conditions like salinity and microturbulence to stay in parts of the water that is moving in the right direction. This is a process that is, like body plans in the animal world, highly diverse.

Let's do a quick review. We have learned about plankton – both the zooplankton and phytoplankton. The plankton drift or swim weakly actively, which puts them largely at the mercy of wave and currents, they are generally small, inconspicuous, and are either autotrophs or heterotrophs. Whereas the nekton are able to actively swim and overcome currents, are heterotrophs, are typically vertebrates (but there are some super cool invertebrate nekton), and are often meroplanktonic. In most marine food webs, the autotrophic phytoplankton are usually the base, then the zooplankton that consume them are next in the web. Next in the web are commonly the nekton that consume the zooplankton. These levels in the food web are called trophic levels. As the energy in the system (recall that it starts with the primary producers that capture the sun's energy and stores it up) moves from one trophic level to the next, the transfer is not very efficient and 90% of the energy is lost to processes like digestion, inefficient feeding, movement, and heat. That means at every transfer, only 10% of the original energy is passed to the next level. That means that by the time you move up 4 or 5 levels in the food web, you would have needed massive amounts of primary producers to support those upper levels.



When we think about what lives in the ocean, most of us think about fish. As a group, fish are vertebrate component of the nekton. In general, fish swim using fins and they breathe by passing water across their gills. Our mammalian lungs are no good at getting oxygen out of water and into our blood, but gills on the other hand are perfect for getting oxygen out of the water and into the respiratory pigments of the fish. Gills have very high surface area to allow plenty of space to exchange oxygen, and they use counter-current flow (meaning that the direction of flow of blood and water are opposite) to help extract oxygen from the water. Fish have a surprisingly wide array of lifestyles. Some produce millions of eggs, while others have only one or two babies in a lifetime that they invest heavy parental care into. In some species, the males and females look alike, in others they look very different, sometimes with males being the larger of the two, and vice versa in others. Some fish are even able to change sex from male to female, or the opposite, in their lifetime. They live in warm water and cold water (sometimes you can even find them frozen in ice) and some species spend part of their lives in freshwater before moving to salt water (or vice versa – recall the American eel you learned about earlier). An amazing amount of biological reorganization is needed for them to make that switch – more on that later!

Fish are believed to be the first evolution of the vertebrate group (recall from biology classes that the vertebrates are the animals with internal bones – vertebrae if you will). They are an ancient lineage and have colonized all aquatic habitats on earth. As far as vertebrates go, the fishes win. There are more species of fish than there are species of all other vertebrates combined. In the interest of time, we will limit our focus on fish to just the modern marine fishes. We generally group the modern fishes into three groups – the jawless fish (called the Agnatha), the cartilaginous fish (called the Condrichthyes) and the bony fish (the Osteichthyes).

Agnathans:

The jawless fish are just what they sound like – fish without jaws. They are a small group with relatively few species and include the lampreys and hagfish. They aren't just missing jaws, but are also missing fins, so they look a bit snake-like, and they have skin rather than scales like most other fishes. Weird fish indeed! Lampreys feed on other fish, sort of like leeches, or vampires. They have sharp teeth that they use to bite and shred the host. They have specialized fluid in their saliva that prevents the host blood from clotting and making more blood available for them to feast on. Below left, lamprey on a fish. Below right, a lamprey mouth.

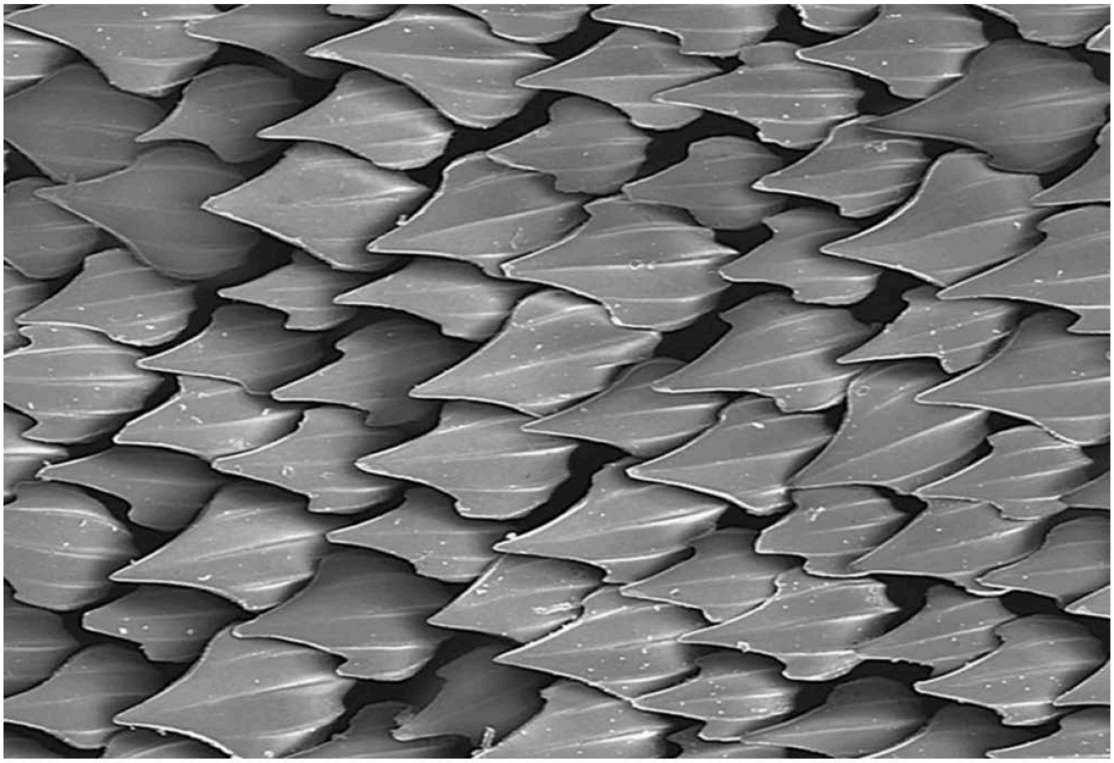
The hagfish, on the other hand, eat things that are already dead – so maybe we can think of them like zombies. Hagfish have loads of glands all over their bodies that produce slime that helps protect them from predators. This slime is a protein-based concoction that has amazing properties that make them a nightmare for fishermen who accidentally find one in their net. The chemical and physical properties of the slime is an area of active research right now with teams looking at it as a possible alternative for nylon threads to make clothes. The hagfish slime is so thick that it can suffocate fish if it gets wrapped up in it. The hagfish itself has a special trick to get out of its own slime net so that it doesn't suffocate –
it ties itself in a knot (https://youtu.be/RrPvMMkQkk0)

(https://youtu.be/RrPvMMkQkk0)
then slips right out of the slime cocoon. Very cool (but sorta slimy and gross too).

Chondrichthyes:

These are the skates, rays and yes, the sharks. In this group of fish, their skeleton isn't made up of bones per se, but cartilage. Yes, the same stuff that is in our knees, or alas, slowly leaves your knees as you age. Cartilage is more flexible than bone – the flexibility of cartilage is why your ears are so easy to bend and not break. Contrary to what many popular culture movies and shows might have you believe, most sharks are scavengers, feeding on fish that have already died or are injured, or other waste in the ocean. The largest of all sharks, growing up to 12 m in length and 21 tons, is somewhat misleadingly named the Whale Shark. It is a plankton feeder, swimming gracefully through the ocean filtering the tiny plankton from the water as it passes through its net-like gills. Here is a **cool and relaxing video (https://www.youtube.com/watch?v=8_X1yO60agY)** of whale sharks at the Okinawa aquarium in Japan – you can see the size of these fish relative to the diver in the tank and to get an idea of just how big they are.

The cartilaginous fishes do not have typical fish scales. Instead, they have what are called denticles or placoid scales (you can see a close up below). These provide a couple of functions. For one, they are more protective than typical fish scales (sort of like wearing chain mail), and secondly the shape of them helps in making their bodies more streamlined which helps reduce drag when swimming. Some clever folks at Speedo jumped on this idea and used a shark skin approach in designing fabric for faster swimming suits. Fully scientific experiments with these suits have shown that the man-made suits might not be having the effect that was intended – the shark-like surface of the suit might not be reducing drag and increasing thrust, but the fact that the suit is tight and forcing the non-streamlined humans into a more streamlined shape. Ah well, it was a good idea.



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One very cool ability that sharks have that is often used to detect prey is eletroreception. This is like a superpower that allows them to detect electrical energy in the water. Water, especially salty ocean water, is an excellent conductor of electricity (jump back to the lecture on amazing properties of water to recall why). Fish generate a small electrical field around their bodies that can be detected by highly sensitive electric receptors in sharks called the ampullae of Lorenzini. These are jelly-filled pores on the head of the shark (skates and rays also have them) that can detect the voltage in the water around them. These pores are incredibly sensitive – they can pick up even the most remote electrical impulses and follow them to their prey. Some researchers believe that they may also use this highly sensitive ability to migrate around the globe using the earth's magnetic field like a map.

Osteichthyes:

The two groups of fish we talked about above have far fewer species than the Osteichthyes, or bony fish. The majority of fish species known today are part of this group – they make up 95% of the fish species. As the name implies, these are fish with proper bones in their skeletons. The bony fish are generally separated further into two groups, the ray-finned and the lobe-finned fish. I will mention the lobe-finned fish very briefly because they are tiny group with only eight living species (most species are known only in the fossil record and have long been extinct). The lobe-finned fish are the lungfish and coelacanths. The distinguishing feature of these fish is that they have a jointed bone that attaches their fins. These effectively look as if they are an arm/fin combo, and it is believed that they could have been used to support the body weight of the fish if it were to crawl up on land – an evolutionary link if you will, between fish and early amphibians.

The majority of the bony fishes belong to the other group called the ray-finned fish. There are a huge number of species of ray-finned fish and a huge range of shapes and sizes. Their hard bony skeleton allows them to be fast and agile. Their mouths are highly specialized and often ‘protrusible’ which means they can thrust it out from their face which helps when they are nabbing tasty bites from the ocean floor. Some species can get very big – the longest is the oarfish who grow to over 50 feet, a likely source of ancient legends about sea serpents.

One of the problems that fish have living in water is that they sink, so they have to keep themselves up in the water. Doing this by swimming is very energetically costly (think about why – water is viscous, so it is hard to move around in, that’s why swimming at the pool is such a great workout), so it is in their best interest to find a way to stay up off the bottom with little effort. The solution is an organ called a swim bladder that allows them to control where they hang out in the water column without having to actively swim up or down – sort of like being in zero gravity. The swim bladder is a pouch that is filled with air, or sometimes lipid in species that live very deep in the ocean. It keeps a fish in a certain level in the water column by maintaining its density equal to the water around it. That is easy enough if the fish is always in one part of the water column because it just has to keep its swim bladder at one density (one amount of air). But what about fish that swim up and down in the water? They move through big density changes as they ascend and descend – recall the change in pressure with depth. How can they, a water breather, get more air into an air sack inside their bodies? In some, the bladder is connected to the mouth and they can gulp in air from the surface, but in others it is a closed sack – so what do those fish do? Good question! They can steal oxygen from their hemoglobin molecules (these are big molecules that take oxygen from the gills and move it around the body to the muscles where it is needed). This happens through a biochemical process that makes the tissues around the bladder more or less acidic; under these conditions the hemoglobin will give up the oxygen.

Some marine fish species live completely in the ocean, while other might start in freshwater (a river for example) and then migrate into the ocean or vice versa. Some of the ray-finned fish who do this are familiar because of their popularity at the dinner table. Salmon are a good example. Salmon actually begin and end their lives in freshwater and spend their ‘teenage and adult’ years in the ocean. This type of lifestyle is called anadromous, meaning that they migrate to streams to spawn. The advantage of this type of lifestyle for these fish is that they are protected from marine predators while they are in the streams as very young and vulnerable fish. Once they are big enough, they can move out into the ocean to take advantage of the abundance of zooplankton and small fish to feed on in the ocean. The big challenge with this first migration is getting their internal chemistry working properly in salt water, after they were all set up to be in fresh water. As you have already learned, salty water is a unique place, so they need to make a number of changes to their bodies that allow them to cope with the new environment. In salmon this process is called smoltification and it is a complex process (one that is fascinating, but beyond the scope of this course unfortunately) involving changes in metabolism, osmoregulation, growth, shape, behaviour, respiration and many more. After a few years at sea (the number of years varies depending on the species and sometimes the stock), the salmon return to the stream in which they were born; amazingly, they know exactly where home is after being thousands of miles away for years. They return to spawn (mate and lay their eggs), so they all come back together in stunning numbers. The photo below shows a sockeye salmon run in British Columbia.

These salmon only get one chance to mate (spawn) when they return to their home stream - a lifestyle that is called semelparous – and they die after laying eggs or sperm. One of the ecological consequences of these salmon runs is that all kinds of fantastic nutrients that were collected in the ocean and concentrated into tasty salmon flesh, get cycled into the forests and streams when they die. Researchers have been able to use specialized chemical analysis (nitrogen and carbon isotope ratios) to trace these ocean nutrients carried hundreds of kilometers into inland forests all the way up through the forest food chain into plants, insects, birds and bears. They have even been able to trace centuries of records of large and small salmon runs back through time in tree rings – amazing!

You now know the main groups of fish in the ocean – what about the nekton that lives in the deep ocean? The biological communities in the aphotic zone (deep enough that there is no light) not only have the challenge of dealing with no sunlight, but they also live under very high pressure, low food availability (less than 1% of the primary production in the ocean makes it to the deep sea), and often extremes of temperature. They exhibit a number of amazing adaptations to allow them to live in these extreme and strange (well, at least strange from our terrestrial or coastal perspective that is) places. Many use bioluminescence to communicate, hunt, or avoid predators in the dark depths. The lack of light means that they cannot rely on photosynthesis for production of energy. Some species get around this with chemosynthesis, or are specialists in feeding on the dead things that drift down to the bottom of the ocean. Pressure in the ocean increases by about 1 atmosphere for every 10 m depth. Deep sea animals have a number of characteristics that help them deal with this high pressure world. They are often very small bodied, have gelatinous body parts and reduced skeletons, have no internal cavities (such as swim bladders or lungs) that would collapse under pressure, and tend to move slowly as a way to conserve energy in low food conditions.

Here is a cool video (https://youtu.be/X8oWnbcLI40)

(https://youtu.be/X8oWnbcLI40)

about vampire squids made with ROV footage. The vampire squid is a species that exhibits a number of these adaptations to life in the deep. The communities of the deep sea are highly varied and as yet very poorly explored.

Now, as promised at the outset of this lecture, your dose of 'weird marine biology' – the zooplankton edition. Let's call this story 'You never know what you will find in the plankton'. The images below show a small species of octopus – on the left is a female, she wears a shell, holds it on with her suckers (yes, that is weird… but wait, it gets weirder). On the right is a male, he is a dwarf (note the scale bar in the photo, he's tiny) and is much smaller than the female. They both live in the plankton, the species name is *Argonauta argo*. The male invests all his lifetime reproductive effort into one package of sperm (called a spermatophore). He holds onto this spermatorphore with his 3rd leg on the left (always, never one of the other seven legs). This leg gets tucked away into a pouch until it is ready to find a female. When it is, for lack of a better word, ripe, the leg bursts out of the pouch and swims away on its own (reminds me of a nasty scene in Alien). The male dies as a result of the trauma. Meanwhile, the sprematophore-bearing legs swims around in the zooplankton on its own until it finds a female, it grabs onto her by its suckers then crawls into her mantle cavity. The female holds onto the leg until she needs it. For a long time, biological oceanographers would find these legs in their plankton tows but didn't know what they were. For a long time it was thought to be a parasitic worm. Goes to show you that you just never know what you will find in the plankton!

Fig. 1. Live juvenile female Argonauta argo, Sea of Japan