THE ENDLESS VOYAGE

"Food for Thought" Episode 120

I think photosynthesis, for me, it's the most important process on our planet. And it really takes energy and material from the non-living world and makes it living and makes it available to human life.

One of the big new discoveries, I would say, in the last, say, 10, 20 years about the oceans is the discovery of these massive numbers of tiny life-forms that we didn't even know existed when I was in college, say, 20 years ago.

Instead of it being a linear sort of set of connections from this plant to this animal, to this animal, to this animal, you have a whole variety of different ways that you can get plants from different sizes, animals of different sizes, all being eaten by larger things.

NARRATOR:
THE WORLD OCEAN IS, AMONG OTHER THINGS, HOME TO A RICH VARIETY OF FISHES. THESE EXTRAORDINARY CREATURES ARE VALUED FOR THEIR BEAUTY, THEIR DIVERSITY, AND BECAUSE THEY PROVIDE BOUNTIFUL SOURCE OF FOOD. BUT AS VALUABLE AS OCEAN FISHES ARE, THERE'S ANOTHER GROUP OF MARINE ORGANISMS WHOSE CONTRIBUTION TO LIFE ON PLANET EARTH IS EVEN MORE CRITICAL. THESE ARE THE PRIMARY PRODUCERS, MOST OF THE SO SMALL THAT THEY CAN'T EVEN BE SEEN INDIVIDUALLY WITHOUT MAGNIFICATION, YET SO IMPORTANT THAT LIFE PROBABLY COULDN'T EXIST WITHOUT THEM.

SEAN CHAMBERLIN, Ph.D., Fullerton College:
Primary producers actually produce organic matter. And that would be probably the simplest definition of a primary producer. They're taking energy from the sun or chemical energy from a hydrothermal vent, using that energy to combine carbon molecules, essentially to create carbon-based organic matter that comprises their bodies, and then through eating and ingestion by other organisms, it comprises the energy and the materials, or the organic matter, of all the organisms that depend on that. So really, primary producers are producing organic foodstuffs—organic matter, carbon-based molecules—on which all other forms of life depend and exist.

NARRATOR:
WHILE ORGANIC MATERIAL CAN BE CREATED FROM CHEMICAL CONSTITUENTS, A PROCESS KNOWN AS CHEMOSYNTHESIS, IT IS PHOTOSYNTHESIS, THE PRODUCTION OF ORGANIC MATERIAL FROM SUNLIGHT, THAT IS AT THE HEART OF PRIMARY PRODUCTION.

ANTHONY MICHAELS, Ph.D., Wrigley Institute of Environmental Studies, University of Southern California:
When you have photosynthesis, the process of taking light to create chemical energy, you're basically producing a variety of different compounds as the fundamental early building blocks of life. Primary production's the word we use for sort of—the activity of plants in the sea. This idea of taking the energy of the sun, these photons that come down from the sun, and converting it into chemical energy. And so we—sun, you know, might give us a tan, but it isn't actually something we can feed on. Plants have the special character of being able to take that energy and create a chemical bond, a carbon-carbon bond or a phosphate-phosphate bond that stores that energy in the chemical bond.

KATHERINE BARBEAU, Ph.D., Scripps Institution of Oceanography, UCSD:
Single-celled plants called phytoplankton, which are—that's where it all starts. And they are really critically important on a global scale in that they take carbon dioxide from the atmosphere, photosynthesize, and turn it into organic matter.

Phytoplankton are the plant plankton. The word plankton comes from the Greek word planktos, which just means drifter. So a very simple definition of phytoplankton would be a plant drifter. We contrast that with zooplankton, which are animal drifters.

NARRATOR:
BECAUSE THEY CREATE THEIR OWN FOOD THROUGH EITHER PHOTOSYNTHESIS OR CHEMOSYNTHESIS, PHYTOPLANKTON ARE KNOWN AS AUTOTROPHS. ZOOPLANKTON, BY CONTRAST, ARE TERMED HETEROTROPHS, BECAUSE THEY DERIVE NOURISHMENT BY CONSUMING OTHER ORGANISMS. PHYTOPLANKTON EXIST IN A VARIETY OF DIFFERENT FORMS, SOMETIMES DESIGNATED ACCORDING TO SIZE.

WILLIAM HAMNER, Ph.D., University of California, Los Angeles:
Ultraplankton and picoplankton and nanoplankton are terms that are used for various size classes. And they may or may not be used even uniformly by biologists. But ultra and pico and nano all mean "little." So that's pretty simple. But phytoplankton are distinguished also by other attributes. So a dinoflagellates, for example, are a group of phytoplankton that have two flagella—they have two long, whiplike appendages, one of which sticks out from one end and helps pull the animal forward, and the other one of which is wrapped around the cell. And when it beats, it spins the cell on its long axis.

DENNIS J. McGILLICUDDY JR., Ph.D., Woods Hole Oceanographic Institution:
They can actually swim, not fast enough to buck an ocean current, but fast enough so they can effectively control their vertical position in the water column, which is a great thing to do if you're a phytoplankton cell. You can swim up to get light and swim down to get nutrients. Actually the most abundant plankton on Earth are very, very small phytoplankton cells called prokaryotes. They don't have a nucleolus in their cell. They're very, very small, just a few microns across, and just tremendously abundant throughout the world ocean. And they look like little green dots under a microscope. Although these are the most abundant, there are just tremendous varieties of other types

of phytoplankton. Beautiful chain-forming diatoms that look like little beads strung together in a nice, long chain. There are phytoplankton called coccolithophores that build these very, very ornate calcium carbonate shells around their bodies.

NARRATOR:
WHILE THERE IS A GREAT DEAL OF VARIETY WITHIN THE PHYTOPLANKTON COMMUNITY, ALL OF THESE DIMINUTIVE ORGANISMS SHARE IN COMMON A CRITICAL ROLE IN THE MARINE ECOSYSTEM.

McGILLICUDDY:
Phytoplankton are the base of the marine food chain. By the process of photosynthesis, these organisms grow, and they double and reproduce and reproduce. And so the way that that material makes it up the food chain is it's eaten by other things.

NARRATOR:
WHILE THE TERM FOOD CHAIN IS STILL WIDELY USED BY SOME TO DESCRIBE THE TRANSFER OF ENERGY BETWEEN ORGANISMS, OTHERS CONTEND THAT THE COMPLEX NATURE OF THIS PROCESS IS BETTER DESCRIBED BY THE WORD “WEB,” RATHER THAN “CHAIN.”

MICHAEL LATZ, Ph.D., Scripps Institution of Oceanography, UCSD:
The classical view of how energy is transferred between organisms was of a food chain. So that there's primary producers, which are eaten by zooplankton, which are eaten by small fish, which are eaten by larger fish. We now know that the transfer of energy occurs more through a food web, so that there are many complex interactions.

Many organisms will switch their food source depending on what's available. Some high-level predators might eat directly on phytoplankton or on lower food levels at one time of the year, and eat maybe higher in the web at other times of year. So it's really not this clearcut path of this flow of material and energies through the marine ecosystems. It really is more like a web of pathways through which energy and materials flow in a marine ecosystem, which make them more complicated.

NARRATOR:
WHATEVER ROUTE ENERGY TAKES AS IT'S PASSED ON FROM ONE ORGANISM TO ANOTHER, PHYTOPLANKTON ARE CLEARLY RESPONSIBLE FOR THE MAJORITY OF PRIMARY PRODUCTIVITY IN THE WORLD OCEAN. BUT SEAWEEDS, ANOTHER FORM OF MARINE ALGAE, ALSO PLAY A SIGNIFICANT PRODUCTION ROLE.

RICHARD ZIMMERMAN, Ph.D., Moss Landing Marine Laboratories, CSU:
Absolute definitions of the distinction between seaweeds and plankton are—can be hard to provide. In general, seaweeds are those algae that live attached to the rocks, pilings, substrate, and have a large macroscopic form that you can see with your eyes. Plankton are generally defined as small, unicellular organisms that drift in the ocean currents. On the other hand, there are algae that drift on the ocean currents like sargassum, that

occupies extensive areas of the tropical and subtropical Western Atlantic—forms the Sargasso Sea. That plant is definitely a seaweed, by all classical definitions based on its morphology, but it exists in a planktonic life-form. It never exists attached to the substrate.

CHAMBERLIN:
Perhaps the most prominent seaweeds are the kelps, and particularly the California kelp—they're very large and fast growing plants that provide really a forest of plants for animals to live in. Kelp forests are renowned for being an environment that acts as a nursery for larval fishes. It's an area where small fishes and other types of animals can find protection both from predators and from some of the sea forces—the waves and currents and those types of things. So seaweeds and kelp forests really play a very important role in our coastal environments. They're less important probably, in terms of…the productivity they provide in terms of carbon and oxygen production, because they are confined to this narrow strip of land along the coast. But that really shouldn't diminish their importance to us as humans, because really a lot of the coastal fisheries and fish stocks are dependant on good healthy stocks of kelps and seaweeds growing along the shore, both for protection for their larval fishes, and as a food source as well for a lot of organisms.

NARRATOR:
REGARDLESS OF WHETHER A PRIMARY PRODUCER IS PLANKTONIC OR OF THE SEAWEED VARIETY, THE FIRST STEP IN THE PRODUCTION PROCESS IS PHOTOSYNTHESIS. AND THAT CAN ONLY TAKE PLACE IF CERTAIN CRITICAL CONDITIONS ARE MET.

SEAN CHAMBERLIN, Ph.D., Fullerton College:
Light really drives photosynthesis. It's those photons from the sun that get captured by the chlorophyll molecules—a lot like a catcher, or somebody with a baseball glove catches a baseball. That's how plants and how chlorophyll catches photons of light—taking that energy and using that energy to combine molecules to create organic matter. So light's really important, and there's a lot of different things that affect light. Light's affected by how far—how deep you go in the ocean, the euphotic zone being defined as the depth at which photosynthesis occurs. So as you go deeper in the water column, light is certainly diminishing. So that's an important factor. Light is affected by ripples on the sea surface, it's affected by the night-day cycle. It's affected by clouds on a daily basis. And it's even affected in a more seasonal basis, because in certain environments we have six months of dark, six months of light. The other important factor for photosynthesis, and for primary productivity are the chemical nutrients, the fertilizers, if you want to think about it that way, on which these plants depend to make their organic matter.

HAMNER:
If there are no fertilizers, the plants simply don't grow. You have to have fertilizers to permit the grass on your lawn to grow. If you ultimately never fertilize it, it stops growing. So the availability of nitrogen and phosphorous is very, very important. Temperature is important. If it's very cold, all of the reactions proceed slowly. If it's

very hot, they proceed very rapidly. So temperature and nutrients are of particular importance in terms of photosynthesis.

NARRATOR:
OCEANOGRAPHERS WHO STUDY PRIMARY PRODUCTIVITY GENERALLY DO SO IN ORDER TO UNDERSTAND TWO VERY IMPORTANT ASPECTS OF THIS PROCESS.

Number one, that primary productivity sets a limit on the amount of material that's available for higher levels of the food chain—those things that we care about, like fish production, for example.

ZIMMERMAN:
The world's most productive fisheries are based on environments that have a higher amount of photosynthesis. And so what we do when we exploit them, is we're extracting energy that was originally captured as photosynthesis. So understanding how primary productivity is distributed around the globe gives us an idea of where we're likely to find high areas of exploitable production.

They're most abundant in the coastal ocean. That's where nutrients are most available. You see the largest amounts of phytoplankton near coastal upwelling zones, for example, where the winds along the coast cause surface waters to flow offshore, therefore bringing up nutrient-rich water from the deep to the surface ocean. We see massive looms of phytoplankton in those sorts of circumstances.

ANTHONY MICHAELS, Ph.D., Wrigley Institute of Environmental Studies, University of Southern California:
We consider the open ocean deserts—as places where there's very little plant production. But the common dogma on this has turned out to be a lot less true than we were letting ourselves believe for many years.

DENNIS McGILLICUDDY JR., Ph.D., Woods Hold Oceanographic Institution:
For example, there's a tremendous spring bloom in the North Atlantic that takes place every springtime. In the winter, there is a lot of heat removal from the surface, and very strong winds, which create very deep mixed layers. So nutrients from the deep sea will be mixed all the up to the surface in the wintertime. Then when the sun comes out in the spring and the ocean begins to stratify, all of the sudden all those nutrients are trapped near the surface. You create an enormous bloom of phytoplankton, which is visible from satellite data, from shipboard observation. It is one of the most striking seasonal variations in biomass on Earth.

Phytoplankton tend to concentrate in areas where the conditions for their growth and reproduction are optimal. The types of environments where we find the highest concentrations of phytoplankton include ice-edge systems—ice-edge ecosystems—so the Antarctic, if you think about this ice that advances and retreats every year; this ice that's twice the size of the United States in volume or in surface area. There are phytoplankton associated with those ice and we find, really, very productive waters in the Antarctic. This is to be contrasted with places like Hawaii, which are very sort of desert-like conditions in terms of phytoplankton growth, where we find very little phytoplankton, primarily because of nutrient limitation. There's plenty of light, but there really aren't those chemical fertilizers, those biologically important nutrients, for those plants to grow on in those areas.

NARRATOR:
CLEARLY, GLOBAL PATTERNS OF PRIMARY PRODUCTIVITY OFFER VALUABLE INSIGHTS INTO WHERE THE GREATEST NUMBER OF FISH ARE LIKELY TO BE FOUND, BUT THE NEED TO UNDERSTAND PRIMARY PRODUCTION GOES WELL BEYOND MAN'S SEARCH FOR FOOD.

The second reason that we really need to understand plankton productivity in the ocean is that the plankton play an important role in regulating the chemistry of the ocean and atmosphere system. Photosynthesis uses carbon dioxide and produces oxygen. By virtue of the fact that phytoplankton do that in the surface ocean, and then when they die they sink to the deep ocean. They take that carbon dioxide with them. So the so-called biological pump is an important regulator in Earth's climate.

CHAMBERLIN:
As far as absorbing carbon, which is going to be very important as a look at increasing carbon dioxide in the atmosphere and look at the effects of the greenhouse effect in increasing carbon dioxide on global climate change, it's not clear yet really whether the oceans are a net source or sink. But they certainly play a large role in the carbon cycle. And the oceans clearly absorb carbon through the process of photosynthesis. So anything that disrupts that cycle could potentially have effects on our climate. So in sort of an indirect way, the oceans—at least the primary producers in the ocean—help control our climate.

NARRATOR:
GIVEN THE CRITICAL IMPORTANCE OF PRIMARY PRODUCTIVITY, THE NEED TO MEASURE IT ACCURATELY CAN HARDLY BE OVERSTATED.

Oceanographers have been wrestling with how to measure productivity for a long time. And there's a real question about whether we've yet got it right.

WILLIAM HAMNER, Ph.D., University of California, Los Angeles:
Originally people studied phytoplankton by pulling very fine nets through the water and then rinsing off the nets. But as they did so, they would find that material was passing through the nets. And so, for many years, phytoplankton were studied by getting samples of water and putting them in large vertical tubes, and letting the plant cells settle to the bottom of the tube, and then sliding the tube away from a slide on the bottom and then looking at the cells that had adhered to the glass surface. As students of phytoplankton became aware that there were even smaller things, they started centrifuging the water and spinning big masses of water faster and faster to produce tiny pellets, and looking at those

pellets using electron microscopes. So the technology has changed drastically as the ability to look at smaller things has improved.

The real transformation came in the mid-50's when Steemenn-Nielson and others decided to use a radioactive isotope called carbon-14 as a tracer. And carbon-14 is just like carbon-12—the natural, stable form of carbon—but it's radioactive. And you can measure radioactivity incredibly easily and very, very sensitively.

McGILLICUDDY:
Perhaps the most straight forward way is to take some water, spike it with radioactive carbon, carbon-14, incubate that water for some period of time, and then filter out that water, take the material that has been incorporated into those phytoplankton, and do a count of the radioactivity of that mass. And one can gauge the rate at which that spiked carbon is being taken up by the plankton.

This is a technique which was used in plant physiology to actually understand the basis of physiology, but very quickly it became sort of an operational tool to go out into the sea. It's a very safe isotope. We're using at a very, very, very low levels, but at the same time, it was a trick which allowed us to look at the details of photosynthesis and actually measure in a broad scale how plants work.

NARRATOR:
OTHER MEASUREMENT TECHNIQUES CAN BE MADE FROM AN ENTIRELY DIFFERENT VANTAGE POINT.

We're at a fabulously exiting period in ocean science right now, because we have available to us now a very diverse set of satellite platforms that can be used to observe the ocean. For example, there are satellites that can sense very subtle variations in ocean color to tell us the abundance of plankton in the surface ocean. And we can create maps of the plankton distribution. Furthermore, we can relate those maps of phytoplankton populations to physical properties of the ocean.

NARRATOR:
RESEARCH INTO DISSOLVED ORGANIC CARBON, A CRITICAL PIECE OF THE GLOBAL CLIMATE PUZZLE, HAS BEEN GREATLY ACCELERATED BY RECENT BREAKTHROUGHS THAT ENABLES SCIENTISTS TO DETECT AND ANALYZE ORGANISMS MUCH SMALLER THAN ANY STUDIED IN THE PAST.

JAMES NYBAKKEN, Ph.D., Moss Landing Marine Laboratories, CSU:
That led us to start looking at bacteria in the ocean. We discovered that the bacteria can take up the dissolved organic material. Now it becomes particulate organic material, because it's in a bacterial cell, which can then, of course, be taken up by some other organism, some heterotroph—and consumed. And so when they started looking at those, they started looking for various kinds of organisms.

DONAL MANAHAN, Ph.D., University of Southern California:
I suppose you can call them the microbial life-forms. They're all planktonic. Many of them are very hard to culture, particularly some of the bacteria and even some of the small plant life-forms.

They were discovered because we had better filters and we can filter out smaller and smaller things out of the water column. And all of these things started showing up in tremendous numbers, and we found out they were photosynthetic.

They're a very recent discovery precipitated by the creation of a tool, the auto fluorescence microscope, which allows us to see these plants.

We had no idea of the biological diversity of the oceans until fairly recently. Now that we're looking at that biological diversity, it becomes very obvious that the oceans play an enormously important role in what we'll call global geochemical cycles—say, the role of the oceans in global warming and removing carbon dioxide from the atmosphere. All of the mathematical models that look at all of these climate issues on planet Earth—the oceans, we know, play an enormously important role in this, and it seems to be growing in importance as we understand all of the microbial processes that are going on in the ocean.

NARRATOR:
OF COURSE, ANY DISCUSSION ABOUT THE LINK BETWEEN PRIMARY PRODUCTION AND GLOBAL GEOCHEMICAL CYCLES HAS TO INCLUDE SOME MENTION OF THE ROLE HUMANS PLAY.

RICHARD ZIMMERMAN, Ph.D., Moss Landing Marine Laboratories, CSU:
We are changing the chemical composition of the atmosphere by increasing CO2. And its impact on ocean productivity is a subject of active investigation around the globe. The other thing that we are doing to change productivity of the oceans is to dramatically increase the delivery of plant nutrients to coastal waters. Agricultural activity, changes in land use practice, and extensive use of fertilization has led to a condition that we call eutrophication. That is, enrichment of coastal waters with the runoff of these nutrients that we apply to our lawns, and our agricultural fields and farms and everything else. Eventually those nutrients make their way downstream into the watershed and cause problems in coastal waters where they can eutrophy the waters. And this results in blooms of nuisance algae, both phytoplankton and macro algae, that change the structure and functioning of these coastal ecosystems.

DENNIS J. McGILLICUDDY JR., Ph.D., Woods Hole Oceanographic Institution:
When that becomes a problem is actually after that material dies and then sinks into the deeper layers of the coastal ocean. As that material then decomposes, it uses up all of the oxygen that is in the deeper part of the coastal ocean, causing what's known as anoxia, or lack of oxygen.

And that produces a water column that goes anoxic to the bottom and subsequently it kills all the fish, because the fish have to have oxygen in order to breathe, but the plants are being produced in such quantity that they're rotting, and the bacteria are using up the oxygen faster than the animals can find it. So we're affecting that environment enormously.

NARRATOR:
THE LONG-TERM IMPLICATIONS OF THAT IMPACT ARE STILL BEING ASSESSED.

So I don't think we can every have a healthy planet without a healthy ocean. But it isn't just for issues getting food and catching fish. It's much more subtle than that now.

NARRATOR:
THE ROLE OF PRIMARY PRODUCERS IN THE MARINE FOOD WEB HAS LONG BEEN RECOGNIZED, AND THEIR LIKELY INFLUENCE ON GLOBAL CLIMATE IS CURRENTLY TO FOCUS OF CONSIDERABLE RESEARCH. AND YET, THE FULL SCOPE OF THEIR TOTAL IMPACT MY NOT BE COMPLETELY UNDERSTOOD FOR YEARS TO COME.

SEAN CHAMBERLIN, Ph.D., Fullerton College:
There's been some speculation in the last 10 or 20 years that phytoplankton actually help to produce clouds. And people have been looking at the role of coccolithophorids, which are a type of calcium carbonate containing phytoplankton, in producing clouds. Because coccolithophorids are known to produce what are known as dimethyl sulfides, and dimethyl sulfides act as particles around which clouds form, and so the degree to which this is happening is still not yet clear. But beyond just providing food for animals living in the ocean, these primary producers are very important for humans as well in ways that we probably don't even think of.

"THE ENDLESS VOYAGE" IS A 26 PART TELEVISION SERIES ABOUT OCEANOGRAPHY. FOR MORE INFORMATION ABOUT THIS PROGRAM AND ACCOMPANYING MATERIALS, CALL: 1-800-576-2988 OR VISIT US ONLINE AT: WWW.INTELECOM.ORG.