Oratie Prof. Laura Villanueva, Utrecht University 14th November 2024

Mijnheer de Rector magnificus, dear colleagues, friends and family

In the vast, mysterious expanse of our oceans, unseen heroes work tirelessly every second of the day. Meet the marine microbes—tiny but mighty superheroes that dramatically shape our planet. While they may not wear capes or have flashy gadgets, their powers are nothing short of extraordinary.

From the depths of dark ocean trenches to coral reefs, marine microbes ensure that life persists. They are the ultimate team players, collaborating with ecosystems to break down waste, produce oxygen, and recycle nutrients—truly the ‘clean-up crew’ of the ocean.

Like the best sidekicks, they nurture other superheroes helping them grow strong and thrive. They teach us the importance of connection and collaboration in achieving greatness.

It’s a great honor to be here with you today as we embark on a journey through the captivating world of marine microbes.

As I stand before you, I want to take a moment to reflect on what sparked my passion for this field.

I was sixteen years old, in high school, when I heard for the first time about marine microbes collaborating with each other forming communities in the early Earth.

This is what we call stromatolites, which still to this day can be seen in some coasts in Australia.

These ancient structures are some of the earliest evidence of life on Earth and played a crucial role in the story of our planet's evolution. Rock-like formations made by layers of microorganisms that date back over 3.5 billion years.

In a time when the atmosphere had very little oxygen, some green microorganisms, named cyanobacteria, produced oxygen through photosynthesis, transforming the planet by filling the atmosphere with the oxygen we all breathe today.

As stromatolites grew, they provided habitat and protected other microorganisms' underneath that could not breath oxygen, helping to pave the way for complex life forms, and showcasing the power of microbial teamwork.

This newly found interest in the ecology of microorganisms led me to study Biology at the University of Barcelona where I took all the microbiology classes that were offered.

Then, I started to collaborate with the microbial ecology group in that same faculty mostly because they were working with microbial mats, which are the modern representatives of stromatolites.

A microbial mat is a colorful, living carpet made of microorganisms that grow together in layers. The upper layer is green because it is formed by cyanobacteria, microorganisms that photosynthesize as plants.

But as you go deep into the sediment, oxygen cannot penetrate and other microorganisms also doing photosynthesis but not generating oxygen, in this case in red, the purple sulfur bacteria thrive.

The red layer is followed underneath by a black layer full of sulfate reducing bacteria that produce sulfide, which is the same compound responsible for the rotten egg smell.

All and all microbial mats are absolutely beautiful, layered cakes full of life where cooperation and competition between microorganisms takes place.

I remember with excitement the first time i saw the marine microbial mats at the estuarine of the Ebro River delta in Catalonia, and I saw and felt in my hand the bubbles of oxygen coming up from them, they were simply ALIVE…truly the tissue of Gaia.

I cannot let you go today without telling you about the Gaia hypothesis. Gaia in the Greek mythology, is the personification of Earth. Gaia is the ancestral mother of all life.

The Gaia hypothesis was proposed by James Lovelock in 1972 who suggested that Earth operates as a single, self-regulating system where living things and their environment work together to create conditions suitable for life.

This idea highlights how interconnected all living organisms are with the Earth's processes.

But long before him, Baas Becking, Dutch botanist and microbiologist, introduced Gaia for the mutual interactions between Life and Earth in his oratie in Leiden in 1931 titled ‘Gaia of leven en aarde'.

The interactions occurring in microbial ecosystems, like in stromatolites and in microbial mats, and their roles in shaping the environment support the connection between our planet and all living things.

Microorganisms, especially marine ones, play also a vital role in the Gaia hypothesis. Despite being tiny, they have a huge impact on the environment by helping recycle nutrients, decompose organic matter, and regulate gases in the atmosphere. For example, they produce oxygen and help control greenhouse gases.

For those who do not know her, this is Lynn Margulis together with James Lovelock. Lynn Margulis also greatly contributed to the Gaia hypothesis as she emphasized the importance of symbiosis—how different organisms, especially microorganisms, work together in harmony.

Together, Margulis and Lovelock highlighted that every organism, no matter how small, plays a crucial role in maintaining the balance of our planet.

Lynn was a force of nature and my first and ultimate scientific role model. I had the honor to get to know her well, during her multiple visits to my PhD supervisor Ricardo Guerrero in Barcelona.

But sorry, I'm getting a bit ahead of myself…did i forget to mention that i went on and started a PhD on the ecophysiology of estuarine microbial mats in the University of Barcelona? From that point on, i was forever hooked up to marine microbial ecology.

All of those very early scientific interactions inspired me in more ways than I could think of:

The love for microorganisms, for the past, for microbial ecology, and the realization that I could be a scientist working at the interface of biology and geology.

While microbial mats are fascinating layers of life that demonstrate the power of microorganisms in shaping environments, they are just one example of the incredible diversity and essential functions of marine microorganisms.

These tiny yet mighty microbial heroes play critical roles in our oceans, influencing everything from nutrient cycling to supporting entire marine ecosystems.

As we dive into the fascinating world of marine microbiology, let's take a moment to appreciate JUST how vast and mysterious our oceans really are.

While many people picture dolphins and colorful fishes when they think of marine life, today, we are going to explore the hidden wonders of the microscopic superheroes that make the ocean their home.

Microorganisms are found almost everywhere. In the marine environment, we can find them in coral reefs, estuaries, mangroves, hydrothermal vents, polar ice, deep-sea trenches, on and under rocks, on gills, fins, claws and even plastics.

Those microorganisms living in the marine environment are what we call the marine or ocean microbiome.

The ocean microbiome is composed of microscopic organisms — most of which are invisible to the naked eye and largely unknown, even though they account for more than 2/3 of the Ocean's biomass.

The ocean microbiome is estimated at 4 gigatons of carbon, that is 4 times the overall biomass of insects on Earth.

In just one drop of seawater, there can be around one million to one billion microorganisms. These tiny organisms, including bacteria, archaea, and phytoplankton, play vital roles in maintaining ocean's health, supporting nutrient cycling, and forming the foundation of marine food webs.

You might think this is a nice picture of the universe full of stars, but this is picture of a drop of seawater where marine microorganisms are stained.

To give you an idea of their importance, just mention that it is estimated that the ocean contains ten to the power of 29 *that is a 10 followed by 29 zeros, of bacteria and archaea, and ten to the power of 30 viruses. That number is so much higher than the number of stars in the universe.

But, who are they? Marine microorganisms include microalgae, bacteria and archaea, protozoa, fungi and viruses.

They are incredibly small, often too tiny to see without a microscope. See here this bar for a scale represents TEN micrometers, which is taking 1 mm, here in red, dividing it into 1000 parts and taking 10.

To help you understand their size, here are some comparisons:

You could fit hundreds to thousands of marine Bacteria or Archaea side by side across the width of one of your hairs.

Phytoplankton, these plant-like microorganisms that perform photosynthesis, can be a bit larger but smaller than a grain of sand.

And marine viruses, these are among the smallest. To put this in perspective, a typical virus is about 10 to 100 times smaller than most bacteria, and marine viruses are often smaller than other viruses we know very well, such as the COVID-19 virus.

These marine microorganisms are not ONLY important in terms of numbers, but they also perform essential functions: They are truly the superheroes of the ocean.

Marine microbes are masters at recycling nutrients. They break down organic matter, returning essential nutrients to the water and supporting the growth of larger organisms.

They are also oxygen producers. Phytoplankton, the plant-like microbes of the ocean, perform photosynthesis, producing approximately 50% of the Earth’s oxygen. Every breath we take is partly thanks to these microscopic heroes.

Marine microbes are climate regulators. By sequestering carbon and influencing greenhouse gas levels, marine microbes play a crucial role in regulating climate.

In fact, marine microbes produce as much oxygen and absorb more carbon dioxide than all the world's forests.

Not only that, but marine microorganisms can also remove carbon dioxide and nitrogen gas out of the atmosphere, incorporating in the in the marine life and further transforming these compounds to fertilize the ocean.

They are also the foundation of the marine food web BECAUSE they serve as a primary food source for other small marine creatures. They support a diverse array of marine life, from fish to whales.

Marine microbes are also disease fighters as they help protect larger organisms by fighting against harmful pathogens.

And they are even producers of beneficial products. Among these marine microbial superheroes, we find those producing antibiotics or compounds with the potential to battle cancer, those providing healthy fats, vitamins, makers of ecofriendly plastic, and cleaning products we use in our daily life.

Marine microorganisms are constantly faced with various challenges, including changes in temperature, salt levels, and nutrient availability.

For example, in deeper parts of the ocean, there's often less light, and the temperatures can be very cold or extremely hot near hydrothermal vents.

They also need to cope with high hydrostatic pressure.

Hydrostatic pressure, which is the pressure exerted by the weight of water above an object, has a significant effect on marine microorganisms, especially those living in the deep ocean. As you go deeper into the ocean, the pressure increases dramatically.

For example, the deepest point in the ocean, known as the Mariana Trench, reaches about 11,000 meters. To put that in perspective, the ocean is as deep as Mount Everest plus five Empire state buildings stacked on top of each other.

Marine microorganisms have adapted to these extreme conditions. Some have special membranes that can withstand high pressure, while others have unique enzymes that function well in these environments.

To survive in these extreme conditions, marine microorganisms can adapt in several ways.

Microbes can change their DNA to develop new tricks that help them survive in challenging environments. Just as a person might learn new skills.

Microbes can turn specific genes on and off to adapt to varying conditions, much in the same way that we adjust our behavior based on social situations—such as being more outgoing at a party or more reserved in a meeting.

Microorganisms produce different proteins to help them adapt to their surroundings. Just the same as people wear different outfits to respond to weather changes, like wearing a raincoat on a rainy day.

Microbes adjust how they use nutrients based on what is accessible in their environment, the same way as we change our diet to achieve health goals.

Microbes can change their outside membranes to cope with shifts in temperature and salinity. Like how we shiver when we are cold or sweat when we are hot.

Microbes use signaling molecules to share information and adapt together as a community. The same way we people communicate and collaborate in group projects

Microbes produce special compounds to protect themselves from environmental stresses. Same way that we exercise or practice mindfulness to manage stress.

These adaptations allow microorganisms to thrive where most other life forms cannot survive.

Since I started my journey as microbial ecologist, one of the questions that kept coming back to my mind is how microorganisms adapt and how to know if they are affected by everything that surrounds them.

I found my answer in microbial membrane lipids which can sense and change very quickly when conditions change, much in the same way when we get ‘goose bumps’ when we are cold.

How did microbial lipids come into my life? I was 23 years old, and I had barely started my PhD in the University of Barcelona working on microbial mats when I jumped into a plane, first time going to the US, and after 4 different planes of decreasing size I made my way to Knoxville, Tennessee.

At the airport I was picked up by a small lady, Sandy White, the wife of David C. White, who took me out for dinner and gave me the keys to one of their cars.

David C. White, DC, was in his early 70s by then, a medical doctor turned into a microbial ecologist working at the Center for Biomarker Analysis of the University of Tennessee at Knoxville.

DC was in love with science, bow ties, and woodturning, one of the most interesting people I have ever met.

He was, above all, passionate about lipids, to prove that, was the license plate of his Toyota saying PLFA.

DC made substantial contributions to microbial ecology.

He developed techniques for extracting and analyzing microbial lipids, which serve as biomarkers for identifying and quantifying different microorganisms in environmental samples.

There I was, with a suitcase full of little vials with microbial mats to be analyzed for polar lipids, polyhydroxyalkanoates and more. I spent countless hours extracting, separating, integrating peaks, to determine if microorganisms in estuarine microbial mats felt stressed or if their growth was unbalanced during a day/night cycle.

DC White believed that research is advanced by using new techniques to study old problems.

DC was an amazing mentor who transmitted to me the love for science and lipid biomarkers.

I ended up coming back to Knoxville up to three times. Sandy and DC host me in their house as if I was part of their family.

We had breakfast on a kitchen table full of hard copies of several scientific journals and we had fancy dinners on the weekends where I discovered that you could speak better English when you have had a glass of wine.

DC believed no single technique is enough, highlighting the necessity for new methods to address complex ecological questions.

His group started combining lipid and DNA analyses in the same sample, which I also used for my microbial mats.

In my time in Knoxville, I also met Ronald Geyer, a postdoc there by that time, who I later visited when he moved to the UFZ Centre for Environmental Research in Leipzig, Germany.

Thanks to him, I also dived in the world of respiratory quinones by using LC/MS. Again in samples of my beloved marine microbial mats.

One of the things I feel passionate about is using different methods, as DC said, “no single technique is enough”. Microbial lipids are amazing to determine microbial adaptation, stress and even identify specific microbial groups, but they are simply not enough when it comes down to knowing microbial communities well.

Edward O. Wilson, an entomologist at Harvard, in his book the Naturalist once said: “If I could do it all over again, and relieve my vision in the twenty-first century, I would become a microbial ecologist. Ten billion bacteria live in a gram of ordinary soil, a mere pinch held in between thumb and forefinger. They represent thousands of species, almost none of which are known to science. Into that world I would go with the aid of modern microscopy and molecular analysis”.

Molecular methods based on DNA and RNA, but also culturing experiments to determine the physiology of microorganisms, are certainly a great option to bridge to the areas that lipids cannot reach. Serendipitously, this is what I ended up doing during my postdocs.

After I finished my PhD in the University of Barcelona, I moved to the US, to the University of Massachusetts in Amherst where I did my first postdoc in the laboratory of Derek Lovely working with anaerobic microbes, who do not breath oxygen.

I did learn a whole lot about anaerobic microbiology, how to handle 20 L gas cylinders without dropping them, and how to work with RNA.

Then, I did another postdoc at Harvard University, at the Center for Systems Biology where I focused on projects about adaptive landscapes of proteins with experimental evolutionary approaches.

Here you can see where my love for connectors and tubing came from.

During my time at Harvard, surrounded by physicists running models all day long, I also came to the realization that what I love the most is a ‘good old’ experiment.

My time in the US was coming to an end and I was eager to return to Europe to be closer to my family in Barcelona.

When I was scrolling job offers, I encountered this one and I knew somehow that they were looking for me. How could be otherwise that there was another crazy person bridging between lipids and molecular approaches? I went all for it.

I was so thrilled when I got an interview! Only to realize, when I was making my travel arrangements, that the Netherlands Institute for Sea Research, NIOZ, was on an island, I didn’t know that the Netherlands had islands, my apologies.

A city girl, 30 years old, a lock of hair colored purple, ended up in a Wadden island full of sheep. A new scientific world opened in front of my eyes.

I started my journey at NIOZ as a tenure tracker in the topic Geomicrobiology, so everything between microbiology, geology, oceanography, and chemistry…always marine, of course, working in an organic geochemistry department. Organic geochemistry studies organic compounds, for example lipids, in geological contexts, and how these compounds influence and interact with Earth's systems over time.

Here, a funny anecdote to the organic geochemists in the house. Claude Zobell, a microbiologist at Scripps, who is considered as the founding father of marine microbiology, was also fundamental for the field of geomicrobiology and petroleum microbiology.

He highlighted the role of bacteria as geologic agents in the early 40s, which made a great impression on geoscientists who were convinced that they could explain geochemical processes in purely physicochemical terms.

At a time when the industry was treating the supply of crude oil as an almost inexhaustible reserve, ZoBell's thoughts were turning to improved oil recovery using bacterial products to aid mobilization, and he also recognized the problems of marine oil spill pollution, and the potential of marine microorganisms to help in those situations.

This anecdote shows how important it is that marine microbiologists and organic geochemists talk to each other.

But let's go back to the microbial lipids. These preserve very well in sediments, which means that they can be used as fossils of the microorganisms that used to make them.

Microorganisms can adapt to changes in their surrounding environment by changing their skin, their lipids. If lipids change and they sink down the water column, they will deposit in the sediment, bury under layers and layers of sediment, and preserve as fossils much in the same way that dinosaurs' bones.

Microbial lipids record the conditions at which the microorganisms that carried them lived, for example, the temperature at which they grew. These characteristics make some microbial lipids from marine microorganisms to be excellent biomarkers for paleoclimatology, the study of the climate in the past.

Back to circa 2009, when we were a smaller department, organic biogeochemistry, BGC, with Jaap Sinninghe Damste as department head. I had to get used to very quickly to the brutal Dutch honesty and the rural surroundings. Remember that, after all, I am a city girl.

The department was heavily populated by geologists back then, which was a steep learning curve for me. Somewhere between the Younger dryas and the Henrichs event, the geology seed was implanted in me maybe it was already there since my love for stromatolites.

For the first time in my academic life, I felt “my people” had my back. The original core group was always there for advice, venting, support, and friendship.

If I would need to go through war, I would choose you as my team every single time.

The BGC department hosted me as one of them despite being that “DNA lady”. I was supposed to bring microbiology and molecular methods to BGC.

That is why i spent most of my time in the molecular lab where I felt at home. There, we have experienced going from DGGGE, to 454 pyrosequencing, illumina, metagenomics, to Cascabel, and to an entire bioinformatics team in the blink of an eye…well 15 years.

My group focuses on the genomic capacity to produce lipids, lipid biosynthetic pathways, namely interrogating microbes for their skills in producing special lipid biomarkers.

In a world of marine microorganisms that are difficult to culture in the lab, looking at their genes is the best option.

There the GDGT era began. GDGT lipids are specific membrane lipids found in Archaea, of which the marine environment is full of.

As they are also used intensively to determine temperatures in the past, the role of my group was to determine who makes them, why, when and how by using DNA methods and targeting the genes involved in the biosynthesis of those microbial lipids.

This era began with my first PhD student Yvonne, and followed by Marc and Martina who did an excellent job focusing on the membrane lipids of the marine archaea Thaumarchaeota in different marine systems.

CLICK.

Significant scientific advances

Something that I have learnt over the years by being at NIOZ is that sea going exploration is important. Especially when it comes to marine microorganisms, we need to continually improve how we access and study these tiny creatures.

Global research expeditions have played a crucial role in this journey, allowing us scientists to collect samples of marine microorganisms from various locations around the globe.

Sea-going research is not only fun and an interesting exercise of teamwork, but also, we should see it as an immense privilege.

I have been honored to be part of three expeditions during my time at NIOZ so far, and that is only possible with the immense support of the NMF department at NIOZ and the crew and scientists on board of the R/V Pelagia.

In the upcoming years, further advancements in marine microbiology will also depend on improvements in collecting data and samples of marine microorganisms that are either non accessible now or, for which, we still lack sampling and incubation instrumentation that will ensure conditions as the ones they normally live on.

Another scientific revolution that has significantly impacted the field of marine microbiology in the last years is the application of molecular methods.

Studying marine microorganisms using molecular methods is like being a detective trying to solve a mystery by carefully examining clues.

By reading, or as we called it “sequencing”, the DNA of a marine microorganism, we can determine who it is and what activities might be performing. Now, we can even do what we call metagenomics, which implies sequencing the DNA of different microorganisms included in an environmental sample.

Microorganisms are everywhere in the marine environment. There are some that are still quite unknown to us, mostly because they are difficult to reach or to work with.

In deep-sea sediments and in marine areas where oxygen does not reach, we find some marine microorganisms, which have been traditionally quite neglected: Breathless, or anaerobic, marine microorganisms that do not breathe oxygen like us, but something else.

These marine areas are called ‘dead zones’ because most marine life, like whales and fishes die, while for anaerobic marine microbes is the perfect playground.

Lack of oxygen or marine deoxygenation is mostly caused by warming due to climate change, pollution and overfishing, all of these caused by us, humans.

Climate change is causing rising temperatures, extreme weather, melting ice, and higher sea levels, which threaten ecosystems, food supplies, and access to clean water.

In the last weeks, we have witnessed intense rainfall and flooding in Spain, that has come with destruction and human lost.

Due to the very evident consequences, in Spain, people are now believing that climate change is real, which is not something so evident to others living in other parts of the world.

Are we still in time to do something about it? or that a climate crisis is serious is something that you only realize when it is too late?

When it comes down to marine microbes, what can we do as scientists?

To know how they are affected by climate change, because that affects the entire marine environment, but also put the focus on anaerobic marine microbes that live in oxygen depleted areas and have the potential to further contribute to climate change by producing greenhouse gases.

With this in mind, a great opportunity came to our door in 2013, when we got a NWO Gravity grant to work together with the best microbiologists in the Netherlands as part of the Soehngen Institute of Anaerobic Microbiology, SIAM.

The role of NIOZ in SIAM was to study anaerobic marine microorganisms, with emphasis on those involved in the cycling of carbon.

During my postdoc at the University of Massachusetts, i gained a lot of experience in growing anaerobic bacteria, so setting up a lab at NIOZ for anaerobic microbiology was a very exciting experience. Then, we quickly started hiring very talented PhDs and postdocs working on microbial lipids and also on marine microbial physiology.

We started sampling Lake Grevelingen in the Netherlands but even went to the remote Black Sea in several expeditions. Experiments were conducted on board of the R/V Pelagia and very precious samples brought back to continue working with anaerobic microbes from the deep waters and sediments of the Black Sea.

Several theses have focused on marine anaerobic microbes involved in the cycling of organic matter, by Saara, methylated and sulfur compounds, by Peter and Daan, and in the methane cycle, by Sigrid, some in collaboration with amazing SIAM partners of Wageningen University.

SIAM has not only been an amazing source of funding for ten years, but also a once in a lifetime opportunity to advance the field of anaerobic marine microbiology.

It also helped in recruiting and training the next generation of marine microbiologists, not only PhDs, some of them here today, but also international students thanks to the EMBO summer school on Breathless microbes.

Another focus of the work of my group in the past years also involves how microbial lipids have evolved and why we should care.

When looking at microbes and their membrane lipids, we can search if they have the genomic capacity to make them.

Same way if I would go your house and check if you have Spanish books in an attempt to decipher if you are able to speak in Spanish, I can also interrogate microbes to their ability to make a lipid.

When we look at the genes of microorganisms, we open a book that tells us their story: how do they make these lipids? Since when? What happened during the course of evolution?

Membranes lipids of the cells of Bacteria and Archaea are structurally different and probably a reflection of the adaptation mechanisms that they had to acquire over time. That leaves us the question on which kind of membrane lipids, which kind of skin, the last universal common ancestor, LUCA had, and how this differentiation, or "lipid divide” took place.

In this kind of research, we have combined lab experiments with omic approaches, and we have even dived to the bottom of the Black Sea looking for answers. The ocean is not only the playground of marine microbes, but it also hides many secrets on how life appeared and evolved on planet Earth.

All and all, after introducing you to the amazing microscopic heroes living in the ocean, their adaptations, their hopes and dreams, their lipids, I hope I have convinced you by now that having a special chair in Marine Microbiology at the Faculty of Science at Utrecht University is really important.

The focus is on marine microorganisms from the past to the present to the future, understanding their diversity and their roles in natural processes, which is crucial for tackling climate change's effects on marine life.

This position aligns with Utrecht University's commitment to sustainable development goals related to ocean protection and climate action.

I am deeply honored by the opportunity to serve as a special chair Marine Microbiology in Utrecht University. I cannot wait for the new collaborations and opportunities that will strengthen the collaboration between the Faculties of Geosciences and Science, and the collaboration with NIOZ, and of course contributing to educating the next generation about the importance of the oceans.

The future of marine microbiology looks bright; however, major challenges remain.

Public engagement in marine microbiology is crucial because it raises awareness of the vital roles that microorganisms play in ocean health. As scientists, we have the responsibility to reach up to non-scientists to all ages and levels and learn how to make the message across, not just from a podium but also in schools, collaborations with artists, journalists, and in community events.

Looking ahead in the future, another major challenge is how support marine microbes in their quest to support the biogeochemical cycles in the ocean

While microorganisms are essential for maintaining Earth's balance, their ability to cope with rapid climate change is limited and threatened by human activities.

To protect our planet, we must work together to reduce our environmental impact and support marine microorganisms and ecosystems to ensure a healthy Earth for the future. It's time to take action and safeguard the environment that sustains us all.