MODULE 3, LESSON 2

BIOLOGY OF ABYSSAL POLYMETALLIC NODULES

LECTURE NOTES

Hello everyone, I'm Ellen Pape, a deep-sea benthic ecologist from Ghent University in Belgium, and today I will give you a brief lecture on the benthic biology and abyssal polymetallic nodule regions. First I will give you a quick recap on what polymetallic nodules are, how they are formed and where they can be found around the world. Then I will explain to you the importance of biological research in abyssal nodule regions, after which I will give you a quick introduction to some general deep-sea benthic biology, after which I will focus on abyssal nodule regions and stress some of the similarities but also dissimilarities with other abyssal ecosystems.

Then I will give an overview of some of the current priority biological research topics, and then I will end with three take-home messages for you. So polymetallic nodules are golf ball or potato-sized rock-like accretions with diameters typically ranging between 2 and 10 centimeters, though they can be a lot larger. Here on the right-hand side you can see a cross-section of such a nodule.

They lie mostly on top of the soft sediments and they contain some metals which are of commercial interest. These are primarily for the nodules - nickel, copper, cobalt and manganese, and this is also why these are being explored with future deep seabed mining in mind. However, these nodules grow quite slow and they grow only at several millimeters per million years.

Now how are they formed? They are formed through a concentric growth around a nucleus, and that could be a shark's tooth, through the deposition of dissolved metals coming either from the water column or from the sediment's pore water or both. And this process is hypothesized to be mediated by microorganisms, so by biology. Now where can these be found? Here you can see a map showing in blue the different regions where nodules can be found, and it shows that they are mostly in the area beyond national jurisdiction as they are outside of the exclusive economic zones which are shown here in white.

They occur at abyssal depths between 3000 and 6000 meters in areas with low sedimentation rates. So when I'm talking about sedimentation, I'm talking about the organic matter but also some inorganic matter that's formed in the surface layers of the oceans where there's enough sunlight for photosynthesis to happen, and then this organic matter and inorganic matter sediments or sinks through the water column and then it winds up at the seafloor. Now you can see that these nodules occur in different regions around the world, and one of those regions is the Clarion-Clipperton zone or the CCZ framed here in orange.

It's located in the northeastern Pacific Ocean and it's one of the areas characterized by high abundances of high-grade nodules. This is also the region where most contractor areas are located, and therefore it's also the region where most biological research has been conducted to date, and this research is being conducted by scientists that work in collaboration with contractors but also independent researchers. Now the conduct of biological research in these abyssal polymetallic nodule regions is important, not only because we want to understand what the ecosystems look like and how they function, but also in light of potentially imminent deep seabed mining.

As a deep seabed mining operations will impact the environment, and here on the right-hand side you can see a diagram showing a deep seabed mining scenario within wide different environmental pressures that are expected to come with it. But what is not known yet is at what temporal scales and at what spatial scales will these impacts be and these effects will last, and what can be done to mitigate these impacts or effects. So that's why there is a need for scientific studies, including biological ones, to be able to predict, assess, and mitigate environmental impacts.

So to be able to predict and evaluate impact you need to know what the ecosystem looks like before an operation commences, and this is also known as the environmental baseline. And what is important to realize is that it needs to include natural spatial and temporal variability, so it's not an assessment at one point in time at one location, no it needs to have an include spatial and temporal variability. It's also important when an operation is happening and you survey your ecosystem after the operation you want to be able to distinguish whether the change that you see, if there is a change, whether it's because of your operation or whether it is just part of the natural temporal variability.

Environmental baseline studies are also a requirement for contractors, a requirement that is implemented by the International Seabed Authority, and it's also a part of the mining code, the recommendations for contractors to assess potential environmental impacts because of their exploration activities. An overview is also given of the different biological components to be studied in their areas. Now as we are covering polymetallic nodules in this lecture and they are found in sediments, I will focus on the benthos.

Benthos are sediment associated organisms and based on their size, different size classes can be delineated. So the group of the largest organisms is termed the megafauna, they are typically larger than one to two centimeters and one of the taxa that are quite prominent in the nodule regions in the megafauna are the halothuroidea or sea cucumbers and they live mostly on top of the sediment surface. Then within the sediment you have the macrofauna.

Macrofauna are larger than 300 microns, so to get these animals from the sediment you need a sieve, a 300 micron sieve. These are dominated by polychaetes or bristle worms. Next up you have the meiofauna, they are larger than 32 microns and they are largely dominated by nematodes, which are unsegmented and of which you can see a picture here.

And last but not least we have the microfauna, everything that's smaller, so that's unicellular eukaryotes but also bacteria and archaea and they can be found in sediments but also in the water column. So what do these benthic organisms feed upon? Well most of the deep sea benthic habitats, and that's with the exception of the chemosynthetic environments, they depend on photosynthesis derived organic matter that's produced through photosynthesis in the surface layers of the ocean, as I've already talked about. So then it sinks down to the water column but while it sinks down through the water column it's being degraded, it's being consumed by other organisms.

So when we're moving to the deep sea and the deep sea floor, only a very limited percentage of that organic matter winds up there. So you can appreciate it's a food poor environment and this is also reflected in the low biomass values of organisms and the low abundance values. So here on the left-hand side you can see a graph showing on the horizontal axis water depth and on the vertical axis biomass and you can see for the different benthic size classes, which are shown here in different colors, there's a decline in biomass with an increase in water depth except for the bacteria.

What is interesting as well is that at the onset of abyssal depths at 3000 meters you can see that maya fauna becomes more important, and meiofauna is shown here in red, it becomes more important than the larger size classes. That being said, so we have low biomass values in the deep sea, we have high biodiversity and there's different theories trying to explain these observations but I'm not going to delve into this deeper in this particular lecture. So now I have introduced to you to some general characteristics of deep-sea benthic ecosystems and they are also valid for abyssal nodule regions.

Now how the nodule bearing regions stand out from the other abyssal ecosystem is that you have the presence of hard substrates under the form of these polymetallic nodules. And that is also why in these nodule regions you do not only have the soft sediment biota, just like in the other abyssal systems which are soft sediment environments, you also have nodule associated biota. Now within the nodule associated biota we can distinguish between different categories.

So first off you have those that live on the outside surface of the nodules. Some are mobile, some polychaetes for instance they build tubes on the outside surface of the nodules, but most of them are sessile so they are attached to the surface of the nodules. So that means they're also not occurring in the soft sediments as there's a soft sediment environment to which they cannot attach.

What kind of taxa can we find within this group? You can find forams for instance which are very variable in terms of shape and size. This is a foram which is quite large, several centimeters big, but this is a foram as well, only a few millimeters big. You can also find sponges which are indicated here by the white arrows on this picture here.

And what is also interesting to know is that the sponge stalks that grow on the nodules are sometimes being used by other fauna. And for instance this was an observation, this was a picture taken in the Peru basin which is south of the CCZ, where an octopus was using the sponge stalks to deposit its eggs. Now the sessile fauna living on the outside surface are filter feeders, so they feed upon dissolved or particulate matter in the water column.

Another group of nodule-associated biota lives inside the nodules within the network of crevices. So nodules are not massive, they actually display a network of cracks filled with sediments and in here you can find fauna as well. This is a picture of a polychaete that was described from the Clarion-Clipperton factory zone and it was found there in the nodules.

You can also find forams again in the nodule crevices, but what you can also find is metazoan meiofauna. And this is actually a figure from a study done by myself and colleagues where we looked at metazoan meiofauna in nodule crevices and also in the surrounding sediment. And we observed nodule crevice meiofauna to be a subset of the sediment meio fauna.

So some taxa from sediments did not occur in nodules, but both of them, both of these substrates were dominated by nematodes, so these unsegmented worms that are highly dominant. So nematodes dominant, so we actually focused a little bit more on that phylum and we looked at community composition and also feeding type composition and we saw it differed between sediments and nodules and we actually found nodules with these to be more prevalent inside the nodule crevices compared to the sediments, pointing towards nodules actually offering a specific ecological niche to these nematodes. Another group of nodule associated biota are the microfauna, so that includes bacteria and archaea inside and outside the nodules.

And this is actually a figure from a scientific paper that was written by Molari and colleagues where they looked at nodules from the Peru basin and they compared the microfauna between sediments and nodules and they actually found that nodules show the lower diversity, but also a distinct composition when compared to the sediment. So here are the sediment samples here in black, the nodule samples are here in red, you can see they are clearly separated. And the nodule communities were typified by higher abundancies of metal cycling groups and groups that were involved in nitrification.

So again, nodules being a specific ecological niche for these prokaryotes. So it is clear that nodules are important for the nodule associated biota because the nodules actually are a substrate for these organisms, but scientists, and maybe others as well, have been wondering about the importance of the nodules for the fauna that lives in the sediment surrounding nodules. And this has been studied by comparing fauna between sediments with different quantities of nodules.

And so based on the current knowledge base, the following table was produced, showing different community attributes for different metazoan size classes. And some of the results were quite consistent. For instance, megafauna was always found to be more abundant in sediments with more polymetallic nodules, but for some groups and some attributes, this was less consistent.

And results were sometimes different depending on what taxon was being studied or what taxonomical resolution was used. For instance, when you're looking either at family level or species level, results could sometimes be different. Now, besides nodule abundance, research has shown there are also other important drivers of these soft sediment faunal communities, which are also important in other abyssal ecosystems.

And those are, for instance, seafloor POC flux, or food availability, and that's important for all groups, for all size classes. Carbonate compensation depth was very recently shown to be important for the megafauna. And so that's the water depths below which organisms can no longer build carbonate shells, and that has been shown to be important for megafauna.

And also seafloor topography was shown to be important for megafauna, and potentially also for other groups when considered at small spatial scales, at least that has been shown for other abyssal systems. Now, what are some of the ongoing biological studies that are being undertaken? One of the topics that is being investigated is the level of biodiversity at different spatial scales, and also the variability thereof, so spatial variability and temporal variability. And this is a really important study, it's part of the environmental baseline characterization, but it's not an easy task, because there are some challenges, of which I will just name a few.

So first off, most of the metazoan benthic species are still undescribed. And that's true for the CCZ, where more than 90% of the metazoan benthic species does not have a scientific name yet. This is also illustrated in this figure here on the top right, showing on the horizontal axis different faunal groups, and on the vertical axis the number of species.

And you can see that the orange part, which reflects the unnamed species, is the largest. And it makes it hard to get an idea about the total extent of biodiversity, what is the level of biodiversity, but it also makes it hard to actually compare data or species lists between different locations, because it could be that the same species is actually named differently by different researchers, by different contractors, because there's no official scientific name yet. What is also a complicating thing is the presence of cryptic diversity, and it has been shown to be present for some groups, but we are not aware of the total extent, and what are cryptic species, cryptic species are morphologically similar, but genetically different.

And this has been shown to be the case for this amphipod species, so that's one species morphologically speaking, but genetic analysis have shown there was actually four genetic species. Why could that be an issue? Well, this could lead actually to potential underestimation of biodiversity when you're only basing yourself on morphological data. And there are other issues that are also present.

Another topic of ongoing studies is actually the quantification of ecosystem functions. So what are ecosystem functions? They are processes that are taking place within an ecosystem, for instance the flow of carbon, and here below you can see a graph showing the flow of carbon between different components in the ecosystem, and also the direction of these carbon flows. And what is also not entirely known yet, or what needs more study, is the importance of biological communities for these ecosystem functions.

And it has been shown in other deep-sea environments that more diverse communities could lead to better ecosystem functioning, as for instance here, higher nematode diversities led to higher respiration rates. What is also largely ongoing are impact studies. So on the right hand side you can see a figure that's a result from a meta-analysis that was done by Goldner and colleagues, and they looked at recovery rates of fauna, recovery from different disturbance experiments that were done in the past in different nodule regions, and they saw different recovery rates depending on the size class, on the mobility of the fauna, and also between the different regions.

What is important to note is that the devices that were used to create these disturbances in these tests was that it was not really representative of a commercial mining vehicle, because for instance they were much smaller, and also the disturbance didn't last as long. And that's why the mining tests or mining component tests are important, because they are more representative of what a commercial deep sea bed mining scenario would look like. And so in 2021, a test was done with this nodule collector, with this pre-prototype nodule collector that was developed by one of the contractors, GSR, and also in 2022 there was another mining test by another contractor, and that's why it's important to actually keep monitoring these impacted sites.

And that's also being done both by contractors and the scientists that they work with, but also by independent research consortia, such as these two European research projects in which a lot of scientists from different domains are working together. So I've come at the end of my presentation, of my lecture, and I have three take-home messages for you.

So what do you need to remember:

1. So first of all, like nodule-free abyssal regions, nodule-bearing sediments are characterized by low benthic biomass and abundancies, but high biodiversity and this is driven in part by, amongst others, sedimentation rates, so food availability.
2. Different from nodule-free abyssal regions, polymetallic nodules provide substrate for sessile fauna that live on the outside surface of the nodules, but also smaller fauna inside the crevice network that they display, harboring communities that are distinct from the surrounding soft sediments. And so that makes it so that nodules are also important drivers of these soft sediment benthic communities, but also, of course, the nodule communities.
3. And then the third point is that the biological baseline and impact studies are needed to predict, assess, and mitigate impacts of deep seabed mining, and they are largely ongoing. And so that was it.

Thank you for your attention.