DRAFT

It’s a Jungle in There:

The Wild and Wonderful World of Microbiomes



By Sarah Kerns

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Dedication:
with love to my wild and wonderful boys, who have assiduously populated their microbiomes since day one

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No Cell is an Island: Microbial communities in Context

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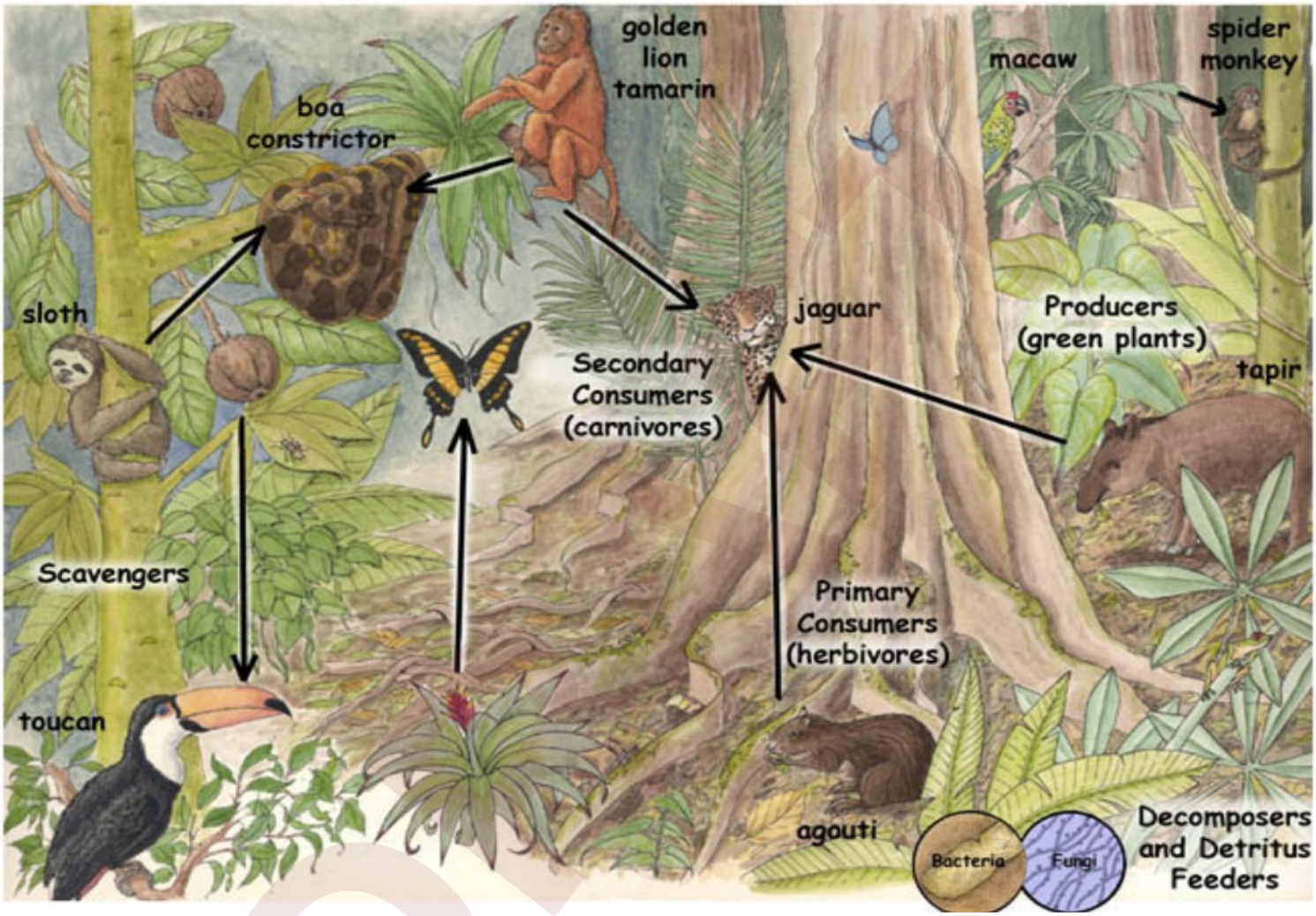
Welcome to the Jungle

In the jungle, lots of plants and animals live together in the same area. They rely on each other to survive. Plants provide food and shelter for the different animals that live in the community, and animals give plants poop for fertilizer, aerate the soil by moving dirt around, and spread seeds for plants. Plants and animals also need each other for the environmental changes they make: plants need carbon dioxide (CO_2) that animals breathe out, and animals need oxygen (O_2) that plants ***respire***. This kind of interconnected plant/animal community is called an ***ecosystem***, and many ecosystems grouped together make a ***biome.***



Ecosystems are not only made of big ***organisms,*** they also contain tiny creatures called ***bacteria***. Even though they are too small for us to see without a microscope, bacteria are an important part of every single biological community. They live in dirt, swim in water, and are on the insides and outsides of plants and animals. Many microbial ecosystems count together to make the microbiome of an area.

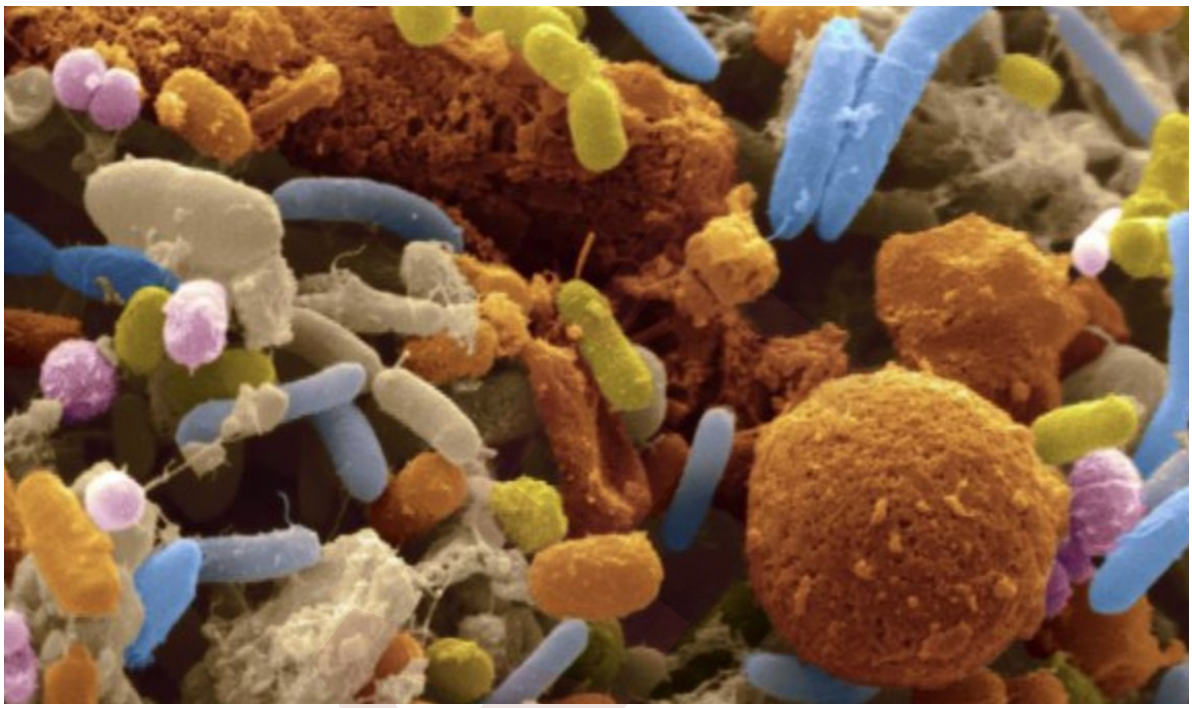
Bacteria rely on each other in a habitat just like plants and animals do- with one giving off things that the other needs, or changing conditions to better suit themselves. Tiny ecosystems, composed of different kinds of bacteria, fungi, and viruses inhabit almost every surface, including surfaces inside our bodies like the digestive tract.

However, not all interactions are helpful. When organisms work together to survive, and both benefit, they are called ***symbiotic***. When one benefits, and the other is neither harmed nor helped, they are called ***commensal,*** and when one organism harms another by taking things it needs, it is called ***parasitic***. Microbiomes, just like jungles, often have some of each type of relationship.

Up Close and Personal

How can a whole community of different kinds of organisms be present without seeing or knowing about them? What are they made of that they can be invisible? Bacteria are only "invisible" to us because they are very, very small. If you use a microscope to look closely enough there is lots to see.

Notice how many cells are in this picture of this microbial community





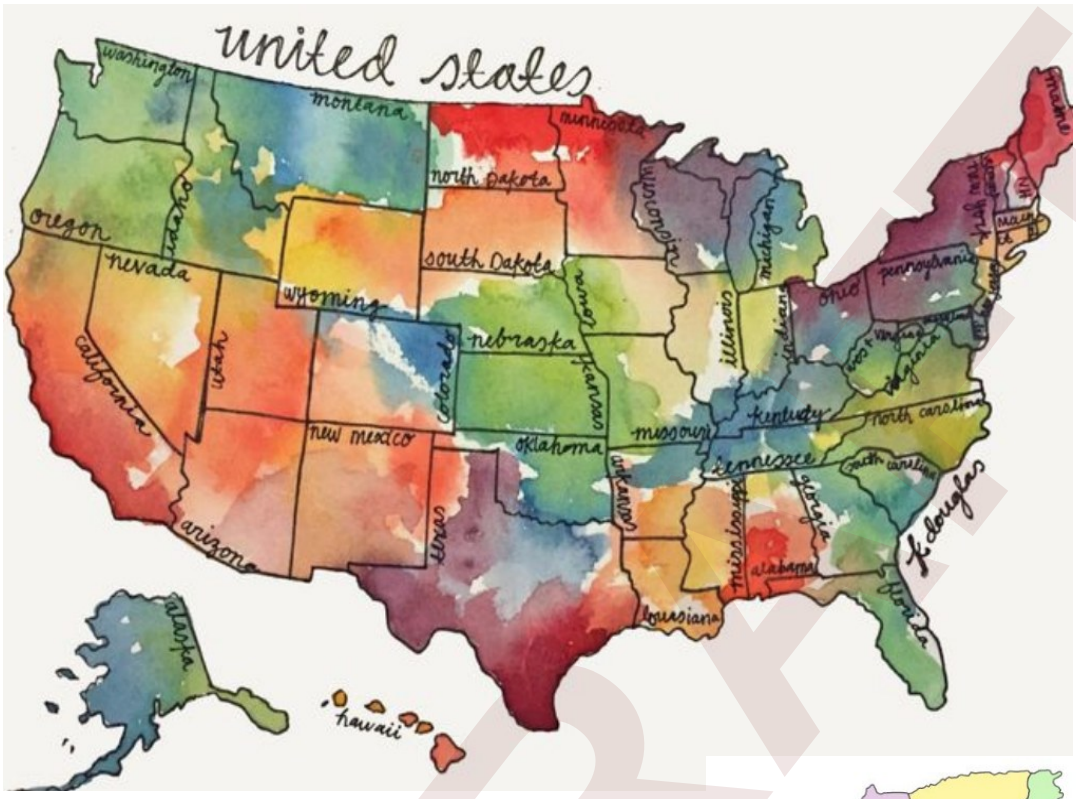
Now compare it to this slice from a blade of grass, also made up of many cells:

Each of these pictures shows a lot of cells together. In each picture, there are different groups of cells and the cells are doing different 'jobs'. So what makes the two groups of cells so different? Specialization and organization.

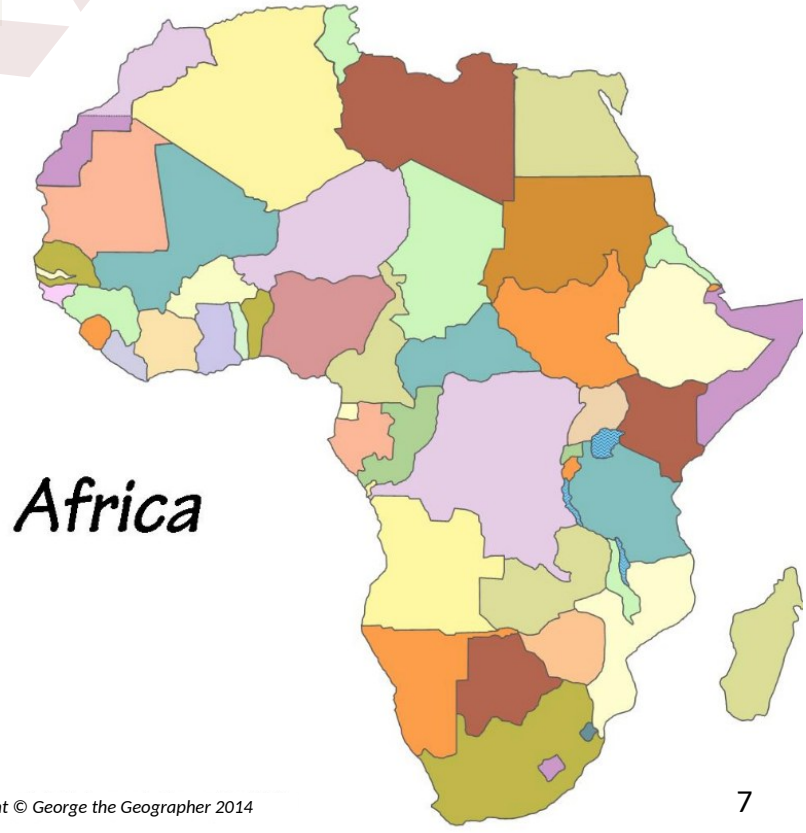
Pieces Make a Whole, Or a Whole Lot of Pieces?

The plant cells in the slice of grass are all part of a **single** organism, but each bacterial cell is a whole organism all by itself. Bacteria are unicellular organisms. For an example of the concept, look at these maps:

They look alike, both are full of 'cells' made from political boundaries, but they are different on an organizational level. The United States is a country, made of 50 different states, it is an 'organism' made of many 'cells'.



The African continent is a 'community' where each 'cell' is a country in its own right. Although it is in proximity and interaction with surrounding 'cells'. Each 'cell', or country, is an entity to itself.



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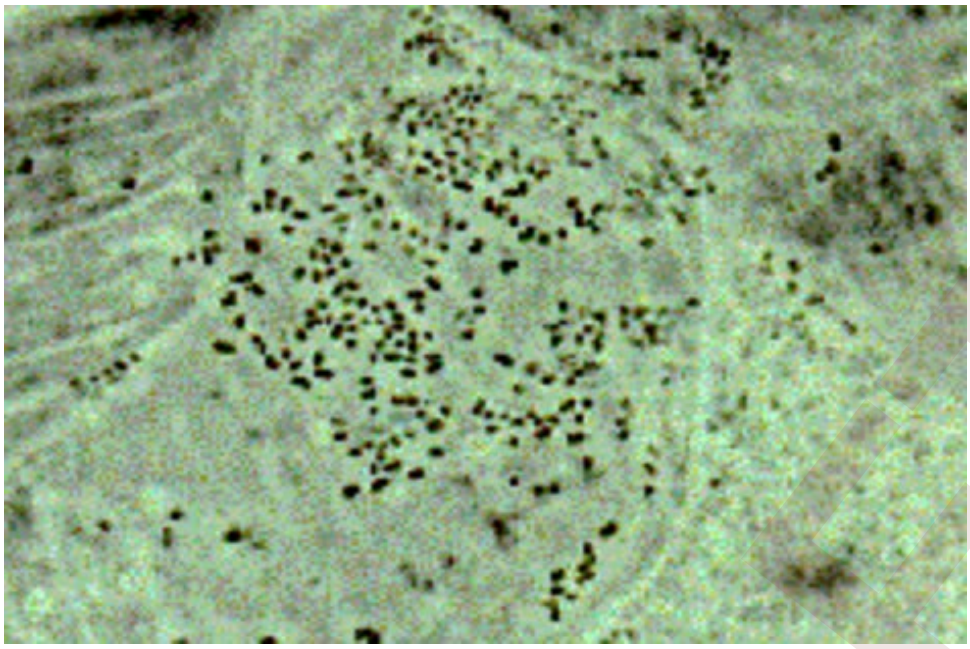
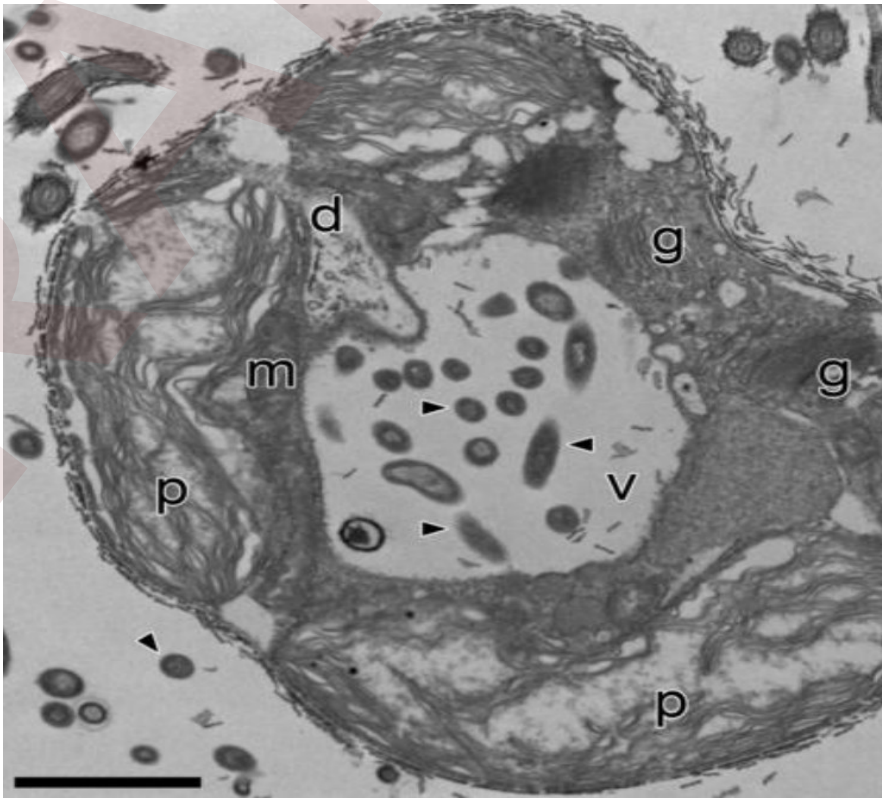
Size Matters

Another way that Bacterial cells differ from plant and animal cells is scale. Bacterial cells are much smaller than plant and animal cells- an average of 50 times smaller.



The light outline in this picture is a plant cell, and the dark spots are bacteria on the outside of the plant cell

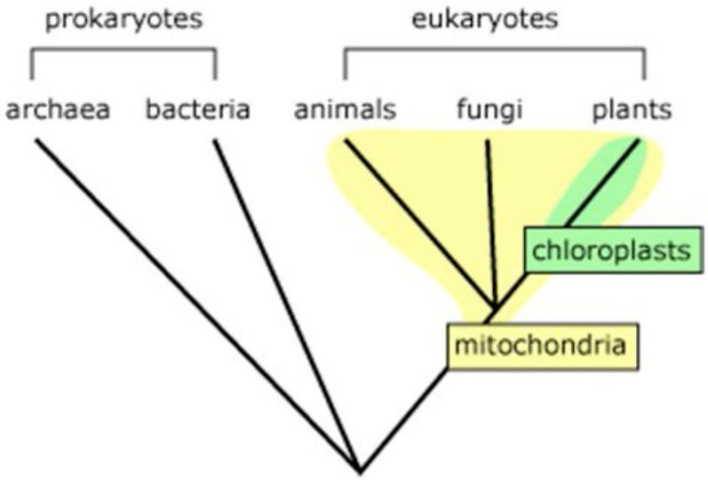


the black arrows in this picture show bacteria inside an animal cell

Even knowing the relative size of cells, it can be difficult to understand just how small bacteria are… for instance, a teaspoon of soil contains more microbes than there are people on earth.

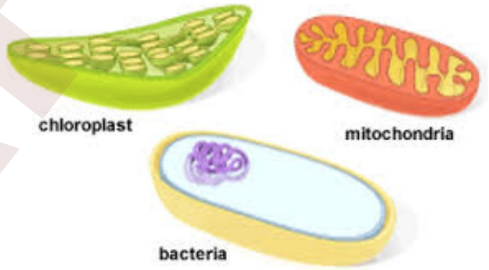
Invasion of the Clones

Bacteria are evolutionarily older than any other living organism. It is thought that they were the first living creatures on earth and we can see some clues of this in their structure.

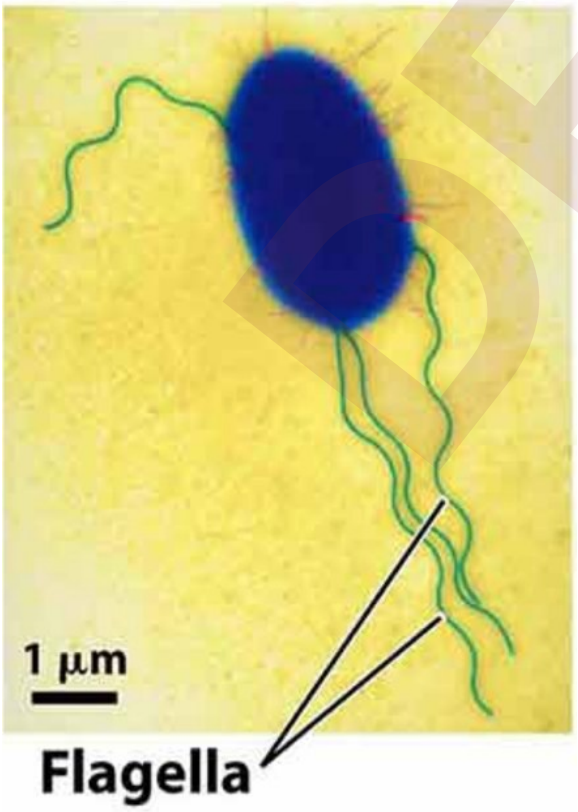


Bacteria are small, they lack ***multicellular*** organization, and they have no membrane-bound ***organelles***, including ***nuclei.*** This makes them ***prokaryotes*** (in Greek, *pro* means *without* and *karyote* means *kernel*, so they are the organisms without a kernel, or nucleus). Prokaryotes reproduce through ***binary fission-*** they just split in half and make two cells out of one- a straight copy, or ***clone***. They have short life cycles so they evolve quickly and can be found in almost any environment on earth.

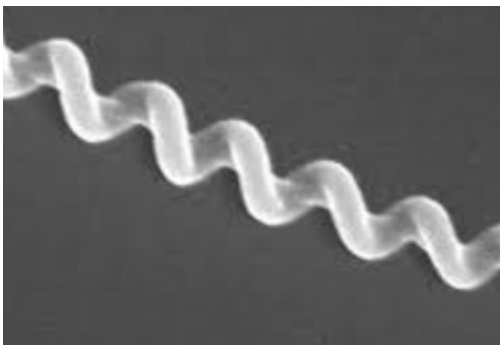
Plants, animals, and fungi, in contrast, all have nuclei, and are called ***Eukaryotes,*** for this reason (in Greek, *eu* means true, so they are the 'true kernel' organisms). They reproduce by mixing their genetic information with another cell's to make an entirely new combination that is different from either of the parents, and they live much longer: months and years compared to the hours and days of bacteria.



Millions of years ago, some bacteria moved to live inside eukaryotic cells, and the symbiosis worked so well that they stayed. These internal bacteria are now inside plant cells (chloroplasts) and most animal cells (mitochondria).

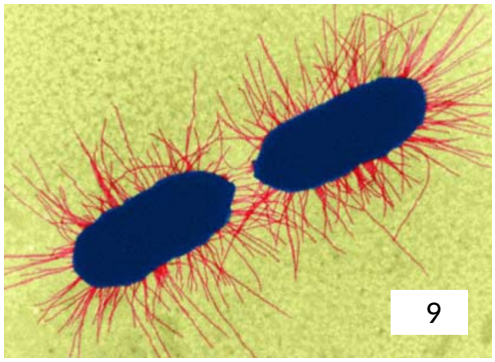


Many bacteria have small string-like appendages- and ***flagella-*** to help them move and attach to surfaces. Flagella are long and wavy and each cell only has a few, they move like a propeller to help bacteria swim.



Some bacteria, called ***spirochetes*** for their spiral shape, have flagella inside their membrane, which makes them look like tiny corkscrews.

Pili, in contrast, are short and stiff. They help bacteria to share genetic information and are (like Velcro) good for sticking to surfaces and each other.



Useful Pets, the Human Microbiome

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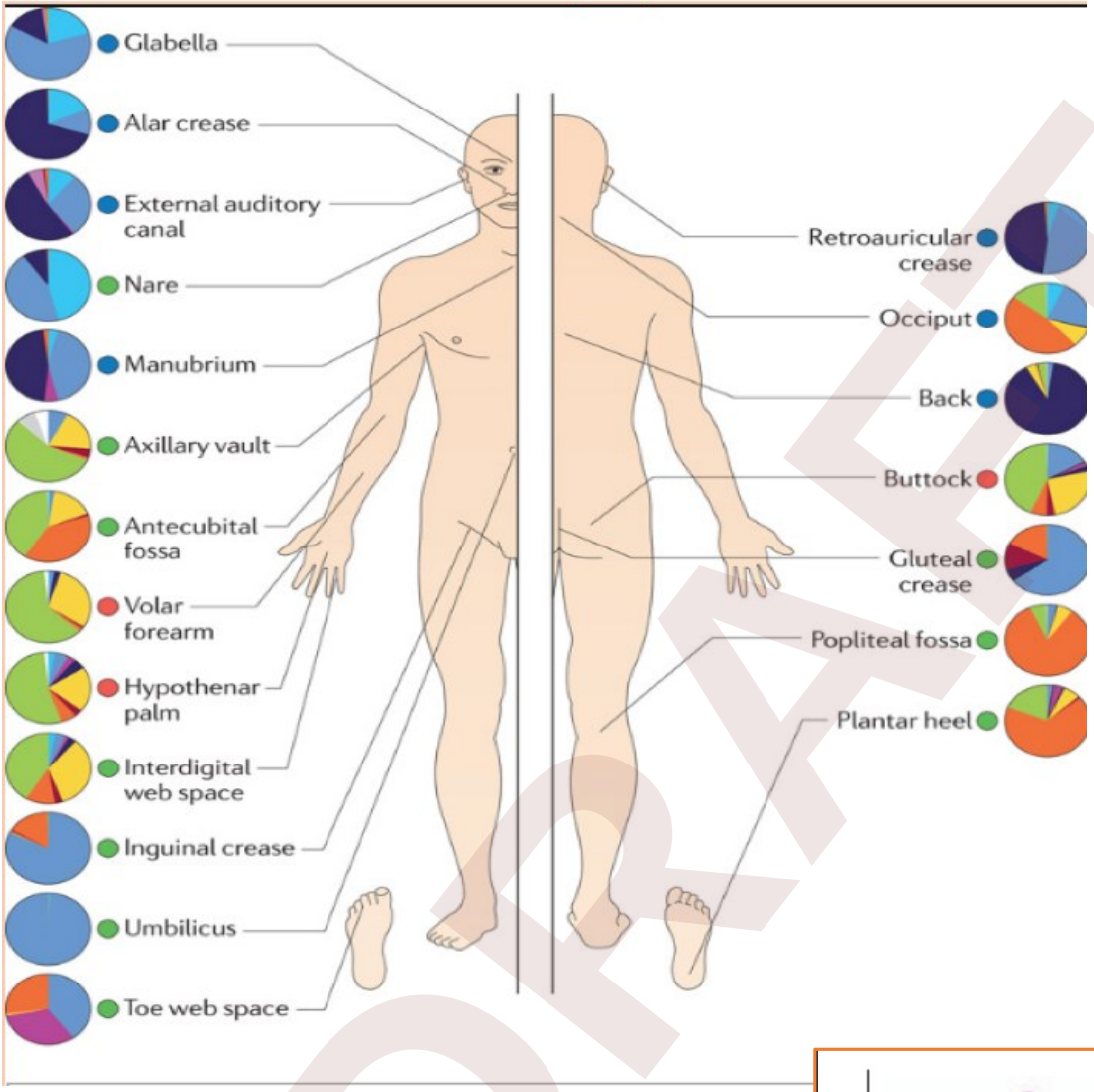
A Biome Made of Habitats

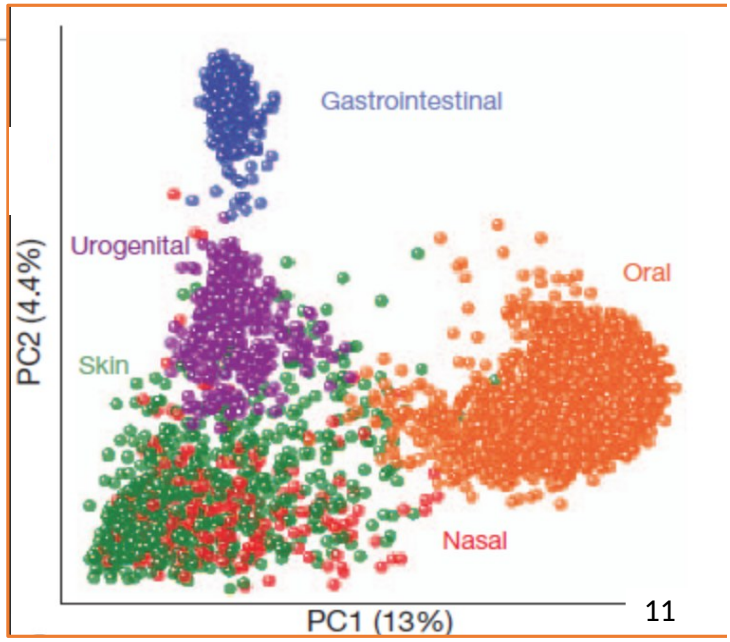
Just as the Earth has many macro (large)-habitats: desert, jungle, swamp, or ocean, our bodies have many micro (tiny)- habitats. The tiny size of bacteria means that even an area as small as the back of your hand, under your arm, or in-between your teeth can constitute a whole micro-habitat containing tens of thousands of microscopic organisms and many full communities.



This body map shows various body habitats, each with different communities of bacteria (each bacteria type is represented by a different color).

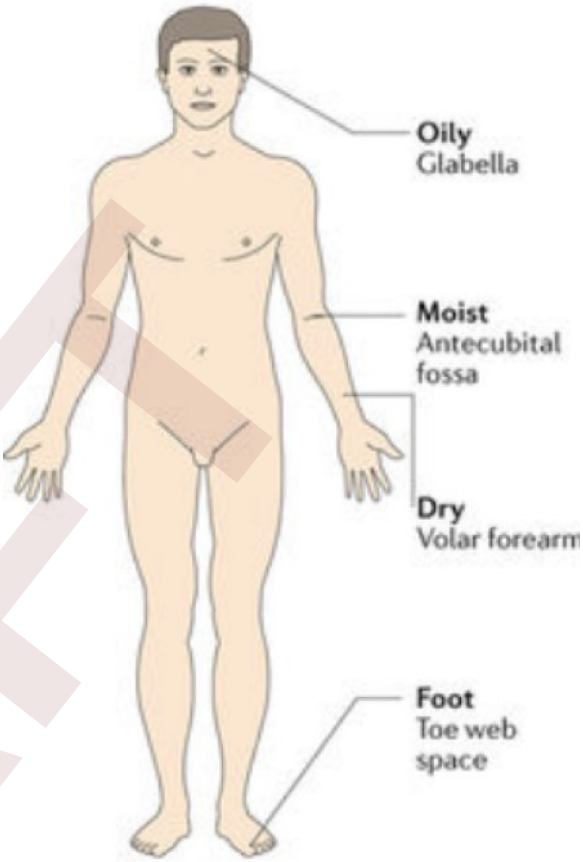
The human body has at least twice as many bacterial cells in and on it as it has human cells! But because they are so small, all those microbes only weigh about 1.5kg, or about as much as your liver.

This graph shows populations of bacteria based on their genetic similarities. We see that bacteria from the gut (gastrointestinal- blue), are most similar to other gut bacteria: because blues group together. We can also see that they are different from the mouth (oral- orange) bacteria because *they* group together in a separate area. Each community lives in a different habitat and has survival adaptations for their own special habitat. These adaptations make them similar to bacteria in the same habitat, and different from microbes in a different one.



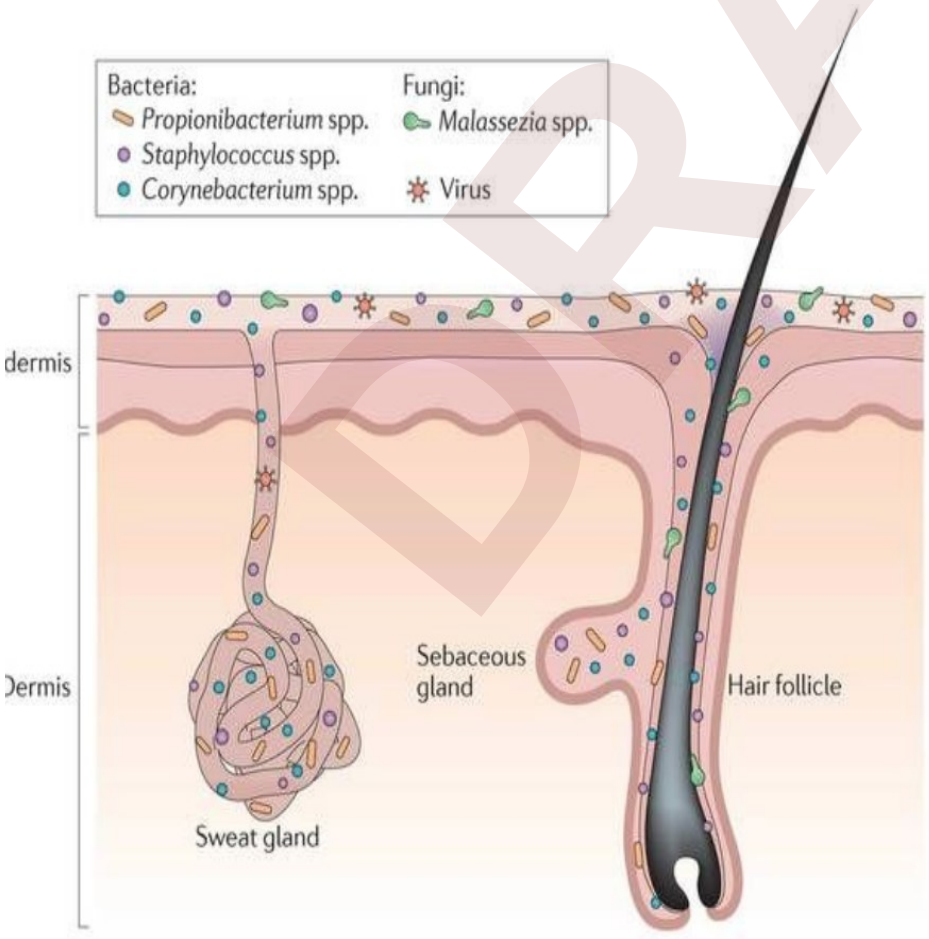
Skin Deep

One place bacteria live on humans is our skin, and since the skin is the largest organ in our body, there are lots of different surfaces and conditions on it: our arms are open to the wind and air, and tend to be dry, while our armpits have extra sweat glands and get less air, so tend to be moist. Our faces are more likely to be oily, and feet get more exposure to dirt and sweaty socks. Each of these different set of conditions requires different adaptations for the bacteria that live in them.



Some bacteria on our skin benefit us by taking up space. It is like camping- If you have your tent set up on a piece of ground, another tent can't be set in that same space. You are competing for the space and inhibiting others from setting up a tent there. Bacteria do this too- they camp out in a spot so that others can't.

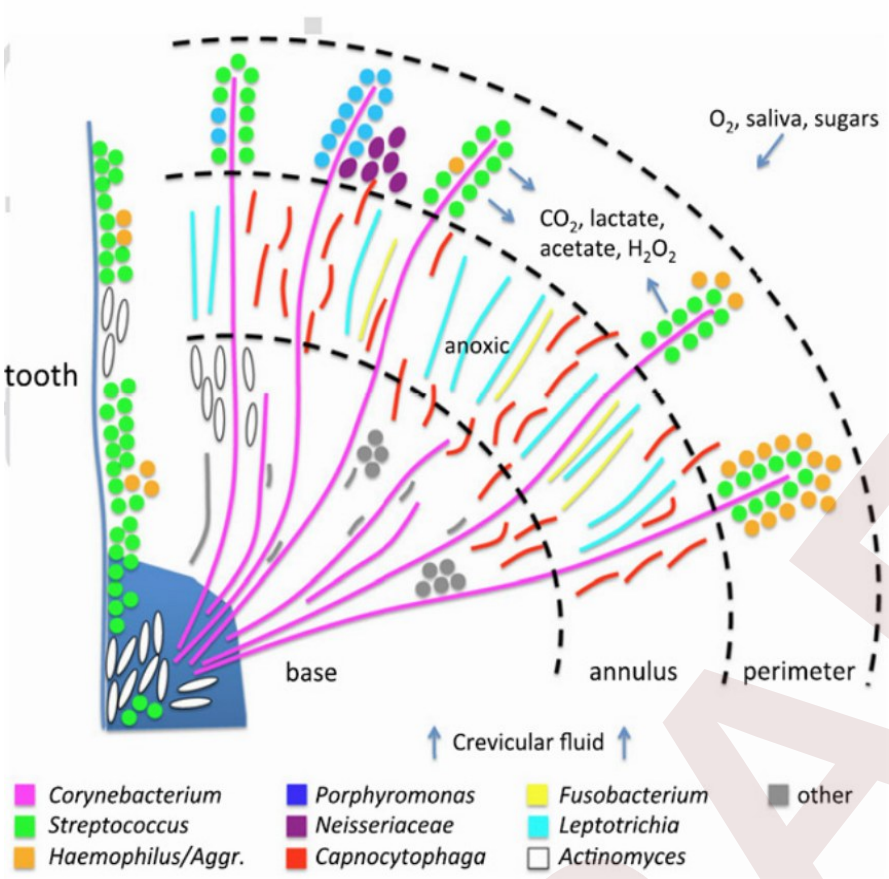
By taking up space and resources, good bacteria keep fungus and bad ***(pathogenic***) bacteria which also live on our skin, from growing out of control. It is an important balance.



Bacteria don't just live on the surface of the skin, they also inhabit sweat glands and hair follicles. They can cause pimples, smelly armpits, and infections, among other things. These issues are a result of imbalance- the good bacteria are no longer keeping the pathogenic ones in check. Injury can cause imbalance at any age, but a common time for issues in the skin microbiome is around puberty. This is because ***hormones*** cause more sweat and oil to be produced- changing the skin environment and causing a ***concomitant*** change in microbial balance.

Don't Look a Gift Horse in the Mouth

Similarly, Microbes near your teeth can either protect them, or cause tooth decay through imbalance.

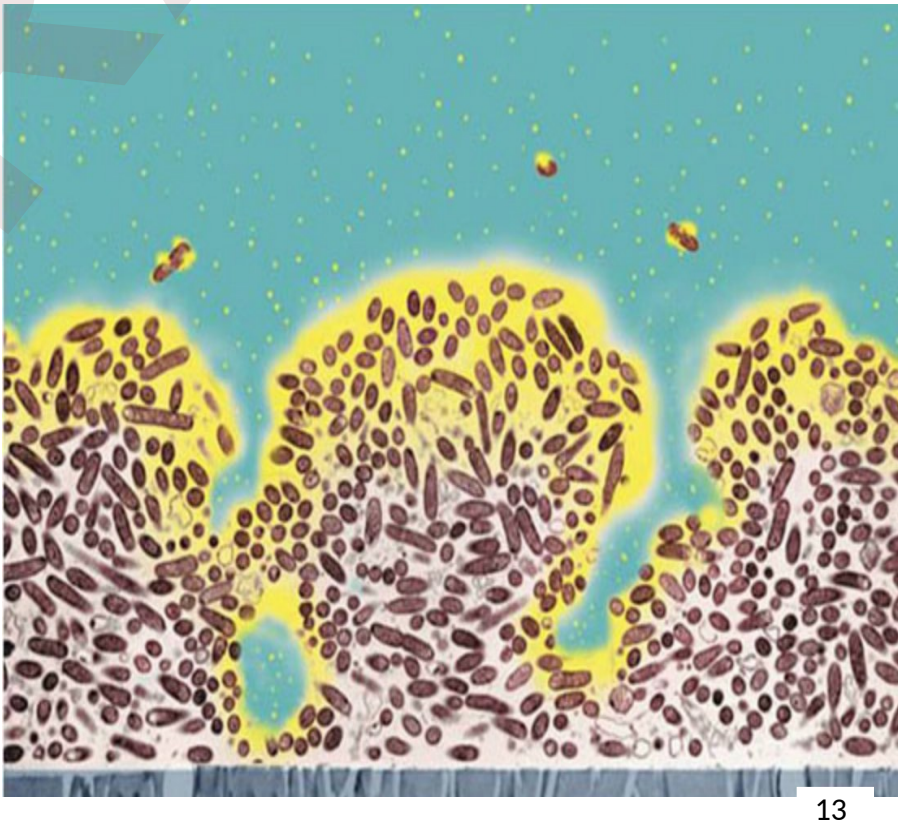


Some mouth bacteria produce acids that eat away at tooth enamel, and others, which are commensal, use those acids in their life cycles. If these two types of bacteria live together, the acid doesn't hurt your teeth because the commensal species 'eats' the acid before it can come in contact with your teeth. But if there are not enough of the commensals to use up the acid, your teeth will be damaged by it.

Balance is essential. Any microbiome community must have many different kinds of microbes present for it to stay healthy. This variation is called diversity. The diversity, or species variety, in a single environment is called ***alpha diversity***, and if a habitat has "high alpha diversity" it means that there are lots of different species in it.

Because bacteria are unicellular organisms, their communities are built based on interaction: they settle together with other microbes in ways that benefit their survival, like a clownfish living inside a stinging anemone.

One such type of grouping is a ***biofilm***. Both the above illustration and the photo to the right are examples of mouth biofilm organization. Notice that within the biofilm there are both microbes exposed to the elements, (in this case, saliva) and ones that are protected by other microbes and not exposed (the white areas of the photo). Often biofilms are mixed communities, containing bacteria, fungi, and even ***protozoa*** that group together for survival.



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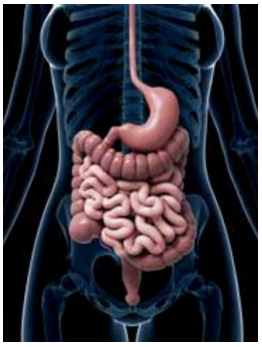
Blood and Guts

The largest proportion of bacteria in the human body lives in the gut, and Science is just starting to uncover all of the important roles that this part of our microbiome plays in our general health.

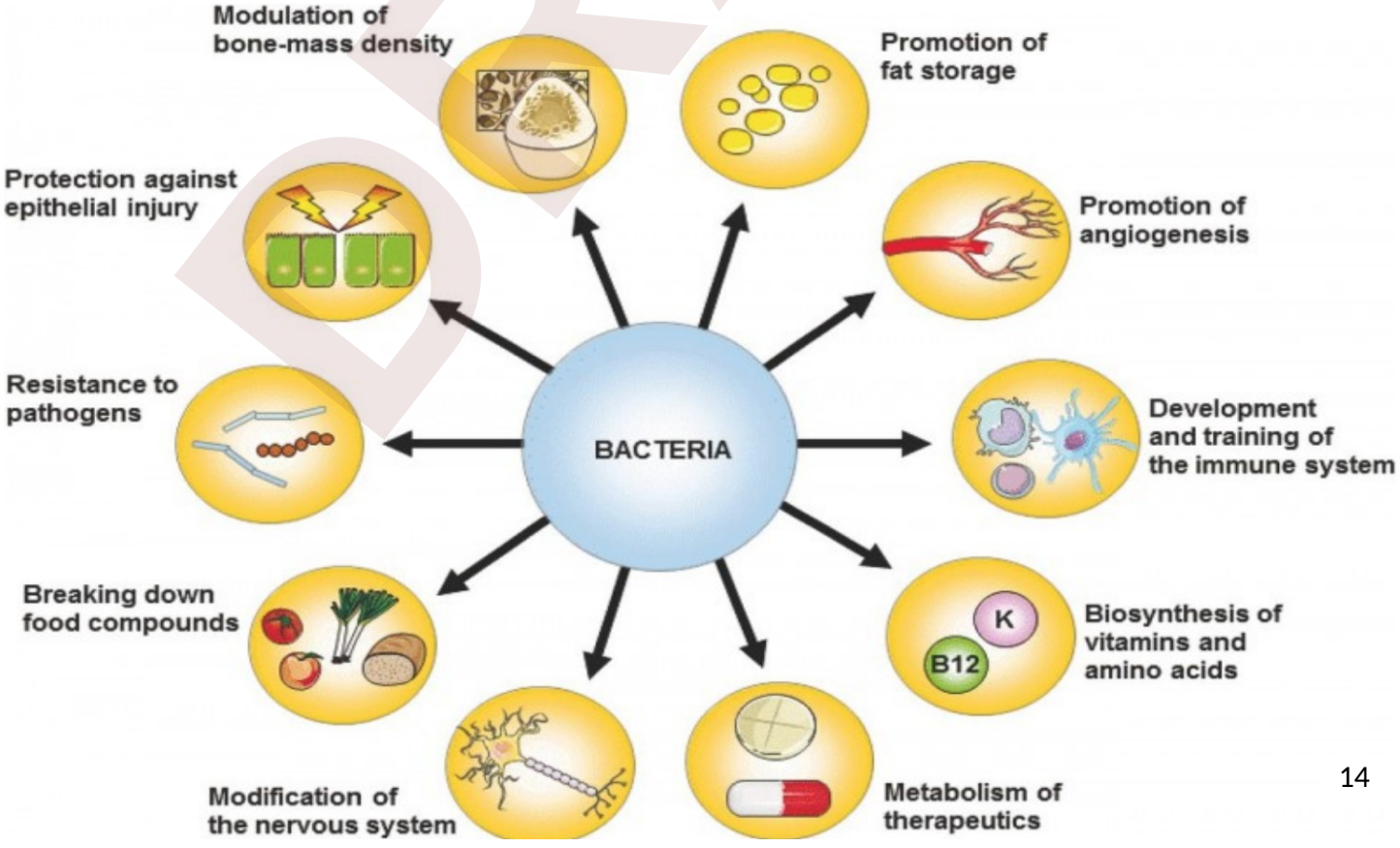


Our specialized gut bacteria survive without oxygen and help to break down food and synthesize vitamins our body cannot make or get on its own. Our gut ***microbes*** are responsible for breaking down our food to make it useable. If we didn't have them we could eat and eat but would not be able to get the nutrients we need from the food.

While gut microbes perform similar roles to those that we have already discussed in skin and mouth, like using up space and resources to exclude pathogenic organisms, and forming protective coatings on surfaces, they also provide other benefits by sending signals that our body can interpret.

In order to communicate with other organisms, and also just as a by-product of living, bacteria produce compounds called ***metabolites.*** These molecules and proteins are different based on the health and environment of their parent bacteria: in different conditions, different metabolites are ***excreted***. This means that metabolites are really good indicators of the bacteria's local environment, and within the human body, they can be interpreted as signals about body condition. Our bodies have learned to respond to this information.

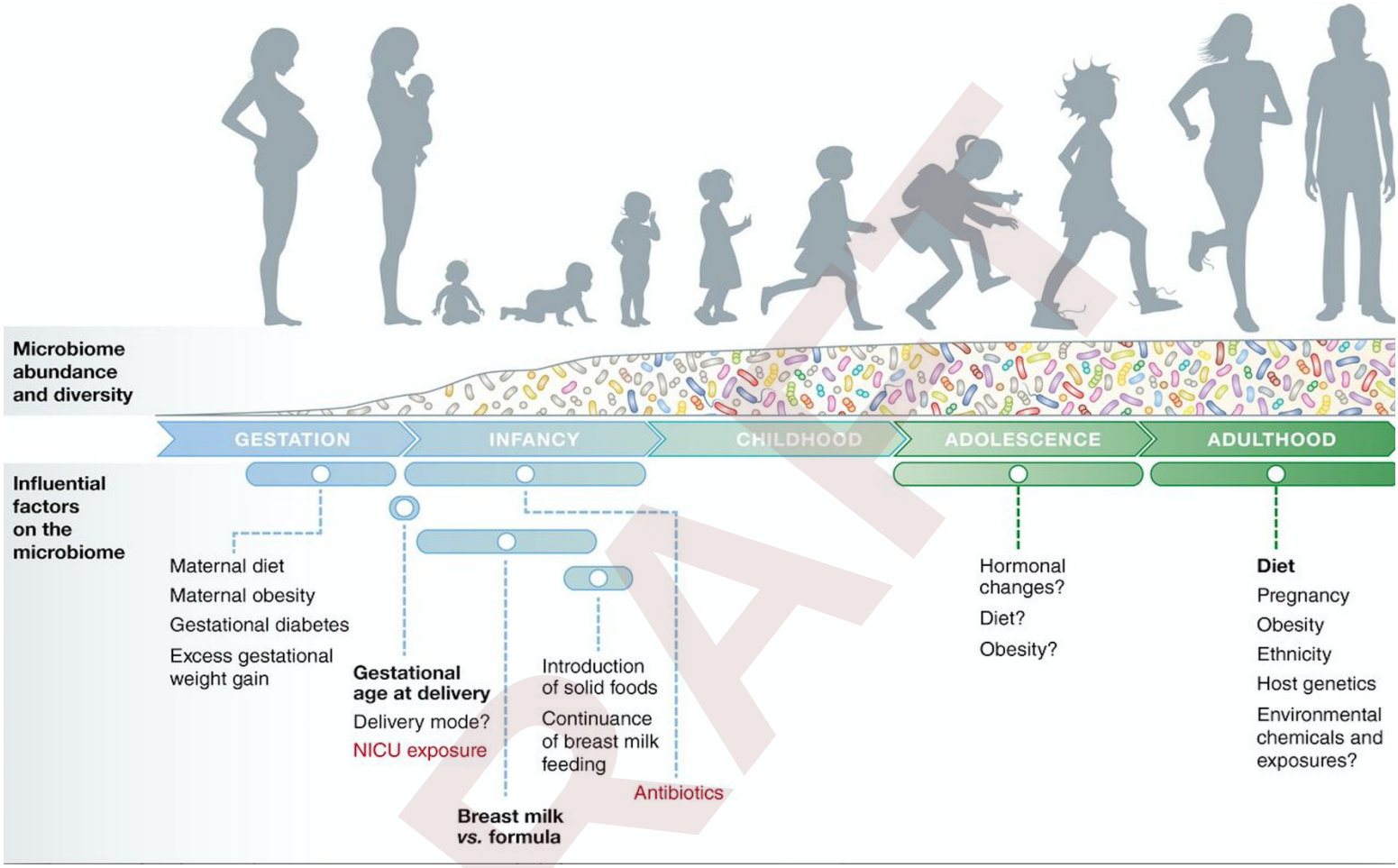
For instance, when a bacterium is well fed, its metabolites show that. The body senses them and may make more blood vessels (***angiogenesis***) to carry the extra nutrients away. Or when there is a pathogenic organism threatening the bacterial survival, it gives off antimicrobial compounds (this is where we get antibiotics!) and the body can sense them as a signal to mount an immune attack on the bad stuff. Bacterial metabolites can even have a strong effect on our mood and ability to think.



Population Bloom

But where does our microbiome come from? Are we born with it?

No. When we are born, we do not have all the bacteria we need to be healthy in and on our bodies. It takes many years to get them. We get them from our mother, our caretakers and friends, our environments, the food we eat, the diseases we are exposed to, and even our pets.



This chart shows some of the things that change our microbiome during our lives. We start as infants with very little bacteria at all, but our bacterial population grows as we grow. Both ***abundance***, or general number of microbes present, and ***diversity*** (the different types of microbes that are there) increase throughout childhood. By adolescence the abundance on and in our body is complete, but the species variation, or alpha diversity, can change throughout our lives.

Our gut microbial community comes mostly from our childhood caretakers and is almost settled by the time we are 3 years old. It lasts throughout our lives and is resilient to change. Small events and temporary alteration due to change in diet or getting sick, are normal, but it can also be changed permanently by serious illness and heavy medication.

Our skin microbial communities are different because they change with each stage of life based on the oils and sweat caused by hormones. Skin micro-communities can be significantly changed from childhood levels by puberty and adulthood. Also, because skin is more exposed to the outside, environmental conditions like weather can play a greater role in the microbes that live there.

A Method to Their Madness: Understanding Microbiome Data

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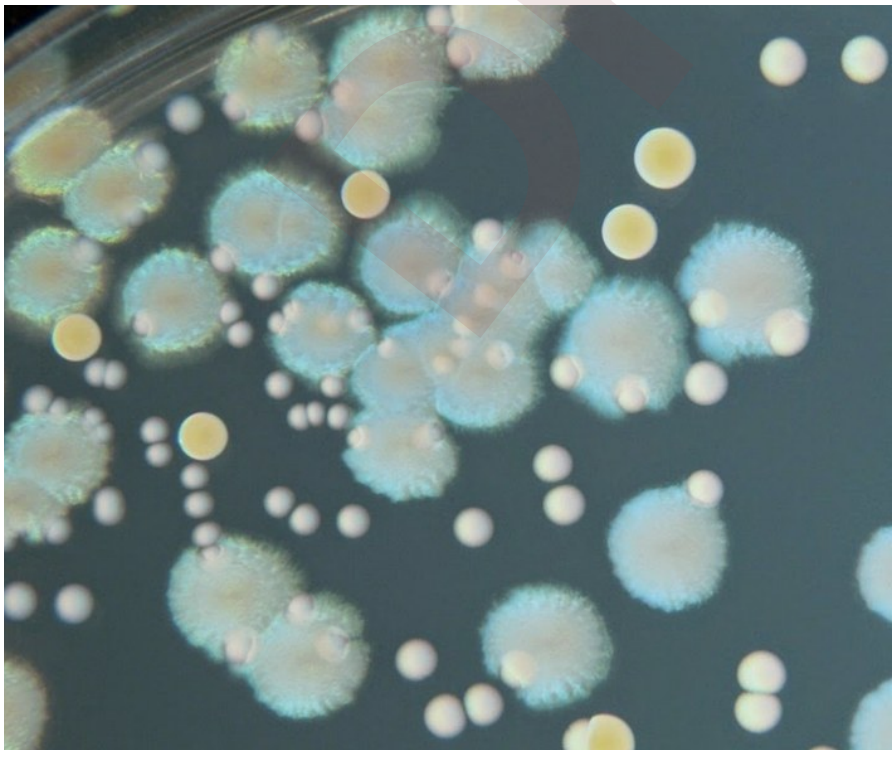
They Have Culture



In order to study how the microbes living on and in our bodies contribute to our body's health and illness, we need to gather data on them. Traditionally, scientists did this by culturing, or growing, bacteria from human samples on goo-lined ***petri dishes***, called "plates". But it was noticed that only a fraction of the bacteria seen in the original samples grew that way. This was called the ***Great Plate Count Anomaly*** because what grew on the plates was only a tiny part of what they had seen under the microscope in the original sample. Can you guess what the problem was?

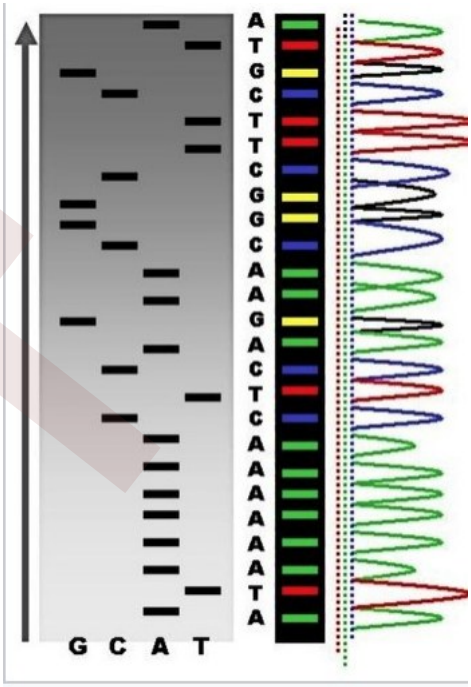
It was habitat. The conditions on the plate and in the lab were not the same as those in and on the body, and many of the microbes were ***fastidious***, meaning they needed specific conditions to grow. Because of air, temperature and food differences between the gooey ***agar*** plates and the human body, many bacteria that lived in and on people could NOT live on the plates. Scientists started getting and storing samples more carefully, and they studied which extra things (called ***amendments*****)** needed to be added to help the microbes to grow. Soon they could grow almost all of the bacteria they had seen in the original samples. There was, however, one remaining issue: it was the microbes that were so rare that they couldn't see them- even under the microscope.



Some rare bacteria (those with low abundance) have been hard to find and evaluate. These hidden bacteria are called ***Microbial Dark Matter*** because, like dark matter in space, even though we cannot see these microbes, we know they are there by seeing the things that they do. There has been progress in locating such hidden microbes through growing them with other microbes from their habitat (called ***co-culturing***), and this makes sense with what we know about how much bacteria within communities rely on each other.

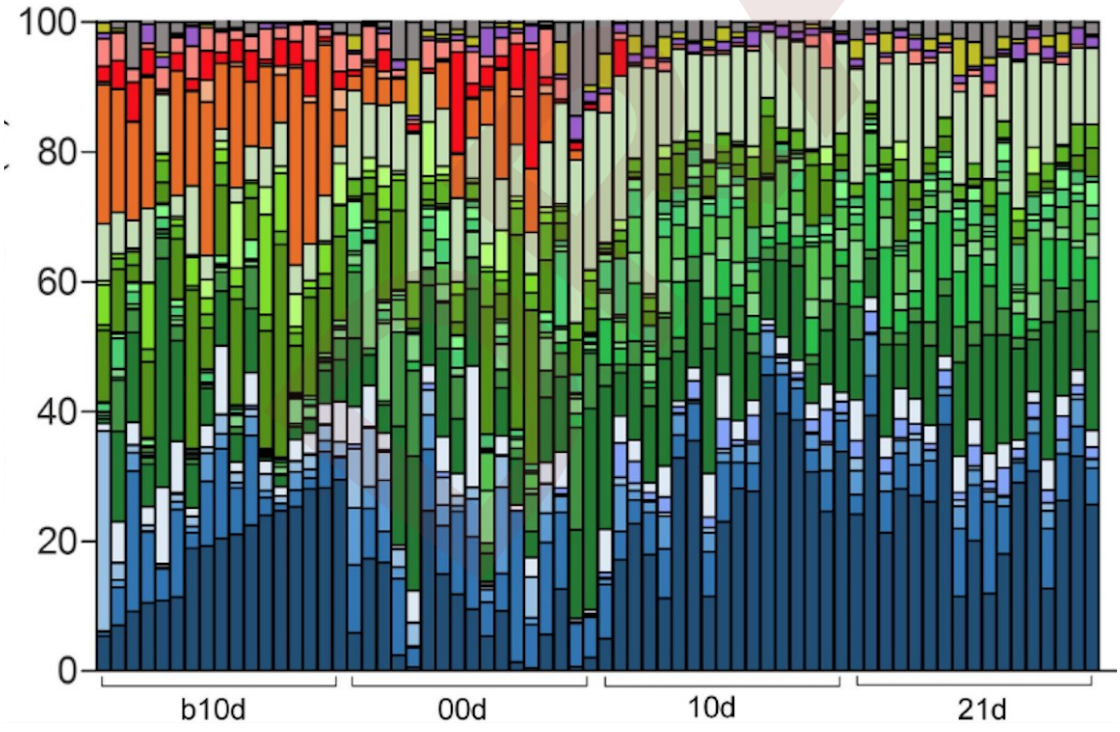
Hitting a Small Target

For these reasons and others, scientists have worked to add ***culture-independent*** (not requiring petri dishes) methods to their list of tricks, but whether using culture-based or simple collection methods, in the end, bacteria are identified and evaluated primarily via genetics. Studying the organism's DNA sequence can give us information about "who" it is, how close a relative it is to other microbes, and what special things it can do. There are two main categories of DNA evaluation: ***targeted*** and s***hotgun***.



Targeted sequencing uses a very specific portion of DNA called **16s**. This small section is present in all bacterial DNA, but each different bacterial 'species' has a slightly different sequence. 16s is like the street where all bacteria live, and those little differences are the numbers on their houses, so you can tell them apart. Once you are on the street, you will only see bacteria, but which specific kind of bacteria depends on whose door you knock on. **16s sequencing** can identify the type, or species, of bacteria present in a sample by matching it to known 'house numbers'. If you live in the Jones's house, you are, by definition, a Jones. If you have a certain pattern, you are by definition a certain type of bacteria. On the right is an example of a DNA sequence.

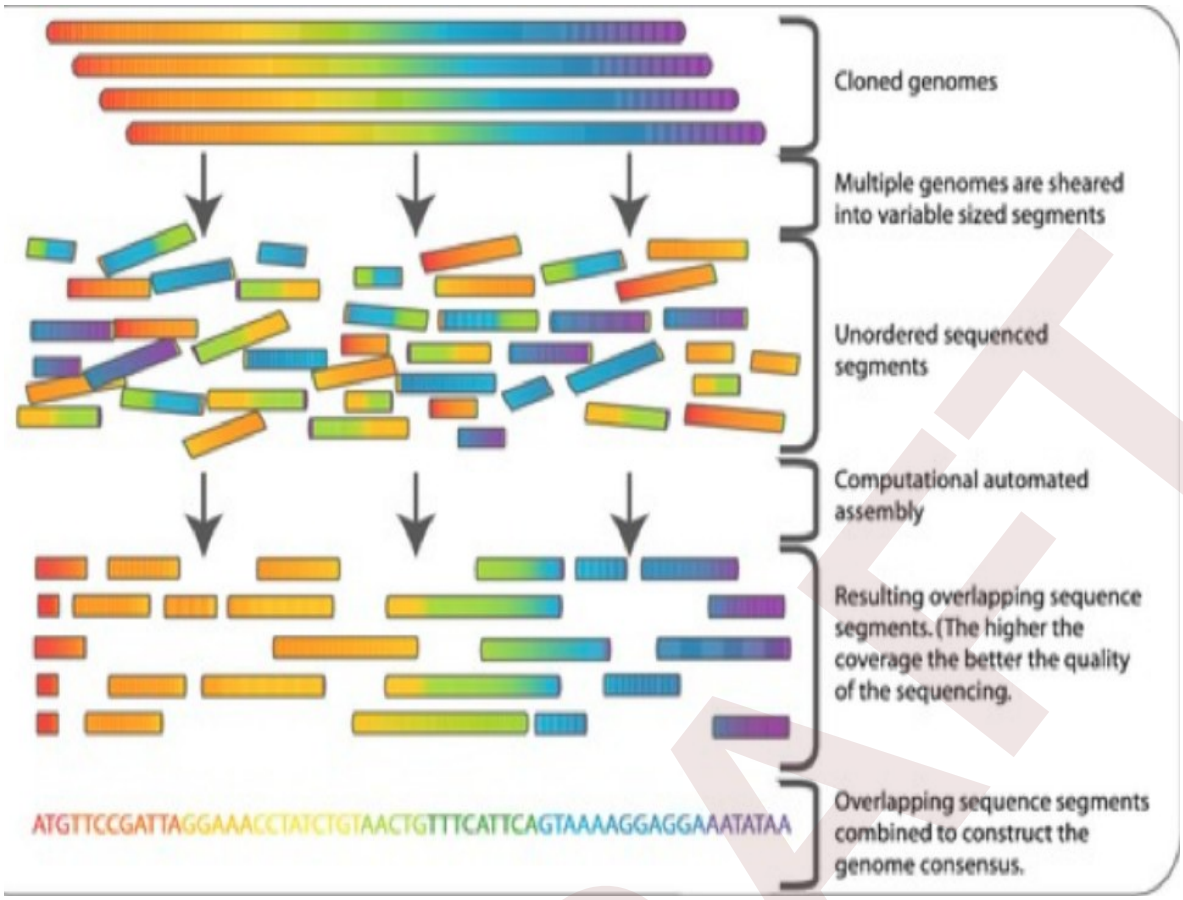
The idea of species is a little bit more slippery with bacteria than it is with plants and animals because of the way they reproduce. For this reason, scientists consider any two bacteria whose DNA are 97% identical, members of the same 'species'. But then they make it complicated by calling it something different. In bacteria 97% identity (or 'species') is called an **OTU** (Operational Taxonomic Unit).



16s sequencing uses one small piece of DNA to label an entire species. It finds the 'street address' and tells us whose house it is. This is a quick and inexpensive way tell "who" is in a microbial community. Here is an example. On this graph each kind of bacteria is a different color and each column is a different sample. So the very first sample has lots of orange bacteria, and not very much dark blue, but the very last sample has no orange and quite a bit of dark blue. This shows us the differences in diversity in the two samples.

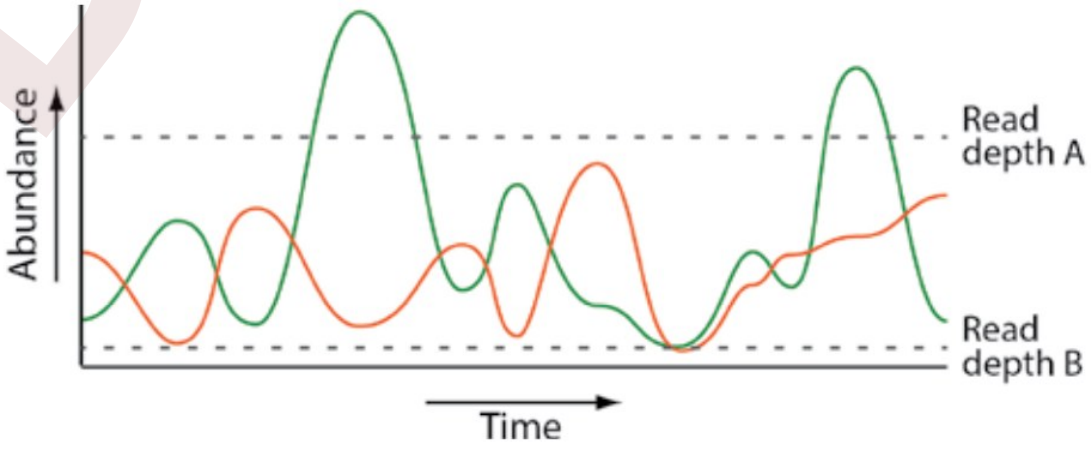
Order from Chaos

Because 16s sequencing only actually looks at a small portion of the DNA, there are some things it is NOT good for. If specific information about ***mutation*** changes or specific jobs done by the bacteria must be understood, scientists use non-specific, or ***shotgun, sequencing***. In this method the entire ***genome,*** (all ***DNA),*** is cut up, and instead of sorting out one small area (as with 16s sequencing) it is all thrown in a big pile to be sorted. A computer pieces it back together like a puzzle. The level of accuracy depends on how carefully everything gets matched which is called the 'depth' of sequencing. This method can give a sequence of all of an organism's DNA.



When shotgun sequencing is performed with more than one bacteria- a mixed community all at once- this is called ***metagenomic*** sequencing. In Greek, *meta* means *beyond* or *over*, and this method gives an overview of genetic sequences for an entire sample. In cases of rare microbes, however, it can still be difficult to get sequences because there are so few pieces to assemble, and **deep sequencing** is performed.

Look at this graph. The green bacteria is very abundant - you can see how high the peaks rise. If you measure at the level marked 'Read Depth A' you might think there were only green bacteria in the sample at all, but if you do deeper sequencing, at read depth B, you will find there is lots of orange bacteria there also.



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Groupthink

A lot can be learned by studying one microbiome, but even more from comparing many. Comparing the information from many microbiomes allows scientists to see patterns and relationships that can lead to better understanding of health and illness, but this process is expensive and if every lab collected enough samples to do it on their own, they would be collecting all the time, with no room for actually using the results! So scientists have decided to work together.

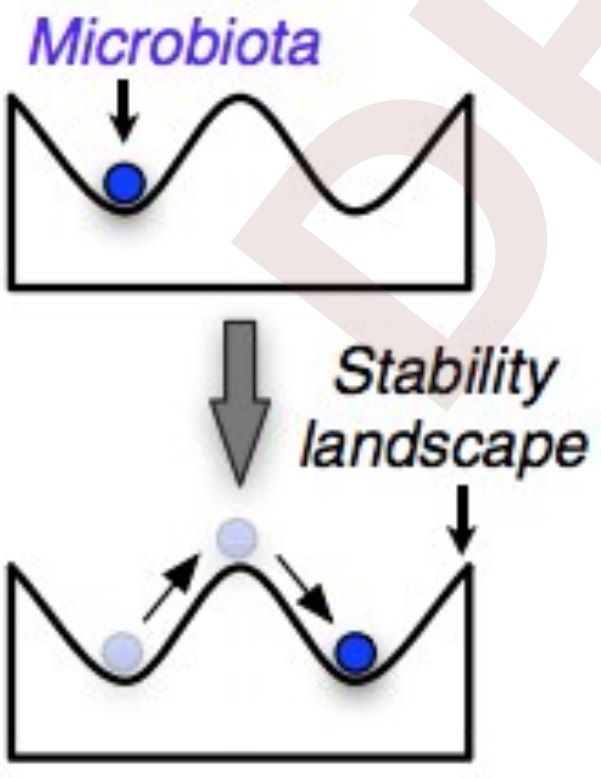
A series of collection, storage, and study guidelines have been agreed so that anytime microbiome data is collected, it can be stored for other scientists to use. There are also governmental and non-profit collection projects like The US Human Microbiome Project (HMP) which has sequenced more than 10,000 specimens from 18 body sites in healthy adults using 16S sequencing. They now have an in-depth sample of the human microbiome.

One of the first questions this vast storehouse of data was used for was:

Is there a basic set of microbes that all humans have which shows that they are healthy?

This question is important because if there were a single definition of healthy, then scientists and doctors would just need to return every person's microbiome to that healthy state to solve a lot of health problems. Sadly, there does not seem to be one. We can see trends, but there are almost as many ways to be healthy, and sick, as there are different microbiomes.

Because microbes rely on each other so much, they can be vulnerable if the system is changed or disrupted. To return to the jungle analogy, when too many bark-eating creatures move it and kill a lot of trees, a jungle becomes a field. A field ecosystem is very different from a jungle, and the plants and animals that thrive in one will not necessarily be able to survive in the other. The new environment may be healthy, or it may not, but the change in trees will alter the entire area's habitat by changing what lives there. Because it will take years for new trees to grow, the new habitat is now stable, making a return to jungle unlikely.



The same is true in microbial communities. If a lot of bacteria die off, that can drastically change the environment, both by removing what the lost bacteria do to the ecosystem (there is no one doing their usual jobs now), and because there is lots of empty space which can be filled by other species (or OTUs). Those bacteria that survived the die-off may take over the empty space, leaving no room for the return of the old population and making a new environment that is hard to change. The new unhealthy state has its own balance and it can be difficult to return to the older, healthy, microbial community.

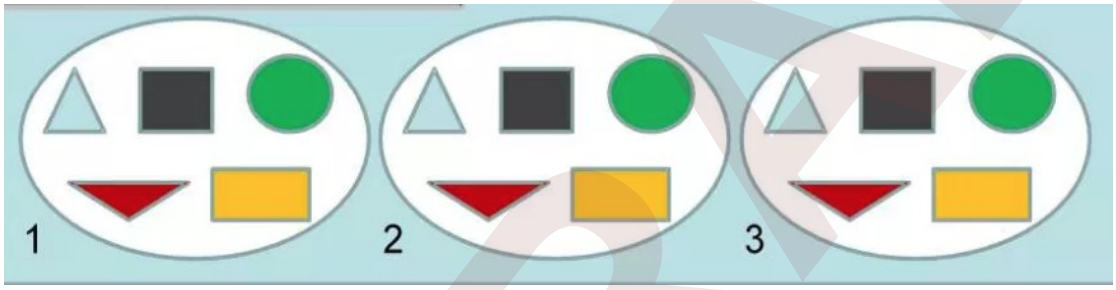
Counting Monkeys

We have talked about abundance, or how much of something there is, in the past. Now let's discuss ***relative abundance***, or percentage. Using our Jungle analogy to talk about monkey abundance we would say "there are 25 Capuchin monkeys in 5 square miles". If we wanted to talk relative abundance we would say " out of the 960 animals in the area, 25 are Capuchin" or "2% of the 960 animals in this habitat are Capuchin monkeys"



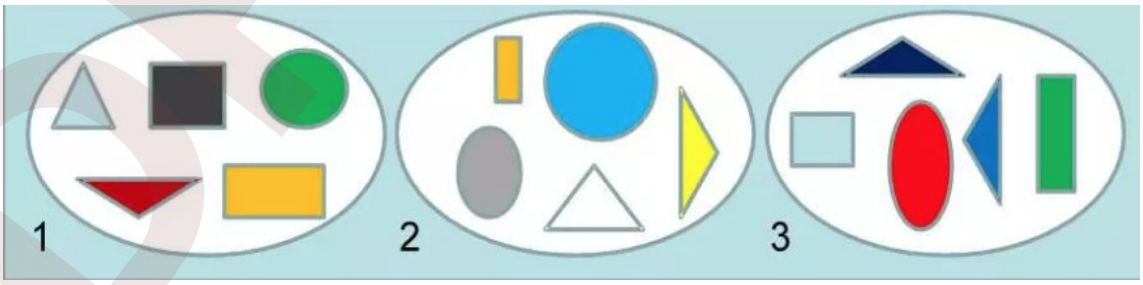
Diversity is another topic we discussed. Alpha diversity, remember, is the total number of species in an area. The alpha diversity of our jungle above would be 960 types of animal total, and each animal's relative abundance would be a fraction of that 960, like the Capuchin monkeys, at 2%.

Alpha diversity is just the total pile of organisms that could *possibly* end up in a sample of any given population while abundance is how much of each *actually* ends up in the given sample. The abundance of something in a sample is a rough estimation of how much of it is in the whole population, because if I had a bucket full of red and yellow beads, but only 4 blue beads in the whole bucket, if I reached in to take out a handful of beads I would get mostly red and yellow beads, because that is what there was most of.



If this were our population, with three different samples, we would say that our alpha diversity is 5- because there are 5 different types of "creature" in the whole population.

If THIS were our population, also with three samples, we would say our alpha diversity is 15- because there are 15 different types of "creature" in the whole population



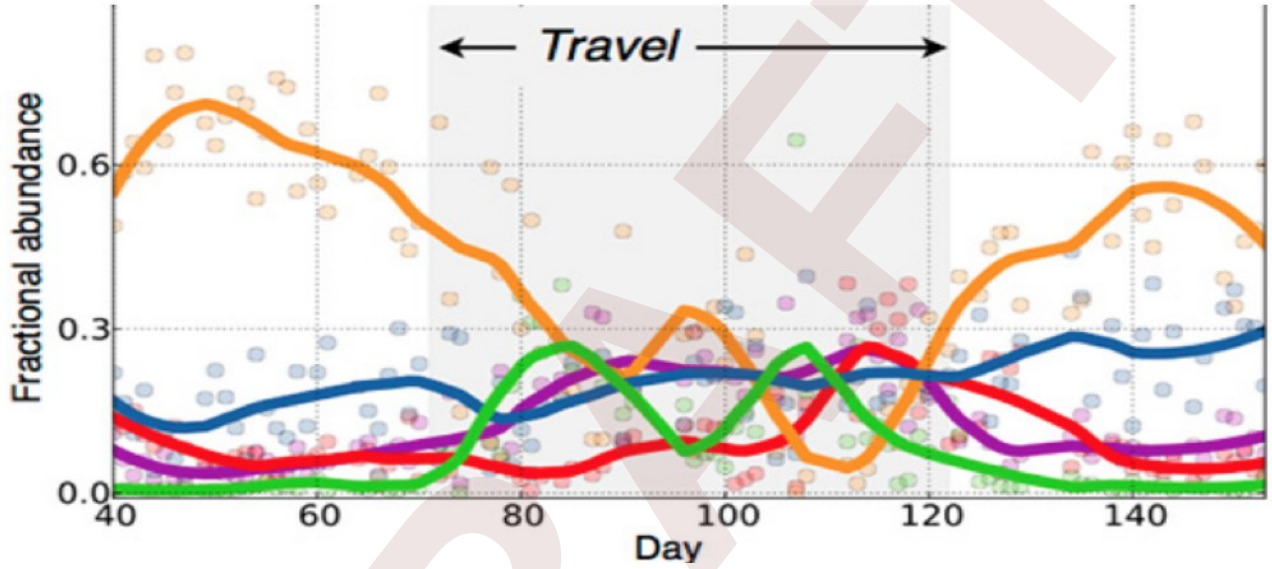
Another important way to compare samples from a population is by difference. Scientists call that kind of comparison ***beta diversity.*** Each of the above boxes represents a different population with three samples taken and recorded (the ovals full of shapes).

The top population has a low beta diversity- a low difference between the samples- this is because in comparing the samples, each is exactly the same. But in the bottom population there is high beta diversity- the samples are all entirely different.

The Biomes, They are A'Changin'

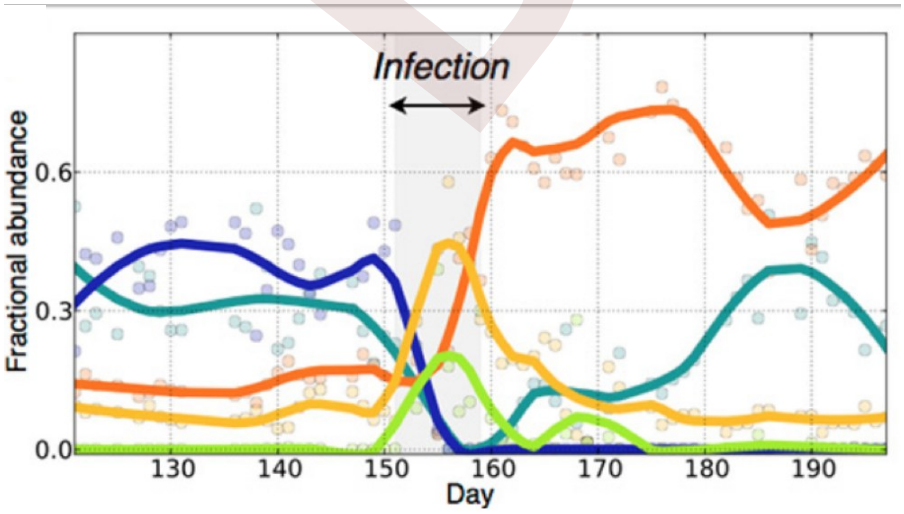
Let's use the idea of relative abundance and alpha / beta diversity to look at the human microbiome. We know that our microbe levels are balanced, and ***resilient*** (meaning that they can change a little and still bounce back). Temporary change from stomach flu or a trip to India, or eating a ton of strawberries won't hurt our microbiome- it can fluctuate some and that is normal and healthy.

Notice the graphs below. They represent human gut microbiota measurements taken over many days. Each day the relative abundance, of each bacteria type was recorded- how much of what kind. Each bacteria type has its own color so we can follow the changes over many days. On day 40 (at the beginning of the graph) there is much more orange bacteria than anything else, but during the travel period (in grey) we see some fluctuation, or change, in bacterial levels. Orange decreases and green and red increase. The change is only temporary. Once travel is over, the balance is restored and the gut populations go back to approximately where they were before travel. This demonstrates the resilience of our microbiome.



When there is a big or permanent change to the microbiome, however, like getting very, very sick or having heavy medication, the healthy balance can be lost, resulting in the bad (pathogenic) bacteria overpopulating and adding a new kind of sickness, called ***dysbiosis***, to the original illness that caused it.

For an example of the loss of diversity that leads to dysbiosis look at the "infection" graph below. Notice that the dark blue microbes are almost entirely lost during the period of infection (in grey). These blue bacteria, like our jungle trees, never return, but orange bacteria, like grass, that had previously been present in low abundance, now take over all the space vacated by the dark blue. This is an example of permanent change, and it also shows a loss of diversity, because the space that was once used by 5 microbe types is now being used by 4. Fewer organisms in a given space means less diversity, which is often a cause for concern.



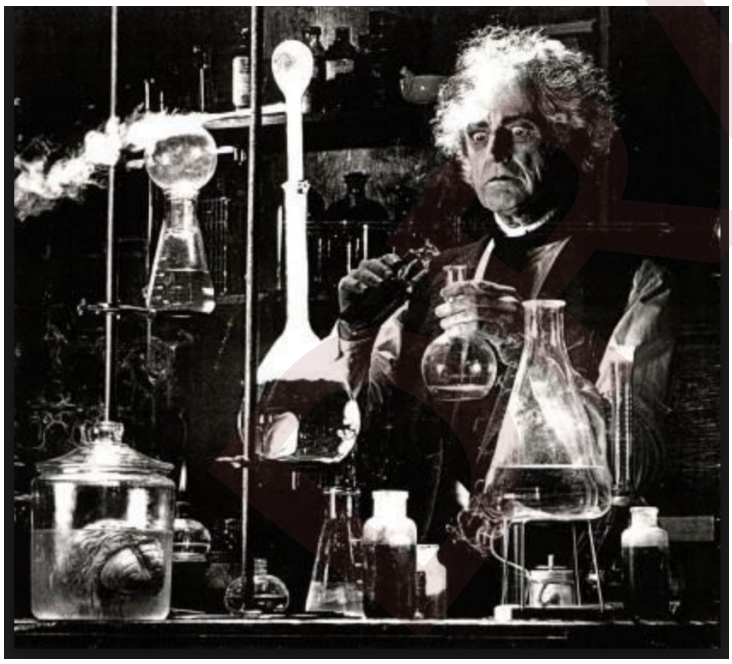
How to Eat an Elephant

There is so much information here, and we have just scratched the surface. It may take a lot more reading before every part of this book is perfectly clear- and this book has only a tiny little bite of all there is to know about microbes and the microbiome. But have you heard the saying about how to eat an elephant? If not, I'm going to spoil the surprise: You eat it one bite at a time.



Science is most certainly an elephant- sized field, and one book can't teach us everything, but this book is a start to understanding the microbiome part of the biological pachyderm. Let's look at all the bites we have taken so far: first, we looked at what a microbe actually is, and its place in an itsy-bitsy jungle. We learned that bacteria are tiny, tiny clones that invade every place on earth- including the insides of cells, and we talked about them as the unnoticed (but very important) pets we gather to us starting in infancy, and the special (hopefully balanced) habitats they make on our skin, in our mouths and in our guts.

We also talked about methods: some of the ways that experiments make normally calm, smart people into mad scientists! When microbes don't show up to dinner (Great Plate Count Anomaly), or when they hide behind the planter so they don't have to talk to anyone (Microbial Dark Matter) we have to find work-arounds (culture-independent methods). This part of the book started getting more complicated and you may need to study further to fully comprehend all the concepts in it. Scientists took many years to invent the tests and methods we introduce, so you may not understand it all perfectly in the very first bite, and that is to be expected.



The last pages you read, the end of this book, are actually the future. Everything about your lifestyle, diet, and location can impact your microbiome, and your microbiome can have huge effects on your overall health. Some of the changes you experience over the course of your life cause minor fluctuations that don't harm you, but others can cause serious problems. Understanding why some fluctuations are dangerous and some are not is an area of study that is just opening. As you begin to understand the questions science is asking and the methods scientists use to answer them, you are standing on the border between the known and the unknown. You are taking the first bites of a great gorgeous meal that could take a lifetime to digest. Welcome (both you and your pets), welcome to the pachyderm banquet…. Could you pass the salt?

Shiny New Words:
Glossary

16s- gene sequence present in all in bacteria
16s rRNA Sequencing- sequencing method used to identify and compare bacteria present within a given sample, regardless of ability to culture the bacteria
Abundance- how much/many of something is present
Agar- a gelatinous substance used to grow (culture) bacteria
Alpha diversity-number of species in a given area
Amendment- something added
Angiogenesis- growth of new bloodvessels
Antibiotic- a compound that kills or limit the growth of bacteria. Originally discovered bacteria, isolated and produced as pharmaceuticals, though synthetic antimicrobials do also exist.
Bacteria- Prokaryotic, single-cell microorganisms that have cell walls but lack organelles and an organized nucleus, including some that can cause disease.
Binary fission-binary means two-piece, fission is to break apart. Therefore, binary fission is reproduction by splitting into two pieces. The product of such division is two clones.
Beta diversity- difference in species composition between sites or samples
Biofilm- a community of microorganisms in which cells stick to each other and/or to a surface with a slimy extracellular matrix
Biomes- a group of habitats and their inhabitants
Cell- the basic structural, functional, and biological unit of all known living organisms.
Clone- a genetically identical copy
Co-culturing- growing microbes together
Commensal- an organism which is benefitted by interaction with another organism without damaging or helping its benefactor.
Compound- A substance consisting of atoms or ions of two or more elements that are chemically bonded together, e.g. carbon dioxide
Concomitant- a phenomenon that naturally accompanies or follows something else.
Conserved- something that is saved. In biology, something that has remained essentially unchanged throughout evolution.
Convention- the standard, accepted way in which something is usually done
Culture- growing something outside of its normal habitat, in microbiology- growing bacteria on media in order to study it.
Culture-independent - a method that does not require the growth or propagation of its sample, also called sample-based, meaning that the sample may be used directly in experiments, rather than growing bacteria from the sample to use.
Deep Sequencing- sequencing a genomic region hundreds or even thousands of times, with the aim of fully characterizing all genetic participants in the sample pool
Diversity- variety
DNA Sequence- the precise order of nucleotides within a DNA molecule, by which information is coded
Dysbiosis- microbial imbalance which causes loss of health
Ecosystem- biological community and their physical environment
Excrete- expel waste
Eukaryote- organisms whose cells have nuclei and other membrane-bound organelles
Fastidious- picky. describes microorganisms that will grow only if special nutrients are present in their culture (growth) medium.
Flagella- a tail-like limb that gives certain types of cells the ability to swim. From the Latin word for "whip"
Genome- the complete set of genetic information in an organism
Great Plate Count Anomaly- the fact that most of the microbes seen under the microscope could not initially be cultured
Habitats- the natural home or environment of an animal, plant, or other organism.
Hormones- steroidal signal molecules produced by the body.
Microbial Dark Matter- rare microbes that are known by their effects, but very hard to culture or identify

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Media Amendments- addition of nutrients or changes in pH to make media more successful at culturing certain microbes
Metabolism- the sum of all life processes in an organism
Metabolites- a substance formed by or during or cellular metabolism
Microbe- any microscopic organism
Mutation- a random genetic change that creates an altered DNA sequence
Organism- something that is alive
Oral- associated with the mouth
Organelle- tiny, specialized structures inside of a cell, often enclosed within a membrane
OTU- Operational Taxonomic Unit a group containing all organisms that are 97% genetic and is used to categorize bacteria based on sequence similarity
Parasite- an organism that benefits from association with another organism, which it harms
Pathogenic- disease-causing
Petri Dish- shallow glass or plastic dish used in bacterial culture, among other things
pH: a measure of a solution's acidity
Pili-hair-like appendages found on the surface of some bacteria, aka fimbria
Prokaryote- single-celled organism without nucleus
Protozoa- an informal term for single-celled eukaryotes, either free-living or parasitic, which feed on organic matter such as other microorganisms or organic tissues and debris.
Relative abundance- the percentage of the total population that a type represents
Resilient- able to spring back to its original shape or form
Respire- exchange gases with the atmosphere, to breathe
Scale- the proportion between the representation and what it represents
Shotgun sequencing- non-specific sequencing. Where a rifle can be aimed, a shotgun just spatters a target area. Non-specific sequencing cuts apart and sequences all DNA in its target area (as opposed to targeted sequencing which sequences on a very particular area of DNA)
Spirochete-a spiral shaped bacterium
Symbiotic- interaction between two different organisms living in close physical association, typically to the advantage of both.
Targeted sequencing- a specific subset of genes or regions of the genome are isolated and sequenced.
Unicellular Organism- organism contained in only one cell
Viruses- an infective agent that typically consists of a nucleic acid molecule in a protein coat and is able to multiply only within the living cells of a host.

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