The Invisible Realm

- We live our lives surrounded by millions of creatures so small they are almost invisible…
- Creatures so strange, so unlike ourselves, they could have been dropped into our oceans from a passing spaceship
- Creatures so abundant, that all by themselves they outweigh all other living things on the planet combined

- There are more bacteria in your mouth right now than the total number of men, women and children on Earth
- And that includes every human being who has ever lived on this planet since we separated from the Great Apes, 6 to 10 million years ago

- We like to think of ourselves as vast, powerful beings, and we certainly are, compared to life forms as tiny as a bacterium or a virus
- But let's put our self image in its proper perspective
- Because what we think of as our own body, isn't really ours at all…

- There are about 100 trillion cells in the human body
- But of those 100 trillion cells, roughly 90 trillion are actually different kinds of bacteria
- Only one out of ten cells in your body is actually your own!

- Now, as individuals, pathogens are pretty fragile
- Pathogens are organisms that cause diseases, creatures like bacteria, viruses, flukes, and nematode worms

- You can wipe out entire populations of bacteria with nothing more than a teaspoon of antibiotics
- I can rain down death and destruction on the thousands of bacteria living on the palm of my hand simply by squishing them into a gooey cytoplasmic pulp…

- But they're scrappy little fighters
- They've killed us by the millions for centuries
- And they've thwarted our most clever attempts to destroy them

- Nobody wants to think of themselves as a giant picnic basket (least of all me)
- But from the perspective of all the millions of germs that have evolved to feed on us, that's exactly what we are
- We're just a meal ticket with attitude…

- The Clorox company did a study in 2006 of surface bacteria in the workplace of nine professions, and found that teachers are exposed to the greatest number of bacteria
- Speaking for my fellow teachers - this comes as no big surprise…

- The study found 17,800 bacteria per square inch of a teacher's work surface!
- And that's not even counting the endless parade of sick students coughing & sneezing on

us

- Accountants and bankers were #2 & #3 – giving whole new meaning to the expression "dirty money"
- Doctors came in at #5 – *why so low?- probably because they sterilize their work space more than most…*
- And who do you suppose had the cleanest desks? – Lawyers! (only 900 per sq. in.)

- All work and no play makes Jack a very dull fellow - but where bacteria are concerned, nothing is sacred
- A study at Oklahoma State in April 2011 found that playing in the band could be hazardous to your health
- They recovered 77 types of fungi, and 442 species of bacteria, many of them pathogenic

- Even instruments that hadn't been played in a long time were crawling with germs
- Reeds and mouthpieces were the worst, but every part of the instruments were infected
- Top honors for the filthiest instruments went to the clarinets

- Given how incredibly abundant microbes are, it might seem surprising that we could have overlooked them for so long
- But they're so minute, so incredibly tiny, that they're essentially invisible

- To us, a kitten is a tiny creature…
- But to a microbe, a kitten is a towering Titan, with its head in the clouds, as vast and inscrutable as the Sphinx

- It's hard to understand how something so small as a microbe could possibly compete with something as big and powerful as us
- Imagine being small enough to ride on the back of a flea, like the bacterium that causes bubonic plague…

- And bacteria give whole new meaning to the word small…
- We can't count the number of angels that can dance on the head of a pin, *but* we *can* count the number of bacteria that could dance there!

- *Escherischia coli* is a common gut bacteria, measuring about 2 microns
- The average pinhead is about 1,000 microns in diameter
- So about 250,000 *E. coli,* a quarter of a million bacteria, would fit comfortably on the head of a pin!

- Remember when I squashed the bacteria in the palm of my hand?
- Unfortunately, most of them probably escaped
- Because on the scale of bacteria, the valleys of my palm and finger prints would be vast canyons for them to hide in

- It took a huge leap of faith for people to conclude that something that small could exist at all
- Even doctors and scientists had a hard time believing in the existence of an invisible world of tiny creatures like bacteria

•And after all, how could something so incredibly small hurt such great big creatures as us?

- Now we know that many of these little creatures *are* very harmful, even lethal
- Some of the most dangerous creatures on the planet are microbes
- Learning more about microorganisms does more than just satisfy our curiosity – it could even save our lives…

- We'll explore this strange and hidden realm together, learning both the good things and the bad things that microorganisms do for us, or to us…
- We'll consider the ways in which we interact with microbes, one organism to another, as competitors and as companions, as predator and as prey

- So follow me now, on our long journey from the plains of Africa to the towers of midtown Manhattan
- Along the way, we've changed our basic lifestyle, from nomadic hunter-gatherers to settled farmers, a change that forever altered our relationship to the microbial world

- As our populations grew and spread, we built the great cities of the ancient world
- But building up dense urban populations made us vulnerable to crowd diseases, like smallpox and measles, triggering the great plagues of antiquity

- And just as our civilization was beginning to recover from the collapse of the Roman Empire, along came the Little Ice Age, devastating agriculture, and causing centuries of famine and hardship
- Crowded into cities, and weakened by generations of poor nutrition, we were sitting ducks for the Black Death

- How terrible it must have been to live through a plague like that, not knowing why everyone around you was dying
- For most of human history, we had no idea that microbes even existed, much less that they were the cause of human diseases
- For centuries we've been engaged in an evolutionary arms race with an invisible foe

- We'll learn about some of the clever strategies that microbes have evolved to invade us, and to exploit us, including resistance to our most powerful antibiotics

- As we've continued to change the world, through our agriculture, our industry, and our technology, we've also created new opportunities for microbes to evolve and flourish, from kitty litter to air conditioning, from the shady depths of Sherwood Forest to the war-torn jungles of Vietnam

- But, as we'll discover, it's not all bad news
- Microbes are essential to our health and welfare – they created the air that we breathe and the type of cells that make up our bodies
- We'd be hard-pressed to survive without them

- They've altered the very course of human history - like the virus that caused the 1918 Flu, which killed 50 to 100 million people in a single year - and the curious case of the germ of laziness, which may have cost the South the Civil War
- Microbes have even been used as tools of conquest and terrorism

- Columbus didn't intend to wage biological warfare against the natives of the New World
- But thanks to his microbial hitchhikers, his voyage, and those of the explorers who followed in his wake, turned out to be deadly for the naïve populations of the Americas

- And now we are poised on the threshold of another great journey, as we turn outward to the stars – will we encounter alien microbes in the depths of outer space?

- Will we prevail in our long struggle against invisible killers like smallpox and plague?
- Will we ever reach a balance where both man and microbe can safely coexist?

- For the foreseeable future, the issue is in doubt – and given the nature of the conflict, most Vegas bookmakers would say that the odds are definitely against us

- For one thing, bacteria evolve a lot more rapidly than we do, because they can exchange genetic information in little snippets called plasmids, without the lengthy (and messy) process of sperm meeting egg

- And face it - we are greatly outnumbered…There are over 2.5 billion bacteria in a single gram of farm soil
- How can a mere six billion humans hope to prevail against countless *trillions* of microbes?

- To answer that question, we need to understand the ways in which populations are controlled and regulated by their interactions with other organisms, and with the Earth itself

- Few organisms ever reach their full reproductive potential – many natural forces combine to regulate them, and keep them in balance with their environment

- Man and microbes are no exception, for which we should be extremely grateful
- If not held in check, in a matter of days the progeny of a single bacterium would outnumber the stars themselves – we'll do the math in lecture 6…

- The idea that nature keeps itself in balance isn't new – it goes all the way back to Socrates, Plato and Aristotle, and it was probably already ancient in their time
- The "Argument from Design" says that all of nature is designed in accord with a predetermined, benevolent, and supernatural plan

- This ancient idea was revived by the Natural Theologians of the 18th and 19th Century, who believed that the balance of nature was a reflection of divine will

- All of the complexity and diversity of life results from the unfolding of the divine plan behind nature
- And strangely enough, that's where the word "evolution" comes from
- It didn't mean change over time, or descent with modification from a common ancestor

- Evolution comes from the Latin evolutio, which means to unroll, to unfold…
- Evolution originally meant the unfolding or unrolling of the predetermined divine plan behind nature
- The natural theologians thought that the balance of nature was an especially eloquent proof of the divine plan

- And so they worried, just like Darwin worried, about the cosmic forces that kept that delicate balance between organisms and their environment
- Why aren't we up to our butts in house flies??

- House flies have seven generations per year, 120 flies per generation - what would happen if they all lived?
- At the end of a single year, that one fly would have nearly six trillion offspring!

- Forget nasty little flies, what about cute little robins? – you can't have too many robins, right?
- A female robin lays four eggs per clutch
- She can lay two clutches in one year
- What if all 8 baby robins survived?

- At the end of one year = 64 robins
- At the end of ten years = 24,414,060 robins
- At the end of 30 years, the entire planet Earth would be buried under a blanket of robins 4.5 miles thick !!
- But that's not likely to happen…..not if my cat has anything to say about it!

- Although most organisms, including humans, have an incredible potential for growth, most of them don't live long enough to reproduce
- Because there are many limiting factors in nature that control the growth of their populations

- These limiting factors usually act from outside the population, so we call them extrinsic limiting factors
- Extrinsic limiting factors are often physical factors - like sunlight or water, like nutrients or food...

- Extrinsic limiting factors can also be living factors, such as competitors or predators, or

even partners in a symbiotic relationship
- Plants are limited by pollinators, for example, and vice-versa

- The pioneering ecologist Charles Elton proposed that the equilibrium in nature resulted mainly from the interaction of organisms, especially predation and competition

- Elton's focus on predation and competition was way ahead of his time…and he was right
- Predation and competition turn out to be *very* important limiting factors in regulating the growth of natural populations, whether man or microbe

- Modern ecologists, incidentally, have learned to appreciate that nature is often *not* in balance
- Many ecosystems are frequently disturbed, by forces like storms, fires, floods, hungry animals, and diseases

- These ecosystems become so well adapted to the forces of disturbance, that they often come to rely on them, what ecologists call non-equilibrium theory

•Pine forests, for example, may eventually become hardwood forests, unless they're frequently burned

- We'll look at several examples of how our disturbance of natural environments has set the stage for outbreaks of epidemic diseases

- Most populations, then, are regulated by a combination of limiting factors - they never reach their full reproductive potential
- Humans are subject to the same fundamental laws of nature - we have to compete with one another, and with other species, for the limited resources we need to survive

- Man is by nature a competitive species
- It's bred in our bones, entwined in our genes…
- We compete with one another for resources, for territory, for jobs, for mates
- And in that respect we're no different from any other organism, including microbes

- But competition in the natural world is about a lot more than who gets the corner office – it's a matter of life and death
- Competition occurs when two or more organisms use the same resource, in a way that affects the birth rate, or the death rate of the competitors - very high stakes!

- Consider the bottled water section in your local grocery store – not usually a hotly contested item…

- But for a brief period every year in hurricane season, bottled water becomes a vital commodity all over town, along with ice, batteries, disposable diapers, and several other everyday items that could suddenly affect the health and welfare of you and your family

- The lines might be long in the local supermarkets, but the folks in line are usually mellow

and friendly
- And when shoppers converge on those last few bottles of water, there might be some disappointment, maybe a little argument, but no actual bloodshed

- Now imagine that same store the night before a hurricane evacuation, with a long line of increasingly worried people
- You'd better believe that when that water supply finally dwindles, tempers are going to flare and a few people might even become desperate…

- What happens in that store the night before a hurricane evacuation could have a significant effect on the survival and reproduction of several people – and *that's* what real competition is all about!

- How intense will the competition get?
- That depends on the number of jugs of water that are left – and the number of people waiting in line to buy them
- Competition often depends on the nature of what we're competing for, and who we're competing with

- Two species can't peacefully coexist if they both need the same essential limiting resource (like a limited amount of bottled water)
- If one species is a better competitor than another, it might even eliminate it altogether – what we call competitive exclusion

- Consider two species of the little protozoan *Paramecium*, grown in a jar…
- Either *Paramecium aurelia* or *Paramecium caudatum* can do equally well under the same conditions

- But *Paramecium aurelia* is a superior competitor, and when you raise both species together, *aurelia* always eliminates *caudatum* – competitive exclusion…

- On the other hand, competition isn't always a struggle to the death - most organisms reach a delicate balance with one another
- But that balance comes at a cost – and the cost depends on what type of creature you are
- It depends on your ecological niche…

- Competition can be intraspecific, between members of the same species
- Competition can also be interspecific, between members of different species

- Time to put on your thinking caps! - Which type of competition is going to be the most intense, *inter* specific, competition between species, or *intra* specific, competition within species?
- The answer is *intra*specific competition!
- *Why?*

- Think about it…intraspecific competition is the most intense, because your needs almost exactly match the needs of other members of your species – you share the same ecological niche
- Oh, you might love mushrooms on your pizza, and I'll be picking them off of mine, but we both agree on the need for pizza!

- A niche is the sum total of a species needs, and the parameters within which it can survive
- Another way of looking at it, as Elton suggested, is that a niche is the role that a species plays in a biological community (niche = job, habitat = address)

- Individuals of different species will occupy a different niche
- And the intensity of the competition between them is going to depend on the extent to which their niches overlap
- To what extent do I do what you do – to what extent do I need what you need?

- Competitors or predators limit the ability of any species to realize their full potential, what we call their fundamental niche
- Competition and predation force organisms into a much narrower niche - the realized niche - what we can actually do, in the face of competition…

- So when man meets microbe, each must give way, to some extent, to the other
- It's a game of give and take…
- And anything that upsets the balance can easily tilt the battle one way or the other

- Consider the flour beetle, *Tribolium*
- Its larvae are commonly found in grain storage areas – they look like the closely related mealworms sold as food in pet stores

- Thomas Park raised flour beetles under several different sets of conditions
- He set up six different types of environments, in six test tubes filled with wheat flour – a flour beetle paradise!
  - > Hot / temperate /cold
  - > Dry / moist

- He added *Tribolium castaneum* to one set of vials, and *Tribolium confusum* to another
- He put equal numbers of both in another set
- When he grew them alone, each species could thrive under any set of conditions
- But when grown together, one species proved a superior competitor, depending on conditions

- In the hot and moist vials, *Tribolium castaneum* won every time, but in the cold and dry vials, *Tribolium confusum* always came out on top
- Between these extremes, they show a graded series of responses, each getting a larger edge as they approach their ideal environment

- When grown alone, each species showed the same fundamental niche

- When grown together, competition forced them into a realized niche
- And as we'll learn next time, it was a big change in our fundamental niche, and the resulting increase in the density of the human population, that made us suddenly vulnerable to many of our worst epidemic diseases…