

# The mind-bending probability o...Sean B. Carroll

## Full Interview

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I'm Sean B Carroll. I'm a biologist, an author and a film producer. And my most recent book is a series of fortunate events, chance and the making of the planet, life and you

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chapter one, life out of chaos, the odds that

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any given planet is going to have complex life. I mean, there's this is really an opinion, because we don't know about life anywhere else in the universe, but most of the scientists that I know and think about this deeply think the likelihood of life elsewhere is very high. It may not be the sort of life we're used to. It's not giraffes and redwood trees, but at least things like microbes. Yeah, I think there's a very high likelihood that it's out there and abundant in our universe. You know as thinking creatures. And we'd like to think of ourselves as among the most complex things on earth. When you think about the history of Earth, if you visited this planet for the first 4 billion years of its existence, you wouldn't necessarily be that impressed with its life. It was largely unicellular for that time period, only in the last half billion years has life gotten big and macroscopic. So if we were to be able to go around the universe and sample life from various places, probably the odds are that most of the time it's going to be microbial that would be biochemically complex, but not necessarily anatomically or behaviorally complex. So hard to judge the frequency with which we're going to find larger, complex, behaving creatures on other planets. A huge number of things had to go right for our species to exist, and for each of us individually to exist, for us to be here. And these are at all sorts of scales, the cosmological scale, the geological scale and the biological scale.

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When you think about the long history of life on Earth, and you might sort of think, well, it's been this progression, and so therefore, almost as though it had a direction, almost had a purpose. And you know that some things are predictable, not at all. When you really unpack the geological history of the planet and the biological history of the planet, it's been a random walk through all sorts of events. So, you know, the Earth is evolving, the physical entity, the Earth is

evolving, and life has to evolve right along with it. And so we need to have this sort of understand this relationship, this coupling between the physical planet that life exists on and what's going on with life itself.



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Intersect those two, and it's an incredible series of accidents that's given us the world we know today. And this is really a deep philosophical rub for humanity. You know, for millennia, philosophers and theologians have sort of asked the question, you know, does everything happen for a reason, or do some some things happen by chance? And I would really say it's only about the last 60 years or so that scientists would be saying, oh my goodness, it's a remarkable series of events that were required for us to be here, and that so many things could have happened in a different way that we wouldn't be here at all, both individually, for sure, and certainly as a species. In the book, I wrote a series of fortunate events. I almost decided it's like a new origin story. I'm gonna forget the first almost four and a half billion years of life on Earth, and start with the asteroid impact 66 million years ago, because that was such a reset for life on the planet that is really the catalyst to the making of the world we know now, and it was the eraser for the world that preceded it. So whatever went on 3.8 billion years ago, and it's murky. It's really hard for scientists to know what's going on. The biochemical events where this happened can't even exclude the possibility that life arrived from somewhere else and that then seeded what happened on Earth. So the origin of life on Earth is a really murky it's incredibly fascinating, but it's really, really hard to get to once you have cellular life about the grade of a typical bacterium. That story going forward, we're really comfortable with in terms of the evolution of physiology and how you harvest energy from the sun and all the chemical reactions of life on earth and all the big geological events, but



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bring it more personally to ourselves. I really sort of mark the beginning of our story at 66 million years ago, because the asteroid impact erased essentially the previous world and opened up the world of mammals from which we evolved. And so I think understanding those last 66 million years is a is a is very rewarding and much more concrete than thinking about 3.8 billion years ago. So what's really remarkable about the time we exist and actually had a role in our emergence is the Ice Age.



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Age. We're living in a really unusual time with respect to Earth's climate. For the last two and a half million years, we've been in an ice age where the ice comes and goes, so it advances across the northern hemisphere and then retreats, advances and retreats. But we didn't drop into that until about two and a half million years ago, and the previous Ice Age was perhaps 300 million years ago. So from, for example, the asteroid impact, 66 million years ago, the Earth was ice free at the poles. Imagine that, you know, forests going pole to pole, and no ice at all. So a very warm planet, very verdant planet, and but it's gone through a gradual cooling over the last 60 or so million years, and dropped into this period of the of the ice ages just two


and a half billion years ago. And so it's interesting to wonder, well, in this unique period, what implications does that have for humanity and for the other creatures on earth, and the implications are profound.

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There's been a handful of events where about 75% or more of all species have been erased from the planet in a short period of time. We refer to those as mass extinctions, about five in the last half billion years. We know the causes of two quite clearly at the end of the Permian, about 250 million years ago, massive volcanism poured enormous amounts of noxious gasses and climate altering gasses into the atmosphere and

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wiped out perhaps more than 90% of species. It was a huge transition in life on Earth. And then 66 million years ago, about a six mile wide asteroid, traveling about 50,000 miles an hour, slammed into the Yucatan Peninsula, and the consequences of that impact, again, led to global change, both climatic change, wildfires, et cetera, that erased more than three quarters of plant and animal species from the planet. So what we know about these mass extinctions is that they're associated with really rapid environmental change, different triggers, but really rapid environmental change. And yet, after each of them, life has rebounded very differently. The sorts of winners and losers are really different after each of these events, and the winners that took over after, for example, the asteroid impact, were mammals, which were relatively small and insignificant for 100 million years prior to that asteroid impact. There's really two big collisions that are a major reason why we're here today, and those collisions easily could have not happened. The first was the asteroid impact 66 million years ago. So imagine this a rock six miles wide. It's probably been orbiting the solar system for, I don't know, a couple 100 million years, or maybe longer. It happens to enter the atmosphere 66 million years ago and slam into the Yucatan Peninsula. So first of all, it's the largest impact we know of on the Earth or the moon in the last half billion years. So it's rare one in a half billion year, or perhaps longer event. Second of all, it could have easily missed the planet, or Third of all, it could have hit somewhere else on the planet. It turns out that geologists think that where it hit really matters, that those rocks on the Yucatan Peninsula contained the right sort of chemical stew, carbonates and sulfates that, when blasted into the atmosphere, created the situation, or contributed the situation, of blocking out the sun and essentially shutting down food production across the planet so and perhaps only one to 13% of the Earth's surface contains that mixture of rocks. So if this asteroid had entered, you know, half an hour earlier or half an hour later and hit, for example, in the Atlantic ocean or the Pacific Ocean, and missed the Yucatan Well, dinosaurs might still be here,

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everything else alive at that time, or at least most of those groups might still be here. Mammals would still be a minor group, and we wouldn't be having this conversation. So

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that's one thing that had to go right. And you know, it's, it's a random collision of a big rock with an enormous rock that happened 66 million years ago, the second big collision, and I think this is most people have heard the story of the asteroid, but the second big collision people don't really know about, and that is the collision that set in motion the Ice Age. Now we'll get to the impact of the ice age on humanity in a minute, but the impact of this collision was to start a gradual cooling of the planet, and that collision is of the Indian subcontinent, the tectonic plate of the Indian subcontinent with the Asian plate. And that was happened about 40 million years ago, and that started building.

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Building, for example, the Himalaya, and that rock building, what that does when rock is exposed on the surface of the planet, that rock actually draws carbon dioxide out of the atmosphere. So a major way that carbon dioxide is drawn down is by reacting with rock and then being sequestered in the ocean. And that process has over then millions and millions of years, eventually drawn enough CO two out of the atmosphere to get CO two levels low enough to tip us into this ice age. You might say, well, wow, you know, how did that happen? Not how did that collision sort of change the world? Or, how did that collision even start? Well, it turns out that little piece that Indian subcontinent, and we call it the Indian subcontinent because that's where it is now, but that was below the equator, down near Madagascar, about 65 million years ago when the asteroid hit and it was zipping northward at a much faster pace than the other tectonic plates were moving around. It was smaller. It was thinner than the other tectonic plates. And those tectonic plates in general, which are where the continents and the oceans crusts are riding on, those were all generated about 140 million years ago when a super continent broke up, sort of like the same way a kitchen plate breaks up when it hits the floor into these various pieces. And one of those pieces was that Indian subcontinent, which then sort of raced nor northward relative to the other plates, and slammed in to the Asian continent. So

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those two big collisions, the asteroid and the Indian subcontinent with Asia, have a lot to do with the climate that we live in today, and the biosphere that we live in today, a biosphere that doesn't have dinosaurs, but is full of mammals, from which primates, our ancestral ancestors, and eventually our species evolved. And it's pretty easy to imagine how the asteroid didn't necessarily have to happen, and certainly that if that plate had broken up in any other possible way, we might still be living in a much warmer world, and our species might never have evolved on the continent of Africa.

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So these two collisions, one really catastrophic, one a little more subtle.

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They were profound events for the future in terms of humanity, because I can certainly say

without the asteroid impact, mammals would still be a minor player on the earth scene. And of course, we're mammals, and we evolved from primates, so and I think the evidence for that is twofold, is that for 100 million years, mammals coexisted alongside dinosaurs, but they were ecologically



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much less significant,



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and then they really took over once you once those were removed, and the second impact, the collision that eventually triggered the Ice Age, this is really important, because now you got to think about our ancestors And our actually the hominid story. The hominid story is not really a story about warm and cold, sort of when you think about the ice ages, it's really about wet and dry. And those wet and dry cycles were pretty frequent, geologically speaking, in places like East Africa and so that puts a lot of pressure on species to evolve these intervals of wet and dry, cold and warm, especially in the northern hemisphere. That's a lot of pushing and pulling going on in the plant life and on the animals that adapt to it, et cetera.



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But here's the most important, salient fact about our history, hominid history, it's during the early and middle part of that ice age that our brains expanded threefold in size. Now this is remarkable. I mean, this is when you think about what brains do, and we're all impressed with our own brains, but hominid brain size was humming along at about 400 cubic centimeters for quite a while, and then it really expands rapidly. And we see that expansion also happening with behavioral complexity. We're making stone tools. We're making stone tools of different shapes, and if you look then over, say, a million, million and a half years, our stone toolkit becomes much more varied. We clearly discover fire, and we're using fire, you know, for warmth, for for cooking, etc. So we are becoming essentially a technological ape.



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And this is marked by this increase in brain size, increase in behavioral complexity, and, you



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know, maybe two thirds of the way into the ice age, we start to reach the brain size of modern humans. So what's going on there? Well, basically, the ape that could by fashioning tools and essentially developing technology, could shape its own environment and.



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is much less than vulnerable to this really oscillating climate that the ice ages had set up. So

is much less than vulnerable to this really oscillating climate that the ice ages had set up. So the Ice Age was sort of the test. The Ice Age was this, you know, these very challenging conditions out of which a line of apes emerged, big brain, tool making, habitat making complex behavior, you know, hunting behavior, etc, apes. And those are, those are our ancestors. So we really have the ice age to thank for our existence, and we have the Indian subcontinent collision with Asia to thank for the Ice Age. It's hard to picture how an asteroid that's six miles wide could impact a planet that's 8000 miles in diameter. It's sort of like a BB hitting the side of a barn. But it turns out, one of the important explanations is that that BB was going 50,000 miles an hour, so it drilled an enormous hole, 120 miles wide, in the Yucatan, which blasted massive amounts of material into the atmosphere and beyond, and when that material rained back down, it was like raining trillions of red hot meteors back upon the surface of the earth. And that was spread across the globe. You can find the fallout of that impact across the globe. I myself have traveled to several sites and been able to put my finger right on the fallout layer from the asteroid. It's a spine tingling experience to realize that the world was so different just below that layer versus just above that layer. But those trillions of red hot meteors, they created an atmosphere that was suffocating. Was probably the temperature of a baking oven. It set off wildfires and the devastation of the plant community, and then all the soot and all of the impact debris that was in the atmosphere blocked out the sun for probably a period of at least, say, one to three decades. And you imagine you block out the sun, you're going to shut down food production, both on land and in the oceans. And what we see is a very clear signature of that even the tiniest creatures in the ocean underwent mass extinctions. And the largest creatures, which, of course, would be most dependent upon a large amount of food, well, they were the first to go so big, dinosaurs on land, mosasaurs in the ocean, et cetera, all this. So nothing really over about 25 kilograms in size, survived on land. Complete Wipeout. We lost essentially the entire tree canopy. So there were lots and lots and lots of birds, for example, 66 million years ago, but almost all those groups of birds disappeared. You lost the you lost the entire tree canopy. So you got to imagine, to take out three quarters of the plants and animals. Life on Earth had to be really awful. It was hell on earth for probably those several decades, and only a few things squeaked by, we think, in the animal world, things that burrowed, things that were semi aquatic. So we can see things like turtles. Some went extinct, but they made it as a group, crocodilians, alligators and crocodiles made it through



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shore birds, maybe burrowing birds. They made it through little mammals, especially those things that you know would sort of form, form burrows and work underground and smaller things, because smaller things are dependent upon less food, and they also have a rapid reproductive rate. So if you're down to a small population, but you can reproduce fairly rapidly, these are things that made it through. But the general picture is hell on earth and a few survivors, we can see the pattern of rebound of life after the asteroid impact, because you sort of imagine, like hitting a reset button, where so much of essentially ecological space was vacated, or the big, you know, certainly the big creatures were eliminated. So there was a lot of space available now to what survived. And we can see that impact, because if you look at frogs today, you can see that post asteroid impact. They've kind of, they flowered, they flourish. They've undergone what we call irradiation. The same with birds, the same with mammals. So the signature, the idea that this was also sort of the catalyst to these animals eventually thriving. We can see that quite clearly, and then in a remarkable discovery of fossils in a place near Colorado Springs, Colorado only reported in the last few years, there's great documentation of essentially the first million years after the asteroid impact, and in that record, great record of mammals, we see mammals becoming larger than they had ever been in their

prior 100 million year history on Earth, very clearly, once you sort of took out the big reptiles that created a lot of opportunity for mammals, so that That pattern is now really well documented in the in the fossil record, and the explosion of diversity that we see in things like frogs and birds and mammals, again absolutely clear in the fossil record, and very clear when we understand the histories of these groups that that now exist on the planet, the degree to which we've evolved as.



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Species since the hunter gatherer times. And you would really say that's probably just 12,000 the last 12,000 years or so, when we settled down and started farming, domesticating livestock, domesticating crops, right? This is, this is a profound change in human behavior. This is the beginning of civilization. This is also going to really increase our population size rapidly when we start deliberately raising animals and plants for food. And, you know, the domestication of pea crops, you know, rice, wheat, corn, all that was deep. You know, eight or 9000 years ago, and happening in different places so behaviorally, our evolution, I think, was profound.



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Our societal evolution was profound. How much biological evolution has happened in that time is a little less clear. 10, 12,000 years is not a lot of time. And of course, by living in large groups and by division of labor and growing our own food, we're taking some of the pressure off that nature had put on us before, right? If you sort of think about, if you just think about us living a more animal like lifestyle, you know, vulnerable to drought, vulnerable to famine, you know, vulnerable to weather events, certainly vulnerable to disease,



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having a more reliable food supply, being in a community that would contribute to the collective security of that community. That's really changing our relationship to nature. And then, of course, in the last couple 100 years, for sure, our ability to control infectious disease through sanitation, vaccination, antibiotics, et cetera, is remarkable, and that's had a huge impact on our lifespan. So if average lifespan, maybe around the turn of the 19th into the 20th century, might have been 40 some odd years, we now know we're talking, you know, 70 plus or 80, depending upon where you are in the world. So these are important biological impacts on us. But I often get the question, is our species evolving? And that I don't have a really clear picture of that. If you go back in time, say, 60,000 years ago when humanity left Africa, when the first



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migration of Homo sapiens out of Africa happened, and this was going to lead to the settling of humans on five more continents, if we had sort of stayed as isolated populations, unconnected,



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not able to travel the sea, is not able to, you



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know, during the ice ages, to go across land bridges and things like this,



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then you would have essentially these sophisticated, you know, human populations in different places, but not sharing genes, not sharing culture.



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That sets up the situation for evolution. I mean, isolation is sort of, you know, evolution's laboratory, you this is why the Galapagos finches are such an example of evolution. Is that living on those islands, that isolation factor gives the opportunity for speciation to occur. So because now we are so connected as a species, essentially sharing genes and culture across the globe that's going to



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work against sort of whatever biological evolution might be underway because of how we've changed our our food supply and changed our relationship to infectious diseases and things like that. So anatomically and physiologically, I would say I don't think we've evolved much. You can see in certain human populations that are specialized to high altitude or certainly across



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different latitudes in terms of with respect to how much sunlight they get, that obviously Northern Europeans and equatorial Africans, we all look differently because those are actually local adaptations, but those aren't fundamentally, you know, speciation events happening. So we're we've adapted to certain local climates. But I wouldn't say that it's as profound in evolution as what was happening, for example, in the early stages of the ice age. I think we should all feel very lucky to be here first as a species for the reasons of understanding that things on the planet could have gone very differently, the asteroid, the ice ages, et cetera. But as individuals, as we've learned more about human biology, we understand really how lucky we are. And if you think luck is just take your one in, and we'll mention a number in a second that you know our individual existence is a series of fortunate events. So, you know, picture, you know, a spherical object with maybe surrounded by lots and lots of, you know, meteors, and there's an impact of just one.



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And then there's big chemical changes. Well, it turns out, you know, I'm not describing the asteroid impact, I'm describing fertilization of an egg by a sperm. And in the fertilization of a single egg, there's about 100 in human fertilization, there's about 100 million sperm on average, that could be contending to be the winning sperm. That's going to then trigger the beginning of human development, and those 100 million sperm are carrying all sorts of genetic combinations from the Father, and that one individual egg is carrying one out of about 8 million different genetic combinations from the mother. So when that one lucky sperm makes it and combines with that one egg at that moment. That's about a one in 70 trillion event, genetically speaking, that any two human parents could, if given this time and space, make about 70 trillion different genetic combinations of babies. So when you think about your own individual uniqueness, you know, we all like to think how unique we are. Well, this is the fact that entitles you to think that way, that you are truly, unless you have a twin, an identical twin, you are truly genetically unique, and there will never, ever, ever be anyone like you, ever again on the planet, or ever before, because that one in 70 trillion, as it turns out, is compounded by a couple other factors. That's just the sorting of the chromosomes in the making of the sperm and making of the egg, and then the combination of those two. But it turns out, in the shuffling of chromosomes in the making of the of the egg and the sperm, there's also events that shuffle segments of chromosomes in so many ways that essentially, there's an astronomical number of different sperm and egg that could be made. Furthermore, there are individual mutations in every sperm and in every egg, randomly distributed in DNA.



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Mutations that didn't exist in mom didn't exist in dad and wouldn't exist by chance, really, in any sibling. So the genetic recipe is getting mixed up at every in every generation on an astronomical scale. So yeah, you are truly genetically unique



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there could you could have had up to 70 trillion siblings, but it's just you and so yeah, I think we should feel fortunate that we are individually here,



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chapter two, the resilience of nature.



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So if humans disappeared from the planet, the planet would definitely heal itself. And



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the reason why that's true, the reason we can assert that, is that the planet's been through hell before, probably worse than this, much worse than this, because of massive volcano eruptions or an asteroid impact or things like that. And within some amount of time, let's say, on the

scale of a million years, and the rebound will start quickly. But you know, within a million years or so, life has really come back, and that really teaches us that whatever sayings we've heard, Life finds a way, or things like that really, really is true. And the evidence for that we should get to in a second, but the evidence for that is Life finds a way in a really short period of time, much shorter than a million years. And that's really important to our most immediate future, what the Earth would look like if humans disappeared. It sort of depends. The stage at which we disappear, what's what's left behind, who sort of the dominant creatures are? What are the most abundant creatures? What sort of ecosystems would we have? We know that certain ecosystems are getting that are getting really stressed, things like coral reefs, which have been around in some form and other for perhaps 300 million years.



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They're pretty stressed. We're not sure if they're going to make it to the end of the century. Tropical forests, pretty stressed, high mountain environments, where now one of the most profound effects of climate change. Or, of course, at high altitudes where you're seeing, you know, glaciers are disappearing, and that means that a lot of high altitude life is is changing. So, you know, if we were to disappear, you know, almost instantaneously, it sort of depends with, you know, the position of all the pieces on the chessboard and and the abundance of relative things as to, as to what will happen. But we know that some of these ecosystems that we recognize, you know, forest ecosystems and things like that, they'll they will re they will rebound, just perhaps, with different dominant species than what existed before, gaging the human impact on life on the planet. That's a pretty touchy subject. Because, on the one hand, you know, humans are a pretty remarkable species. I mean, I think we can look at ourselves and be very proud of our persistence, and, heck, we're the only species that's left the planet and, you know, touched the moon. You.



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Yeah,



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and of course, we do all sorts of interesting things, like



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music and painting and making movies.



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At the same time, we've had a huge ecological footprint, and especially so in the last couple 100 years and since the Industrial Revolution. And so for a lot of biodiversity on the planet. That's been bad news, that if you're if your scale is to say, Well, what's happened to biodiversity on the planet during sort of this human flourishing, where we become so

numerous? You know, we only hit a billion around the year, 1800 a billion humans. And it took a century to double that. And then now it's doubling, I know maybe perhaps something like every 13 or 15 years. I mean, not adding a billion every 13 or 15 years. So



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that requires a lot of resources. So we're using



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the land surface, we're using fresh water, we're harvesting lots of wild things like fish. That's a big ecological footprint, and we can tell certainly, just maybe over the last 50 years where this has been studied more intensively, we've had a big impact. For example, for every three vertebrates, those are animals with a backbone that would be fish and amphibians and mammals and birds and reptiles, for every three that were alive on the planet 50 years ago. Only one exists now. So we've taken out that's not species, that's numbers. In other words, the abundance of wildlife is dramatically reduced in just the last 50 years. So we have to think about why is this so what are we doing or not doing that's contributing to this disappearance of our fellow creatures? And I think the constructive way to go into that is not to beat ourselves up too much. I think that gets us into the, you know, humans are bad, and I think gets us into a very pessimistic and negative mindset. Because I think while the loss of biodiversity is extremely concerning,



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I'll describe it perhaps as a silver lining, or at least the good news that is not shared, that is not talked about nearly enough,



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is nature's resilience and how, if given a chance, and that chance means habitat, time and some protection. Nature can rebound, and nature can rebound dramatically. And I'm talking about both individual species and whole ecosystems. So I think it's really important that we don't bog ourselves down in sort of living in the past and and, you know, beating up humanity for what it's done. Literally, we didn't know much about how the world worked 50 or 60 years ago. There have been so many discoveries in ecology about how ecosystems work that, you know, I'm just going to hold ourselves innocent by sort of ignorance as



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recently as 50 or 60 years ago. Now, we do know better, and part of knowing better, the actual good news is, is that systems and species can rebound, and there's evidence for that



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all over the planet. But for some reason, these stories are greatly under told, I don't think of the earth as an organism. I really think of the Earth as harboring all these different branches of the tree of life. And then over the course of time, the sort of the abundance on those different branches has changed, and new branches have grown, and old branches have died off. But if you look across today, I think, I think one thing that we are

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limited in our ability to realize is just how abundant other species were in prior times, in human historical times that you know, just take something like sea turtles. Who doesn't love sea turtles, right? Their numbers used to be massive. Now, good news is in some places, they're coming back, but they're still only coming back to a fraction of how they existed before, or shore birds. I mean, the congregations of birds existed in the 19th century in certain places were would be jaw dropping to our eye today, dugongs and manatees whales. You know, we're all thrilled now to see a whale, and people love going whale watching, and that's great. And whales are rebounding, but we knocked a lot of whales to perhaps one or 2%

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of their original force. And so, you know, whales are whales are a thrill because they're a rare sighting. They used to be far, more abundant people living today. They have to read about these accounts. They have to hear about them. You know, third hand from some talking head that

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life was wildlife was so much more abundant on the planet in very recent times as.

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We, you know, spread out and started writing these chronicles of what, you know, we found when we went to various lands or waters, astonishingly more abundant. And if you say something like, you know, lions. Now, in the probably the middle of the 20th century, there might have been a quarter million lions, you know, we're down to maybe 20 to 30,000 lions. They've disappeared from somewhere around, I know maybe 16 or 18 countries they used to roam in. So decreasing ranges, decreasing numbers. I'm still thrilled. I need to see lions. This is like something, you know, I have to go see lions and giraffes. Like some people need a hug. Okay, I got to see them,

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but they are less abundant, far less abundant than they used to be, really, not so long ago. And I think if people really had



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had that experience, if they really could sort of see and feel how much wildlife has been diminished. And I think a good number of people do do sense this. They want a different planet. I do have a fair amount of faith that humanity wants a little better planet than what we have right now. And I take that faith from seeing how people react to when places and species recover. They're They're thrilled, they're exhilarated. They're rooting for things. They're rooting for whales. They're rooting for manatees. They're rooting for tigers. You know, they they root for their local forest. They love it when a, you know, a local lake or beachfront is, you know, is rejuvenated. So I think people want a healthier planet. So we just need to help them know what, what? What can be done to make this, you know, a much more



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abundant place while society has been humming along and enjoying all these advances in, for example, in agriculture and medicine. In the last 50 or 60 years, ecologists have learned a lot about how nature works. So you almost have to think that we didn't have a really good clue about the relationships between creatures and really how some things happen in important ecosystems, until fairly recently. So on the one hand, I'm also going to say, I think that gives us a little bit of



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amnesty for some of the things that we might have done before, because we were just simply not knowledgeable about it. But as we've learned these things, I would say



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I've codified these into a set of rules called the Serengeti rules. I call them the Serengeti rules because you can see them in operation in the magnificent Serengeti, you can see them in operation all sorts of other places, like Lake Erie. But I don't think Lake Erie rules would have sold as many books. So



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a couple of those rules that are really important is that some animals are more important than others, meaning they have an outsized impact on the communities in which they live. And so if you've always, you know, there's sort of this, sometimes this poetry about nature of you know, every creature has its place and its purpose, and everything is equally important. That's not true. The





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functioning of these ecosystems are sometimes much more dependent upon certain individual species or small groups of species than others. That's really important knowledge, because if

we lose those species, those communities can collapse, and if those communities are somehow compromised, reintroduction or boosting those species can have great knock on effects on the overall health of the ecosystem. Similarly, we know that some species have really strong indirect effects on others. So for example, in the Pacific Northwest, the trees need salmon.

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What

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the trees need salmon that basically, you know, rivers don't have a lot of nutrients. A lot of the nutrients in those rivers comes in from the ocean in the form of salmon bodies. And when those salmon, for example, they lay their eggs, which are food for creatures, but when they are taken by all sorts of carnivores, and when those carcasses are left on the stream banks, the nutrients from those carcasses fertilize them, of course, feed all sorts of carrion species, but they also fertilize the trees, and we can actually trace those nutrients from the ocean into the trees in the Pacific Northwest. Who would have thought of such things? And that, for example, the kelp beds in the Pacific Ocean, they need otters, and the trees in Yellowstone need wolves. So this, these hidden connections between species and ecosystems. We there. We didn't imagine them almost. Perhaps they were hard to believe at first, but now that we understand they're there, we now understand why it's important sort of the domino effects that ripple through ecosystems. We now understand why it's important to be aware of those things. That's just an example of a couple of the rules, but these are general rules. You'll see these things operating in all sorts of systems, whether it's, you know, coastal oceans or a freshwater lake or a tropical forest or the African savannah. These are general rules. The number one driver of the loss of biodiversity on the planet is habitat loss. Then and then that lost habitat is because humans have been taking over more and more. Say, Let's just talk about land. Yeah.

 40:00  
Is that we've been taking over more and more of the land for our purposes, and the number one use for us is growing is our food is food production. Now, as it turns out, though, you know, our food production is kind of a haphazard sort of thing. There's no central planning for the world that decides, you know, what's the right mix of foods that would, you know, feed humanity. It's driven by market forces, by history, by all sorts of things. So here's a shocking fact, an overwhelming amount of that land surface is devoted to livestock production, either growing the food for livestock or actually livestock grazing. And then here's another Inconvenient Truth, which is, but livestock, like beef, is actually a relatively poor source of calories and protein for humans. It's certainly a very inefficient source in terms of how we use our land and use our resources. So, you know, we like beef. I like beef. Lots of people like beef, but it turns out, the scale that we're doing it, we've been cutting down forests and mowing prairie and creating all sorts of spaces for our large animals, but our large animals don't provide

 41:22  
for essentially for the ecological effect, death provides the calories and protein that for example

for essentially, for the ecological error, don't provide the calories and protein that, for example, plants do. Colleague Pat Brown, founder of Impossible Foods, describes, you know, cows as a very inefficient food technology. You know, much like horses were not as efficient as automobiles or whales were not as efficient as electricity

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in that. And it's a pretty simple ecological principle, which is, you know, all that plant matter that's going into a cow, essentially, a cow is transforming plant matter into, you know, muscle protein that we're going to eat, right? That's an inefficient process that cow only captures a little bit of the nutrition and energy that's present there in the plants, so that when we come along and eat the cow, it's a very inefficient way for us to get our nutrition. So what I'm stumbling around there explaining is that we have cleared a lot of the land on this planet for our livestock, though, now realizing that that livestock is not the most efficient way for us to get calories and protein. So let me talk a little bit about the resilience of nature, and I'll maybe, I'll start with some maybe for more familiar examples, 1960s

 42:34

the crisis was that things like bald eagles and peregrine falcons were disappearing. We're down to fewer than 500 breeding pairs of bald eagles in the lower 48 states. That's the national symbol right in the United States, when it was discovered, understood that that was because of the use of the DDT pesticide, which became concentrated in the food chain. So these Raptors were feeding on things that fed eventually, you know, all the way down eventually on insects that were

 43:03

consuming this DDT,

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and other life forms that were absorbing the DDT, they were concentrating it in their own bodies, and that was making, for example, their eggs very fragile, and reproduction of these birds collapsed When DDT was removed from the environment. These populations rebounded. So for example, today, there's more than 70,000 breeding pairs of bald eagles. So that was just a case. Take that threat away. Take that pressure away from bald eagles. They rebounded. Peregrine falcons rebounded.

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Turn of the last century,

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the fur trade loved otter fur, right? Otters had this great water repellent fur, et cetera. Well, we almost drove otters along the Pacific Rim. Sea otters to extinction, perhaps down to as few as 1000 animals. When that trade was banned in the early 20th century, otters came roaring back, and now otter populations are back up, 100,000 plus, et cetera. The same thing has been seen with whales,

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when we took the pressure off whales, things like Northern Pacific humpback whales have rebounded. Blue whales, the largest animal that's ever lived, Blue Whales have rebounded from their lows. So those are individual species, if you take the pressure off, same with manatees, same with grizzly bears. Take the pressure off, their numbers come back, okay. But what about systems? And a story I'll tell comes out of southeastern Africa. In the country of Mozambique, in

 44:38

the 1960s there was a park, really, in the geographic center of Mozambique called Gorongosa, and it was a jewel. And jet setters from around the world would go there, because there was incredible concentration of wildlife in the center of the park. And they would see elephants and Buffalo and hippo and lions and all that. But Mozambique in the mid 70s, after.

 45:00

Its independence from Portugal, had a horrific civil war that lasted nearly 20 years,

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killed a million people. 5 million people were displaced, and Gorongosa was pretty much the geographic center of that conflict between rebels and government. And so wildlife was were killed for meat. They were poached for to, you know, things like ivory to be sold on the black market and such that by the mid 1990s you probably had maybe 98% of the large animals of Gorongosa had been decimated.

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And that's really the way things might exist today, if not for an American philanthropist named Greg Carr and the Mozambican government who formed a partnership in the early 2000s

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to try to restore Gorongosa National Park. And I've been there twice in the last 10 years, and I'm really happy to report that Gorongosa is now home to



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probably 50 times as many large animals as existed there 20 years ago, that the herds of elephant are thriving, that the hippo numbers are growing, that the Lions have rebounded from virtually gone to perhaps about 180 individuals. It's a remarkable comeback story. It's essentially now one of the best known



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restoration stories on the planet, because Gorongosa was given up for dead, but it illustrates the general principle that the habitat was still there. The animals were gone, but given some seed stock, what was left, and a little bit of introduction, but really small numbers of animals that nature will fill that space and so, and that's in a short period of time, the dramatic change was evident just in the first decade. By two decades, it's quite clear gorongos is almost like full up again, like you almost have, almost to the maximum carrying capacity for these large animals. So the important message to shout from the rooftops is that, yeah, nature is resilient. And not only can nature come back, it can come back in a time period right under our own eyes. If I said to you, you know, in 100 years, if we just behave differently, things might be better. It's like, well,



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but if I tell you that, in five or 10 years, you'll see an impact of accommodating this ecosystem or accommodating this species, and in 20 years, you might see full recovery.



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And that is, that should be motivating. And when we see that happen in other places, for example, one of the things that's starting to happen across the globe is that dams are coming down. There was a real period where dams were going up. We're doing lots and lots of damming across the rivers of the world to use water for power, for use water for agriculture, et cetera. But after a real sort of go go period, a lot of those dams are very old. They're not really meeting their original purpose. They're expensive to maintain. They may actually be a risk to human populations if they collapse or if they fail.



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So a lot of dams are coming down, and when those dams come down, sometimes deliberately. For example, a great model case is the Elwha River in Washington State. If those dams have been up for you know, 80 or 100 years, you might wonder, can a river ecosystem rebound if, for example, just think about the salmon run from the Pacific into the Elwha River, which it was a Salmon River. You know, if, if salmon haven't gone up river for 100 years, what will happen when the dams come down, when that physical obstacle to their spawning up river comes down, and the answer is,



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they'll go up river, they'll come back. The populations are definitely rebounding. The river ecosystem is coming back. So even in severely disturbed ecosystems, you can see recovery. Same story in Yellowstone National Park in the United States. It's a pretty famous story of reintroduction of wolves, which had been exterminated from the lower 48 and the last wolf was killed in Yellowstone in about 1924 so there have been no wolves for 70 years in Yellowstone. And you might say, so what you know, we can get a lot. We can get along without these large predators. Well, that's been shattered by ecological discoveries. These large predators play a really important role. And the case of Yellowstone, essentially, trees need wolves.



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Think about that for a second. Trees need wolves. How do you draw, you know? How do you draw that connection in your head? Well, it's by wolves controlling the browsing and grazing of, for example, deer and elk that was absent for 70 years, it was stunting plant and tree life in Yellowstone. We didn't quite realize it, but once we realized it, and yet, wolves were reintroduced in 1995 and within a decade, you could see changes in the landscape of Yellowstone, and those changes led to increased abundance of other sorts of creatures. So.



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Yeah, but the other thing that we've discovered about how these ecosystems work is that some animals are more important than others, and in the case of things like the yellow of Yellowstone, that apex predator, the wolf, its removal had all sorts of knock on effects we didn't recognize, but its reintroduction had all sorts of knock on effects where it increased the abundance of other creatures that we didn't expect, for example, certain types of trees or beavers or trouts in the stream. And so over the last 50 years, have we, as we've learned about all sorts of hidden connections and ecosystems we're realizing, first of all, why were some of our actions so damaging? But the flip side of that coin is why a little bit of action now can be so rewarding, can be so positive, because the reintroduction of wolves has knock on effects. The reintroduction of, for example, wild dogs in goragosa has knock on effects. And that these systems, these sort of webs of life, can be re stitched just by the introduction of certain key creatures. And that should give people immense hope. These stories are playing out on many continents and in many localities across the globe. We heard a lot of anecdotes during covid of sort of animals coming out from sort of the shadows or sort of appearing, you know, on our doorsteps or on a coastline, or whatever it might be. And I think, you know, people were really warmed by



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by seeing some of those changes in behavior, and, of course, seeing some some more wildlife. And that's probably just a glimpse of, you know, the way nature would be if we weren't in the way. And I think the more aware we can become of when we're in the way. Take, for example, just our highways. Okay? Our highways separate nature into islands, essentially, right? A big, you know, four lane or six lane highway, that might as well be a wall. It's a death trap, of course, for animals that need to cross it. But as we recognize that, what can we do to

accommodate that movement. And what you're seeing across the globe, again is the building of corridors, wildlife corridors, overpasses and underpasses around highways to enable that movement around so I think if we just become a little more aware of how we change their behavior,

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we can give them a little more room. Same thing we're we know that, you know, lit building, office buildings, tall office buildings, at night,

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they're the responsible for a lot of bird strikes. A lot of bird deaths are have to do with colliding with tall buildings. We can change our lighting schemes to be more friendly, for example, to birds. So some of this is not really, you know, changing our daily habits. It's just taking into consideration other creatures and what they need to to, you know, carry on their their lives. And so I think getting into that mindset, and I think people are really warm to this. I think if you give people, you know, just especially something that really doesn't need to convene them at all. You just give them the opportunity to to allow nature to thrive a bit more around them. I think many, many people will will respond to that. So biodiversity is really important to our existence, because we rely upon, you know, fresh air, fresh water,

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healthy land,

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healthy oceans for our own existence, and

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that's largely the work of creatures on this planet, from earthworms and fungi in our soil, you know, to, of course, the plants and trees that generate The oxygen

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to, of course, the fish stocks that and and other ocean life that that we both rely on for food, but also make the ocean a functional place. So human health, and I think we're, you know, going to sense this more acutely as the years click by, human health depends upon healthy ecosystems. Of course, freshwater being another obvious one. So we have a stake in the ecological health of the planet. That's just a scientific fact. I think we also have a stake in the health of the planet, really, in terms of even our own mental health. I think that there's plenty of evidence that contact with nature



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is a positive thing for humans, and that we need some of these spaces,



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coastline, ponds, lakes, forests, et cetera, for our own sense of well being, and when that's lost, you know, perhaps most dramatically by things like, you know, wildfires and things like that, when we really see terrain destroyed, you know, I think that that alters our sense of well being and our and our hope for the future when we think about what we need to do,



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let's just take.



55:00

One aspect of something we know we need, we need fresh water, okay? And we're here, and water is in the news a lot, right? Because one thing we know that climate change is doing is it's changing the distribution of fresh water, and it's changing at a time where water resources are under a lot of demand for all sorts of human activities.



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Well, you know, polluted water doesn't do us much good,



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silty water doesn't do us much good.



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Algal choked water doesn't do us much good.



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So all those things are the result of not necessary, of not managing the systems around water sensibly.



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We there's things like watershed. So for example, when you see a nice, clean stream running off a mountain, the mountain, the soil and the trees are doing a lot of the work to make that water clear. When we denude a mountain, when we cut down the whole forest and all the dirt runs into the water, then we now have not only silty water, but that will affect the ability of the land to hold the water and essentially release it slowly over the seasons. So we're learning, or we've certainly learned, sometimes the very hard way, that

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things like we need tree covered mountains for our fresh water supplies. So does wildlife well? Wildlife also needs those forests to live in. So the coexistence solution is we need the fresh water. It just turns out that we're given that fresh water by keeping the ecosystem intact, coexistence is sort of going to be it could be intentional. It could also just be a byproduct of managing ecosystems more sensibly, even for our own benefit. And I think fresh water is going to underscore that again and again in the coming years and decades, because the distribution of fresh water is changing, and the way we've sort of had the luxury, sometimes in the past, of having an abundance of water, and therefore, as you know, rivers became contaminated, or, you know, lakes became stagnant, or whatever, those weren't perhaps, you know, immediate crises, but there's so much. I grew up on the edge of Lake Erie, okay, as a kid, I never swam in it. I never fished in it. I never ate anything that came out of it. What a waste of resources. What a tremendous waste of resources. I mean, just think about the United States and our inland water sources and goodness Lake Erie. When you know, you can look at accounts from Lake Erie of you know, from the early 19th or late 18th century. Oh my gosh, you know, like there was a, it was a buffet, right? Of you know, food and things like this. And, of course, its water resources are immense. So this is about changing our mindset, and that we've been sort of in the I'll put it this way, and this will get a little bit more. This is where I think people will have some different feelings. But we've sort of treated the environment. Our laws are sort of like we sort of draw limits at what you can't do to the environment because it's too harmful, right?

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And maybe we should be sort of thinking more about what we can do to make the environment more healthy. And that's a little bit shift of a mindset. And you see that mindset changing, for example, in countries like Ecuador and Panama, who've written laws, in some cases, into their constitution called rights of nature and the idea, and this is a big philosophical step, and this might be very too much far, you know, much farther than some people are willing to go. But for those countries, they're making really tough choices. They're saying their their biodiversity resources are so important, it's an existential question for the country, and they're foregoing certain other things in order to preserve their biodiversity. So in Ecuador enshrined in their constitution the rights of nature basically enshrine the right for ecosystems and species to exist, and that human activities that threaten those species or systems with extinction

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shall be banned. In other words, that's triable and have been tested in court. And that means, for example, mining projects, multi billion dollar mining projects that aren't happening. Panama just passed that law in 2022 and just in December of 23 their Supreme Court ruled on about a

just passed that law in 2022 and just in December of 23 their Supreme Court ruled on about a \$10 billion mine project that wasn't going to go forward. So places that perhaps see more acutely their quality of life and their country's future being wedded to the health of their local ecosystems are drawing a line in the sand now and saying no, no further destruction. We have to.

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Figure out how to work with what we have, how to coexist and cannot. We cannot tolerate, for the law in the long run, further destruction. And I think for you know, heavily industrialized countries like ours, I think maybe we can take a little bit more

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nuanced approach and just say, Look, we we can do things that will be much more constructive for coexistence, that are in our own species interest. Let's prioritize those things. They're not ridiculously expensive. In fact, they're probably cheaper in the long run than the damage that we would cause. I think there's a reason why fatalism is called fatalism. It's fatal

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I mean pessimism and hopelessness. I mean they're going to be self fulfilling, you know, prophecies. And I had to, I had to, sort of examine this question for myself. About 10 years ago, I really started spending more time with ecologist I really wanted to answer the question for myself, you know, is nature doomed, or is there time to change the road we're on? And I reached the conclusion, perhaps most

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catalyzed by Gorongosa, but many, many other stories from all large and small, that no there is time to change the road we're on. Because, in fact, nature can rebound so quickly, and that some of this is really just our learning how to coexist, and we don't necessarily have to inconvenience ourselves too much to just make things bit more hospitable

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for nature. I also think there's a lot of reward. I think people need, they need to participate in things that are constructive and positive with regard to the future, and so to participate may simply mean, you know, thinking about the plants you plant in your garden or on a windowsill,

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what you use on your lawn,



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maybe participating in some neighborhood or local event that might clean up a pond or Clean up a lake or something like that. There's ways to contribute where you'll see the fruits of that contribution in relatively short order. And I think that can make people feel better about themselves, better about



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the present, and a bit more hopeful about the future. And I don't think it's pollyannish. I don't think it's a case at all. No matter what we do, you know, it's sort of doomed. No, look at these stories. Look at, look at species have come roaring back when given a chance, and or look at the systems that have come come roaring back. So it's not going to be great everywhere. There are going to be places that are going to collapse and going to be, you know, essentially,



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you know, really dark chapters, but because biodiversity is is really affected by local forces,



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this is where we have local control. I understand with respect to climate change, because we globally share our climate that we understand we need treaties, we need global action. We need, you know, industrial countries to act in concert, et cetera. And that seems, you know, overwhelming to an individual, but I know so many, I'll just call them, conservation entrepreneurs, young people, individuals who just got something rolling, and it may have grown over some period of time to something that's almost, you know, kind of remarkable sort of scale. But I think there's a lot of room for Initiative, a lot of room for joining action in small numbers and small groups, small organizations that can have an outsized impact. And, you know, in some ways, it sort of goes to the more philosophical question of, you know, what are we doing with our time we spend here on the planet? You know, do you want do we want to sit in our armchairs and essentially just, you know, forecast doom. Where do we want to get up off our asses and do something? And I think it's part of the responsibility of the scientific and educational community to say, No, there's things that we can all participate in that can make our lives better and make our lives better soon. And that thrill that people had, you know, looking out their window during covid and seeing, you know, a Fox Run by or whatever it might be, those thrills are readily available. We do not have to have another pandemic. So the really important fact about biodiversity loss is it's generally due to local factors.



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The silver lining to that is, is that local action can restore



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it. This is



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the truth that needs to be echoed around the globe, but it's being demonstrated around the globe in in so many different ways,



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all sorts of scale, small to larger scale,



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little bit of effort, big return.



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Chapter Three, the evolution of humanity. So human life has changed so much in modern times. You know, I think that



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if.



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If someone could parachute in from, say, you know, 1800 to the modern day, it would be a bewildering experience in so many facets of our living, whether it's you know how we make our food, of course, you know, transportation, energy, disease, medicine, you know, enormous transformation of how we live, and that has given us great quality and quantity of life.



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So I think it's, you know, it's a lot to celebrate, but of course, it also creates some collateral things that we struggle to manage. So our lives have changed a lot by really gaining control over a lot of nature. If you consider nature, you know the vulnerability to the elements, which includes things like drought and famine, which are going to affect, you know, the abundance of food and and water, infectious disease, wild animals, etc. Almost all that has changed for most people on the planet. And so that's really changed fundamentally, the quality and quantity of life. And central to a lot of these changes are, for example, the science of biology that we have, you know, gained control over agriculture, over medicine, over our own body physiology, by discovering how more and more about how nature works, and that knowledge has been power.

The most powerful medical advancements are probably in the prevention and treatment of infectious disease. So that you look into history, you know lots of child mortality due to infectious disease. You know lots of lives cut short from what we now know as biologically possible because of infectious disease. So, you know, we didn't know about viruses and bacteria, you know, until the last 150 years, and we didn't know much about how to manage them until probably the last 70 to 75 years. So the advent of vaccines, of antibiotics, of antivirals and of better sanitation has dramatically reduced what people deal with. I mean, a very in the 19th century, a very large percentage of Americans had TB, you know, now we would kind of think about that disease as you know, where did that go? In the 1960s in the United States, there was a rubella outbreak, I think it was something like 12 million people, sometimes called the German measles.



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We don't hear the word rubella much because it's the R and the MMR vaccine, and so everyone's vaccinated against it as a child. But can you imagine 12 million cases, and it's serious, lots of collateral effects on



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especially on children, and those things have disappeared. So we can, we can pluck, I mean smallpox, which killed 10s and 10s and 10s of millions of people, not only has been controlled, it has been eradicated from the planet, from every nook and cranny of the planet. Smallpox is gone, one of the greatest killers of humans in very recent times. So, you know, freeing ourselves of these things that caused death and disability,



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that's that's a fundamental change in our outlook, a fundamental change in the quantity of life that people experience with respect to agriculture and food production. A remarkable statistic is that in around 1900 perhaps 40% of the United States labor force was involved in farming and agriculture in some way. That's now 2%



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and that 2% is providing a lot more food for a lot more people than it ever did, and, of course, exporting around the world. So the efficiency of agriculture, the productivity of agriculture, is remarkably different. Some of that is due to automation, a lot of that is due to automation, but a lot of that is due to discoveries about better seeds, better ways of nourishing crops, better ways to fight off plant diseases that would have caused crop failures. So



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we enjoy a much more secure food supply than we did 100 years ago. Something that's generally true about nature, including our bodies, is that everything is regulated. And what I mean by regulated, it means that in our bodies there's all sorts of substances, some that are in

mean by regulated, it means that in our bodies there's all sorts of substances, some that are in very small amounts. Some of them are sort of medium amounts. Some are in large amounts, and that those levels, those amounts, are kept in check by some of the body systems, by all sorts of regulatory systems. Some of that is feedback regulation, and that's important, because sometimes if we have too much of one thing that's a disease, too little of something that's also a disease. So for scientists to figure out the rules of regulation in the body, to know what the right level of insulin is, or what the right level of for example, even as.



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You know red blood cells are that's been really important to how to managing health and managing all sorts of situations. So what's true for the body is also true in broader nature. It turns out there's rules in nature that govern the relative abundance of plants and animals, and when we understand those rules, we know better how to manage those places for sustainability, for their health and our health. So the scientific quest to understand the rules of life has really practical motivations for ourselves, for example, for medicine, if you think about things like, I mean, cancer is a space essentially a disease of abnormal regulation. Your some population, skin cells, white blood cells, brain cells, or whatever is out of control, growing out of control, and that's obviously a life threat. We need to understand the rules that govern how cells multiply and why certain things run amok out in nature we're trying to manage, because we're such a big part of we are nature's manager. Now, whether you like it or not, we've taken it over. We're trying to manage nature for the long run so that we have the things that we need, and hopefully nature can persist. So we need to keep exploring



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these interactions, whether they're interactions within the body, or their interactions out there in nature to manage our future. You see the payoffs in medicine, every discovery, every new medicine, the way we manage so many diseases, that's entirely the fruit of the last 50 Years of understanding these basic rules. We need that same sort of mindset to be taken outdoors into nature so that we can manage the planet better. If we managed our bodies the way we manage the planet, there would be a revolution.



1:11:48

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