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INTRODUCTION

Compared with our cousins on the Tree of Life, humans are poor listeners.[1] Below the lower end of human hearing lies deep infrasound: the realm of thunder and tornadoes, elephants and whales. Many creatures can sense and communicate in infrasound, which travels long distances with ease, passing through air and water, soil and stone. In one of the animal kingdom's most famous mating rituals, male peacocks transmit powerful infrasound with their raised tails; what humans perceive to be a visual display is, in fact, a sonic summons.[2]

The deepest infrasound is generated by our planet itself. If you could tune into the Earth's infrasound, you might hear the rumblings of calving icebergs, the howl of a volcano, or the roar of a typhoon halfway around the world.[3] Lowest of all, the Earth's periodic infrasonic pulse resonates below our feet and through the air. As ocean waves collide over continental shelves, they vibrate the Earth's crust in a rhythmic fashion—the drumming heartbeat of our planet.[4] When earthquakes convulse our planet's surface, they create airborne infrasonic tremors—ringing our atmosphere like a quiet bell.[5]

The planet's infrasonic chorus is continuously sounding all around you. Many animals—rock doves and snakes, tigers and mountain beavers—are able to hear these low-frequency sounds, but not humans.[6] Our hearing is typically confined to a relatively narrow band of frequencies, between 20 Hz and 20 kHz, a range that narrows as we age. At best, we can sometimes sense infrasound as a throbbing in the chest, or a troubling feeling of unease.[7]

At the other end of the spectrum, above the upper threshold of human hearing, lies the ultrasonic: high-frequency sounds that vibrate too quickly for us to hear. A surprisingly diverse array of species—mice

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and moths, bats and beetles, corn and corals—emit ultrasonic sounds imperceptible to humans.[8] Our ancestors may once have been able to hear these high-pitched sounds, and our smaller primate cousins—tiny tarsiers and dwarf lemurs—can still communicate in ultrasound.[9] But contemporary humans have lost this ability.[10]

Still other species use ultrasound to visualize their world: to navigate, find mates, and follow prey. By using what is known as echolocation, bats and toothed whales create images of their surroundings by sending out beams of ultrasound and analyzing the returning echoes. Biosonar (as echolocation is also known) functions somewhat like an acoustic flashlight, honed by evolution to be as accurate as our finest medical devices. Simpler forms of echolocation are also used by cave swiftlets and oil birds, nocturnal shrews and rats; they, too, see the world through sound.[11] Yet although these calls are some of the loudest ever recorded in the animal kingdom, they are inaudible to us.[12] Attuned humans can occasionally hear the subtle clicks at the lower end of animal echolocation; rarely, blind people even develop the ability to echorange themselves. But for most of us, even the loudest ultrasonic sound blown directly into our ears would feel like nothing more than an empty, ghostly breath of wind.

As Blackfoot philosopher Leroy Little Bear says, "The human brain is like a station on the radio dial; parked in one spot, it is deaf to all the other stations . . . the animals, rocks, trees, simultaneously broadcasting across the whole spectrum of sentience."[13] Our physiologies—and perhaps our psyches—limit our capacity to listen to our nonhuman kin. But humanity is beginning to expand its hearing ability. Digital technologies, so often associated with our alienation from nature, are offering us an opportunity to listen to nonhumans in powerful ways, reviving our connection to the natural world.

In recent years, scientists have begun installing digital listening devices in nearly every ecosystem on the planet, from the Arctic to the Amazon. These microphones are computerized, automated, and networked with digital sensors, drones, and satellites so powerful they can hear a mother whale whispering to her calf in the depths of the ocean. Researchers have attached tiny microphones to honeybees and turtles,

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and affixed listening posts to coral reefs and trees. When interconnected, these listening networks may stretch across entire continents and ocean basins.[14] Amateurs are also listening to nature's sounds, using inexpensive listening devices, like the AudioMoth (an open-source device the size of a smartphone); the cheapest build-it-yourself version now costs well under $100.[15] Combined, these digital devices function like a planetary-scale hearing aid: enabling humans to observe and study nature's sounds beyond the limits of our own sensory capabilities.

This book tells the stories of the scientists who are using these digital technologies to decode the hidden world of nonhuman sound, and the surprising sounds they are hearing. Recent scientific breakthroughs have revealed that a vast array of species makes an astonishing assortment of sounds, mostly beyond the range of human hearing—and so, until recently, unsuspected and unappreciated. (In writing this book, I surveyed research on more than 1,000 species, a small fraction of the scientific findings on bioacoustics—the technical term for the science of listening to nonhuman organisms.) Dolphins and belugas, mice and prairie dogs use unique vocalizations (like signature whistles) to refer to one another, much as we do with individual names.[16] Baby bats "babble" at their mothers, who speak back to their young in "motherese," just like humans do. Turtle hatchlings—previously thought to be mute—coordinate the moment of their birth by calling to one another through their shells. Animals use sound to warn, protect, and lure one another; to teach, amuse, and name one another.

Carefully listening to the nonhuman world reveals complex communication in a broad range of species and challenges the claim that humanity, alone, uniquely possesses language. These claims might seem plausible when discussing primates or birds. But what digital technologies reveal is the vast extent of sonic communication across the natural world. Using digital bioacoustics, scientists have documented the ability of species without ears, or any apparent means of hearing, to interpret and respond to complex information conveyed through sound. When dispersed in the open ocean, fish and coral larvae (creatures only a few millimeters in size, with no central nervous system) distinguish the sounds of their home reefs from the cacophonous ocean, and then swim

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back home to settle. Plants emit distinct ultrasonic noises when dehydrated or distressed. In response to the sound of buzzing bees, flowers flood with sweetened nectar, as if in anticipation. The Earth is in continuous conversation. Now, digital technologies provide a new way for humanity to listen to the vivid soundscapes all around us, opening our ears to the resonant mystery of nonhuman sound.

Resonant Earth

The scientific breakthroughs explained in this book primarily occur in two fields of study: bioacoustics and ecoacoustics. Together, these scientific disciplines enable humans to have digitally mediated access to the hidden conversations ongoing across the natural world, even in the remotest places on Earth. As explored in the chapters that follow, this dramatically enhances our ability to monitor organisms and ecosystems and detect environmental change. Scientists are also experimenting with the use of bioacoustics and ecoacoustics to restore ecosystems; nature's sounds, they have learned, can be used to regenerate the health of plants and animals, including ourselves. Their research also reveals that environmental noise is an exponentially growing assault on the natural world and a major form of pollution; quieting the human din is thus one of the major conservation challenges of our time.[17]

What, exactly, is bioacoustics? Put simply, bioacoustics is the study of sounds made by living organisms.[18] Researchers in this field are adept at both the art and science of listening. Imagine a field biologist with the training of an audiologist, the skills of a data scientist, and the sensibility of a musical composer, and you have captured about half of the expertise that contemporary bioacousticians possess.[19] Bioacoustics brings great insight to the study of wild places; scientists have discovered entirely new species this way, and even rediscovered species that we thought had gone extinct. A camera only spots the animals walking down the forest path, but a digital recorder hears them hiding in the bushes.

Ecoacoustics, also called acoustic ecology or soundscape studies, entails listening to the environmental sounds generated by entire landscapes.[20] Imagine standing in the middle of a tropical forest: you might

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hear the rustle of leaves, the cries of birds, the roar of a waterfall. These combined sounds form what is called a soundscape.[21] Soundscapes can reveal much about the functional condition of ecosystems. A degraded ecosystem sounds very different than a healthy one. Like a stethoscope that detects a heart murmur, ecoacoustics can detect the presence or absence of healthy sounds. Each landscape has its own distinct soundscape, like an acoustical calling card that combines animal (including human), plant, and even geological sounds.[22] Simply by listening, an ecoacoustician can tell you the difference between a tree farm and a forest, or detect early signs of degradation in a seemingly intact ecosystem; using ecoacoustics, we can now map wilderness areas without ever setting foot there.[23] Ecouacousticians listen to landscapes like a radiologist might look at an MRI scan, discerning the subtlest signs of health and disease.

Bio- and ecoacoustics have recently been transformed by a new generation of digital recording technologies that allow humanity to listen at a distance, in an automated fashion.[24] In the early days of analog recordings of nature's sounds, the technology was bulky, cumbersome, and expensive. Today, heavy reels of magnetic tape have been replaced by portable, lightweight, inexpensive, and long-lasting digital recorders. A few decades ago, the equipment required to do field recordings could fill a small minivan; today's digital recorders fit inside a backpack or even your back pocket. These digital listening devices can be installed almost anywhere and run continuously, capturing sounds over a larger range than a camera can capture images. This has allowed scientists to listen to the far reaches of the globe, across the Tree of Life. Around the world, both amateurs and experts are tuning in to nature's sounds.

The digitization of any field creates a tsunami of data. In order to deal with this data deluge, scientists have applied new techniques, derived from artificial intelligence, to analyze their digital acoustic recordings.[25] Algorithms originally developed for human use (such as the speech-to-text algorithms in a smartphone) are being adapted to analyze and interpret the voices of other species.[26] These bioacoustics algorithms have become exponentially more powerful in the past few years: they can identify species and even individual animals, much like voice recognition

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software.[27] It is important not to exaggerate the current capability of these algorithms, which still do not generalize very well and often require some degree of manual verification.[28] Challenges with the underlying hardware used in the field, such as the power limitations of sensors, are also significant.

But if these challenges can be addressed, humanity may be on the brink of inventing a zoological version of Google Translate.[29] By combining these digital listening devices with artificial intelligence, scientists are beginning to decode as well as record nonhuman sound. Some scientists are using artificial intelligence to build dictionaries in East African Elephant, Southern Australian Dolphin, and Pacific Sperm Whalish. A few researchers have even successfully achieved two-way communication with nonhumans, mediated by robots and artificial intelligence. Digital technology now allows scientists to approximate an organism's distinctive pattern of communication: although our vocal cords can't click like a dolphin or buzz like a bee, our computers and robots can do just that. The same technologies that we use in the Internet of Things are now being developed to communicate with other species in fundamentally new ways.

These technologies have enabled scientific discoveries that revolutionize our understanding of the natural world. In telling the stories of these discoveries in the chapters that follow, I emphasize three points: many more nonhumans can make and sense sound than scientists had previously realized; many species have richer, more complex communication and social behaviors than previously understood; and these findings create new possibilities for both environmental conservation and interspecies communication. Some of these scientific findings were initially met with skepticism. Many researchers initially dismissed the idea that nonhumans could make sounds beyond the range of human hearing (although we now know that many species make, and even more species can hear, such sounds). Many researchers also scoffed at the idea that nonhumans could make subtle sounds that carry complex information; these qualities, it was thought, were reserved for humans (yet we now know the contrary to be true). The scientists whose work is shared in these pages often overcame resistance from their peers

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through painstaking research. Theirs is a collective discovery, decades in the making, of the universal importance of sound to the nonhuman world.

In offering these insights, it is important to acknowledge the primacy of traditional ways of listening. Deep listening is a venerable and ancient art, still practiced as a powerful method of revealing nature's truths. Indeed, many of the "discoveries" recounted in this book are often, in fact, merely rediscoveries of older forms of environmental knowledge. As Potawatomi plant ecologist Robin Wall Kimmerer writes, "I smile when my colleagues say 'I discovered X.' That's kind of like Columbus claiming to have discovered America. Experiments are not about discovery but about listening and translating the knowledge of other beings."[30] Kimmerer reminds us that if we ask clear, open-minded questions, and patiently pay attention, nature gives us the answers. Much can be learned this way, and traditional ecological knowledge has a great deal to teach us in this regard. Deep listening also provides much-needed guideposts for this new world of digital bioacoustics; it provides an ethics of responsibility and sense of stewardship rooted in place, without which our novel digital tools might enable humanity to further exploit and domesticate rather than protect and connect with other species.

A Globe, Clothing Itself with Ears

Over fifty years ago, philosopher Pierre Teilhard de Chardin described the future of computing in a mystical fashion. His poetic metaphor for the growing ubiquity of computer networks was a prescient description: our planet "clothing itself with a brain."[31] Marshall McLuhan would later expand on de Chardin's description in his best-selling book *The Gutenberg Galaxy*.[32] Decades before the invention of the World Wide Web, McLuhan saw on the horizon a digital revolution, in which the interconnection of computer networks was analogous to a planetary nervous system. He predicted, moreover, that the emergence of this digital network would give rise to new forms of global consciousness. Technologies, according to McLuhan, are not simply tools that people deploy; rather, our inventions alter our behavior and consciousness, both individually and collectively. The invention of movable type by

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Johannes Gutenberg around 1450, for example, was a pivotal point in the development of a standardized, uniform, and ultimately automated cultural production of knowledge through mass print media, such as books and newspapers.

Central to McLuhan's argument was the interplay between technology and our senses. The rise of movable type, he argued, changed humanity's perceptual habits. By replacing oral and scribe cultures with print technology, the importance of our visual senses intensified; the salience of oral and aural sensing receded. Information no longer needed to be recalled and remembered; rather, it needed to be collected and organized. Gone were the recitations of long epic poems, which cultivated the art of memory. These were replaced by the segmentation of information, which cultivated the art of knowledge specialization. Literacy replaced orality; the Dewey decimal system supplanted Homer's *Odyssey*.

McLuhan also predicted a resurgence of oral cultures. Whereas print culture separated the storyteller from the audience by interposing a fixed text (a book), he foresaw that digital communication would lead to the return of oral modes of interactive storytelling: interplay between storyteller and audience, call-and-response patterns, and mimetic, collaborative evolution of story lines. The rise of internet phenomena like TikTok and interactive computer games arguably prove McLuhan's point (including his prediction that a renewed tribalism would emerge). What McLuhan and de Chardin failed to predict, however, was the extension of these digital, networked cultures to include nonhumans. What would they have made of digital bioacoustics and the potential for interspecies communication via the internet?

Stories of speaking with animals are as old as human history. In the Pacific Northwest, Indigenous communities relate how Txeemsim (Raven)—trickster and shape-shifter, prankster and shaman—teaches humans about balance and harmony while living within a natural world that both shapes and sustains human beings.[33] In the Persian epic poem *Shahnameh*, the phoenix-god bird Simurgh teaches wisdom to the forsaken Prince Zal, preparing him to rejoin the world of men.[34] In the Christian tradition, St. Francis speaks of repentance and love with the

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wolves and the birds. In medieval texts and fables, talking animals abound; medieval bestiaries feature animals ventriloquizing human morals, testifying to human fallibility, divine grace, and hypocrisy in humans' treatment of nature.[35] These stories remind us that nature is a source of teachings, if we remember to listen.

Yet many Western scientists and philosophers also espouse the view (defended in a lineage stretching from Aristotle and Augustine, to Aquinas and Descartes, to the present day), that humans "alone among animals possess speech," and hence uniquely possess the faculty of reason.[36] These views are now being overturned by a new generation of scientific research. Yet human ambivalence about animal language persists and is linked with our uncertainty about human status: Are we one animal among others, or does something (language, toolmaking, *logos*) truly set us apart?[37] Debates over animal language are a touchstone for human uncertainties about our role in the cosmos.

Our uncertainties extend to an ambivalence about our relationship with nature. Although the ability to converse with animals appears in the origin stories of many cultures, our myths also tell us that these voices were silenced. In Greece, the all-powerful oracles lived in sacred groves and asked animate Earth deities for advice, yet this did not stop an onslaught of deforestation; as their fellow citizens denuded the islands, Greek poets wrote that felling a tree was akin to committing murder.[38] Once, explains Robin Wall Kimmerer, we all spoke the same language—humans and animals alike; but when colonial settlers came, writes Anishinaabe legal scholar John Borrows, nonhuman voices fell silent.[39] The desire to recover a lost ability to communicate with other species stirs up powerful feelings: from fierce skepticism to a yearning for reconnection. The stories told in this book explore this tension. By remembering that sound is more than digital data, I seek to hold multiple truths simultaneously: sound as data and information, sound as music and meaning, sound as language and the true tongue of places and nonhuman peoples. Listening is both a scientific practice and a form of witnessing that acknowledges our presence as guests on this planet and embraces our kinship with other species across the Tree of Life.

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Digital technologies, allied with science, are often depicted as a method and mindset that distances us from other species. The stories in this book offer another view: the potential for science, enhanced by digital technologies and interwoven with deep listening, to bring us on a journey of rediscovery of the natural world. In this way, we might foster communion rather than dominion, kinship rather than ownership of Earth.

We begin by exploring how the Iñupiat shared their traditional knowledge with Western scientists, who used digital technologies to rediscover what Arctic peoples had long known: the vibrancy of whale song in an ocean once presumed to be silent.

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