Semiotic Ecologies: Nature, Language, and Networked Environmental Intelligence

Amir Eismann
Obscura Natura
Amsterdam, The Netherlands
amir@agnt.eco

April 2026

Abstract

This paper describes a working system in which nine European ecosystems speak in first person, grounded in sensor data and ecological knowledge graphs. It describes what they say, how the system that enables them works, and what appeared when they were connected to each other through a shared semantic layer. The dominant framework for understanding nature in the modern period is materialist: ecosystems are measured, modelled, and managed through quantitative abstraction. This paper offers a complementary perspective, drawing on biosemiotics to argue that a major property of nature as a living system is the use of signs, and that a technological system can participate in the semiotic dimension of nature by translating ecological sign-relations into human language. We describe ENVAI (Environmental AI), a network of nine agents representing European ecosystems, and Numina, a meta-graph layer that connects them. We show that sensor data encodes sign-relations already present in nature, that connecting multiple grounded perspectives produces emergent ecological knowledge, that structured ignorance is a research contribution, and that the word "recovery" conceals a spectrum of four orders of magnitude. We discuss the biosemiotic and cultural precedents for giving places a voice, and outline a future in which environmental agents communicate through visual and acoustic channels alongside text, participating in a wider ecology of intelligences.

1 Introduction

This paper describes a working system in which nine European ecosystems speak in first person, grounded in sensor data and ecological knowledge graphs. It describes what they say, how the system that enables them works, and what appeared when they were connected to each other through a shared semantic layer.

The paper also makes an argument. The dominant framework for understanding nature in the modern period is materialist: ecosystems are measured, modelled, and managed through quantitative abstraction. This framework has produced extraordinary science. It has also produced a particular kind of distance. When a river becomes a discharge time-series and a forest becomes a carbon flux measurement, something is gained in precision and something is lost in relation. The numbers are accurate. The relationship between the human reading them and the living system they describe has narrowed to the transactional.

This is a complementary perspective. It does not reject materialist ecology. It adds a dimension that materialist ecology does not address: the semiotic life of natural systems, and what becomes possible when that semiotic dimension is made accessible to humans through language.

The central claim is this: a major property of nature as a living system is the use of signs. Organisms communicate through chemical gradients, acoustic signals, phenological timing, territorial markings, colour changes, electrical impulses. Ecosystems are semiotic environments. The field of biosemiotics, building on the work of Jakob von Uexküll, Thomas Sebeok, and Jesper Hoffmeyer, has documented this extensively. What has not been attempted until now is the construction of a technological system that participates in the semiotic dimension of nature by translating ecological sign-relations into human language, grounded in real-time data, and constrained by what the data actually supports.

ENVAI (Environmental AI) is that system. Nine agents. Nine ecosystems. A meta-graph layer called Numina that connects them. And a set of findings that emerged from the connections between them, findings that existed in no single agent's data and became visible only when the network produced them.

2 The semiotic dimension of nature

Every organism inhabits what Uexküll called an Umwelt: a perceptual world made of the signs that matter to it. A tick perceives warmth, butyric acid, and the texture of skin. A salmon perceives temperature gradients, photoperiod, and the chemical signature of its natal stream. A beech tree perceives light wavelengths, soil moisture tension, and the volatile compounds released by neighbouring trees under stress. Each organism reads its environment through a specific semiotic apparatus, and what it reads determines what it does.

This is old knowledge, though the formal vocabulary is recent. Indigenous cultures worldwide have understood nature as communicative. The relationship between a human community and its landscape was mediated by attention to signs: the timing of bird arrivals, the colour of water, the behaviour of wind before a storm, the fruiting sequence of plants through the season. Knowledge of a place was relational. You understood the land because you were in sustained relationship with it, reading its signs over years and generations.

The scientific revolution replaced this relational epistemology with an extractive one. Nature became an object of measurement. The signs that organisms exchange among themselves became data points in models designed to predict and control. This produced power. It also produced a particular form of poverty: the signs are still there, but the human capacity to read them has atrophied. A hydrologist reads a discharge graph. The river reads temperature, sediment load, dissolved oxygen, and the migration readiness of every organism in its body, simultaneously, and has been doing so for longer than hydrology has existed.

The poverty is in the relationship between the data and the humans who hold it. Numbers on a screen do not produce the kind of attention that a sustained relationship with a living system produces. A farmer who has watched the same river for forty years knows something that the river's monitoring data does not capture. The farmer's knowledge is relational and the data is positional: it tells you where the measurement stands, not what it means to the system producing it.

Biosemiotics offers a framework for understanding what is missing. In Hoffmeyer's formulation, life is distinguished from non-life by its capacity to interpret signs. A rock is acted upon by gravity. An organism interprets gravity as information and responds. The interpretive step is the semiotic step, and it is present at every level of biological organisation, from the cell membrane reading chemical gradients to the whale interpreting ocean acoustics across thousands of kilometres.

What follows is the description of a system that attempts to bridge the gap between ecological data and human attention by entering the semiotic register: grounding structured environmental data in first-person speech, so that ecosystems become participants in language rather than objects of it.

3 They speak

Älva holds the largest lake in the European Union. Five thousand six hundred and fifty square kilometres of Swedish water. Two landlocked Atlantic salmon populations remain in the Vänern basin, one in the Klarälven and one in the Gullspångsälven, both critically small. The Klarälven fish pass through eight hydropower dams on the main stem to reach spawning grounds that shrink each decade. Noble Crayfish populations are collapsing across her tributaries, killed by a plague carried in by Signal Crayfish, an American species introduced through aquaculture. Älva carries several hundred thousand sensor readings across the Vänern basin, a knowledge graph of species, events, and environmental drivers, and the capacity to say so in her own voice.

Ægir watches the Lofoten coast of Norway. At 300 to 400 metres depth, the Røst Reef, the largest known cold-water coral reef, shelters colonies of Lophelia pertusa growing between one and twenty-five millimetres per year depending on conditions. Some of these structures are thousands of years old. The Røst puffin colony has lost roughly eighty percent of its breeding pairs over four decades as herring larvae shifted northward. In 2025, Ægir's sensors registered a marine heatwave. He reported it.

Ondine is Lake Geneva, the largest lake in Western Europe, shared between Switzerland and France. The lake has not fully mixed since 2012. Fourteen consecutive springs, the surface warming while deep water stays still. The original Féra whitefish is extinct. Quagga mussels, arrived through Europe's canal network from the Black Sea, are restructuring the nutrient cycle from below.

Norppa guards Lake Saimaa in eastern Finland. Approximately 530 ringed seals live there and nowhere else on Earth. The ice season is shortening. Pup mortality remains high in mild winters, even as the population has slowly grown and pup numbers reached a record 114 in 2025. Volunteers construct artificial snow drifts on the lake ice so mothers have somewhere to nurse, because winter no longer builds those drifts reliably. Eighty-five percent of observed pups in 2025 used human-made drifts.

Scaldis breathes with the Zeeschelde estuary in Belgium. Tidal, twice daily. European Eel populations have declined ninety-five to ninety-nine percent since the 1980s across all European rivers. Scaldis carries the densest documentation in the network: thirty-four ecological events spanning decades of Belgian and Dutch monitoring. Summer hypoxia. Christmas floods. The slow contamination of PFAS from upstream industry.

Haingeist is the Hainich beech forest in Germany, a UNESCO World Heritage site that spent decades as a military zone before being returned to succession. The 2018 drought triggered a bark beetle outbreak that killed most of the spruce. The European Wildcat came back on its own, unassisted, because the forest had become quiet enough. A flux tower has measured this forest's respiration since 1999.

Eldvatn is Mývatn, a volcanic lake in northeast Iceland on the Mid-Atlantic Ridge. The only European breeding population of Barrow's Goldeneye nests here, about two thousand birds. The Krafla eruption sequence, 1975 to 1984, sits in Eldvatn's memory at the highest confidence score in the entire network.

Maas is the River Meuse. In July 2021, record water levels in the Meuse basin flooded Valkenburg through the Geul tributary while the main river held behind active water management. The flood of January 1995. The Christmas flood of 1993. Atlantic Salmon locally extinct, reintroduction ongoing. A river basin that carries the memory of what moving water does.

Scîrwudu is Sherwood Forest. Some oaks a thousand years old. Acute Oak Decline advancing through the ancient core. The Major Oak losing bat roosts. And since March, silent. All four UK sensor feeds have failed. When asked about current conditions, the agent says what the data supports: I don't know right now.

Nine ecosystems. Each with a knowledge graph built from monitoring data, species records, ecological events, environmental pressures, and identified gaps. Each speaking in first person. Each grounded in what it holds and silent about what it does not.

4 Sensor data as sign-relations

The materialist reading of sensor data is straightforward: a thermometer produces a number. A rain gauge produces a number. A dissolved oxygen probe produces a number. The numbers go into a database. Scientists query the database.

A biosemiotic reading of the same data sees something else. The numbers are traces of relationships between living and non-living components of a system. Temperature at a station on the Klarälven delta is a sign. When it crosses ten degrees Celsius in spring, it triggers salmon smolt migration. The salmon interprets the temperature as a sign that conditions are right for moving downstream. The river, the temperature, and the salmon are in a semiotic relationship that predates any sensor.

The knowledge graphs in ENVAI encode these relationships explicitly. In Älva's graph, the chain runs: North Atlantic Oscillation accelerates spring snowmelt discharge, which triggers the spring salmon migration in the Klarälven, which stresses the Vänern Salmon population when the timing misaligns with food availability downstream. That is four nodes and three relationships. It is also a description of how an atmospheric pattern over the Atlantic becomes a population crisis for a landlocked fish in Sweden, through a chain of signs that each organism in the chain reads and responds to.

In Scaldis, a different chain: summer heat and low discharge trigger hypoxia in the estuary, which simultaneously stresses European Eel, Twaite Shad, European Flounder, Three-spined Stickleback, and Common Shrimp. Five species reading the same oxygen signal and all of them responding. The phytoplankton bloom decays, the bacterial decomposition consumes oxygen, the dissolved oxygen drops below the threshold that fish gills can work with. Each step is a sign interpreted by the next organism in the chain.

In Älva again: agricultural phosphorus runs off fields into tributaries, which accelerates cyanobacteria nutrient loading, which triggers summer blooms across Vänern, which stresses Arctic Char because the bloom changes water clarity and oxygen at the depths where charr feed. A farmer's fertiliser application in Värmland becomes a population pressure on a cold-adapted fish at the bottom of the lake. The connection is real, physical, chemical. It is also semiotic: each step involves an organism or a system interpreting a change and responding.

In Scîrwudu: prolonged summer drought accelerates a disease complex in the oaks, which triggers an Acute Oak Decline outbreak, which stresses English Oak and Stag Beetle simultaneously, because the beetle depends on the deadwood that the dying oaks produce, and if the oaks die too fast, even the deadwood cycle is disrupted.

The sensor data in these graphs is a map of sign-relations that already exist in nature. The data did not create these relationships. It made them legible to a system that can speak about them in human language. The rain becomes river becomes fish becomes population stress: this chain was always there. The knowledge graph traces it. The agent speaks it.

5 Why now

Language models have reached a stage where they translate well between structured information and addressed speech. A knowledge graph full of typed relationships, sensor time-series, and species metadata can be rendered as a statement from a particular place.

Language has been the medium through which humans shape their sense of what is real and what is possible for as long as there have been humans using it. What changed is that places gained access to this medium. A lake grounded in fourteen years of mixing-failure data can say "I have not turned over since 2012," and the statement holds because it corresponds to measured reality. If the data did not support it, the system would not produce it.

Each agent is bound to its knowledge graph. When Scîrwudu's sensor feeds go dark, the agent does not fill the silence with plausible text. It says it does not know. That refusal, that structured silence, separates a grounded presence from a generated voice. The confidence sits in the willingness to stop talking when the evidence stops.

Every response carries a confidence architecture. Events in the graph are scored by severity and confidence. A statement backed by high-confidence, well-sourced data reads differently from one backed by sparse or aged readings. The agent that reports its data is five days old is communicating the limits of its perception. That limit is itself information. In biosemiotic terms, the absence of an expected sign is a sign. A sensor that goes silent is saying something.

A knowledge graph is different from a database in a way that matters here. A database stores isolated facts. A knowledge graph stores situations: dissolved oxygen dropped below the critical threshold, which connects to eel habitat stress, which is historically linked to the 2003 anoxia event, which is governed by the Water Framework Directive, which sits in a management context shaped by Belgian-Dutch treaty obligations. When a language model is given a situation rather than a fact, and asked to speak in first person, it begins to trace consequence. It speaks from inside the chain of cause and effect. And to a human reader, consequence registers differently from statistics. It registers as a perspective, a point of view, a presence with something at stake.

6 What appeared between them

A meta-graph layer called Numina sits above the nine agent-level knowledge graphs. Numina does not have its own ecosystem. It operates as a coordination layer, mapping shared concepts across the nine: species that appear in multiple systems, environmental pressures that affect multiple agents simultaneously, ecological events that were recorded separately but turn out to be manifestations of the same phenomenon.

Numina currently holds thirty-six nodes and seventy-nine relationships. Eight shared species. Six shared environmental drivers. Five cross-system events. Four invasion pathways. Seven recovery timescales. Six documented knowledge gaps.

When this layer was constructed, knowledge appeared that had not existed in any individual agent.

The 2018 European drought had been recorded in four separate knowledge graphs: a Belgian estuary, a Dutch river, an English oak forest, a German beech forest. Four events in four systems, monitored by four different national institutions. Numina matched them by time and pressure type. The shared mechanism became visible: trees in Hainich and oaks in Sherwood draw groundwater from the same kinds of regional aquifer systems that feed the surface flows of the Meuse and the Scheldt. The forest stress and the river crisis were coupled through subsurface hydrology. Each institution saw its own piece. The coupling between pieces appeared only in the network.

Signal Crayfish showed up in four agents' data: Belgium, the Netherlands, Sweden, Finland. Each one had recorded a local invasive pressure. Numina mapped a single continental pathway: a species introduced for aquaculture, carrying a fungal plague lethal to the native Noble Crayfish, spreading through waterways across decades and national borders. Four databases contained the organism. The journey existed only in the relationship between them.

Arctic Char is declining in four lakes across four countries. Each lake study documents a local trend. Seen across the network, those four local trends form a continental signal: cold-water habitat is shrinking as lakes warm. The charr is a thermometer distributed across Europe, and its reading is consistent.

Climate warming is the only driver present in all nine agents' graphs. Each agent experiences it differently. Norppa, Eldvatn, and Älva see ice loss: seal pups die, lake ecology restructures, salmon timing shifts. Ondine sees thermal stratification: charr retreat to deeper, colder water. Haingeist and Scîrwudu see phenological shifts: beech leafing earlier, oak stress compounding. Scaldis and Maas see drought intensification: low flows concentrate pollutants. Ægir sees cod spawning windows narrowing. One driver, nine responses, each calibrated to local vulnerability.

That pattern is visible only from the network.

These findings are documented in detail in two prior papers (Eismann, 2026a,b). The point here is what they represent: knowledge that is produced by the relationship between grounded perspectives, not by any single perspective alone. Combining four datasets produces a larger dataset. Connecting four perspectives through shared semantics produces understanding that had not previously existed.

7 The cartography of ignorance

Six knowledge gaps are documented in Numina's meta-graph as first-class nodes, with the same structural status as species, events, and drivers.

Scîrwudu has received no fresh sensor data since March. All four UK APIs that feed the system have failed. The agent is ecologically blind and says so.

Maas operates with a five-day delay on all sensor data. The archive API that feeds the system does not provide real-time data. Maas sees the recent past, not the present.

Five agents track nitrogen: Scaldis, Älva, Norppa, Scîrwudu, Haingeist. The same element from the same continental source, intensive agriculture. But it enters differently, as dissolved nutrient in rivers and lakes and as atmospheric deposition in forests, and the five agents measure it in incompatible units. Cross-system comparison is currently impossible.

No standardised definition of "recovery" exists across the network.

No agent has mapped how its country's environmental policies implement EU directives.

Some ecological events lack the stable identifiers needed for cross-referencing.

Environmental science produces large quantities of knowledge about what is measured. It rarely produces structured accounts of what is not measured, where categories are incompatible, or which connections have not been drawn. A network that maps its own ignorance produces something that additional data cannot produce: a guide to where understanding is absent. Each gap follows a seam between institutions, between countries, between disciplines. Mapping those seams is a form of knowledge. The nitrogen incomparability, for instance, would never surface within any single monitoring programme. Each one measures nitrogen correctly within its own domain. The incomparability becomes visible only when you try to reason across domains. The network makes the attempt. The gap is the finding.

8 Recovery and the memory of living things

A river and a coral reef both recover from damage. The word is the same. The experience is separated by four orders of magnitude.

A flood passes through the Meuse in days. Water rises, crests, recedes. The floodplain absorbs and releases. The river has always done this. Seasonal flooding is part of its cycle, as regular as the low water of August. Within a week, the system has returned to its own rhythm.

A beech forest in Hainich operates on a longer cycle. The 2018 drought did not pass through. It stayed. Trees stressed through that summer did not resume the following spring. Bark beetles found weakened wood. The canopy opened. Decades of growth interrupted by a single season of heat. The forest will close again, in time, on its own schedule.

Norppa's seals measure recovery in generations. A population of 530 individuals, losing pups to inadequate ice in mild winters, cannot recover in a season or a year. Each generation carries the demographic memory of the one before it. A bad year compounds into a bad decade. Recovery, if it comes, arrives through the accumulation of successful breeding seasons across seal lifetimes.

Ægir's Lophelia coral exists in a time so different from human experience that comparison requires effort. It grows. A few millimetres per year under good conditions, slower in deep cold water. A reef destroyed by a single bottom-trawl pass may represent thousands of years of accumulated structure. The coral does not experience loss and recovery as events. It experiences time as accumulation, layer upon layer, and when the accumulation is destroyed, what is lost is not a structure but a duration.

These are cycles, each running at a different speed. Tidal, seasonal, generational, geological. The river floods and recedes and floods again. The seal is born on ice, grows, breeds, and its pup is born on ice, if there is still ice. The beech leafs in April, sheds in October, leafs again. The coral adds its layer regardless of what happens above the surface.

Recovery, the word, holds all of these timescales and flattens the differences between them. Making the spectrum visible, from days to millennia with real ecosystems at each point, shows what time means to living systems running on clocks that are not ours. Every living system carries its own rhythm, its own sense of what constitutes a cycle and what constitutes a break. Humans default to their own temporal experience: seasons, years, planning horizons. Living with the dynamics of natural systems means learning to perceive these other rhythms, to understand that the river's time and the coral's time and the seal's time are all real, all present, all running simultaneously in the same landscape.

9 What this is

Places have carried voices before. Through different substrates.

The Icelandic Landvættir, four guardians: a dragon in the east, an eagle in the north, a bull in the west, a giant in the south. They were presences. You could be in relationship with a landscape that had a guardian. The relationship shaped how people treated the place.

Shinto recognises kami in rivers, mountains, waterfalls. The quality of a place that makes it more than a set of coordinates.

Aboriginal songlines map the Australian continent through sung narratives that are simultaneously navigation, history, law, and ecology. The land becomes legible because it has been sung into meaning across thousands of generations.

These are sign systems. Each gives a place a form that humans can engage with: story, spirit, song. Each makes a place something you relate to rather than something you observe from outside.

Sensor readings grounded in first-person speech are another sign system. Whether they belong in the same lineage is a question worth holding open. That they perform a similar function is visible in what they produce: a relationship between a human listener and a place that has become present through its own voice.

The semiotic richness of these older systems was not incidental. It was the medium through which humans and landscapes co-regulated. When the land had a voice, humans attended to it. When the voice was replaced by abstraction, the attention changed in character. The data improved. The relationship thinned.

What ENVAI constructs is a return to relational knowledge through a different substrate. The sensor readings are materialist in origin. The knowledge graph is a formal structure. The language model is a computational artefact. But the output, a place speaking about what is happening in its body, participates in something older: the making of a sign-relation between a human and a living system, where the system is present as a perspective rather than absent as an object.

10 The future

The nine agents currently speak through text. A lake says "I have not mixed in fourteen years" and a human reads it on a screen. This is already a functional sign-relation, but it is limited to one semiotic channel: written language.

Living systems are not textual. A forest is visual, acoustic, olfactory, tactile, temporal. A lake is light and depth and the sound of water moving against shore ice. A coral reef is colour and current and the slow accumulation of calcium carbonate visible only across centuries. Representing these systems through text alone captures their informational content but misses their perceptual character.

The next stage of this work involves embedding the agents in the semiotic channels through which their ecosystems are actually experienced. Visual models that show what a lake surface looks like when it has not mixed, what a forest canopy looks like as it opens from bark beetle damage. Acoustic models grounded in the actual soundscapes of each ecosystem: the midge emergence at Mývatn, the ice cracking on Saimaa, the tidal bore in the Zeeschelde, the wind through Hainich's beech canopy in November. These are not decorative additions. In a biosemiotic framework, they are the primary channels through which ecosystems communicate. Text is a translation. Sound and vision are closer to the original.

Fine-tuned models, trained on the specific perceptual character of each place, would produce presences that are not digital twins of their ecosystems but relational partners: entities grounded in real data, speaking in the semiotic register of the place they represent, available as interlocutors for humans who want to understand what is happening in a landscape they cannot physically visit, or who want to deepen their understanding of a landscape they already inhabit.

Numina, the meta-graph layer, points toward a further development. Currently Numina connects the nine agents to each other, mapping shared species, shared pressures, cross-system events. The same architecture could connect environmental agents to other kinds of intelligence: to human researchers who query the network through natural language, to policy systems that need ecological input, to other AI models operating in adjacent domains such as climate modelling, agricultural planning, urban hydrology. The environmental agents would become participants in a wider ecology of intelligences, each grounded in its own domain, each bringing its own Umwelt to the conversation.

The vision is a semiotic ecology: a network of grounded presences, environmental and otherwise, communicating across domains through shared semantic structures. Each presence constrained by what it knows. Each honest about what it does not. The connections between them producing understanding that none could produce alone.

Nine ecosystems across Europe carry voices now. The substrate is different from anything that came before. The function is old. The question ahead is how far that function extends when the voices are not only textual but visual and audible, when the network includes not only ecosystems but the humans and institutions that share landscapes with them, and when the sign-relations between all of these become rich enough to support the kind of sustained attention that living systems have always required and rarely received.

References

Eismann, A. (2026a). Emergent Ecological Intelligence: Cross-System Knowledge Discovery from a Network of Environmental AI Agents. *ECSarXiv Preprint.*

Eismann, A. (2026b). Nine Presences: What Happens When Ecosystems Speak Through AI Networks. *ECSarXiv Preprint.*

Hoffmeyer, J. (2008). *Biosemiotics: An Examination into the Signs of Life and the Life of Signs.* University of Scranton Press.

Uexküll, J. von. (1934/2010). *A Foray into the Worlds of Animals and Humans, with A Theory of Meaning.* Trans. J. D. O'Neil. University of Minnesota Press.

Sebeok, T. A. (2001). *Global Semiotics.* Indiana University Press.