

Profile of Andrea Rinaldo

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Science Writer

By 1985, Andrea Rinaldo was losing interest in fluid mechanics. The newly appointed full professor of hydrodynamics at Italy's University of Trento had excelled in studying the intricacies of eddies, vortices, and fluid flow through porous media. But Rinaldo, lacking excitement, yearned for new avenues of research, seeking, he says, his road to Damascus.

As part of his quest, Rinaldo attended a lecture at the University of Genoa, on the Mediterranean coast, a short drive from Trento's mountain campus. The lecture, by Venezuelan hydrologist Ignacio Rodriguez-Iturbe, caught Rinaldo's attention with its intriguing title: "Chaos in Rainfall." At the time, Rinaldo's experience with hydrology consisted of one unremarkable undergraduate class, but the idea of applying the complex nonlinearity of chaos to something as basic as rainfall sparked his interest.

Rodriguez-Iturbe's lecture provided the excitement, novel research opportunities, and complexity in simple natural phenomena that Rinaldo sought. In the 28 years that have followed, Rinaldo and Rodriguez-Iturbe, both members of the National Academy of Sciences, have joined together to investigate how water moves through and influences landscapes and populations. Rinaldo's work has focused on the fractal nature of river networks and the water-borne vectors of cholera. His foray into hydrology, commenced at that fortuitous lecture in 1985, has become a life-long journey.

Saving Venice

Rinaldo was born in 1954 in Venice, Italy. In November 1966, when Rinaldo was 12, a storm surge from the Adriatic Sea, heavy rainfall in the mountains, and an unusually high tide together submerged Venice under six feet of water. Inspired to save the city he saw as "fragile and beautiful," Rinaldo decided to pursue the same career as his father, grandfather, and brother: hydraulic engineering.

Rinaldo attended the 800-year-old University of Padua, majoring in civil engineering. But his college years were marked by another passion: rugby. Rinaldo played lock for Italy's national rugby team, the Azzurri, in four games from 1977–1978, including a game against New Zealand's renowned

All Blacks. "Quite a distinction, if I may," he says. "One of the best games we've ever had."

Rinaldo says his work ethic was born on the rugby field. "It's unforgiving," he says of the sport. "The best trained, stronger guy wins. It's your own inner drive. The result you get is the natural and direct consequence of the work you put in." The sport also taught him to respect rules. "If you cheat," he says, "you get punched."

A knee injury at age 24 ended Rinaldo's rugby career. He was about to graduate with a five-year degree in civil engineering, but was by then leaning away from a professional engineering life, preferring instead an academic career that would constitute a life-long extension of his scholarship.

Rinaldo attended Purdue University for his doctorate studies, moving to West Lafayette, Indiana, "a very different place from Venice," he says. His dissertation explored numerical spectral methods for solving the Navier-Stokes equations, which describe fluid behavior and techniques for modeling complex 3D phenomena, such as a wake in fluid trailing behind a sphere (1).

Chaos and Fractals

Rinaldo returned to the University of Padua in 1983 as an assistant professor, and his wife, a physician, began work at the university's leukemia treatment center. In 1985, Rinaldo was named a full professor at the University of Trento, a surprise given his age of 30 years, and budding academic career.

But that same year found him growing dissatisfied with fluid mechanics. "What's new?" he recalls asking himself. Ignacio Rodriguez-Iturbe's "Chaos in Rainfall" lecture at the University of Genoa opened up a new vista, at once filled with the randomness of chaos and the self-organization of water-etched landscapes. Rinaldo soon approached Rodriguez-Iturbe to begin a continuing collaboration.

The two men met only three years after mathematician Benoit Mandelbrot published *The Fractal Geometry of Nature* (2), a book exploring scale-independent patterns in natural systems. Mandelbrot mathematically described such natural structures as snowflakes or coastlines, which display consistent



Andrea Rinaldo at EPFL. Photo courtesy of École Polytechnique Fédérale de Lausanne.

patterns on scales from millimeters to kilometers. The same principles apply to river networks.

"If I take a map of a creek behind your home," Rinaldo explains, "and take out the scale bar, that may as well be the Amazon." He and Rodriguez-Iturbe began studying self-organization to investigate why natural processes produced the same structures at any scale.

A previous paradigm held that chance shaped natural structures. Rinaldo and Rodriguez-Iturbe proposed a different theory of optimal channel networks (3). Landforms, such as river networks, shape themselves through evolution and selection, they wrote, forming according to necessity as well as chance. Natural structures evolve toward an optimal state, Rinaldo says. For example, a river network will organize itself to optimally dissipate the potential energy of high mountain precipitation by routing the flow through a series of branching streams toward an ocean or lake.

Rinaldo and Rodriguez-Iturbe's work on this subject culminated in a 1997 book, *Fractal River Basins: Chance and Self-Organization* (4). Writing the book, however, proved a challenge. Since beginning their collaboration, Rinaldo had arranged for a joint appointment at the universities where Rodriguez-Iturbe taught, allowing the two to work together frequently. But during the time they wrote their book,

This is a Profile of a recently elected member of the National Academy of Sciences to accompany the member's Inaugural Article on page 2417 in issue 7 of volume 111.

Rodriguez-Iturbe was spending time in Caracas, Venezuela, while Rinaldo continued to work from Italy. He had returned to the University of Padua in 1992 to fill the Chair left vacant by his retiring mentor and close friend, Claudio Datei.

In a time when e-mail was new and long-distance telephone charges steep, the two turned to text-based Telex machines to relay messages and continue their work. “It’s very difficult to write equations in a Telex!” Rodriguez-Iturbe says. “We’d describe equations in words.” He says that the difficulty of communication might have induced many other scientists to give up. Rinaldo’s enthusiasm, however, gave the project life. “His enthusiasm was fantastic,” Rodriguez-Iturbe says. “It really carried the day for me.”

In a review of the completed book, University of Wisconsin-Milwaukee meteorologist Anastasios Tsonis wrote: “I find three principal motivations behind writing a scientific book: to unify questions, solutions, advancements, and discussion on a particular topic; to summarize one’s lifetime work; and to have fun” (5). Rinaldo and Rodriguez-Iturbe, Tsonis wrote, accomplished all three.

Amid their busy schedules, Rinaldo and Rodriguez-Iturbe, now at Princeton University, continue to set aside several weeks every

year to visit each other. Strolling around the pond at Princeton’s Institute of Advanced Studies or churning through blackboards in classrooms, the two men devote time to what Rodriguez-Iturbe calls “hard thinking.” “We kind of isolate ourselves,” he says. “Long conversations, for hours, sometimes with very long silences in front of a blackboard. And we argue a lot.”

Rinaldo fearlessly questions long-held assumptions, stripping problems down to their basic elements, according to Rodriguez-Iturbe. “He’s kind of a pit bull,” Rodriguez-Iturbe says. “He sinks his teeth into a topic and he won’t let go until he sees the bone.”

Water and Ecology

Over the course of several of these talks, the two men began to define the field of ecohydrology, which describes hydrologic controls, such as soil moisture, on biological systems, such as plant growth in a semiarid landscape. Rinaldo sought to investigate how river networks serve as corridors for species biodiversity, population migration, and the spread of disease.

Rinaldo and his colleagues, including Rodriguez-Iturbe and Princeton graduate student Rachata Muneerakul, began constructing models of ecosystems. In one, each node in the model represented a

metacommunity, or a small ecosystem. The team used this model to simulate changing fish populations in the Missouri and Mississippi river networks, finding that variable river runoff influenced fish dispersal and habitat size, ultimately affecting population biodiversity (6).

Rinaldo also turned his attention to population migration, using as an example the American westward migration in the 19th century. He found that a diffusion model of migration, in which migrants diffuse isotropically through space, could not adequately explain the rapid rate of westward expansion. But a simple assumption, in which colonizers diffused along river networks, better modeled the speed of the migration wave (7).

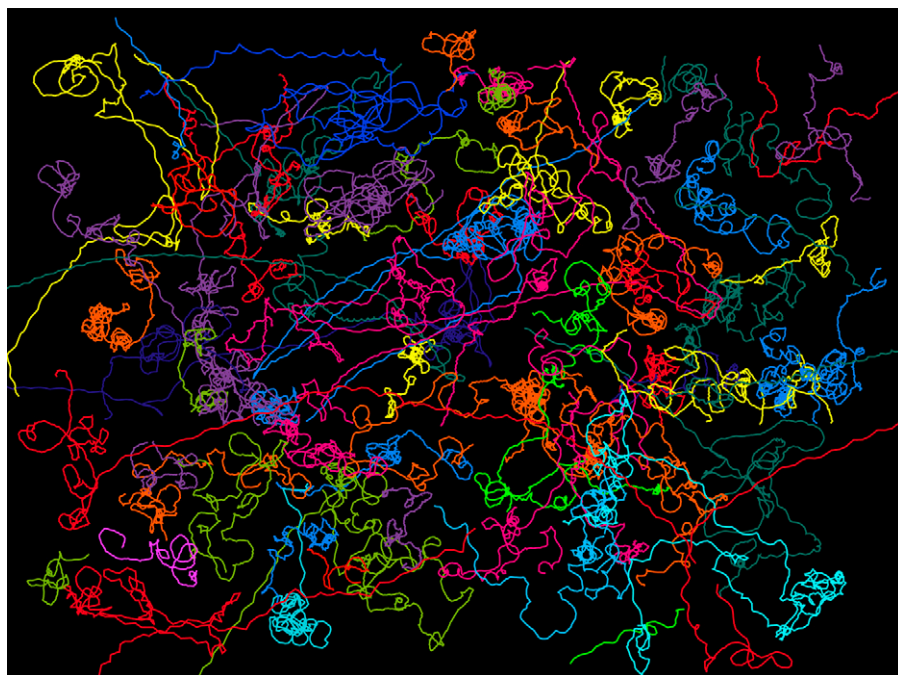
Moving to the École Polytechnique Fédérale de Lausanne (EPFL) in 2008 (while retaining a part-time appointment at Padua), Rinaldo developed a spatial model of a different type of population migration: a water-borne disease epidemic. Rinaldo’s team, including Rodriguez-Iturbe, EPFL ecohydrologist Enrico Bertuzzo, and University of Milan ecologist Marino Gatto, published a spatially explicit model of cholera epidemics in 2008 (8, 9). In a January 2011 (10) paper, the team used their model to predict the spread of cholera in Haiti following the devastating 2010 earthquake. The model proved prescient (11). “You have a river network,” Rinaldo says, “which is a connector of nodes—human settlements—which have the dynamics of an infection, and the transport of pathogens would be supplied by the waterways, which is absolutely what happens.”

Europe Rising

The research was funded by a prestigious Advanced Grant from the European Research Council. Rinaldo says that European science, funded by such grants, is poised to soar. “If you give the same opportunity of salary and research as the top US private research universities,” he says, “and then you provide the quality of life and the culture of Europe, then you have a chance.”

EPFL in particular, he says, has become a prominent science and technology center in recent years, a rise Rinaldo attributes to the vision and leadership of neuroscientist Patrick Aebischer, the school’s president. “You walk the roads and alleys of the campus and you feel it. It’s just phenomenal,” he says.

Rinaldo and his wife of more than 30 years raised three children in Europe’s international environment. Rinaldo is proud of his children but has one regret. “None of my kids are professional rugby players!” he



Trajectories of individual *Tetrahymena* sp. protists, tracked in Rinaldo’s Laboratory of Ecohydrology at EPFL. Such studies of mesoscopic-scale movement and reproduction support theoretical work on directional dispersal in networked environments (13). Image courtesy of Andrea Giometto.

jokes. He remains involved with the sport as a board member of the Federazione Italiana Rugby, the national rugby governing organization. This role recently earned him an audience with Pope Francis following a rugby match between Italy and Argentina. The Argentine-born pope, Rinaldo says, received both teams' players and officials and extolled the character-building virtues of the sport. "See where rugby takes you?" Rinaldo says.

Rinaldo was elected to the National Academy of Sciences in 2012. His Inaugural Article (12) describes the optimal channel network theory of fractal river network development and explains the mathematics behind river networks' evolution toward an optimal configuration. Universal principles govern stream channel formation, Rinaldo writes, regardless of local geology, vegetation, climate, or scale. The paper revisits some of Rinaldo's foundational accomplishments.

Rinaldo's future, according to Rodriguez-Iturbe, is at the forefront of investigations into how ecohydrological dynamics are linked to the changing precipitation patterns associated with climate change. These avenues of research, Rodriguez-Iturbe says, constitute "the most exciting years ahead for hydrology."

In late January 2014, Rinaldo traveled once again to Princeton, New Jersey to talk, think, and debate with Rodriguez-Iturbe while strolling around Princeton's frozen pond. The two debated, relentlessly wondering: What's next? What's new? Excitement fills Rinaldo's voice as he describes the meeting. "Great fun," he says, with palpable relish, "great fun."

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