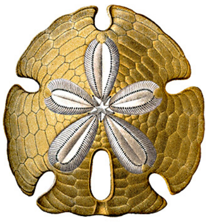


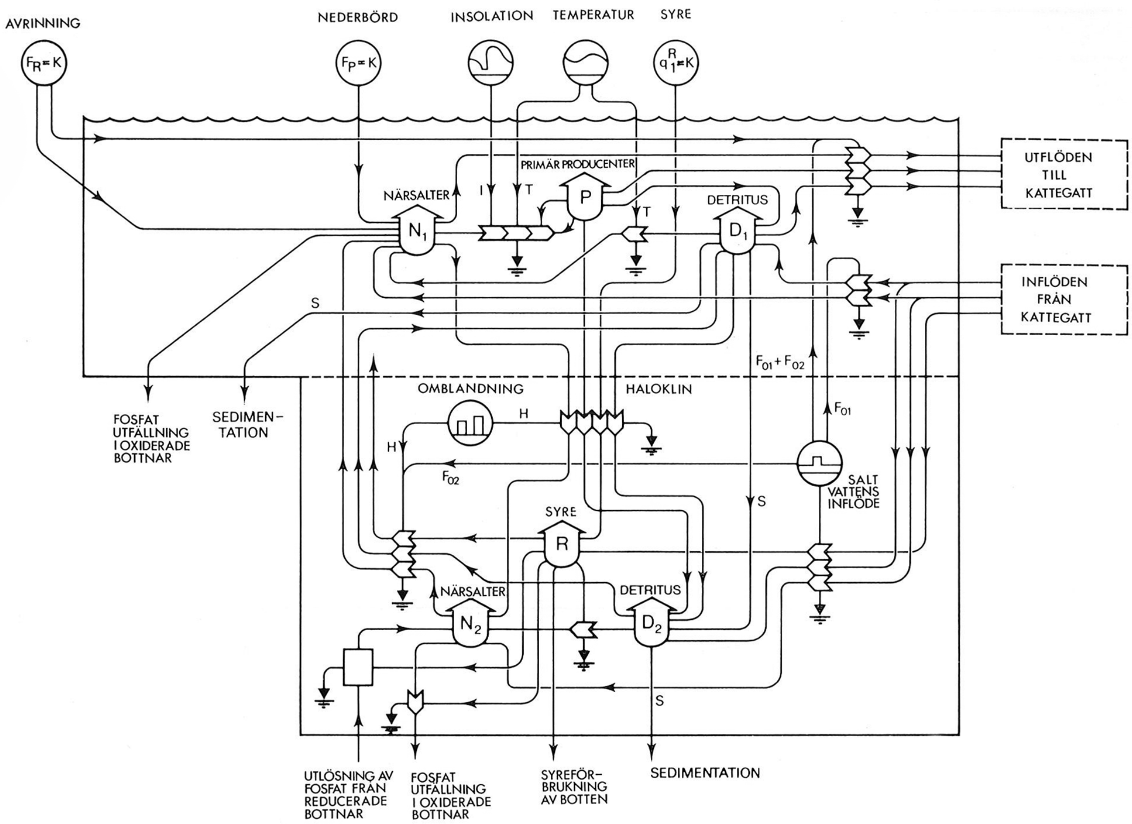
Complex systems

Anna Tunlid

SAND DOLLAR – symbol of the integration of ecology and economics.

How to understand the relationships between the various parts of nature? How do different organisms influence each other, and how do they interact with their environment? Questions of this type have occupied researchers in ecology throughout its more than hundred-year history. The figure on the next page illustrates how, in the 1970s, system ecologists tried to present interactions in nature. So, it is not an electrical circuit diagram, even if it appears so at first glance; instead, it is a model of part of the Baltic Sea's ecosystem. Hiding behind the symbols are plankton, algae and nutrients; each symbol represents various functions and processes in the system and how they connect through a flow of energy and matter. The variables are chosen based on the processes to be analysed, and the model is delimited to represent a given subsystem. By studying, analysing and bringing together several different subsystems of this kind, ecologists hoped to be able to construct what they called a total model of the Baltic Sea's ecosystem. The purpose was not only to visualise the relationships between various parts of the ecosystem, the diagram was also the foundation for building computer models that could calculate the flows between the system's components. These models had a stated practical purpose: using computer simulations, ecologists hoped to be able to forecast future trends in the Baltic Sea and how it would be affected by human activities and degrees of environmental pollution.

Ecosystem models were thus developed to both describe and quantify basic processes in the ecosystem. Like all models, they were also an expression of a particular understanding for and of nature: they highlighted what was perceived as essential and the connections and relationships that were considered important, while other aspects were left in the background, simplified or entirely ignored. Despite the ambition of describing the ecosystem



THE ECOSYSTEM OF THE BALTIC SEA visualised by Fredrik Wulff in 1974, using energy circuit language.

in its entirety, in some regards the ecosystem models were strikingly reductionist: complex relationships between different organisms and their habitats were transformed to energy flows in the system. The ecosystem's overarching structure and function were more important than the biology of individual species.

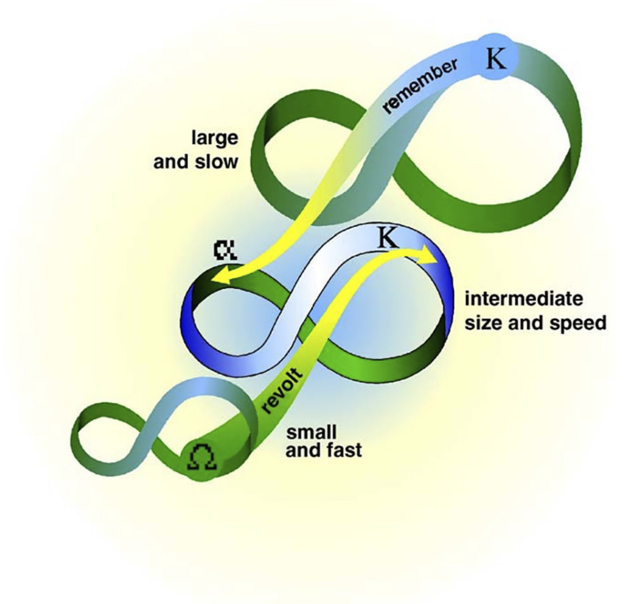
These models were not the first attempt to understand and describe nature's complexity. Models and metaphors occur frequently in the history of biology. An early example of a metaphor was the organism, or superorganism, which meant that a natural unit and its dynamics – often a plant community – were compared to an individual organism. This emphasised qualities such as stability, predictable growth and some degree of organisation between its constituent parts. In the post-war years, alongside the organism, the machine became an increasingly common metaphor. Using this, nature was described using physical units and principles such as energy, matter and the laws of thermodynamics. In turn, the machine metaphor was easy to link to systems thinking. This had been introduced in biology in 1935 through the ecosystem concept, coined by the British botanist Arthur Tansley. The systems concept was inspired by the physical sciences and was an attempt to increase ecology's scientific status by linking the research field to prestige-filled physics. Systems thinking was further reinforced after World War Two due to the increasing interest in systems theory, particularly cybernetics and information theory. For ecology, this meant that nature now began to be studied as a complex system that was governed through feedback and self-regulation. One early proponent of this systems-oriented perspective was the American ecologist Howard Tom Odum who, along with his brother, Eugene Odum, was pioneering in the expanding research into ecosystems. In Odum's systems thinking, all relationships and phenomena in nature could be transformed into energy units and energy flows, and he developed a specific language, the energy circuit language, to describe and analyse the relationships between the various parts of an ecosystem. The picture that was initially discussed is one example of how this energy language was constructed. According to Odum, it could be applied to all systems, something he attempted to demonstrate in his much-discussed book *Environment, Power and Society* (1971). In the book, he not only described how ecosystems could be understood using energy principles, but also complex social phenomena such as politics and religion. Odum's systems thinking, based on the concept of energy, was thus something that went far beyond descriptions of nature's functions; it also formed a model for understanding how social, economic and ecological systems were interconnected.

Human impact on nature or ecosystems has long been a frequent idea in ecological research. The issue has rather been whether and, if so, how mankind and various manmade activities can be included in models of nature. Researchers have held many differing and often diametrically opposing opinions. A field of research in which the relationship between humans and nature is the very starting point is ecological economics, which was established at the end of 1980s, with AnnMari Jansson as one of its pioneers. AnnMari Jansson had worked on the abovementioned Baltic Sea project, and was greatly inspired by Odum's ideas about the interplay between nature and society.

In 1991, ecological economics was given an institutional base at the Academy of Sciences' Beijer Institute, a research institute that was founded in 1977 using a donation from financier Kjell Beijer. The Beijer Institute was initially focused on studies of energy and human ecology, but in the early 1990s it faced restructuring. Several proposals about what the institute should focus on were submitted to the Academy of Sciences. One of these was formulated by Bengt-Owe Jansson, former head of the Baltic Sea project, and economist Karl-Göran Mäler. They felt that the institute's focus should be the integration of ecological and economic systems. In their submission to the Academy of Sciences, they stated that the utilisation of natural resources had resulted in an extremely serious situation for all human civilisation. This situation required a collected, multidisciplinary research effort of the type that ecologist and economists had begun to establish within the framework of a systems perspective. Such a perspective was necessary, they said, to lay a foundation that could promote sustainable development and allocate the Earth's resources between different countries and generations.

From the very beginning, the Beijer Institute's new focus involved many researchers from different countries, and the institute has also come to receive a great deal of attention in international contexts. Over the years, many ecologists and economists have worked in major interdisciplinary research programmes of various kinds. Numerous projects have dealt with complex systems and how they work, and new models and metaphors have been developed. A previous idea that nature strives towards an ideal state of equilibrium – a natural balance – if it was able to develop without external disruption, has been replaced by models that instead focus on change, reorganisation and development. A concept that is central to the new models of complex systems is *resilience*, which was introduced in ecological contexts at the start of the 1970s. Originally, resilience was an ecosystem's ability to resist disturbances, i.e. the ability to absorb external change and yet continue to function in a given state of equilibrium. But the concept has also gained another meaning, one which emphasises the system's long-term ability to manage change and continue to develop and be renewed, even in an entirely new state. In other words, instead of models of nature based on a given, stable state of equilibrium, the new models emphasise nature's intrinsic potential for adaptation and renewal, and not least its ability to exist in new, completely different states of equilibrium. The idea of a natural world in balance has thus been replaced by perceptions of nature that are based on change and development – but which also encompass a greater measure of uncertainty and unpredictability.

Within the framework of overarching systems thinking, resilience has also come to be applied to social-ecological systems, in which the social and ecological systems are regarded as completely integrated. In this context, resilience deals with the systems' long-term ability to manage change and simultaneously continue developing. This entails an emphasis on resistance, adaptability and flexibility. Also in this way of thinking, conceptual models have been developed to describe the systems' dynamics and how various parts and processes are linked together. One of the models that illustrates how interlinked systems undergo different phases of change and adaptation has even been given its own name, *panarchy*. The dynamics, complexity and emergence of new and unexpected states are central to this model.



PANARCHY – a model that illustrates interaction between dynamic systems of different scales.

The idea of resilience has had great influence and been taken up in the UN's work on sustainable development, among other things. In more applied contexts, resilience thinking is often talked about, which shows that the concept has broadened from the scientific context to a way of thinking and a basis for policies and actions. Resilience has become a framework within which the complex dynamics between humans and the environment can be handled. It has thus moved from a descriptive to a normative context, which not only describes how something *is* but also how it *should* be, leading to entirely new questions and problem complexes. Applications of the concept of resilience in the system's social dimensions has been criticised by people who believe that these basically scientific models do not so justice to political and cultural conditions such as power relationships, conflicts of interest, differing values and norms. It remains to be seen how future research into complex systems can deal with challenges of this kind, and the extent to which shared concepts and models can be used to describe social and ecological systems. In other words: what will be emphasised and what will be omitted in these models?

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The anthology *Ecology Revisited: Reflection on Concepts, Advancing Science* (Dordrecht, 2011), edited by Astrid Schwartz and Kurt Jax, includes several articles relating to the importance of concepts and models in ecological research. The ecosystem concept's development has been analysed by Joel B. Hagen in *An Entangled Bank: The Origins of Ecosystem Ecology* (New Brunswick N.Y., 1992). The ecosystem project about the Baltic Sea is discussed in Anna Tunlid, "The Askö Laboratory: The field station as a place for fostering scientific collaboration and development", Helena Ekerholm, Karl Grandin, Christer Nordlund & Patience A. Schell (eds.), *Understanding Field Science Institutions* (Sagamore Beach, 2018). See also Thomas Söderqvist, *The Ecologists: From Merry naturalists to Saviours of the Nation: A Sociologically Informed Narrative Survey of the Ecologization of Sweden* (Stockholm, 1986). A description of the growth of the research field of ecological economics is found in two articles by Inge Røpke: "The early history of modern ecological economics" and "Trends in the development of ecological economics from the late 1980s to the early 2000s", *Ecological Economics*, vol. 50:3–4, 2004, and vol. 55:2, 2005. The Beijer Institute's history is described in *The Beijer Institute: The International Institute for Energy Resources and the Environment* by Carl Gustaf Bernhard (Stockholm, 1991). There is extensive literature on complex adaptive systems and resilience, but a general article by Carl Folke is "Resilience: The emergence of a perspective for social-ecological system analysis", *Global Environmental Change*, vol. 16, 2006. The interlinking of social and ecological systems and the concept of *panarchy* is covered in Lance H. Gunderson & C. S. Holling (eds.), *Panarchy: Understanding Transformations in Human and Natural Systems* (Washington, 2002). For a critical discussion of the concept of resilience from a social science perspective, see Muriel Cote & Andrea J. Nightingale, "Resilience thinking meets social theory: Situating social change in socio-ecological systems (SES) research", *Progress in Human Geography*, vol. 36:4, 2012.