"remainder" was (~98%?) because they did not provide any analysis of land-use change or the total growth change for the region. Not only is the title of the article misleading, but also we consider the conclusions about growth enhancement due to changes in environmental conditions misleading because the analytical methods are not sufficiently robust to estimate such changes.

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A History of the Ecological Sciences,

Part 5: Byzantine Natural History

Emperor Constantine I departed from Rome and built a second capital, New Rome, in 324–330 AD at the former Greek state of Byzantion. Later, New Rome became Constantinople, and the Roman Empire was divided into a Greek East and a Latin West. The empire had become too large to rule from one place; over time the two parts drifted apart, and the West declined and ceased to be an empire before the year 500, whereas the East persisted for another thousand years. The Greeks continued thinking of themselves as Roman citizens, but historians assign the name Byzantine Empire to their entity.

The Byzantines had a distinct civilization, blending ancient Greek, Roman, and Christian cultures. Two components of this heritage, Roman and Christian, neglected science, and this fact helps to explain why the Byzantine contributions were much weaker than those of ancient Greece. However, there is also a strong correlation between a civilization's expansion or contraction and its vitality. An expanding civilization generally has an expanding economy, which stimulates culture. Conversely, a shrinking civilization experiences cultural decline, and a stagnant civilization also experiences a stagnant culture. The Byzantine Empire expanded for a few decades during the 500s, but otherwise it was either stagnant or contracting (Kazhdan et al. 1991*c*). For a time, there were three important centers of learning—Athens, Alexandria, and Constantinople—but in 642 the Arabs overran Egypt, including Alexandria, and Athens gradually declined to the point of academic insignificance; at Constantinople, theology gradually became as important or more important than philosophy and science (Kazhdan 1991*e*). Medical education became centered at hospitals, which were a Byzantine invention (Scarborough and Talbot 1991*b*). Handicapped by cultural and politico-economic limitations, Byzantine science reached only the level of ancient Rome's.

The Byzantines did make some original contributions to science (see Théodoridès 1963, Vogel 1967), including botany (Egerton 1983) and zoology (Petit and Théodoridès 1962:182–190, Kádár 1978:20–29), but more often they assembled compendia of ancient knowledge: medical encyclopedias, pharmacopoeias, an agricultural handbook. They also wrote the earliest known manuals on veterinary medicine and falconry. However, their greatest contribution to the history of science was preserving ancient Greek writings on science and transmitting them first to the Arabs and much later to the Latin-speaking Europeans.

The Byzantines also synthesized pagan and Christian learning. Basil (c. 329–379), bishop of Caesarea in Cappadocia (Baldwin et al. 1991), was a leading Church father who is credited with establishing a precursor of the hospital (Miller 1985:54). His writings included an influential work, *On the Hexaemeron*, which attempted to reconcile pagan learning with the Genesis story of creation in six days (Glacken 1967:187–195, Olson 1982: 164–177, Baldwin 1991). Plato taught that God shaped the world out of preexisting matter, and Aristotle taught that the universe is eternal, with no beginning or end; Basil rejected both claims, because Genesis contradicts them. While this exercise is more theology than science, he also argued that one should study nature to learn details omitted from the Book of

Genesis, and also to gain an appreciation of God's wisdom, power, and beneficence. Although some Church fathers, mostly those writing in Latin, rejected science as pagan nonsense, Basil's outlook prevailed. Science continued, in a Christian context. The Hexameral tradition drew upon ideas of providential ecology that had developed from Herodotos to Cicero.

Byzantine medical authors are often dismissed as being better at organizing existing medical knowledge than at making original contributions. That claim may be true, but recent research shows their supposed lack of originality to be somewhat exaggerated (Scarborough 1985*b*). The first Byzantine medical encyclopedist was Oribasios of Pergamum (c.325–after 395). At the request of Emperor Julian, he summarized the extensive medical works of his townsman, Galenos. His summary was widely used by later authors, but it does not survive (Baldwin 1975, Scarborough 1991*c*). However, his summary undoubtedly was important when writing his own encyclopedia, which does survive. Three other such encyclopedias were compiled within a century of each other by Aëtios of Amida (fl. c.530–560), Alexander of Tralles (525–605), and Paul of Aegina (died after 642). Aëtios' comprehensive treatise consisted mainly of quotations that he compiled from earlier works (Kudlien 1970*a*, Scarborough 1991*a*). Alexander's works include a letter on intestinal worms (1933–1937, Volume 2:103–113), probably the first separate writing on the subject (Kudlien 1970*b*, Scarborough 1991*b*). Paul was practicing medicine in Alexandria when Arabs conquered it; he remained there and his *Epitome of Medicine* was influential on Arabic-language medicine (Thomas 1974, Scarborough and Talbot 1991*d*). Paul's is the only one of these encyclopedias translated into English. He believed elephantiasis was an incurable cancer (IV, 1) and that intestinal worms develop in people who eat too much (IV, 57). He mentioned that some believed that Dracunculus or Guinea Worm arises from a nervous concretion, but devoted most of his discussion to its extraction (IV, 59). The last medical encyclopedist, Joannes Aktoarios (c.1275–after 1328), wrote almost a millennium after Oribasios, but medical progress during the interim was rather modest. New information that was available to him was on whipworm infestations (Hohlweg 1985, Scarborough and Talbot 1991*c*). All of these encyclopedists discussed human parasites (Hoeppli 1959:10–17, Théodoridès 1966:133–136). They focused on recognizing parasites or their symptoms and providing remedies. That rabies is transmitted by the bite of rabid dogs or other animals was well known, but the Byzantines had no reason to link this disease with parasites (Théodoridès 1985). Many remedies were based on tradition rather than on first-hand knowledge, and some of them were ineffective. No general understanding of parasitism emerged. If the Hexameral tradition influenced medical thinking, it would have been difficult to appreciate the dangers parasites posed, because, according to that tradition, the creation was beneficent.

The Byzantine (or Greek Orthodox) Church strongly opposed astrology, because it implied a lack of free will and was a holdover from paganism (Pingree and Kazhdan 1991). Nevertheless, it flourished, and often did so at the royal court. Ptolemaios' *Tetrabiblos* was used, but it was not the most popular resource. Summaries or compendia of various works, including *Tetrabiblos*, were compiled during the 300s–600s, and these predominated until the 900s–1000s, when Arabic astrological works were translated into Greek, introducing new perspectives. This new material prompted new summaries and compendia, written from the 1000s until the late 1300s. As in antiquity, Byzantine astrology was pseudoscience in its most important form, emphasizing the influence of heavenly bodies on earthly life.

Botany as a pure science was not of much interest, but there was considerable interest in pharmacological botany. This topic is not closely tied to ecological sciences, but it is nevertheless interesting to note that a magnificent codex (a book, not a scroll) of Dioscorides' *Materia Medica* and some other writings was a present to Princess Anicia Juliana in 512. The Anicia Juliana Codex has 498 colored illustrations of plants (252 plant names are provided by Basmadjian [1938]), and also illustrations of various animals. This codex was a kind of bridge between ancient and medieval Greek traditions of plant and animal illustrations (Cutler and Scarborough 1991). In 1562, the Holy Roman Emperor purchased this treasure from the Turkish sultan, and it is now in Vienna. It has been reproduced in two facsimile editions, the first (1906) in black-and-white photographs, and the second as a magnificent colored codex (1965–1970). Later commentators on Dioscorides added botanical details to his accounts (Riddle 1985).

Timotheos of Gaza (fl. c.491–518) was a poet and armchair zoologist (Scarborough 1991*d*) who wrote a popular animal book that survives in a single, incomplete copy of a later paraphrase. He compiled it from earlier sources, and it generally resembles the animal stories of Aelianus and the two Oppians, on which he drew. He relied most upon the Aristotelian *Historia Animalium*; he did not use Plinius' *Naturalis Historia*, which was in Latin and probably unavailable at the eastern end of the Mediterranean Sea. Timotheos' interests could be called ecological, but his judgment was uncritical. The first chapter of *On Animals* is on the hyena, which he claimed sometimes mated with wolves or bears, producing lone wolves that prey on men or animals; it steals decomposing bodies from graves; it sees equally well during night or day; it vomits up its food to attract dogs, then catches them; if a dog sitting on a roof casts a shadow in the moonlight, the hyena catches the shadow and uses it to pull the dog off the roof; hyena bile improves eyesight. His book did not advance zoology, and it illustrates how far public understanding had declined.

Most Byzantines suffered from a superiority complex, which inhibited interest in travel or geography, and they, no more than the Romans, bothered with the mathematical geography of Ptolemaios (Kazhdan 1991*b*). An Alexandrian, Kosmas "Indikopleustes" (Indian Navigator), wrote a popular *Christian Topography* during the first half of the 500s, which included observations that he had made as a merchant on a voyage from Africa to India (Baldwin and Cutler 1991). However, his main goal was not so much to increase geographical knowledge as it was to support a Biblical world view. The only chapter concerning natural history is a hodgepodge of information more or less about the island of Sri Lanka (1897, Book 11). Emperor Constantine VII (905–959, r.945–959) was well educated; he both sponsored and helped to compile several reference works (Toynbee 1973:575–580), including *On the Administration of the Empire*, which provides geographical information on the Empire and surrounding lands (Kish 1978:177–183). As the Empire declined, 1100s–1400s, interest in the wider world revived.

Encyclopedias on agriculture and veterinary medicine compiled for Constantine VII in the mid-900s discussed parasites of plants and animals. Kassionos Bassos, during the late 500s or early 600s, had compiled *Eklogai* from earlier agricultural writings; now lost, it was an important source for the popular *Geoponika*, which survives (Kazhdan 1991*c*). It intermixes folk beliefs and magic with farming lore, and it seems less critical than ancient Roman writings on agriculture. Nevertheless, it was soon translated into Arabic, Armenian, Latin, and Syriac, and more recently into English (1805–1806; a sampler is in Bodenheimer 1958:189–191) and Bassus (1998, in Spanish). Greek writings on hippiatrika (horse medicine) from the 300s became the basis for the surviving *Hippiatrika* (Oder and Hoppe 1924–1927, Doyen-Higuet 1985, Fischer 1988, Karasszon 1988:110–115). Although Byzantines cared about the health of dogs, sheep, goats, pigs, and birds, the importance of cavalry for national defense led to an emphasis on horses.

During the 900s, an unknown author wrote an *Epitome of Aristotle's Zoology*, and probably about 1100, Michael of Ephesus wrote commentaries on each of Aristotle's zoological works (Kazhdan and Talbot 1991*a*). Byzantines shared their ancestors' interest in hunting and fishing, and their own notable contributions to this literature were on hawking or falconry, "the sport of kings." The two best-known authors of such works were Constantine Pantechnes (active 1190s), a metropolitan (church official) in Philippopolis (Kazhdan 1991*d*), and Demetrios Pepagomenos (active early 1400s), a physician and scholar in Constantinople (Diller 1978, Macrides 1991). They drew upon earlier traditions and writings. Pepagomenos' book contained exact observations on worms in the eyes of falcons (Vogel 1967:285).

As the Turks conquered more and more Byzantine territory, well-educated Greeks began seeking refuge in Italy. This was an important trend, because there had been few Europeans who could translate Greek texts into Latin, and few Greek texts available to translate. Before the 1400s, most ancient Greek works known in Europe had been translated into Latin from Arabic, and a translation of a translation contains errors that can only be eliminated by a direct translation. Theodoros Gazes (c.1400–1475/6) was a prominent example of these refugees (Geanakoplos 1984, Kazhdan and Talbot 1991*b*). He was born in Thessalonike, which had been besieged often during the 1300s and early 1400s, and finally fell to the Turks in 1430 (Gregory 1991). By then he was teaching in Constantinople, and about 1435 he emigrated to Italy and probably carried Greek texts with him. He taught Greek in Ferrara, Naples, and Rome, and published an introductory Greek grammar. He translated a number of Greek works into Latin, including some by Aristotle. His translations of Aristotle from Greek increased the accuracy of works already known from Arabic translations. Of greater interest for us was his translation of Theophrastos' *De historia et de causis plantarum*, which was unknown in Europe prior to publication of Gazes' translation in 1483. Gazes was no botanist—he undertook the translation because of Pope Nicolas V's sponsorship—and he made a number of errors that might have been avoided by someone knowledgeable about the plants of the Mediterranean basin. Nevertheless, his translation became very important for the history of European botany; it was republished six times during the 1500s, and the large 1644 Greek and Latin edition of over 1200 pages was amply illustrated and annotated by two botanists (Greene 1983:Chapter 10).

Byzantine natural history hardly rose above the level of Roman natural history, and our primary debt to that civilization is for its preservation of ancient Greek science. Without that legacy, modern science, including ecological sciences, would have arisen much more slowly than it did.

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The Ecosystemic Life Hypothesis II: Four Connected Concepts

In the first article in this series (Fiscus 2001), I introduced the ecosystemic life hypothesis as a potential solution to the conceptual roadblocks that I encountered when trying to define ecological health. I also showed how definitions of life and ecosystem are often blurred, and suggested that this lack of clear operational definitions for fundamental concepts hints at the convergence of ecosystem science with big questions like, "What is Life?" In this second article, I present four concepts that weave life and ecosystem together further, and explain why they may be inextricably linked. Taken together or "connected," these concepts suggest a path toward a revised set of first principles for ecology. I present them separately, and then attempt to synthesize their mutual implications—for my original problem with ecological health as well as for ecological science itself.

Lotka and coupled transformers

The first of these pivotal concepts is Lotka's idea of coupled transformers: two functional types that exist as obligate companion processes, are necessarily interdependent, and are indivisible (Lotka 1925).

> *Coupled transformers are presented to us in profuse abundance, wherever one species feeds on another, so that the energy sink of one is the energy source of the other. A compound transformer of this kind which is of very special interest is that composed of a plant species and an animal species feeding upon the former. The special virtue of this combination is as follows. The animal (catabiotic) species alone could not exist at all, since animals cannot anabolise inorganic food. The plant species alone, on the other hand, would have a very slow working cycle, because the decomposition of dead plant matter, and its reconstitution into* CO_2*, completing the cycle of its transformations, is very slow in the absence of animals, or at any rate very much slower than when the plant is consumed by animals and oxidized in their bodies. Thus the compound transformer (plant and animal) is very much more effective than the plant alone.*

Other quotations provide evidence that Lotka worked from a whole-systems perspective as opposed to a focus on mere "interaction" of predator and prey treated as *separable* parts of a system. For example:

> *It is customary to discuss the "evolution of a species of organisms." As we proceed we shall see many reasons why we should constantly take in view the evolution, as a whole, of the system (organism plus environment). It may appear at first sight as if this should prove a more complicated problem than the consideration of the evolution of a part only of the system. But it will become apparent, as we proceed, that the physical laws governing evolution in all probability take on a simpler form when referred to the system as a whole than to any portion thereof.*

And again later:

> *... the concept of evolution, to serve us in its full utility, must be applied, not to an individual species, but to groups of species which evolve in mutual interdependence; and further to the system as a whole, of which such groups form inseparable part.*

Thus Lotka suggested evolution as the dynamic basis for defining life and ecosystem (Lotka 1925). He also suggested that the inseparability of part and whole in living systems lies at the mutually beneficial energy and matter transformations embodied in the plant–animal system taken as a unitary whole. I call his coupled transformers "coupled complementary processes," and see them as a general theme varied multiple times in nature. (The main other case is the male–female duality).

In summary, I interpret Lotka's work to argue that (1) coupled transformers are an important dynamical element of living systems. (2) Coupled transformers are a general, fundamental theme that is varied many times in nature. And (3), it is best to adopt a holistic treatment of life and its environment as a single evolving system.

Howard Odum and ecological system preceding origin of life

Howard Odum depicted the origin of life (Fig. 1) as ecosystem first and cells later (Odum 1970). It is important to note that his origin-of-life scenario depended on physically driven cycling within an aquatic system ("circulating seas," as he said). I see Odum's view of the interdependence of production and consumption as Lotka's coupled transformers in another form. Odum's work as a whole