Ecologies of Construction

Ecology, Ecosystem, Industrial Ecology

Learning objective

Purpose: To establish the historical and intellectual link between the development of the field of ecology and the environmental movement resulting in an examination of the emerging field of industrial ecology. Students should be able to **trace the origins of industrial ecology** back to the foundations of evolutionary science, ecosystem discovery and studies in complex systems. In addition, the class will be able to outline the most productive and identify the clearly problematic aspects of the analogy used to justify the adoption of a link between the attributes of natural ecologies and those of anthropogenic systems of production and consumption.

Agenda

1. Trace intellectual and historical development of ecology
    a. Evolution and population studies (Darwin and Malthus)
    b. Adaptation, Community Succession, Population interactions
    c. Natural communities as "complex organism" (ecosystem, Gaia)
    d. Mathematical ecology and systems modeling
2. Describe the foundation of industrial ecology
3. Examine in detail the question of the analogy/metaphor between these two

Primary reference texts for lecture:

Real, L.A. and J.H. Brown. ***Foundations of Ecology***.

Odum, E.P. **The Strategy of Ecosystem Development**. Science, 1969.

Graedel, T.E. and B.R. Allenby. **Industrial Ecology, 2nd Edition.**

system

I. An organized or connected group of objects

1. A set or assemblage of things connected, associated or interdependent, so as to form a complex unity; a whole composed of parts in orderly arrangement according to some scheme or plan; rarely applied to a small or simple assemblage of things

1802: Paley Nat. Theol. Xxv. *The universe itself is a system, each part either depending on other parts, or being connected to other parts by some common law of motion.*

Source: Oxford English Dictionary

System

Interconnected parts but let’s go a step further:

A system exhibits high-level behavior that includes **adaptation, resilience and self-regulation**.

Let’s keep these in mind over the next few weeks. These three terms will prove particularly useful to us.

Because, you could use these three to ask questions like,

“Would a community qualify as ***sustainable*** if it were able to (1) **adapt**, displayed an unusual level of (2) **resilience** under environmental and social change and were (3) **self-regulated**?”

population and evolution

I. Malthus (population)

II. Darwin (evolution)

III. US Naturalists (ecosystem – ecology)

   i. Stephen Alfred Forbes (1844–1930)

   ii. Henry Chandler Cowles (1869–1939)

   iii. Frederic Edward Clemens ((1874–1945)

   iv. Rachel L. Carson (1907–1964)

   v. Eugene P. Odum (1913–2002)

Source: Oxford English Dictionary

Darwin, in turn had read 6th edition of ***Essay on Population*** (1826) of Robert Malthus in 1838 after returning from his five-year naturalist's voyage around the world.

Malthus, ***Essay on Population***:

1. Populations, left to grow unchecked would grow geometrically,
2. Populations would then outstrip food supplies (and other necessary resources, like wood fuel),
3. Therefore, utopia was impossible (writing at the time of utopian thinking).

Darwin, upon reading Malthus surmised that this meant that populations would experience intense competition for resources. This would lead to:

1. **within species** competition leading to those best adapted to environmental conditions winning out ("survival of the fittest", phrase coined by Darwin's compatriot Herbert Spencer 1820-1903, philosopher and evolutionist – armchair reasoning),
2. **between species** competition leading to species splitting into new species adapted to particularities of the environment and taking advantage of special capabilities (like flight, or speed) to compete.

Darwin referred these thoughts as the **law of Malthus** as applied to the natural world.

ecology

I. The science of the economy of animals and plants; that branch of biology which deals with the relations of living organisms to their surroundings, their habits, and modes of life etc.

1873: Haeckel's Hist. Cret.: *All the various relations of plants and animals to one another and to the Outer world, with which the Oekology of organisms has to do…*

Source: Oxford English Dictionary

Ecology was first coined as "oecology" by German zoologist, Ernst Haeckel in the 1860s and used in publication some time later.

Haeckel coined the term to serve the need for a word that described the multifaceted struggle for existence that **Darwin** had discussed in his 1859 treatise ***On the Origin of the Species***.

In America, **the term ecology** was first used by a group of **botanists** frustrated by limitations of descriptive methods of natural history.

They were more interested in contributing to **physiological (dynamic) studies** of the relationship between organisms and their environment.

Close behind were the **zoologists** – primarily in their population studies of species in the wild.

In America, much of this pioneering work was done at the newly established land-grant colleges at the end of the nineteenth century.

ecology

The science of ecology has matured into studies that address three distinct areas:

I. Adaptation (evolution – survival of the fittest)

II. Population Interactions

III. Community Succession

Source: Kingsland, S.E. Defining Ecology as a Science. In: Real. Foundations of Ecology.

Ecology, as a field, has been criticized as a scientific "fad" – a passing fascination for soft science.

This is especially true for us – as **industrial ecology**, as a field, has received similar criticism (by association).

In fact, here at MIT, the **Engineering Systems Division**, and the **Technology, Policy Program** are still considered by some in the community as secondary at best and deeply flawed by others.

It is not uncommon that these meta-studies are generally met with skepticism by the hard sciences. Biology was also met with skepticism here at MIT.

In any case, the zoologists and the botanists arrived at three distinct studies that continue to dominate the study of natural ecology:

1. **Adaptation** - driven primarily by evolutionary theory and now genetic studies,
2. **Population interactions** – characterized by much field work and mathematical modeling of population/food relationships, and
3. **Community succession** – possibly the most holistic of the three addressing the changes in habitat and environmental conditions that result from the complex relationships between species (flora and fauna) and their surroundings. Succession is something that we will return to when discussing urban centers (because this is a **spatial** study).

Much of this work ultimately led to questions regarding the relationships between populations of wild species and changes in their context (whether it be the health of other species or the conditions of the environment; atmospheric, oceanic, geological etc.). As **Stephen Forbes** put it in his pioneering work of 1887, ***The Lake as a Microcosm***, "all species are bound up with others within the community" That is all species were part of a system – an **ecosystem**.

This also inevitably led to questions concerning the "**health**" of natural systems and their robustness, resilience, and adaptability. And soon, with the growing environmental impact of the growing post-civil war economy of the US, questions were asked about the **relationship between human activities and the natural world**.

"The beauty of the living world I was trying to save has always been uppermost in my mind – that, and anger at the senseless, brutish things that were being done. I have felt bound by a solemn obligation to do what I could – if I didn't at least try I could never be happy again in nature."

(1962)

Rachel L. Carson

There has never been a more poignant and effective examination of the direct consequences on human actions on the natural world was the work of Rachel Carson.

With the publication of **Silent Spring** (1962), Carson publicized the effect of misusing pesticides.

This was a new brand of naturalist – one that viewed the relationship between human activities and the natural world as primary.

This reflected a development in ecological studies to conceive of the collection of species within a defined are as a large "complex organism". That is, the object of study for ecologists could be more than one species or even a colletion of species, but could be the entire web of relationships and interdependencies that characterized this super organism.

One observation that came from these studies was that some natural areas – especially those untouched by human settlements or other intervention – had seemed to reach a final stable state. This "climax state" – it was theorized – was able to remain essentially unchanged for millions of years.

Competing views on this:

Henry Chandler Cowles: sand dunes in the Chicago region emphasized dynamic interaction between plants and underlying geological formations (1899).

Frederic Clements: studied more stable grasslands and conifer forests of American west and was author of the climax theory (1920s).

With the Dust Bowl of the 1930s, there was clear evidence that the health of the ecology – espeically in that case – the practices and composition of agriculture could have a dramatic effect on the local environment.

ecosystem

I. A unit of organic relations often encompassing a great variety of species and interactions between those species and the surrounding material and energy resources.

1935: A.G. Tansley in Ecology XVI, p.299: *The fundamental concept appropriate to the biome considered together with all the effective inorganic factors of its environment is the ecosystem…*

Source: Oxford English Dictionary

In 1935, partly as a response to this work, the British ecologist, **Arthur G. Tansley**, coined the word, "**ecosystem**" to refer to the collection of organisms that define a biome and the exchange between it and the inorganic matter of the environment. That is, the full understanding of the geochemical and biological relationships that occur within an area.

Clearly fundamental to this definition is the acknowledgement of a **dynamic exchange of materials and energy**.

As part of this understanding came the work of **Charles Elton** (1927). In ***Animal Ecology*** he developed the idea of the ecological "**niche**" – and abstract ecological "space" that was defined by a very particular network of energy and material exchanges. This "niche" was also used to convey a unit that could be the object of competition between similar species.

“Organisms have not just adapted to different physical environments; they also modify and improve the environment for their own good – just like people.”

(October 1998)

Eugene P. Odum

Jumping now to the late 1940s and 1950s, Eugene P. Odum developed theories that were to draw various strains of ecology studies into a new science called “**ecosystem ecology**”.

Odum considered the study of ecosystems to be one determined more by physics than biology in that it was a study of the flow of energy from recycled chemicals through a thermodynamic system. Earth’s various life forms competed for shares of this energy currency and ecosystems – including human society – could be conceived as living organic communities… “as large and diverse as possible within the limits set by available energy input and the prevailing conditions of existence.”

Odum’s work established ecosystem ecology as a distinct discipline apart from biology. It is interesting to note that Odum was the son of a sociologist and **regional-planning advocate**.

An important part of Odum’s work was the notion of ecological succession:

From, Odum, E.P. 1969. ***The Strategy of Ecosystem Development***. Science. Vol.164.

Ecological succession is defined as:

i. An orderly process of community development that is reasonably directional and, therefore, predictable,
ii. It results from modification of the physical environment by the community; that is, succession if community-controlled [the environment sets the pattern of growth, the rate of growth and the ultimate limits of growth],
iii. Culminates in a stable ecosystem in which maximum biomass and symbiotic function between organisms are maintained per unit of available energy flow.

Other sources:

Ponting, C. 1991
Green History of the World.

Diamond, J. 2005
Collapse.

Origin of the analogy to natural systems: *Industrial Ecology*

self-regulating natural systems = self-regulating human systems

Source (reading): Ausubel, J. 1992. Industrial Ecology: Reflections on a colloquium. Proc. Natl. Acad. Sciences. Vol.89:pp.874-884.

Odum's work, among others inevitably leads to a conception of the earth as one large ecosystem – self-regulating and engaged in an enormously complex flow of energy and materials.

And now we arrive at a key point where ecologists took up Darwin's original conjecture – derived from the Malthus **Essay on Population** – that the natural world was necessarily self-regulating; that is, populations were regulated by limitations in food supply and other resources.

Ecologists such as Odum took this a step further and produced work that implied that human systems could also self-regulate – not through catastrophe like mass starvations, conflict and chaos, but through design, science and engineering and planning.

If one believes this, then **what better model for self-regulation than the natural world?**

But are there any human examples of self-regulating models?

Read from Ponting.

Dick Cheney has characterized…
"conserving or rationing" as 1970s-era solutions to the US' energy shortages.

In a speech in Toronto, Mr Cheney said that "conservation may be a sign of personal virtue, but it is not a sufficient basis for a sound, comprehensive energy policy."

(April 30, 2001)

Dick Cheney

Does conservation have a role? What is it? How is it implemented?

Is Cheney right that conservation is an individual virtue that has not held sway over time as an important driver of collective, societal behavior?

Other sources:

Ponting, C. 1991

Green History of the World.

Diamond, J. 2005

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Industrial Ecology (Ausubel)

Do sociotechnical systems have long-range environmental goals? (Diamond, Ponting)

Is Odum correct in this statement that organisms generally improve their environments? (climax environments and self-regulating natural systems)

How is the concept of industrial ecology useful and timely?

Source (reading): Ausubel, J. 1992. Industrial Ecology: Reflections on a colloquium. Proc. Natl. Acad. Sciences. Vol.89:pp.874-884.

First question – give examples. What about Diamond – read from Green History of the World.

On the third question - Industrial ecology is useful and timely:

1. as a powerful metaphor and analogy for analytical and design studies, and
2. as a central research and teaching field that can host a great variety of disciplines.

Let's look at some specifics on the metaphorical and analogical links between natural and industrial ecologies.

natural — industrial

natural	industrial
I. Adaptation	I. Production Design/engineering
II. Population Interactions	II. Consumption Behavior (firms/individuals)
III. Community Succession	III. Planning Cities/regions

Source: Kingsland, S.E. Defining Ecology as a Science. In: Real. Foundations of Ecology.

Now let's look at the analogy – the links between natural and industrial (human/anthropogenic) ecology.

Industrial Ecology (Clark and Dickson)

What is sustainability science?

What are the most valuable contributions of S&T to sustainable development?

What are questions of "sustainability science"?

Source (reading): Clark, W.C. and N.M. Dickson. 2003. Sustainability science: The emerging research program. *PNAS*. Vol.100, No.14: pp.8059-61.

Sustainability science

"to harness science and technology (S&T) for sustainability focus on the dynamic interactions between nature and society – with equal attention to how ***social changes shapes the environment*** and how **environmental change shapes society**." (Clark and Dickson)

Contributions of S&T

Yield-enhancing (agriculture), land-saving, nature-society interactions, energy systems, ecosystem resilience, ***industrial ecology*** and earth system complexity.

What are the questions of sustainability science (from Clark and Dickson, page 8060 (2))?

"What determines the vulnerability or resilience of the nature-society systems in particular kinds of places and for particular types of ecosystems and human livelihoods?"

Definitions of Industrial Ecology

industrial ecology: employing the behavior and attributes of natural ecologies as an analogue at various scales, the study of **human-induced material and energy flows** and transfers between the anthroposphere and the global bio-sphere for the purpose of **synthesizing** a network of interrelated industrial processes that promote the responsible and sustained use of renewable and nonrenewable capital.

Excerpts regarding the definition of industrial ecology follow below:

1. *The idea of an industrial ecology is based upon a straightforward analogy with natural ecological systems. In the industrial context we may think of [the food web] as being use of products and waste products. The system structure of a natural ecology and the structure of an industrial system, or an economic system, are extremely similar.* (Frosch 1992)
2. *Somewhat teleologically, industrial ecology may be defined as the means by which a state of sustainable development is approached and maintained. It consists of a systems view of human economic activity and its interrelationship with fundamental biological, chemical, and physical systems with the goal of establishing and maintaining the human species at levels that can be sustained indefinitely, given continued economic, cultural, and technological evolution.* (Allenby 1992)
3. *Industrial ecology can best be defined as the totality or the pattern of relationships between the various industrial activities, their products, and the environment…Industrial ecology, a systems view of the environment, pertains to the future.* (Kumar and Patel 1992)
4. *The emerging discipline of industrial ecology is an attempt to (re)establish an intricate mesh of exchanges of goods and services in order to minimize environmental impacts of economic activities. To achieve these goals, industrial ecology must concentrate not only on the role and features of products, technology ,and industry, but also on the combined socioeconomic and environmental system. (Ruth 1998)*

Sources: Frosch, R. 1992, Allenby, B.R. 1992, Kumar and Patel 1992, Ruth, M. 1998

Industrial ecology is at once both an emerging field of **analytical** studies and an **aspirational** territory for design and engineering.

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IPAT (Master Equation)

$$I = P \times A \times T$$

I: total environmental impact

P: population

Earth's population is still rapidly increasing. It has been predicted that a leveling off at 8 to 10 billion people should be reached by 2050. Current population is 6 billion.

A: affluence

Affluence is measured in terms of GDP (gross domestic product); that is, in monetary terms. Often the IPAT equation uses a per capita ratio for this term such as ***GDP/person***.

This term varies greatly from region to region. However for most regions of the world from 1960-2000, the growth of real per capita income has increased (exceptions are Sub-Saharan Africa and Latin America during the decade 1980-1990).

T: technology

This term is actually a measure of the degree of environmental impact per unit of gross domestic product. It is labeled 'technology' because technology substantially determines the value of this term. However, the most common ratio used to describe this term is environmental impact/unit of GDP ***environmental impact/GDP***.

Therefore, the IPAT equation becomes:

Env. impact = Population x (GDP/person) x (env. Impact/unit GDP)

Sources: Graedel, T.E. and B.R. Allenby. 2003. Industrial Ecology. Prentice-Hall, NJ.

Let's refer to the Chertow reading (Chertow, M. The IPAT Equation and Its Variants. JIE. Vol.4, No.4: pp. 13-29).

Once used to identify single element **most environmentally damaging**.

Now, industrial ecology has turned it around to identify opportunities, mostly technological that can **lessen our environmental burden**.

IPAT Equation (Chertow)

In one of its original formlations: I = P x F, please explain.

How does the IPAT equation relate to the Kuznets curve?

What is ecological modernization?

Source (reading): Chertow, M. 2001. The IPAT Equation and Its Variants. *JIE*. Vol.4, No.4: pp. 13-29.

I = P x F

F = impact per capita.

Emphasized the **central role of population** as (Ehrlich and Holdren 1971) “the most unyielding of all environmental pressure” page 15, Chertow.

Why?

Kuznets curve:

y-axis: environmental impact (particulate matter, CO2): ***I***

x-axis: per capita income (dollars, measure of GDP): ***A***

Ecological Modernization

The term used in Europe for the use of technology to minimize environmental impact.

Notice that not much is said here about consumption and conservation. Industrial Ecology has been criticized as a field that serves, primarily, a corporate, industrial world. Individual responsibility, voluntary conservation, reduction in affluence have been historically underserved.

IMPORTANT: Because industrial ecology is, if anything, **an optimistic field** that is reflected in its reversal of the IPAT equation from tracking pollution to revealing technological opportunities.

Yet, see the issue of the Journal of Industrial Ecology, ***Special Issue on Consumption and Industrial Ecology***, Vol.9, No.1-2, Winter/Spring 2005.

Mention voluntary carbon emissions offset purchases New York Times article, February 20, 2007).

The “field” of Industrial Ecology (IE)

1. **Analysis (mapping resource consumption)**

   A. Theory
      - Physical accounting
      - Natural capital
      - Ecological economics
      - Other (such as SOHOs, etc.)

   B. Methods
      - MFA, LCA, TMR, ***IPAT*** equation and others
      - Resource metrics (energy, emergy, exergy etc.)
      - Environmental/ecological footprint
      - Other

The “field” of Industrial ecology (IE)

2. **Design (or engineering or the “science of sustainability”)**

   A. Theory
      - Dematerialization (e.g. services for things)
      - Green chemistry, Distributed energy (DE)
      - Closing resource consumption cycles
      - Others including changing consumption patterns

   B. Methods
      - Extended Producer Responsibility (EPR)
      - Design for Environment (DfE)
      - Design for Disassembly
      - Other