Managing Human and Social Systems

Environmental Management Handbook, Second Edition

Edited by
Brian D. Fath and Sven E. Jørgensen

Volume 1
Managing Global Resources and Universal Processes

Volume 2
Managing Biological and Ecological Systems

Volume 3
Managing Soils and Terrestrial Systems

Volume 4
Managing Water Resources and Hydrological Systems

Volume 5
Managing Air Quality and Energy Systems

Volume 6
Managing Human and Social Systems

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Contents

SECTION VI ENT: Environmental Management Using Environmental Technologies

SECTION VII PRO: Basic Environmental Processes

13

Limits to Growth

Brian D. Fath

Introduction

In thermodynamic-based systems science terminology, the Earth is considered a closed system. This means that it is open to energy exchanges, but not matter exchanges. Regarding energy, the Earth receives on average 1,300 W/m^2 of solar radiation at the top of the atmosphere and radiates or reflects a near equal amount back to space (the current increase in greenhouse gases causes a small difference in the radiation balance enough to be responsible for the current observed warming). The amount of matter on the Earth is more or less fixed, with only negligible exchanges from receiving meteorite impacts or outgassing. The Earth's matter is distributed in the following way: The Earth has a polar radius of 6.37×10^3 km, giving it 501.1 million km^2 of surface area, of which 70.8% is covered with water. The overall volume of the Earth is 1.08×10^{12} km^3, with a mass of 5.98×10^{24} kg. Those physical dimensions are hard evidence of the limits of the available space and material resources. The *Blue Marble* (Figure 1) shows this celestial body in all its complexities, opportunities, and beauty; and it also shows starkly the scale and boundaries of the one world that humans and all known species have. This photo, taken during the Apollo 17 Lunar Mission in 1972, coincided with the emergence of the modern environmental movement (more on that below). It was not the first environmental movement, but those ideas from the 1970s still cast a strong shadow on the discussions today that deal closely and explicitly about living in balance on the Earth as represented in among other things, the United Nations Sustainable Development Goals.

The ideas of bio-physical limits impacting human growth and resource consumption are not new. At the turn of the 19th century, Thomas Malthus was already writing about the convergence of population growth and food supply. He foresaw an inevitable turning point in which the finite resources of the planet could not support an exponentially growing population. His dour predictions later became the face of resource-limited, doom-and-gloom environmentalism, referred to as Malthusian. This discouraging perspective is a label that most modern environmentalists try to avoid, while still holding the reality of his concerns. At the time Malthus was writing, the global human population was around 1 billion, and today is approaching 8 billion, moving from abundant nature and scarce humanity to abundant humanity and scarce nature. Yet, there is not an absolute food shortage in terms of total calories produced, only hunger due to regional and distributional dilemmas. In fact, obesity is a more serious and growing problem in many countries than food deficiencies. Nonetheless, the effort that humans have taken to supply this food has meant the conversion of most arable land to agriculture leading to extensive direct impacts

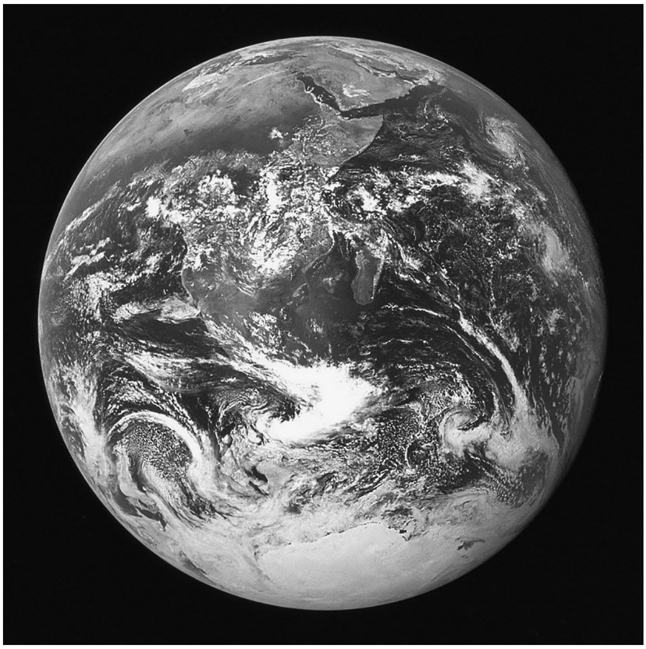

FIGURE 1 The *Blue Marble*, view of the Earth from Apollo 17 (1972).

such as habitat loss, soil degradation, and biodiversity loss. It has also led to the doubling of nitrogen flows through industrial fixation (as a result of the Haber–Bosch process) and the tripling of phosphorus flows (benefitting from massive industrial, fossil fuel-based mining efforts). The proximate result of increasing the amount of these typically limiting nutrients expands food supply, but the production of both nitrogen and phosphorus is highly fossil fuel-intensive creating energy supply dependencies. Furthermore, excess nitrogen and phosphorus that runs off agricultural fields creates massive eutrophication problems that are evident in almost every heavily populated estuary and water body in the world. Agricultural production to meet the world's needs is also responsible for rapid groundwater withdrawals, pesticide applications, and abundant greenhouse gas emissions at numerous stages from the fossil fuel use, to soil alterations, to methane from rice and livestock production. So, while the verdict is not in regarding absolute constraint of food production on human population growth, it does appear clear that we are in fact not feeding the people of the planet in a sustainable manner, nor whether it is even possible to do so at this scale. Malthus' concerns should not be dismissed lightly.

Environmental Limits

Recognition of limits can also be found in the seminal writing of George Perkins Marsh. Marsh wrote *Man and Nature* in 1864, which was one of the first scientific treatises on the impacts humans have on nature and the consequential conditions that coincide. Marsh warned that we should take notice of the scale and extent to which humans can continue to modify nature for our own benefit. Presciently, he wrote:

> A certain measure of transformation of terrestrial surface, of suppression of natural, and stimulation of artificially modified productivity becomes necessary. This measure man has unfortunately exceeded.
>
> **Marsh (1964)**

It is interesting that he recognized that humans will and must modify their environments similar to any species. There is a feedback in which the modifications, the other ecological interactions, and the environmental conditions reach a dynamic balance if the system is to sustain over time. Of course, this does not mean that the systems become rigid without change or variation because innovation, adaptation, evolution, information gain, and learning all allow for continual resilience and flexibility to meet the self-enhanced, recursive dynamic conditions. The path dependency between the interaction of the ecosystem constituents is one of the key features of living systems. Nonetheless, when humans erode too much land, deforest too many hectares, divert too much water, degrade too much habitat, etc., there are limits to which the ecosystem can recover and continue to provide the services we have come to expect. The diminishment first comes in the form of provisioning services when farms and fisheries fail, but then impacts cascade to supporting and regulating services, undermining the capacity of the land to regenerate and function sustainably. Continuation of an approach that overuses and abuses the natural resources will lead to eventual ruin, as Marsh noted in many earlier civilizations, which has been the topic of a recent plethora of research and books describing the collapse of complex societies (e.g., Tainter 1988, Diamond 2005, Kriwaczek 2010, Cline 2014).

The United States of America was settled on the notion of boundless space and opportunity, a land of cornucopia, which influenced not only the profligate physical resource use but also the psychological engagement that one had with resources. However, around the time that Marsh was writing, the transcontinental railroad was being completed. In 1869, the Union Pacific and Central Pacific railroads were joined in Promontory Point, Utah Territory, enabling rapid transportation access across the United States. Travel that previously took 4–6 months could be completed in 6 days. A few decades following both Marsh and transcontinental rail, another measure of limits was recognized in the closing of the Western frontier. The 1890 census showed the first time the disappearance of a contiguous frontier line of a migrating population. The westward wave of expansion was not endless as it had been (naively and myopically) perceived. Historian Frederick Jackson Turner used this moment to refer to the "closing of the American Frontier" (1893). At this bifurcation point, it should have been obvious that the solution to resource shortages, for example, in the form of eroded agricultural land, could not be found by simply relocating to the next plentiful area. While there was still plenty of "under-utilized land" (from a human economic perspective), the new reality meant filling in the middle states rather than experiencing an expansionary boundary. It should have been a time to rethink and reformulate our relationship with land and nature, thus confronting limits and working within constraints. However, the notion of boundless resources remains deeply held by many and institutionalized in many core economic practices (e.g., debt-based money supply, Ponzi-style retirement benefits, high future discount factors). Therefore, recognizing and accepting bio-physical limits was not the first impulse when faced with this new reality.

Ethical Limits

In the 1940s, limits were given another dimension by Aldo Leopold and his *Land Ethic* referring now not only to physical limits but also moral ones. He questioned, why would we pursue certain things (namely economic growth through resource consumption and technologies with unintended consequences) if the result is to destroy and degrade the life and ecosystems around us, loss of species and wild places. He eloquently wrote:

> Our grandfathers were less well-housed, well-fed, well-clothed than we are. The strivings by which they bettered their lot are also those which deprived us of [passenger] pigeons. Perhaps we now grieve because we are not sure, in our hearts, that we have gained by the exchange. The gadgets of industry bring us more comforts than the pigeons did, but do they add as much to the glory of the spring?
>
> **Leopold (1949)**

He elaborated this new perspective in what he called a Land Ethic:

> A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.
>
> **Leopold (1949)**

His Land Ethic puts an environmental ethic clearly on the table as to what is right and wrong, expanding the boundaries of moral concern to the living environment and to the land itself, thus providing new limits of our actions. This ethic is informed by an ecological as well as a systems perspective. Leopold called on humans to constrain certain activities if those actions were detrimental to natural systems. He recognized, for example, the intricate balance cascading between the predator wolves and soils passing through the grass and deer. Too few wolves meant consequences for the soils. There are limits to the control which humans can exert over the ecosystem with a desire for favored species in certain times and places (e.g., the domestic chicken is the most abundant bird in the world, and *Zea mays* (corn) the most abundant plant). In the ensuing decades, we have better knowledge of complex systems, and with this we can have better management, but that does not obliviate the presence of limits imposed from outside and fostered from within. The Land Ethic allows one to see that beyond our own immediate sphere we interact with other bounded spheres, thus implying that the limit we sense is in fact an indication of another system beyond that we are pushing up against. In a zero-sum interaction, expanding our boundary, for example, into nature, diminishes nature. However, there are many non-zero-sum interactions and relations prevalent in ecosystems and complex adaptive systems. The challenge is not to completely disengage when we encounter another system, but to acknowledge it, respect it, work to understand it, and then try to find a way to engage it for the benefit of both parties (see, e.g., Fiscus and Fath 2019).

Socio-Economic Limits

These ideas of limits coalesced in a seminal work by Meadows et al. sponsored by the Club of Rome in the *Limits to Growth* report released in 1972. Their conclusion was based on the results of one of the first global systems dynamics models developed that included state variables representing human population, agricultural productivity, industrial production, resources, and pollution. The dire results were that under no scenario would unlimited growth be able to continue, and the only steady state was found by strict conditions of stable population, 100% use of renewable resources, and investment in business that equaled depreciation. The report was an important contribution to the debate about limits from a bio-physical perspective but was largely ignored by economists and politicians since the approach did not fit their existing growth-oriented mental model. The study was dismissed out-of-hand as having no relevance since their models—absent of any environmental resources or feedbacks—could grow forever. The Meadows et al. model was viewed as Malthusian and overly doom-and-gloom, a stigma that dogged the environmental community for decades. Nonetheless, the Club of Rome work continued as decadal update reports were published showing the projections were in line with reality.

Coincident with the release of the original *Limits to Growth*, the modern environmental movement was gaining traction (as stated above, spurred on by images such as the *Blue Marble* and the Spaceship Earth concept). In the United States, it was a period of aggressive federal policy protections for the environment (Table 1), most passing with very wide margins in both the House and Senate and signed by both Republican (Nixon and Ford) and Democratic (Carter) Presidents. Shy of 50 years later, the pendulum has swung far the other way. Concerted efforts within the United States Congress to dismantle or weaken these Acts, in particular the Endangered Species Act (ESA), is rampant; including news just today (August 13, 2019) of efforts to sign a Presidential Executive order to weaken ESA protections. It would be humorous if it were not sad that one prime argument against the ESA is the stated negative impact that it may have on the economy. However, measuring the success of this

TABLE 1 Major United States Legislation Passed in the 1970s during the Resurgent Environmental Movement

Coastal Management Zone (1972)
Clean Air Act (1972)
Clean Air Act Amendments (1977)
Comprehensive Environmental Response, Compensation and Liability Act (1980)
Endangered Species Act (1973)
Federal Land Policy and Management Act of 1976
Fishery Conservation and Management Act of 1976
Marine Mammal Protection Act (1972)
National Environmental Policy Act (1970)
National Forest Management Act (NFMA) of 1976
Forest and Rangeland Renewable Resources Planning Act of 1974
Noise Pollution and Abatement Act of 1972
Marine Protection, Research and Sanctuaries Act of 1972
Resource Conservation and Recovery Act (RCRA), enacted in 1976
Safe Drinking Water Act (SDWA) (1974)
Surface Mining Control and Reclamation Act of 1977 (SMCRA)
Toxic Substances Control Act of 1976

legislation by its economic contribution is fundamentally misunderstanding its purpose. Framing the ESA as a failure due to its hindrance of capital gain is historical revisionism. The language of the ESA was clear that protections were being put in place precisely because of a lack of concern for the environment and an alarming over-prioritization of economic growth at the expense of ecological limits. The first sentence of the ESA reads:

> (a) Findings—The Congress finds and declares that—(1) various species of fish, wildlife, and plants in the United States **have been rendered extinct as a consequence of economic growth and development untempered by adequate concern and conservation** (emphasis added).
>
> **Endangered Species Act (1973)**

The whole point of the legislation was to put a brake on growth and remember the limits of nature. It was also encouraging that the drafters of the legislation appreciated and recognized the interconnectedness of nature and that species are part of larger ecosystems.

> (b) Purposes—The purposes of this Act are to provide a means whereby **the ecosystems upon which endangered species and threatened species depend may be conserved** … (emphasis added).
>
> **Endangered Species Act (1973)**

The tension between pressures for economic growth and environmental constraints continued and elevated in the ensuing decades.

Flourishing within Limits

The idea of limits has been renewed but with a more positive outlook. In particular is the perspective that the presence of a limit does not need to invoke immediately negative connotations. For example, Jane Jacobs (2000) has focused on the opportunities that constraints and limits bring about. She insightfully remarked that

> Natural principles of chemistry, mechanics and biology are not merely limits. They're invitations to work along with them.

In other words, our understanding of thermodynamics, the periodic table, and biological principles should help to design smarter and better performing systems than without this knowledge. Ecosystems and socio-economic systems are self-organizing and thrive even in the presence of constraints. Think back to the energy flows mentioned in the opening, around 1,300 W/m^2, yet that is enough energy to drive atmospheric circulation, global ocean currents, and complex ecosystems in almost every niche on the planet. Nature has evolved to utilize this energy in a very efficient and also robust manner, resulting in highly complex, diverse, well-functioning systems that arose and are maintained all within the real-time bio-physical constraints.

The message to learn from ecosystems is elaborated in Jørgensen et al. (2015), *Flourishing within Limits: Following Nature's Way*. The authors, all systems ecologists, have drawn upon ecological theory of growth and development to identify a number of attributes that are evident in ecosystems. Using these properties and approaches—within the known bio-physical constraints—ecosystems are able to thrive and flourish, as the most diverse, complex, integrated, and sustainable systems on the Earth.

In a nutshell, the idea is that ecosystems are constrained by both the available resources as inputs and outputs as they reside as gradient-enhancing conduits between these two flows (see Figure 2, Fath 2017). In addition to solar energy, the rate of material availability is controlled by the bio-geochemical cycles at local and global scales. The rates of water, carbon, nitrogen, phosphorus, etc. all have local and global

TABLE 2 Fourteen Properties Observed in Ecosystems

1.	Ecosystems conserve matter and energy
2.	There are no trashcans in nature
3.	All processes (in nature and society) are irreversible
4.	All life uses largely the same biochemical processes
5.	Ecosystems are open systems and require an input of work energy to maintain their function
6.	An ecosystem uses surplus energy to move further away from thermodynamic equilibrium
7.	Ecosystems use three growth and development forms: (1) biomass, (2) network, (3) information
8.	Ecosystems select the pathways that move it most away from thermodynamic equilibrium
9.	Ecosystems are organized hierarchically
10.	Ecosystems have a high diversity in all levels of the hierarchy
11.	Ecosystems resist (destructive) changes
12.	Ecosystems work together in networks that improve the resource use efficiency
13.	Ecosystems contain an enormous amount of information
14.	Ecosystems have emergent system properties

Source: After Jørgensen et al. (2015).

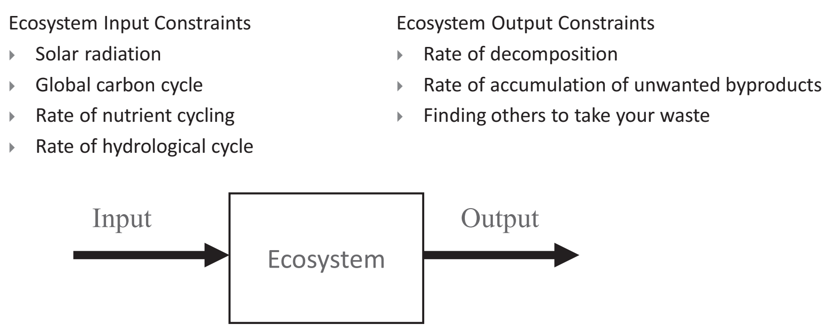

FIGURE 2 Some basic constraints that ecosystems have evolved to thrive within.

constituents that influence what is available and these constraints then lead to the type of ecosystem observed whether it is a tropical rain forest, deciduous forest, steppe grassland, or Arctic tundra, for example. On the output side, the main constraint is that the products and flows out cannot exceed the capacity of the environment to assimilate them. Often this occurs by linking processes such that the output of one process is the input to another in an integrated, coupled fashion. The most obvious example is photosynthesis and respiration in that the former takes in CO_2 and gives off O_2, while the latter does the opposite. Other wastes, such as organic ones, need to be decomposed and returned back to elemental constituents. Therefore, the rate of decomposition is a main factor for the uptake of outflows, which are biologically mediated and influenced by temperature and water (warm, wet environments have faster rates of decomposition). The biomass foundation for fossil fuels occurred during a time period when for various reasons, the material was unable to be decomposed and therefore was buried under conditions that promoted the conversion to fossil fuels. Today's society is generating plastic pollution faster than it can be decomposed, and will likely also leave a recognizable and discernable (and perhaps useful) layer for future generations, and also likely that some organisms will eventually evolve better processes to decompose plastics thus reaching a new balance between production and consumption.

There are of course key differences between nature and society, namely a temporal aspect that ecosystems happen in the present, in real time—although the consequences, building biomass, building soils, establishing drainage patterns, and biogeochemical cycles, etc. have lasting effects. Socio-economic systems operate with a more future-oriented perspective, in that while the actions are short term, there is thought for a future pay-off. For example, a lion takes only what is needed to satisfy the immediate hunger. There is no utility in killing more prey at that moment as they would be absconded by competitors or would spoil; there is no profit motive or line of credit. A hunter today has in mind to take as many prey (or fish or trees or minerals, etc.) as possible since the surplus can be exchanged for other goods or services or turned into a storable currency commodity. It is not clear how to reconcile this basic difference. Humans cannot and should not give up the intellectual foresight that has evolved, but rather it could be used to see the systemic consequences of actions that exceed the limits, that exceed the regenerative rates provided by nature's processes. The remaining question is both philosophical and one of management, which is: How to align our activities within these available flows and constraints?

Conclusion

If humanity desires to stay within limits, then a first consideration is to know where those limits are. How much resources can humans use from the environment and still be within the limits? A standard ecological concept is one of carry capacity, the maximum number of individuals that can be maintained in an area without degrading that area. Carry capacity is a dynamic concept—it can move higher as we innovate new efficient methods and technologies as observed in agriculture since the time of Malthus; yet, it can also move lower as we despoil forests and fields with logging, erosion, and desertification as observed by Marsh and other witnesses to the collapse of civilizations. Metrics such as Ecological Footprint and Ecological Biocapacity that try to make estimates of both the consumption (footprint) and the resource (Biocapacity) have shown that we have outstripped our resource base. Ecological Footprint exceeds Biocapacity, and at a global level, attention is drawn to a notion called overshoot day, which for 2019 occurred on July 29. Meaning on that date, humanity had already used all the resources "sustainably available" to it for that year. After this date, the remainder of the year represents overshoot or dipping into future reserves and leaving future generations with reduced resources. Given this temporal aspect, we see that limits are not simply bio-physical but also ethical as Leopold instructed. Yet, a rigorous debate continues to this day as to whether there are limits of any kind or not. This creates tension between perspectives on policies and approaches, as some see limits as absent or challenges to overcome, while others want to recast the human scale to accommodate them. The planetary boundaries highlighted through the text give a clear indication of one scale of limits. If perhaps we break beyond the Blue Marble and our progeny lives elsewhere than within the Earth's gravitational pull, then this will shift and delay the ultimate confrontation with those concrete limits. Can this line always be receding into the future? I prefer to take care of the home that we do have on which we have co-evolved rather than rely on one that is only in our imagination.

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