The theory of population-environment links

DOCUMENTATION of population-environment linkages has all too often consisted of a simple listing of population trends side-by-side with environmental trends, on the assumption that one is the direct cause of the other.

Effective measures for dealing with how human populations affect the environment require a good understanding of the way things interact. We need an overarching theory of population-environment linkages, but so far there is no consensus on what such a theory would look like.

Research into the links between population factors and the environment is relatively young and undeveloped, and still riddled with controversy. The subject is complex and demands a broad and deep knowledge of demography, economics, and social and environmental sciences, which few possess. Family planning and environmental politics are contentious areas, and personal views on these often color scientific research and theories.

Most theorists agree that overall human pressure on the environment is a product of three factors: population, consumption per person and technology. Population is the total number of people, consumption relates to the amount each person consumes, and technology determines how many resources are used and how much waste or pollution is produced for each unit of consumption.

The best known standpoints often emphasize a single one of these factors as the dominant cause of our rising environmental impact. For some, this is inexorable population growth. For others, it is polluting technology. Still others stress excessive consumption, policy and market failures, or common ownership of key environmental resources.

A SYSTEMS APPROACH

All of these viewpoints are correct some of the time. None of them is correct all of the time. A comprehensive theory must include all factors, and recognize that their relative importance may vary at different times and in different places.

In every human interaction with the environment – even in the simplest societies – the three major elements are in play. They can be linked in the famous formula introduced by Ehrlich and Holdren:

I = P x A x T, or

Impact = Population x Affluence x Technology[1]

More explicitly, environmental impact is the product of population, multiplied by consumption per person, multiplied by the amount of resources needed, or wastes created, while producing each unit of consumption.

Ehrlich used the formula to show that population growth was the dominant factor in environmental damage. In reality, at various historical times, different elements have been uppermost. The

The IPAT formula

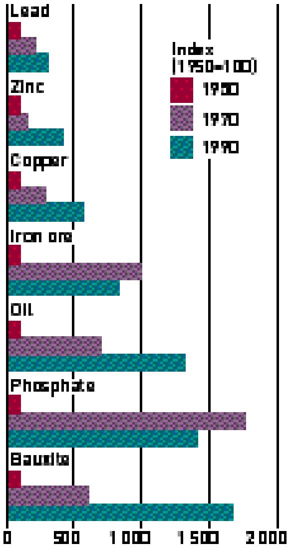
The IPAT or IPCT formula is necessarily a simplification. The technology element can usually be broken down into two separate elements: the amount of resources used to produce each unit of consumption, and the amount of waste or pollution generated for each unit of resources.

The impact measured in the IPAT formula is not true environmental impact, but takes the amount of resources used or pollution produced as a proxy for environmental damage. In many situations an extra factor has to be added to arrive at the true damage: the sensitivity of the environment. So a fuller formula would read:

I = P x C x Tr x Tw x S

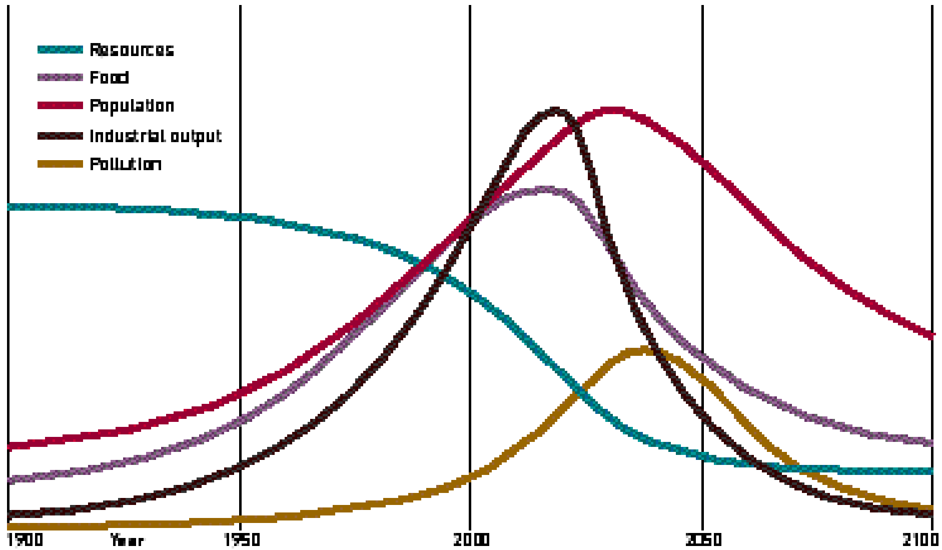
Tr refers to the technology of resource use, Tw to the technology of waste management, and S to the amount by which the environment changes in response to a given amount of resource extraction or pollution. In practice, S is hard to quantify.

ABUNDANCE...



Source: Simon.

CATASTROPHE...



Source: Meadows et al.

Abundance: Julian Simon's chart from *The Ultimate Resource 2*, shows how known mineral reserves have increased with time, despite higher use and growing populations.

Catastrophe: The business-as-usual scenario from *Beyond the Limits*. As resources are assumed to run out, industrial output and food production drop, leading to a collapse of human populations.

increase in arable area in many parts of Africa up to around 1980, and the deforestation that went with it, was mainly driven by population growth. There was little rise in consumption of agricultural products per person, and little improvement in yields. By contrast, the dramatic rise in human output of chlorofluorocarbons from the 1940s onwards was due overwhelmingly to the introduction of a new technology.

Of course, the impact also depends on the sensitivity of the environment, and this is not always predictable. It has certain thresholds which, if crossed, lead to rapid depletion and degradation. Resources such as fisheries, forests and groundwater have a maximum sustainable yield, beyond which they will be unable to replenish themselves. Sinks for our wastes, such as soils, rivers, lakes, oceans and atmosphere, have critical loads for various pollutants, beyond which important aspects of their productivity will degrade.

Sometimes the environment may successfully evolve as human pressures increase. At other times it may change suddenly when human pressure exceeds certain thresholds. When erosion strips soil close to bedrock, yields fall abruptly. If global warming melts the polar icecaps, major ocean currents may cease or shift direction, producing faster climate change.

Although the IPAT model as it is written assumes independence of each of the PAT elements, the authors recognize that these are not independent in the real world, rather they interact with each other. In the 1980s, for example, slower population growth appeared to facilitate faster growth of consumption in developing countries. Higher income levels tend to improve environmental technology – wealthier nations have a greater willingness and ability to pay for environmental quality.

Reality is still more complex. There are many other factors which affect each element of the "pressure" side of the equation. Population change, for example, is determined by fertility, mortality and migration. Each of these, in turn, is affected by a host of other factors, from patterns of breastfeeding and the status and education of women, to child health, availability of contraception, the distribution of land and income, and the opportunities for migration.

This complexity is best viewed using a systems approach, which helps to overcome the polarization found in the most prominent views of population-environment linkages.

The systems approach has two key differences from conventional approaches. It does not focus on a single factor, but instead builds in as many potential factors as possible; and it does not see human impact on the environment simply as a one-way street. There is feedback. Changes in the environment have an impact on human welfare. This is primarily as a result of:

- resource depletion or degradation and the resulting shortages and scarcities;
- loss of a valued amenity such as natural wilderness areas or beautiful landscapes;
- impacts on human health and fertility.

These environmental problems in turn produce a human response – often driving us to alter our behavior so as to reduce the problems.

There have been several attempts at producing diagrams showing these complex linkages and feedbacks, but the number of factors and cross-links involved in the real world makes them extremely complex[2]. One of the most successful attempts to produce a dynamic model of the population-environment relationship is the study of Mauritius by the International Institute for Applied Systems Analysis (IIASA)[3].

When attempts are made to quantify linkages in order to attempt projections, radical simplification is usually necessary. The *Beyond the Limits* studies by Meadows and colleagues, for example, modelled all resources through the behavior of a single fictitious non-renewable Resource, and all pollution through a single fictitious Pollutant which affected human health and agricultural yields[4].

The interactions and uncertainties when studying whole ecosystems or the whole Earth are so great that quantitative forecasts are virtually impossible. All that can be offered are "what if" scenarios that show the possible consequences of a range of trends.

MALTHUS VERSUS ADAM SMITH

The systems approach helps resolve another conflict in the theory of population-environment linkages, over the way in which humans respond to environmental problems of their own making.

On one side is the "Malthusian crisis" approach, exemplified by Ehrlich and the *Beyond the Limits* studies. In this approach, the pressure of resource demands and pollution loads can build up and are predicted to reach crisis level if business continues as usual. Unless drastic action is taken, catastrophe follows: economy and society collapse, death rates rise and populations fall. We do not achieve adaptation by choice or plan – it is forced on us by nature. However, Malthusian scenarios usually suggest that catastrophe can be avoided – as long as humanity heeds the warning signs and takes the necessary steps in time[5].

On the opposing side is what might be called the "economic adaptation approach", fervently championed by economist Julian Simon. In this scenario, humans adapt to the problems that our development produces, for the most part smoothly and without grave setbacks. In the process we gain increased productivity and efficiency, and improved human welfare. Simon saw population growth as an asset, producing more brainpower to deal with any specific problem[6].

A more sophisticated adaptation approach was put forward by Ester Boserup in her classic book *The Conditions of Agricultural Growth*. Boserup suggested that population growth was the principal force driving societies to find new agricultural technologies[7].

Unlike Simon, Boserup did not claim that the process ran smoothly. She acknowledged that population pressure could cause serious resource shortages and environmental problems, and it was these problems that drove people to find solutions. Nor did she claim that things were always better after the adaptation.

They could often be worse. For example, when hunter-gatherers with growing populations depleted the stocks of game and wild foods across the Near East, they were forced to introduce agriculture. But agriculture brought much longer hours of work and a less rich diet than hunter-gatherers enjoyed. Further population growth among shifting slash-and-burn farmers led to shorter fallow periods, falling yields and soil erosion. Plowing and fertilizers were introduced to deal with these problems – but once again involved longer hours of work[8].

The major flaw with both the adaptationist and the Malthusian approaches lies in their claim to universality. In reality, both may be true of different civilizations at different historical periods, and a comprehensive theory must be able to account for both approaches.

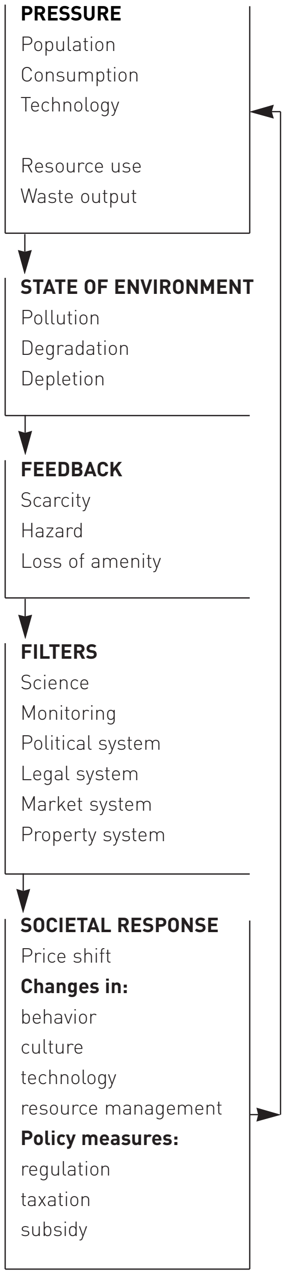
Malthusian crises in history

History has seen Malthusian-type crises when whole civilizations failed to adapt to the consequences of their own pressure on the environment and suffered total or partial collapse. Salinization drove farming out of southern Mesopotamia. Deforestation may have brought the Maya and Easter Island civilizations to an end. In medieval Europe the extension of farmland into marginal areas brought soil erosion and declining yields. Poor harvests led to malnutrition, lowering resistance to disease and culminating in the Black Death.

Societies can collapse if, for one reason or another, they are unable to adopt the technology that might save them. When the climate cooled in 15th century Greenland, the Viking settlers could have survived by abandoning their livestock-based economy and adopting Inuit lifestyles, but the leap was too great and their communities died out.

In one way or another these are all failures of adaptation: failures to change technologies or ways of managing resources in time to prevent the collapse of a key resource.

The pressure-state-response model



HUMAN ADAPTABILITY AND ITS LIMITATIONS

Humans, by nature, are adaptable. That is why we have been so successful as a species. Through the course of our history, we have radically changed our cultures, our technologies, our consumption patterns, and the number of children we have. In modern times we have changed all of these at unprecedented rates.

Adaptation is possible even in apparently extreme situations. In the 1930s the Machakos area of Kenya had almost no tree cover and rapid soil erosion. Enforced colonial soil conservation programs achieved little. But from the late 1970s onwards indigenous methods of soil conservation were introduced, and there was a massive wave of tree planting. Soil erosion diminished, crop yields rose and fuelwood availability increased – all this at the same time as population continued to grow rapidly. This success story depended on farmers being able to respond freely to market demand, and having *de facto* ownership of their land so that they could benefit from their own tree planting and terracing efforts[9].

Nonetheless, much of sub-Saharan Africa, at least during the period from 1970 to 1990, was trapped in a Malthusian-type scenario. Rapid population growth was increasing pressure on the land, yet agricultural technology was not adapting fast enough, leading to deforestation, soil erosion and, in many places, stagnant or falling yields. For dryland Africa the technologies and crop varieties still do not exist to allow crop yields to keep pace with population growth, leaving migration as the only way to relieve the pressure for many marginal groups. Of course in many countries inadequate governance, market imperfections and endemic conflict made the task of adaptation all the more difficult.

A systems approach sees our interactions with the environment in terms of pressure, state, feedback and response. The *pressure* is the particular human activity, such as carbon dioxide (CO_2) emissions or fish catches, causing an impact. The level of pressure is determined by population, consumption and technology, and by the level of resource use and waste output these generate. The *state* is the resulting condition of the environment – in these cases the atmospheric concentration of CO_2 and global mean temperature, and the size of fish stocks.

Changes in the environment act as feedback when we notice a problem – a resource shortage, an effect on human health, a new hazard or the loss of an amenity, such as the disappearance of a species or wilderness area.

How we respond to the feedback depends on various filters through which we process environmental information: our level of monitoring and scientific understanding, the form of ownership or management of the resource, the freedom of the market to respond to scarcities, and the biases in the political or legal system that determine an adequate response.

The *response* is the policy or action taken to deal with the environmental problem, such as regulations regarding fuel efficiency, carbon taxes or fishing quotas. Our responses, in turn, change the pressures we load onto the environment, completing the cycle[10].

Failures of adaptation can occur at many points in the cycle. In general, feedback works very well in free markets with privately controlled resources like mines or land. In these cases the people affected are able to take direct action to remedy their problem. Where farmers and entrepreneurs have the freedom and incentive to respond to shortages, they can shift to other resources or change their technology very swiftly. This is why the world, by and large, has not faced any constraining scarcity of key inputs – the raw materials required for producing energy or food, for example.

Even in these situations, technology does not automatically keep pace with growing population and consumption pressures so as to reduce environmental impact or keep it constant. Fuel efficiency is constantly improving in cars, for example, but not fast enough to counteract the growth in car ownership and the mileage driven.

Feedback does not work at all well in the case of commonly owned or non-owned resources – such as groundwater, fishing stocks, and the oceans and atmosphere which we use as sinks for our liquid and gaseous wastes. As Garrett Hardin pointed out, lack of ownership or management arrangements encourages individuals to overuse commons for their own private advantage, even if this means degrading the resource. Each user gains the full advantage of their overuse, but suffers only a very small share of the losses it causes. This is the well-known "tragedy of the commons"[11].

In traditional societies, if shared resources seemed to be under threat, users often agreed on rules for their management. But in modern societies the people affected are often unable to take direct action, and must channel their demands through the political and legal systems.

Effective feedback depends on information about the environmental change and its effects passing a long sequence of filters, any of which can act as a blockage or a bottleneck. An emerging problem must first be recognized as a problem, yet many environmental changes are slow, hard to identify and require monitoring. The people affected must be able to make their voices heard in the political and legal system. Yet large sections of society may be unable to do so in countries without effective democracy, a free and investigative press, high levels of literacy and access to an affordable legal system.

Finally, there must be a good scientific understanding of how to remedy the problem. All environmental impacts are extremely complex. They involve the interaction of many different agents and elements, and often the outcome can be unpredictable. Oversimplistic solutions can often lead to further problems. The systems approach allows us to see the Malthusian and adaptationist outcomes as special cases occurring under different conditions.

The human response to environmental change can be effective and timely when:

- the impacts are perceived and properly understood;
- those affected can act directly or compel the political and legal system to act;
- the science is good and the measures are well-chosen.

Under these circumstances, the economic adaptation model applies. However, our responses may be delayed, inadequate or misguided when:

- we do not perceive the problem or properly understand its causes;
- blockages and bottlenecks prevent the smooth flow of information;
- market or democratic imperfections prevent appropriate action;
- the appropriate technology or management techniques or institutions have not yet been properly developed.

When the delays and mistakes are serious enough, severe environmental damage can occur. Sometimes, if a critical resource is involved, this can lead to the collapse of societies and steep population drops. In these situations the Malthusian model applies. However, such cases happen rarely and only under extreme circumstances.

In today's world we have a mixture of these two patterns. In our use of privately controlled resources, we generally adapt well and the supply of key inputs like food, minerals or energy is maintained. In our use of commonly owned or non-owned resources or waste sinks, we do not as a rule adapt well.

In one area after another, problems have not been effectively dealt with until they have become highly visible and had a strong impact on very large numbers of people. In one area after another we have exceeded the maximum sustainable yield or the critical load of pollutants: marine fish, coral reefs, acid deposition, greenhouse gases, the ozone layer.

The oceans and atmosphere are crucial to the stability of all ecosystems on Earth, and determine the productivity of all the natural resources on which humans depend. Yet these are non-owned resources, and we have been in the habit of allowing problems to mount to critical levels before acting. They are also resources where gradual change can suddenly become catastrophic. It is possible that in this case a Malthusian situation – a situation of failed adaptation – could arise for the whole human race.