Biogeochemical Cycling of Radionuclides in the Environment

Francis R. Livens
Institute of Terrestrial Ecology, Grange-over-Sands, Cumbria LA11 6JU

Ecosystem Structure

Radionuclides in the biosphere become entrained in the biogeochemical cycling processes which circulate nutrients and other elements around the components of ecosystems.[1,2] Within any ecosystem, six components can be identified: firstly, producer organisms, largely green plants, which can manufacture food from simple inorganic materials; secondly, macroconsumers, mainly animals, which ingest other organisms or organic matter; thirdly, microconsumers, bacteria or fungi which derive energy from decomposing organic detritus; fourthly, organic compounds, which provide links between biotic and abiotic components of the system; fifthly, inorganic materials, which provide reservoirs and are involved in materials cycling; and sixthly, climatic regime, temperature and other physical influences.

Ecosystems are not static. They are characterized by flows of energy, food and materials and their composition and structure change over time as they evolve. They are diverse, that is they are composed of a number of interdependent species, and this diversity also changes as the system develops.

The biological components of an ecosystem, taken together, make up its "biomass." In a reasonably productive terrestrial system, for example a meadow, typical values for the biomass might be (Table 1):[1]

Table 1. Details of biomass

Component	Organisms	Density (number per m^2)	Mass/ $g\,m^{-2}$
Producers	Herbaceous plants	10^2–10^3	500
Macroconsumers	Insects and spiders	10^2–10^3	1–10
	Soil animals	10^5–10^6	2–20
	Birds and mammals	0.01–0.03	0.3
Microconsumers	Bacteria and fungi	10^{14}–10^{15}	10–100

As well as making up a large part of the system's biomass, the microconsumer organisms are responsible for a large part of the biological activity.

Ecosystem Development and Response to Change

The development of an ecosystem need not proceed at a uniform rate[3]. Localised disturbances, for example windblow in a forest, can set back small areas to an earlier developmental stage. Over time, a patchwork pattern of small areas, all at different stages, develops. Overall, the system is at a steady state, but within the system, the structure, composition and productivity of individual patches can vary widely.

The diversity of a system affects its ability to respond to change.[4] In a system where one or two species dominate, changes which affect these will clearly have more serious effects than in a more varied system, where the effects of change will tend to be less abrupt and less severe. The rates at which different ecosystem processes operate vary widely. Those with rapid turnovers respond quickly to perturbations, whilst other processes may take decades or even centuries to return to a steady state. Thus, both the amount of perturbation and its rate are critically important in determining a system's response.

As well as responding to external changes, organisms, acting together, are capable of drastically changing the physical and chemical nature of their environment.[1] Man is probably the most obvious example, but the development of coral islands and the communities they support is another. Biological effects of this type may be localised, but can also be global. An example is the control of the atmosphere's oxygen content by green plants.

An ecosystem will tend to resist change as much as possible.[5] As long as there is not an excessive amount of stress, little change is observed. This arises from feedback mechanisms which operate within the system and act to maintain a steady state. Minor stresses lead only to small deviations from the previous steady-state structure. Only if there is excessive disturbance are the feedback mechanisms overloaded, leading to catastrophic and irreversible change.

Succession in Ecosystems

As the production and decomposition processes develop in an ecosystem it will change.[6] The production and growth characteristics of the organisms change, as do the element dynamics within the system. Early on in an ecosystem's development, production is high, since the species present are fast growing and short lived. Materials cycling tends to be rapid at this stage. As the system matures, the fast growing species are succeeded by slower growing organisms and the rates of production and materials cycling fall. Eventually, the system reaches a steady state. Again, the rates of these processes are important. Changes in production processes occur over a time scale of tens to hundreds of years, but processes such as weathering or soil development require thousands of years. The evolution of a system is greatly influenced by climatic and environmental factors, such as temperature, moisture, soil fertility, *etc.*

Biogeochemical Cycles

In the biosphere, the elements are caught up in biogeochemical cycles.[1,7] Both "reservoir" pools, which tend to be large, slow moving and usually non-biological and "exchange" pools, which are smaller and more rapidly cycled, can be identified. Micro-organisms play a major role in many cycles, with the sulphur cycle being a particularly good example. The over-all effect of biogeochemical cycling is to produce a constant interchange of nutrients and trace elements between different pools. Radionuclides may be chemically unique and have their own cycles or they may be isotopes or analogues of biologically important elements and follow their cycles. An example of the latter is caesium, which follows potassium closely in many environmental processes. The extent of an element's cycling and its steady state distribution will depend on its physico-chemical properties and on the chemistry of the cycles in which it is involved.

Examples

There are many possible examples of radionuclide cycling in ecosystems. The behaviour of caesium in freshwater systems has been extensively studied, especially since the Chernobyl accident. In a detailed study of Windermere, inflow, outflow, sedimentation and redissolution rates were determined and it was found that there was, overall, a removal of caesium from the water column by sedimentation on sinking particles, especially algal debris.[8]

In marine systems, the stable form of technetium is the pertechnetate anion, TcO_4^-. This ion behaves very conservatively in waters and is concentrated effectively only by brown algae, organic sediments and a few marine organisms. There are, consequently, no widespread sinks for technetium in marine systems, so it is expected that the majority of the marine inventory will remain in the dissolved phase until it decays.[9]

References

1. Odum, E. P., *Fundamentals of Ecology*, Saunders, Philadelphia, 3rd edn., 1971.
2. Anderson, J. M., *Ecology for the Environmental Sciences: Biosphere, Ecosystems and Man*, Arnold, London, 1980.
3. Heal, O. W., and Horrill, A. D., *Terrestrial Ecosystems: an Ecological Context for Radionuclide Research* in *Ecological Aspects of Radionuclide Release*, ed. Coughtrey, P. J., BES Spec. Pub. No. 3, Blackwell, Oxford, 1983, pp. 31–46.
4. Bormann, F. H., and Likens, G. E., *Pattern and Process in a Forested Ecosystem: Disturbance, Development and the Steady State*, Springer Verlag, New York, 1979.
5. Hardin, G., *Persp. Biol. Med.*, 1963, **7**, 58.
6. Gorham, E., Vitousek, P. M., and Reiners, W. A., *Ann. Rev. Ecol. System.*, 1979, **10**, 53.
7. Krauskopf, K. B., *Introduction to Geochemistry*, McGraw-Hill, New York, 2nd edn., 1979.
8. Hilton, J., Davison, W., Livens, F. R., Kelly, M., and Hamilton-Taylor, J., *Transport Mechanisms and Rates for the Long-lived Chernobyl Deposits. Final Report to the Department of the Environment*, HM Stationery Office, London, 1988, pp. 1–85.
9. Beasley, T. M., and Lorz, H. V., *A Review of the Biological and Geochemical Behaviour of Technetium in the Marine Environment* in *Technetium in the Environment*, eds. Desmet, G., and Myttenaere, C., Elsevier, London, 1986, pp. 197–216.