CHAPTER

14

Perspectives

Save for a few incoming meteors from space and volcanic emanations from the deep Earth, the surface of our planet, the arena of life, is a closed chemical system. The surface environment, including the atmosphere and the oceans, is a thin peel, roughly 50 km in thickness at the outside of the Earth's 6371-km radius. Certainly, the characteristics of Earth's surface have changed dramatically through geologic time, especially as Earth cooled and violent degassing of the mantle diminished. The most profound change appears due to life itself—the oxygenation of Earth's atmosphere about 2.5 billion years ago.

We study biogeochemistry with the recognition that many of the characteristics of the Earth's surface are determined by life. Earth is very different from its nearest neighbors, Mars and Venus, where pure geochemistry prevails. On Earth, rock weathering and the fluvial transport of materials to the sea are driven by plant-root and microbial activity in soils. The composition of seawater is determined by biotic processes that remove materials from the surface waters and deposit them in marine sediments. Many of the trace gases in the atmosphere are derived from the biosphere; they have short residence times in the atmosphere and must be restored to it by biotic activity. The constancy of Earth's atmospheric composition for the past 10,000 years is rather surprising, reflecting a close balance between biotic activities that produce and consume its gaseous constituents.

Today, when we study biogeochemistry, we see the pervasive influence of the human species on our planet's chemistry. We extract carbon from the Earth's crust at a rate that is more than 36× greater than the natural exposure of organic carbon in rocks at the Earth's surface; the mobilization of some metallic elements by mining is several-fold greater than their natural release by rock weathering (Table 14.1). The atmosphere's composition is changing rapidly as our expanding population taps into the Earth's resources in search of a better life for all peoples (Hofmann et al. 2009). A few decades ago, we missed the opportunity to institute worldwide programs for family planning that might have stabilized the Earth's human population at levels that would minimize our lasting impact on the chemical conditions of our planet. Our similar efforts today may trim only a billion or so from the population that is expected in 2050—9.3 billion neighbors for each of us (United Nations 2011).

With the increasing number of global citizens now expected, we must strive for a planet that will be habitable by many people for the foreseeable future. With the changes in Earth's chemistry that are now in progress, we are not on a sustainable course. The paradigm of growth, which has so long dominated economic theory, is obsolete. Preservation of natural

TABLE 14.1 Estimates of the Global Flux in the Biogeochemical Cycles of Certain Elements, Illustrating the Human Impact

Element	Juvenile flux[a] (1)	Chemical weathering (2)	Natural cycle[b] (3)	Biospheric recycling ratio[c] 3/(1+2)	Human mobilization[d] (4)	Human enhancement 4/(1+2)	Reference for global cycle
B	0.02	0.19	8.8	42	0.58	2.8	Park and Schlesinger (2002)
C	30	210	107,000	446	8700	36.3	Chapter 11
N	5	20[e]	9200[f]	368	221	8.8	Chapter 12
P	~0	2	1000	500	25	12.5	Chapter 12
S	10	70	450	5.6	130	1.6	Chapter 13
Cl	2	260	120	0.46	170	0.65	Figure 3.16
Ca	120	500	2300	3.7	65	0.10	Milliman et al. (1999), Caro et al. (2010)
Fe	6	1.5	40	5.3	1.1[g]	0.14	Muller et al. (2006)
Cu	0.05	0.056	2.5	23.6	1.5[g]	14.2	Rauch and Graedel (2007)
Hg	0.0005	0.0002	0.003	4.3	0.0023	3.3	Selin (2009)

Note: All data 10^{12} g/yr.

[a] *Degassing from the Earth's crust and mantle; sum of volcanic emissions to the atmosphere (subaerial) and net hydrothermal flux to the sea (Elderfield and Schultz 1996) and for N, fixation by lightning (Chapter 12).*

[b] *Annual biogeochemical cycle to/from the Earth's biota on land and in the oceans, in the absence of humans.*

[c] *Following Volk (1998).*

[d] *Direct and indirect mobilization by extraction and mining from the Earth's crust or (for N) industrial fixation. (Sources: From U.S. Geological Survey,* http://minerals.usgs.gov/minerals/pubs/commodity; *Klee and Graede, 2004.)*

[e] *B.Z. Holton (personal communication, 2011).*

[f] *Biological N fixation on land and in the oceans totals ~300 Tg N/yr (see Figure 12.2).*

[g] *Human enhancement in the atmosphere (Table 1.1) and rivers (Table 4.8).*

habitat is the foundation for the preservation of biodiversity, and night-time satellite photographs of the Earth's surface show that we have already left little of nature that is not fragmented, traversed, or converted to human use (Figure 14.1; Ellis et al. 2010, Hannah et al. 1995, Watts et al. 2007). As humans capture an increasing fraction of the planet's productive capacity (NPP), there will be a diminishing proportion left for the other species to persist with us (Haberl et al. 2007, Butchart et al. 2010).

And those species matter! Numerous studies show that sustainable levels of ecosystem function, on land and in the sea, depend on the rich diversity of life on Earth (Naeem et al. 1994; Tilman et al. 1996, 2001; Engelhardt and Ritchie 2001; Worm et al. 2006). With fewer species, ecosystems are less productive, more vulnerable to disturbance, and less likely to

FIGURE 14.1 Night-time view of the world from satellite-derived measures of brightness. *Source: From http://eoimages.gsfc.nasa.gov/images/imagerecords/55000/55167/earth_lights.gif.*

TABLE 14.2 Annual Variation of NPP (% of 5-year mean) of Major Species and of Total Aboveground NPP in an Alaskan Tundra Ecosystem

	Production (% of average)					Coefficient of Variation (%)
	1968	1969	1970	1978	1981	
Eriophorum	77	58	148	101	116	35
Betula	30	52	55	248	121	88
Ledum	106	138	62	103	91	27
Vaccinium	135	172	96	28	71	56
Total production	93	110	106	84	107	11

Source: From Chapin et al. (1996). Used with permission from Cambridge University Press.

recover. Table 14.2 shows how a relatively stable total ecosystem NPP derives from the compensation of individual species in individual years. The stable conditions of our planet's chemistry are vulnerable to progressive biotic impoverishment. Often, increasing variability in ecosystem properties is the vanguard of impending collapse, analogous to similar observations in economics and medicine. (Scheffer et al. 2009, Carpenter et al. 2011). Biodiversity is the basis of stability in our life support system; maintaining biodiversity is more than a pastime for nature lovers.

If there are lessons in biogeochemistry that should guide the human practice of life, we should look for ways to transition to a zero-emission society, in which every product extracted from the Earth's surface is used and reused, without effluents delivered to the common pool of air and freshwater. Soil management is paramount, especially for elements such as phosphorus, for which there are limited supplies and no substitutes. We should look to ways to grow our food, without exogenous inputs, that will maximize yields while allowing us to maintain as much natural land as possible.

At root, almost every global environmental problem is the direct result of the exponential increase in the number of humans on Earth. As our population continues to rise, the material expectations of individuals will raise the cumulative impact on the planet's resources. Rising standards of living often reduce human fertility rates, but not fast enough to keep total resource consumption from increasing (Moses and Brown 2003). While the biosphere will no doubt survive of our species, without our stewardship, life will become increasingly unpleasant for most citizens, who will live on a hot, dirty, and crowded planet.

In every population of organisms studied to date, exponential population growth is followed by dramatic collapse (e.g., Klein 1968). In the history of our own species, wars and plagues have set us back temporarily along our inexorable trajectory toward the current world population peak (Turchin 2009, Zhang et al. 2011a). It is almost inevitable that water scarcity will grow worse as populations increase in arid regions, and that food security will become harder to achieve in many regions where climate grows hotter and rainfall becomes less predictable (Lobell et al. 2011). For those living in affluent countries, this will be unpleasant, while for those living in regions already suffering from food or water scarcity, this decline will be disastrous (Miranda et al. 2011).

Making meaningful changes will be inconvenient, but it is not too late to build a future where we waste much less energy, fertilizer, food, and water and in which we build innovative tools to better capture, store, and use the unlimited energy of the Sun to fuel our daily lives. For this to make a difference, we need to embrace a new culture of personal and corporate responsibility that values minimizing environmental impacts and maximizing long-term resource sustainability, over short-term economic gains and growth driven only by human numbers. The only other viable alternative to slow our impact on the biosphere would be to reverse our own trajectory of population growth. If we do not intentionally choose to use less, it is nearly certain that future droughts, famines, disease, and war will choose an alternative future for us.

Recommended Reading

Speth, J.G. 2008. *The Bridge at the End of the World*. Yale University Press.