# Chapter 14
# Sustainable Development Within the Norms of the Biosphere's Carrying Capacity

While humans, in the process of their economic activity, constantly destabilize the environment, the biota, from the moment of its appearance, has supported its stability and its sustainability as a necessary condition of survival. At the earliest stages of life on Earth, single-celled prokaryotes carried out this work, forming the platform of the modern biogeochemical machine (Zavarzin 2004). Later on, multicellular organisms took on the same mission. Primarily these were plants and fungi, which, together with protozoans, form the main part of the Earth's biomass, fill the atmosphere with oxygen, swallow up excess carbon dioxide gas and participate in sediment formation. The World Ocean owes much of its leading role in stabilizing the planetary environment to zoo- and phytoplankton. And at a time when more than 60% of land ecosystems have been destroyed, it is the ocean depths with their still only slightly disturbed biota that serve as the main channel (sink) for removal of excess anthropogenic carbon from the atmosphere. However, even the World Ocean is unprepared to bear the mounting man-made burden.

So, according to estimates by John Houghton and his co-authors, the World Ocean and its ecosystems currently swallow up more than half of atmospheric carbon arising from burning fossil fuels. The rest of it accumulates in the atmosphere. Ocean ecosystems also absorb about two-thirds of "excess" carbon formed on land areas destroyed by economic activity, with the preserved territorial ecosystems swallowing up the remaining third (Houghton et al. 1996). In this way, we can plainly see the violation of the closed-loop cycle of this most important nutrient, leading to its gradual accumulation in the atmosphere. Among everything else, this is, without a doubt, fact number one, unquestionably bearing witness that human influence on the biosphere has already passed the acceptable limits, and that we can consider humanity's exit beyond the ecological carrying capacity a done deal.

You have seen the concept of **the biosphere's *carrying capacity*** (also called economic, ecological or assimilating capacity) as the most important limiter of material human activity before. And while there can be no doubt as to its preeminent role in posing the problem of sustainable development, giving us our most important instrument for a quantitative approach, scientific circles have still not come to a single mind



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concerning the concept. Biotic Regulation Theory proposes its own line of thinking in an attempt to provide a scientific basis for it. And though this line of thinking has not yet gained widespread acknowledgment, there is no convincing alternative under review, either. We will, therefore, ponder upon it further, all the more because it has been developed in sufficient detail and distinguishes itself through its logical construction.

Let's begin with the fact that humans, like any other species on Earth, exist within the bounds of a particular energy corridor that characterizes their maximum share of overall energy flows in the biota which they can use for their own needs without risk of environmental disruption. Here we are talking about energy already created by plants on land and phytoplankton in the ocean through photosynthesis and stored in the form of organic material, called *primary production*. The yearly magnitude of this organic material created on a given territory has received the name g*ross primary production*, 15–70% of whose plant-stored energy is spent on their own growth and respiration (Leith and Whittaker 1975). Thus, only the remaining portion takes part in the further cycle, used by consumer organisms of the next trophic level. That portion represents *net primary production*. A typical example of net primary production would be the yearly falling of leaves, dry branches and seeds at temperate latitudes.

But this is only the tip of the iceberg, because the essence of net primary production flow contained in organic plant material is in the transfer of energy from one group of organisms to another, from one trophic level to the next, and the overall number of levels can reach four, five, or even six. As materials from field research conducted in a large number of different ecosystems has shown, the rule for distributing this flow of energy applies itself strictly and shows itself equally characteristic for the most varied natural communities. In sum, allowing for simplification and rounding, the results establish that **90%** of net primary production in ecosystems goes to use by bacteria and fungi, which also play the role in regulating the environment. **Ten percent** is used by invertebrates (arthropods, worms, molluscs, etc.). With concern to vertebrate animals, they receive less than 1% of energy circulating in the biota (Fig. 14.1).

The demonstrated characteristics show high stability and clearly preserve (or preserved prior to our time) their values within a narrow interval of possible variation over a period of tens of millions of years. Biotic regulation theory factually equates the universality of this distribution to an ecological law (Gorshkov 1981; Gorshkov et al. 2000). In this way, the 1% energy corridor for large animal species developed through evolution should be viewed, according to Gorshkov, as a kind of defense mechanism, protecting the biota from chance fluctuations arising in flows of organic material synthesis and decomposition.

However, the question is fair: how much variation from this parameter value is acceptable for the system? Let's go back to the drawing in Chap. 10 (Fig. 10.2) where we discussed the nature of climatic sustainability maintained by the biota. The illustration presents this sustainability in the form of a symbolic ball, located in a "climate hollow." The insignificance of the systems divergence from input parameters testifies to the perfection of the regulatory mechanism. But since we are not dealing with a scalar value or a variation interval but with a region of n-dimensional space in which the quantity value of *n* is unknown to us, the value of a given parameter is less important to us than the "construction" of the climatic hollow, i.e., the ball's area of sus-

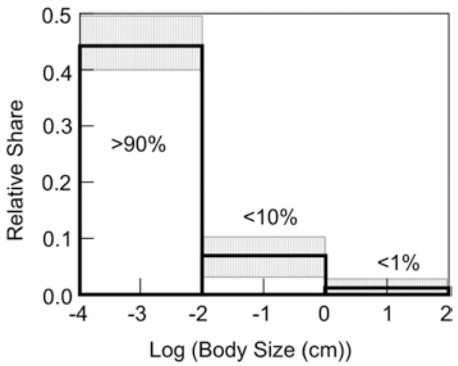


**Fig. 14.1** Distribution of organic material decomposition (destruction) speed by organism body size (l) among those living on land. (1) bacteria and fungi, (2) invertebrates, (3) larger animals (starting from rodents). The solid line represents the universal distribution of organic material destruction observed in undisturbed ecosystems. Percentages correspond to the share of use of net primary production by each of the three groups of organisms. The area under the solid descending line is equal to unit. The thatched portion represents variation from mean distribution in separate ecosystems Source: Gorshkov et al. (2000, p.79)

tainability and its "size." However, Biotic Regulation Theory does not encompass this type of question, reducing the whole problem to a single variable, energy, and through its silence supposes that this persistence of parameter is an inseparable quality of the defense mechanism of Earth's biota. But such a presupposition requires, in our opinion, a corresponding basis which, unfortunately, the authors have left out.

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As we have said, the most important task of the biota according to Gorshkov's conception is, at both the global and local level, supporting the high level of impermeability in the cycle of matter, i.e. the maximal parity between the processes of organic matter synthesis and decomposition, without which the environment would quickly degrade to a state unsuitable for life. This task, Gorshkov claims, is decided by the efforts of the great multitude of mutually uncoordinated autonomous individuals (organisms) which make up the living membrane of any ecosystem. He supposes that the extant type of internal correlation among living individuals in the population stabilizes itself on the basis of competitive interaction and that selection is executed only if all individuals in the population are completely independent and mutually uncoordinated. Otherwise, the removal of a defective individual from the population would be completely impossible, just as it is impossible to remove a diseased organ from an organism (Gorshkov et al. 2000). Only under this condition does it become possible to minimize the great many chance fluctuations that threaten the survival of any complex organized system.

Indeed, according to Gorshkov, bacteria and saprobiontic fungi, responsible for 90% of organic decomposition, are either self-sustained organisms (bacterial cells) or weakly-coordinated multicellular structures (fungi) made up of filamentous structures—spores—a few microns in breadth, which can be found by naked eye or with the aid of a magnifying lens. The vegetative body—the fungal mycelium—looks like a web, or a fluffy, velveteen frost, or even a thin film. On the forest floor, these fungal filaments can reach 35 km for each gram of soil cover.

Something similar occurs among plant-producers. They are also multicellular structures made up of weakly coordinated parts (modules) for which even the lifespan may differ. So at mid latitudes, the leaves of trees retain viability for the course of a mere season, which cannot be said of the trees' roots and trunks. Thus the death of some part of a plant, such as when herbivores eat its branches, does not lead to the death of the whole organism and even stimulates the development of its other parts, a possibility absolutely excluded from the strictly coordinated bodies of animals. At the same time, leaves of the very same tree may compete with one another for sunlight and nutrition (Gorshkov et al. 2000).

In this way, plants, fungi and bacteria have all reached a balance between organic synthesis and organic destruction by fundamentally the same route. Environmental complications arise only once you introduce a "disturber of the peace" to the ecosystem—vertebrate animals.

So, if you take consumers of the second order—rodents, lagomorphs, ungulates, primates, most birds that feed on plant biomass—then, as calculations show, their metabolic power by projection area surpasses that of plant productive power by several orders of magnitude. And if you compare human metabolic power (about 150 W at a body projection area on the order of 0.5 $m^2$) with the average power of photosynthesis (0.1 $W/m^2$), the difference in energy flows used as calculated by surface area unit adds up to more than three thousand times (Makarieva et al. 2014).

Therefore, animals, depending on body size, need to consume food synthesized by plants over a territory hundreds or thousands of times greater than their projected area, and also eat in mere hours what plants took a year to synthesize. As a result, animals are forced to constantly move about their feeding grounds, which is a necessary condition of their survival. At the same time, animals devouring accumulated plant production inevitably leads to its sharp variation since the consequent restoration of biomass occurs at an entirely different rate. This variation, in turn, overlaps with variations in excrement in the environment left by animals after food ingestion, which also leads to violation of its stationary state.

Therefore, according to Gorshkov, the existence of large animals, from mice to elephant's is possible in conditions of a highly closed matter cycle only with a minimization of their disruptive influence on the ecosystem, according to which the average usage quota for plant production must not go far beyond the limits of natural fluctuation. And since the variation of consumed biomass grows along with the size of the animal, we should see parallel to this a corresponding reduction in the quota accruing to the species in accordance with observed distribution of use of net primary production by organism body size (Gorshkov et al. 2000, p. 104). And the biota resolves all the tasks through its own specific methods in each case.

So, if the population density of some herbivore species grows too dense, among plants the share may increase of breeds that have thorns or possess a taste repulsive to animals. We all know of plants that influence the numbers of one or another species by means of medicinal, or, on the contrary, poisonous or narcotic substances. Meanwhile, the community that best reacts to variations in large animal numbers in one of the above-mentioned ways receives an advantage over its neighbors whose ability is more weakly expressed, and in the process of competitive struggle will come out the winner.

In this way, the theory follows, in relation to a biotic community developed by plants, fungi and micro-organisms, large herbivorous animals are just as much a component of the environment regulated by them, as well as the nutrient elements contained in the soil and air, whose stable concentration the biota maintains century after century.

With concern to predators, at the top of the ecological pyramid, they cannot exceed their optimal numbers while maintaining stable numbers of prey. Therefore, under natural conditions, predators cannot violate ecological equilibrium, and their function in the ecosystem is founded on removing defective individuals with altered heritable programs from the population and reducing it to equilibrium state. And, clearly by no coincidence, the growth of polymorphism in herbivores that arises from serious disruption of habitat and decay of the associated genetic program, is, as a rule, accompanied simultaneously by parasites and predators. We observe an analogous correlation between plants and plant-eating insects, where the increase in such polymorphism in the former is accompanied by population growth in the latter. Situations like this arise after forest fires, clear cutting or other major disruptions to the natural environment (Isaiev et al. 2001).

And, so, when large animals truly represent a danger of destruction to biotic communities, it is primarily conditioned upon them exceeding a certain critical limit to population growth. Therefore, normal behavior in higher animals with a preserved heritable program is usually directed at maintaining a stable population density. Both because of limited birth rate during food shortages, as shown in the example of tundra wolves (Chap. 2), and due to control over feeding grounds by animals themselves through the use of, for example, sound signals warning that territory is occupied (McNab 1983), etc. Migration of animals at times of excess population density serves the same purpose, as does activation of parasites and predators, aiding in the reduction of herbivore populations. Such intra- and interspecies interactions, in Gorshkov's opinion, are absolutely necessary to provide competitive advantage to biotic communities. After all, ultimately it is not species that survive, but communities (if, of course, you accept the axiom that intercommunity competition truly represents the dominant type of relationship).

But why does the biosphere need animals at all, if it got along just fine without them over the course of hundreds of millions of years? And even today, the share of energy flows going to them is so low that they cannot play a noticeable role in the biosphere's overall energy system. Nonetheless, the universal spread of large animals bespeaks a place occupied in the biosphere clearly necessary for ecosystems. They, too aid in the maintenance of environmental stability, though one must look beneath the surface to explain this contribution. This is how Viktor Gorshkov approached a solution to this problem, lumping large animals together with "reconstructive" plant species.

As we said in Chap. 12, these species play an important but specific role in the process of succession, shifting the concentration of food substances in the environment toward a direction disadvantageous for themselves but advantageous to the next generation, paving the road, it would seem, to the climax community's rebirth. External physical disruption of the biota, however, whether by fire, volcanic eruption, hurricane or other meteorological extreme, takes on a randomized and irregular character, and, under conditions of extended preservation of the climax phase, reconstructive species required for the post-disruption stage are gradually pushed out of the ecosystem. At this time, they exist as isolated individuals, making up a disparate population to which the mechanisms of competition and selection practically do not function. This, in turn, incurs the decay of their genetic programming.

Therefore, under the threat of reconstructive species degrading and disappearing, the biota should have a mechanism for regular disruption of ecosystems, which would support the "reconstruction" population at its minimum necessary level. And here, clearly, large animals carry this function out, playing the role of persistent ecosystem disruptors, independent of the major external disruptions. Bringing destruction to vegetative cover, they create beneficial conditions for the survival of reconstructive plant species that multiply in number upon the zone of destruction (Gorshkov et al. 2004).

In this light, it becomes clear not only what the ecological mission of ambulatory animals is, but why they occupy so humble a place in the biota's overall energy system, where inanimate organisms—plants, bacteria, fungi—play the main role. If you were to cut off large animals and birds from the whole mass of organisms dwelling on Earth, you could compare the biosphere to an energy generator providing that group of species with the energy necessary for life at an energy conversion efficiency of no higher than 1%. The other 99% of the biosphere's energy power goes toward supporting environmental stability (Gorshkov et al. 2000, pp. 104–105). Such, according to Biotic Regulation Theory, is the biospheric energy structure developed through evolution, allowing the maintenance of a highly closed matter cycle as flows of organic synthesis and decomposition coincide with exactness on the order of $10^{-4}$ (see Chap. 12).

Today, however, the extent to which this biochemical cycle is closed has lowered by nearly an order of magnitude as is visibly demonstrated on the bar chart below (Fig. 14.2). At first glance, it differs little from what was presented in Fig. 14.1, as long as you don't count the added dotted line. But this chart characterizes the current disrupted state of the biosphere, directly linked to the economic activity of humans. And we are allowed to judge the quantitative side of this by the biosphere's carrying capacity—that unit of the acceptable extreme of human civilization's influence on the environment on which, in Martin Holdgate's phrase, many ecologists first cut their intellectual teeth.

Humans, after all, also belong to the category of large animals. And, if you follow Biotic Regulation Theory, the same ecological limits listed above apply to them as well as to the animals they have domesticated. And in order not to cut the branch we are sitting on from under us, humans and all of their business ought to fit themselves into the bounds of the energy corridor that the biosphere has assigned to all large animals. Granted, given the current level of knowledge, we can only speak of the size of this "corridor" with certain caveats. Thus, we should more likely speak of an order of magnitude, perhaps close to 1%, but nonetheless differing from it. To put it mathematically, the number is $1 + \boldsymbol{\varepsilon}\%$, in which the value $\boldsymbol{\varepsilon}$ has not yet been determined by science.

But let us take Gorshkov's lead with $\boldsymbol{\varepsilon} = 0$. Then, based on that assumption, the size of the biospheric corridor humans should fit into along with other large animals comes to an order of magnitude of 1%. This assigned 1% energy quota that humans can access without undermining environmental sustainability is most conveniently expressed in scale of net primary production. Its size could be expressed in organic carbon mass

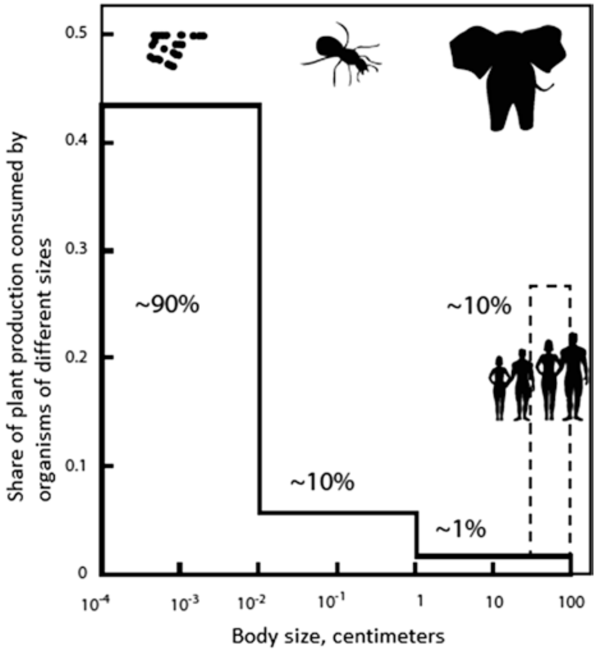


**Fig. 14.2** Share of organic material consumption on land by size of organism (bacteria and fungi, invertebrates, large animals), taking into account anthropogenic disruption of the biosphere. Solid line—universal distribution observed in all undisrupted land ecosystems. Area under the solid lines is equal to 1 (100%). Figures in percentages correspond to the share of consumption by each of the three organism groups. The dotted line characterized modern anthropogenic disruption of the land biota. Area under the anthropogenic column corresponds to food for humanity and livestock, as well as forest consumption. Source: Biotic Regulation Website: http://www.bioticregulation.ru/life/life2_r-6.php

(tons) or in terms of power (watts) adequate for the quantity of biomass produced by plants on a given territory in a year beyond that expended on growth and respiration by the plants themselves. And if the energy power of the whole land biota has an order of 100 terawatts (TW, $10^{12}$ W), then 1% of that would be equal to ~1–2 TW. Based on a valuation of summary mass of synthesized organic carbon (~$10^2$ GtC/year), we receive an order of magnitude of 1.0 GtC. Therefore, **1–2 TW** (in power units) or **1.0 GtC** (in units of organic carbon mass) gives us a quantitative idea of the biosphere's carrying capacity—the maximum size, beyond whose limits human civilization must not go if concerned for maintaining stability of the global environment.

Today, however, we have already surpassed that limit by an order of magnitude. One-two terawatts corresponded to civilization's power at the start of the previous century when, Gorshkov supposes, it stepped across the forbidden boundary. And it is clearly no coincidence that the rapid increase in atmospheric $CO_2$ also began around 1900, after which humanity went over the limits of the 1% energy corridor. At that time, Earth's population added up to 1.6 billion people and had already destroyed or seriously deformed ecosystems over 20% of Earth's territorial surface. In this way, accounting for then existing technology and assuming that E = 0, the "geographic equivalent" of the biosphere's disruption threshold might be considered 20% economic integration of land area.[1]

But what does this 20%, this one-fifth of the land's surface that we have long passed by, mean if the dizzying gallop of Twentieth Century has overstepped this boundary three times over and the area of destroyed ecosystems has now surpassed 60%? This is also an indicator of extreme disruption in the biosphere, whose compensatory capacities, clearly, are close to exhaustion. The violation of the closed-loop nutrient cycle shows this ($CO_2$, nitrogen and phosphorous compounds) as does the progressive loss of biodiversity. The transition of many recently renewable natural resources, most of all water, into the pool of unrenewable or only partially renewable resources clearly demonstrates this as well. So do many other signs, of which we spoke in Chap. 1. All of these troubling symptoms demand the most serious attentions, even regardless of how one handles this theory or that.

But if this first critical boundary for civilization has already been crossed, that opens up the question of the next, far more dangerous threshold, when environmental degradation becomes irreversible and the biosphere loses its capacity for regeneration for an indeterminably long, even on a geological scale, period of time. And here we'd like to turn our attention to the claims of so-called "technological optimists" putting their faith in the unlimited possibilities of scientific and technological progress which has more than once pulled humanity back from the brink and must, therefore, have a handle on the current ecological threat. Because, in light of the biosphere's limits of mass and energy, hopes for artificial environmental regulatory mechanisms destined someday to replace the natural mechanisms look especially groundless.

Indeed, who could doubt that humans have a very long way to go before they learn to regulate and manage the environment with the same energy conversion efficiency and at the same energy level accessible to the biosphere, even if you assume humans capable of mastering such technology at all? The biosphere itself came to it through a multi-billion year process of evolution. And in order to more clearly imagine mankind's abilities as far as creating an artificial environment is concerned, let us again recall the basic "expense account" of the total energy budget our Earth has at its disposal thanks to the solar radiation it receives.

The overall power of this radiation on the boundary of Earth's atmosphere adds up to $10.5 \times 10^6$ kJ/m$^2$ per year. Of that quantity, about 40% is immediately reflected by clouds, atmospheric dust, ice cover and mountaintops, and another 23% is swallowed up by the atmosphere, transforming into heat energy or expended on water evaporation. In this way, the Earth's surface and its vegetative cover is reached by just half of the original solar radiation, or about $5 \times 10^6$ kJ/m$^2$ per year (the actual amount of energy in a given place depends on its geographic latitude). From this

[1] Notably, human rights advocate and member of the Soviet Academy Andrey Sakharov came to a very similar assessment in 1974, well recognizing the link between the preservation of the natural environment and destructive human activity. In his article, "The World in Half a Century," it says that to provide a sustainable biospheric balance for the future, it is necessary to divide land into settled and little-inhabited land at a ratio of 3:8 (Sakharov 1990).

half, however, only 25% of light energy has the wavelength suitable for photosynthesis, and only about 0.4% of such rays are used by plants for pure biomass increase, which is roughly 1% of the energy that gets to plants (Green et al. 1984, vol. 1 Ch. 9.2.1, vol. 2 Ch. 12.3.4). It is this insignificant share of the sum total of solar energy that gives rise to energy flows in the biota, whose total energy power, 100 TW, allows it to maintain stability of temperature, climate and other environmental parameters.

By the way, theoretically, this is still not the limit and the biota could, in principle, increase its power by an order (of magnitude), for example, by accounting for plants of the $C_4$ group, which synthesize carbon based on the tetracarbon acid cycle (Govindjee 1982). These include, in part, corn and sugar cane. However, as calculations have shown, the biota's current power is at the biological limit of sustainability of the current climate, beyond which unpredictable surface temperature fluctuations must surely follow (Gorshvov 1990). Therefore, even if we suppose that humans will someday have an unlimited source of "ecologically pure" energy (cold fusion, solar cell installations in space, etc.) and are able to take management of the environment in hand to provide the same closed-loop matter cycle with the same energy conversion efficiency as the modern biosphere, they would still not be able to go beyond the limits of the biosphere's current power without risk of permanently unbalancing the climate. And, meanwhile, 99% of all energy expended by civilization would need to be spent on maintaining environmental stability. (After all, even today the cost of efficient purification equipment can reach half the cost of an operating business.)

So, what would then be left to satisfy our own wants and needs? About the same and even less than we could have at our disposal with a natural biosphere without expending a single kilowatt on maintaining environmental stability or even thinking about how to deal with the task of a living biota. And now, tell us, is there even the slightest shred of truth behind the ruminations that humans could someday get by without nature?

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