

Schmalhausen's Law

Ivan Ivanovich Schmalhausen was a Soviet evolutionary biologist working at the Academy of Sciences in Minsk. In the 1940s his book *Factors of Evolution* appeared and was denounced by T.D. Lysenko, whose neo-Lamarckian theories of genetics were then on the ascendancy. At the close of the 1948 Congress of the Lenin Academy of Agricultural Science it was revealed that Stalin had endorsed Lysenko's report to the Congress in which it was affirmed that the environment can alter the hereditary makeup of organisms in a directed way by altering their development. Schmalhausen was one of the few who affirmed his opposition to Lysenko and spent the rest of his life in his laboratory studying fish evolution and morphology.

In the West, Lysenko's views were simply dismissed. But Schmalhausen could not ignore the Lysenko agenda which insisted on a more complex interpenetration of heredity and environment than genetics generally recognized. Along with Marxist and progressive scientists in the west such as C.D. Waddington in the UK, he accepted rather than ignored the challenge. As a result he developed a more sophisticated approach to these interactions which explained the observations of some of the better studies cited by Lysenkoists.

Schmalhausen argued that natural selection was not only directional, producing new adaptations to new circumstances, but stabilizing. That is, if a characteristic of a species causes it to be well adapted, then random variation in the characteristic caused by external or internal disturbances would reduce the fitness of the organism, so natural selection will operate to prevent such disturbances. The development and physiology of the species will be selected to be *canalized*, that is, insensitive to such random disturbances. These disturbances come not only from the environment but also from genetic variations from individual to individual. Genes are selected which work in such a way that most genetic combinations produce more or less

viable and similar offspring. Thus, individual genetic variation remains hidden because of the canalization of development.

The selection to produce canalized development and physiology operates over a restricted range of natural conditions that characterize the usual or normal environmental range to which the species is subjected during its evolution. However under unusual or extreme conditions where selection has not had the opportunity to operate, these genetic differences show up as increased variation. This claim provided an alternative explanation to the observation that populations that are apparently uniform under normal conditions show a wide range of heritable variation under new or extreme conditions. Whereas Lysenko argued that these populations were uniform genetically and that the environment created new genetic variation, Schmalhausen argued that the environment revealed latent genetic differences which could then be selected.

Waddington developed this line of reasoning further with his idea of genetic assimilation: suppose that there is some threshold condition in the environment for the development of a particular trait. Much below threshold none of the individuals show it, much above threshold they all do. But under some intermediate conditions some will be above and some below threshold. If environmental conditions change so that it is advantageous for all individuals to manifest the trait then those with the lowest threshold will be favored by natural selection. The average threshold in the population will decrease and eventually produce organisms whose threshold is so low that the trait always appears under any conditions in which the organism can survive. Then the trait has become "assimilated:" an environmentally induced condition has become fully genetic.

Schmalhausen's realization that natural selection operates to change the sensitivity of physiology and development to perturbations, but that this selection operates only under the usual and normal range of environmental and genetic variations experienced by the species in its evolution, leads to a result with very wide implications. That result, which we shall call "Schmalhausen's Law," is that when organisms are living within their normal range of environment, perturbations in the conditions of life and most genetic differences between individuals have little or no effect on their manifest physiology and development, but that under severe or unusual general stress conditions even small environmental and genetic differences have major effects.

Two examples of the application of Schmalhausen's Law are in the determination of species distribution and in the effect of toxic

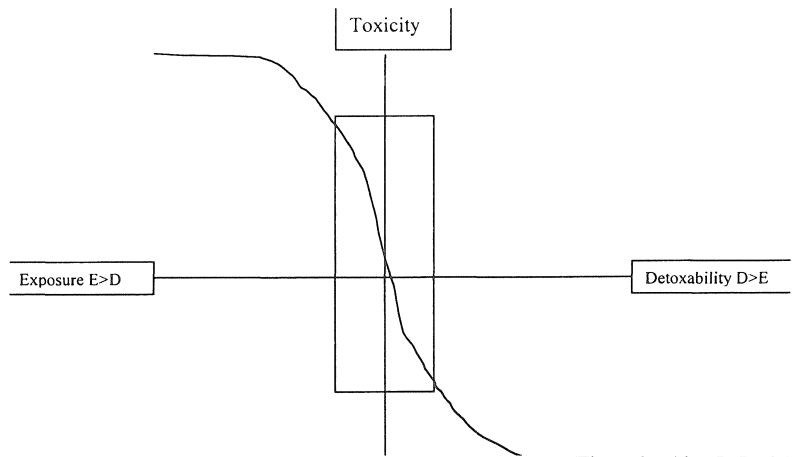
substances on population health. Both show the danger of predicting the outcome of perturbations in natural populations using the results of experiments on single factors under controlled conditions.

In biogeography: At almost any location on the earth, the ecological community is made up of species near the boundary of their distribution and also species that are in the middle of their range. When the environment changes, this has a major impact on the species near their boundary. Some may become locally extinct, others may experience great expansions of their abundance and their range, while others will remain more or less as they have been. Further, populations near their boundaries are especially sensitive to changing conditions and are more likely to show big differences from year to year. Therefore simple predictions about the effect of climate change are bound to err if they take into account only the direct physiological impact of the environmental change on species one at a time, out of the context of their community interactions. On the other hand, species in the middle of their range are likely to show less effect of an environmental change. Therefore when we ask, how will a 1°C change in temperature affect the distribution of malaria, we have to ask how close to their boundaries not only the vector mosquito but also its natural enemies and competitors are located. Different localities near the boundary will respond differently for no obvious reason, just because of the extreme sensitivity to even undetectable changes of circumstance.

The thresholds of toxicity: Tolerable levels of toxic substances are often set on the basis of experiments with animals. Usually the work is done with standardized healthy animals under well controlled conditions so as to minimize “error” due to individual differences or variation in the environment. However this methodology underestimates the impact of a toxin for a number of reasons. If an organism is exposed to a toxic substance of external or internal origin, it has various mechanisms to detoxify that substance. But the toxin is still present. If there is a constant level of exposure, the toxin will reach some level of balance between new absorption of toxin and the rate of removal. This equilibrium depends on the level of exposure and the maximum capacity of the detoxification system to remove the poison.

But of course we know that the environmental exposure is not constant for all members of a population or even for any one individual over time. And we also know that different members of the population differ in their detoxification capacity and that it may vary over time for the same person. Furthermore, this variability matters and cannot be averaged away.

What good is a model that assumes constant conditions? Here we see one of the powerful ways in which models are both useful and dangerous in science. In physical and engineering sciences it is often possible to isolate a problem sufficiently to ignore external influences, assume that all switches are the same in what is relevant, that all salt molecules are interchangeable and so on. Then we can measure accurately and get equations that are as exact as we need. But in ecological and social sciences this is not possible. The populations are not uniform, conditions change and there is always an outside impinging on the system of interest. We cannot even believe the equations too literally. But we can still study these systems. First, we find the consequences of models under unrealistic conditions that are easily studied and give precise results. Then we ask, how do departures from those assumptions affect the expected outcomes? In this case, the standing level of toxicity, a measure of damage done to organism, is a mathematical function of $d - e$, the maximum detoxification capacity minus the exposure (see Figure). The maximum removal rate has to be greater than the exposure or else, according to the mathematical model, the toxicity will accumulate without limit. In reality, it will accumulate to the point where other processes which were negligible in the original model, take over. These might involve any of the consequences of toxicity such as cell deaths. In relatively unstressed conditions, when d is greater than e the graph of toxicity plotted against $d - e$ decreases from zero as capacity exceeds exposure by greater and greater amounts. Furthermore, it is concave upward.



(Figure by Alan P. Rudy)

That is, it is steeper the closer we are to $d = e$ and flattens out when detoxification capacity is much greater than exposure. If we measure the dose response curve in the range where capacity is much bigger than exposure then the results will show little effect of the poison and we will be reassured by claims that there is no detectable effect. Testing is often carried under optimal conditions on uniform populations of experimental animals in order to get uniform results, reduce the error, and avoid “confounding factors.”

If different stressors are confronted by the same detoxification pathways, they can be added at the level of exposure and act synergistically at the level of toxicity. Therefore if we look at only one insult at a time, the other “confounding factors” increase the damage beyond what we expected.

In the United States, exposure varies with location and occupation. The poor, excluded and marginalized communities such as inner cities, colonias and reservations are often subject to multiple exposures due to incinerators, maquiladoras, poor water quality, malnutrition and unsafe jobs. Therefore even toxic substances which meet EPA standards will prove more harmful than expected. But these effects will be hard to detect since we will observe an array of health impairments rather than a single harm appearing to different degrees.

Similar arguments hold if the capacity to detoxify varies among individuals: because of the shape of the curve relating toxicity to detoxification capacity, the average toxicity in the population is greater than the toxicity at average detoxification capacity. Once again, if detoxification capacities are reduced then each unit of insult has a bigger effect than expected.

We suspect that detoxification capacities are undermined in the course of life for all of us after the first two decades, but that adverse conditions accelerate this erosion so that vulnerability increases more rapidly and life expectancy is reduced, for example, by some five years for African-American women and seven years for African-American men.

The variability of results: Since under stress, when $d - e$ is small, small differences in either one can have big effects. A population which is at a disadvantage will show big differences among people for reasons we cannot explain, and different poor communities will differ widely in the rates of adverse outcomes. This can easily be misinterpreted: it appears as if under the “same” conditions some do well and others badly, and we can then blame those who do badly. But what really is

happening is that under conditions of any kind of stress, small differences have big effects.

Schmalhausen's Law focuses our attention on the historical relation of a population with its environment, the responsiveness of the physiology to familiar and to new stressors, and the inherent variability of both organisms and environments.

