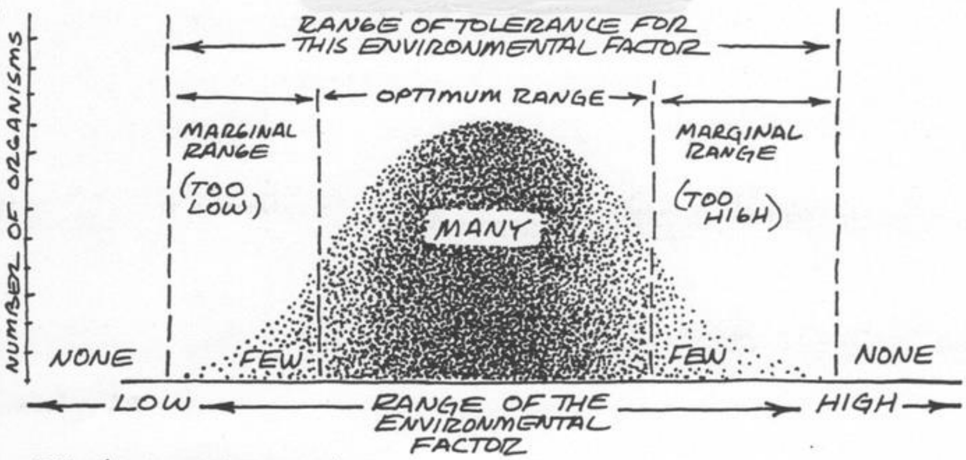
RANGE OF TOLERANCE

- IN 1840 JUSTUS VON LIEBIG SUGGESTED THAT THE GROWTH OF A PLANT WAS MOST CRITICALLY DEPENDENT ON THAT ONE REQUIRED NUTRITIONAL FACTOR THAT WAS IN THE SHORTEST SUPPLY. NUTRITIONAL FACTORS INCLUDED WATER, NITROGEN, POTASSIUM, PHOSPHORUS, ETC. THIS IS KNOWN AS "LIEBIG'S LAW OF THE MINIMUM."
- IN 1911 VICTOR E. SHELFORD, AN AMERICAN ECOLOGIST, POSTULATED THAT AN EXCESS OF AN ENVIRONMENTAL FACTOR MAY REDUCE AN ORGANISM'S ABILITY TO SURVIVE, JUST AS THE SCARCITY OF A REQUIRED FACTOR MIGHT DO. IN OTHER WORDS, AN ORGANISM HAS A LIMIT OF TOLERANCE FOR ANY ENVIRONMENTAL FACTOR.
- LIMITING FACTORS: ANY ORGANISM REQUIRES A COMPLEX OF ENVIRONMENTAL CONDITIONS AND HAS A DEFINITE RANGE OF TOLERANCE TO ANY ONE OF THEM. ANY ENVIRONMENTAL CONDITION OR FACTOR WHICH NEARS OR SURPASSES THE LIMITS OF TOLERANCE FOR THAT ORGANISM BECOMES A LIMITING FACTOR FOR IT.

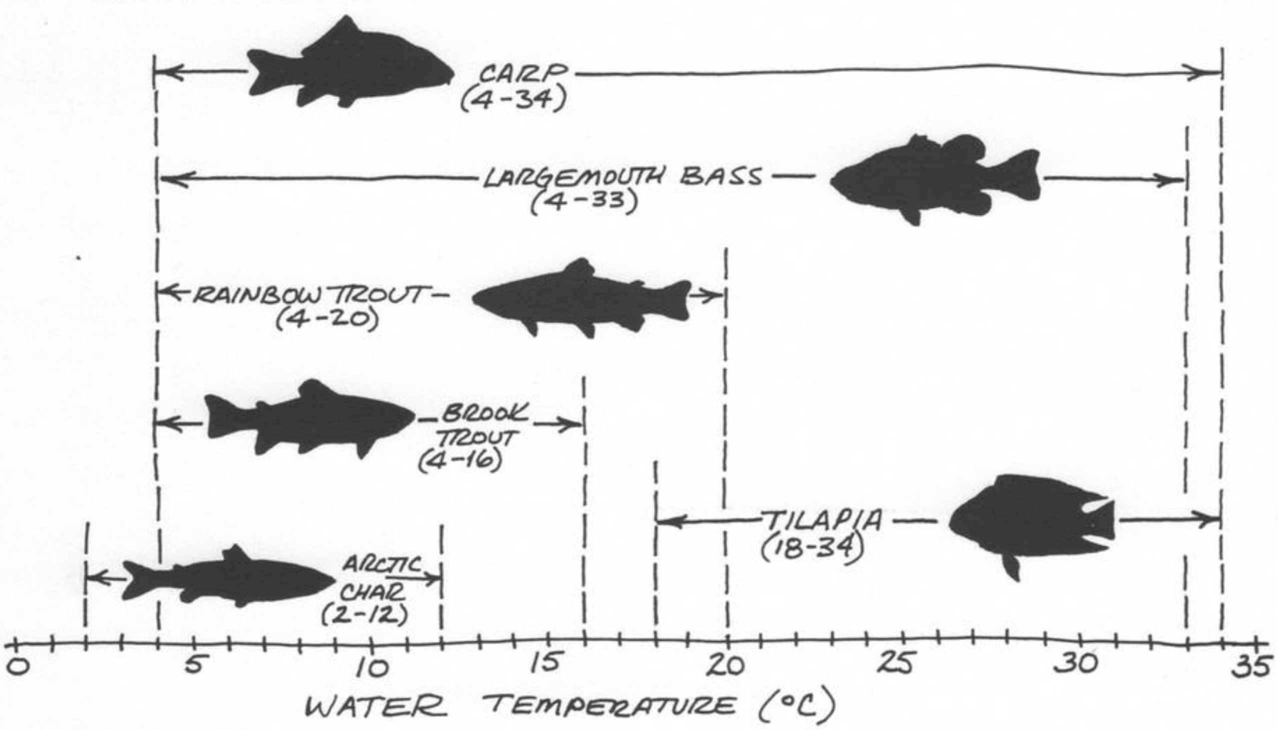


EXAMPLES OF ENVIRONMENTAL FACTORS

- SOIL MOISTURE
- SOIL TEMPERATURE
- SOIL pH
- SALT CONC. IN SOIL
- WATER TEMPERATURE
- WATER pH.
- SALINITY OF WATER
- UV LIGHT INTENSITY
- VISIBLE LIGHT INTENSITY
- HUMIDITY
- ANNUAL TEMPERATURE
- ANNUAL PRECIPITATION
- SALT CONC. IN SOIL
- OXYGEN CONC. IN WATER
- ETC.

FIG. 1 AN ORGANISM'S RANGE OF TOLERANCE.

FIG. 2. RANGES OF WATER TEMPERATURE TOLERANCE FOR SELECTED FISH SPECIES



STENOTHERMAL (STENOTHERMOUS) — RESTRICTED TO A NARROWER RANGE OF TEMPERATURE CONDITIONS.

EURYTHERMAL (EURYTHERMOUS) — CAPABLE OF TOLERATING A WIDER RANGE OF TEMPERATURE CONDITIONS.

REFERENCES: 22, 27, 50

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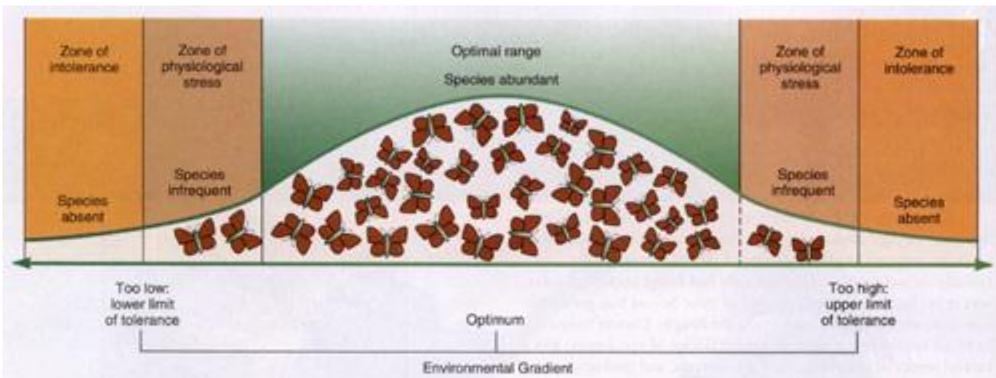
Homeostasis and Environmental Factors

In order to live, you must maintain your internal body temperature within a certain range, whether the outside temperature is freezing or 117 degrees Fahrenheit. In order to have your nerves and muscles working properly, you must maintain your electrolyte balance within a certain range, whether you are hiking across the desert feeling really thirsty, or sitting in front of the TV with a beer. These are examples of **HOMEOSTASIS**, which means **maintaining constant internal conditions regardless of changes in external conditions.**

To stay alive, organisms must maintain homeostasis. The result (as the glossary in your textbook explains) is "a dynamic steady state in a living system." In order to maintain homeostasis, organisms need to live under a certain set of environmental conditions with all the necessary critical environmental factors. This is shown in Figure 3.2



What does figure 3.2 in your textbook really mean?

Each species of animal, plant, or any living thing needs a certain set of environmental conditions if that species is going to survive. For example, the population of butterflies in Figure 3.2 needs to have the temperature of the environment within a certain **range of tolerance** in order to survive. If the temperature gets too hot or too cold, all of the butterflies die. This area outside the range of tolerance is called the **zone of intolerance**. But, just like people, not every butterfly in the population likes to be at exactly the same temperature. And just like people, not every butterfly can survive extreme temperatures at the edge of the range of tolerance. That is why this range of tolerance describes the conditions needed for the **population**, not the individual.

In the middle of the range of tolerance is the range where most of the butterflies are the most comfortable. This is the **optimum range**. As long as the temperature remains in this range, the population of butterflies will be healthy and reproductively successful. But look at what happens near the edges of the range of tolerance. If the temperature starts to get just a little too hot or just a little too cold, some of the butterflies in the population die. Even the ones that survive will probably be under some physiological stress. So this is called the **zone of physiological stress**. You would feel the same way if your environment became too hot or too cold. For instance, if the temperature inside the biology lab dropped to 40 degrees Fahrenheit or climbed to 105 degrees Fahrenheit, very few students in lab would die, but most of the students would be feeling stressed!

How well the butterflies can survive if the temperature changes depend partly on how rapidly the change takes place. Think of it like sitting in a bathtub of hot water. You can tolerate the water a lot hotter if you gradually add hotter water. This is called **acclimation**. Once you become acclimated to the hotter water, you can gradually add a little more hot water, until it almost feels scalding. Through acclimation, you can tolerate near-scalding temperatures, much better than you can tolerate jumping right into a scalding hot bathtub.

But acclimation has its limits. As the water gets hotter, you find yourself entering your zone of physiological stress. At some point, you will cross into your zone of intolerance. You suddenly reach a point where the next drop of hot water is more than you can tolerate. That point is called a **threshold effect**, where you cannot tolerate the water that hot. You then either die or get out of the bathtub. If the population of butterflies cannot get out of the heat, they just die.

This threshold effect is essentially "the straw that broke the camel's back." It can happen suddenly, without warning. In fact, the threshold effect is why many environmental problems seem to appear suddenly. We do not always see when a population of butterflies, or a forest full of trees, or an entire ecosystem is in the zone of physiological stress. But then there is a threshold effect and suddenly butterflies, trees, or entire ecosystems begin dying. That is when we know there is a problem!

Adapting to Environmental Stress

It is a basic law of the natural world that there will always be environmental stress. Remember the Red Queen in "Through the Looking Glass" by Lewis Carroll? The queen told Alice that "around here you have to run as fast as you can, just to stay in the same place." Scientists use this same idea, called the Red Queen Hypothesis, to describe the effect of environmental stress on living things. Living things must be able to constantly adapt to changes in the environment just to stay alive.

Environmental stress doesn't affect just **individual** organisms. Changes in environmental conditions can put stress on **populations**, **communities**, or even entire **ecosystems**. Examples of environmental stress that could affect an entire ecosystem include fire, flood, drought, volcanic eruption, hurricanes, disease, predation, competition, erosion, overgrazing, deforestation, overhunting, habitat destruction, pollution, and pesticides. Some of these are natural, while some are caused by humans. Some occur gradually, while some are sudden and catastrophic.

Whatever the cause, these types of stress can bring about changes in an individual organism, a population, a community, or an ecosystem.

- Environmental stress on an **individual** organism can bring about changes in physiology, behavior, or reproductive ability, or even cause death.
- Environmental stress on a **population** can bring about a decrease in the population, cause a loss of genetic diversity, or even cause extinction.
- Environmental stress on a **community** or an **ecosystem** can disrupt the flow of energy in the food chain, disrupt the cycling of essential nutrients, or even cause the entire ecosystem to collapse.

So how do organisms, populations, communities, and ecosystems adapt to environmental stress? Each has its own way:

- **Individual organisms survive through acclimation.**
- **Populations survive through evolution and adaptation.**
- **Communities and ecosystems survive through ecological succession.**

Individual Organisms Survive Through Acclimation

Acclimation occurs when individual organisms make physiological modifications to adapt to changes in the environment. This is much easier if the changes are occurring slowly. Think back to the earlier example of a bathtub of hot water. You can tolerate really hot water if you add hotter water gradually. You make the water a little hotter, let yourself become acclimated, then make the water a little hotter yet. By becoming acclimated you are able to tolerate really hot water much better than you can tolerate jumping right into a scalding hot bathtub. The same holds true for a variety of environmental stresses. If an individual organism can become acclimated to changing conditions, that organism will continue to live. If not, it will die.

Populations Survive Through Evolution

Genetic mutations occur randomly during reproduction, and are transmitted to the offspring. These changes in the DNA can be seen as changes in anatomy, physiology, or behavior of that offspring. Some mutations are harmful, and that organism dies. Some mutations aren't really noticeable, and have little effect on survival. But some mutations are helpful, and may give that organism an increased ability to survive changes in environmental conditions. These beneficial mutations lead to evolution in the population.

We need to stop for a moment to clear up any misconceptions you may have about evolution, and the difference between acclimation and evolution. Students quite often make this mistake, so I want to make sure you understand. Only a **population** of organisms can undergo **evolution**! An **individual** organism can only become **acclimated** to changing conditions, and does not change it's DNA!

Here is an example: Suppose you have a population of insect pests in your garden. You can spray a pesticide, and kill most of them. But if you keep spraying the pesticide on a regular basis, the number of individual insects in the population climbs right back up to where it was before you sprayed the first time. People say "the bugs are becoming resistant." Does that mean that **INDIVIDUAL** insects evolve and become resistant? NO! Only an insect born with a genetic mutation that allows it to survive the pesticide will survive. Most of the insects in the population do not have that mutation, so most of the population dies. Then the few survivors reproduce, lay eggs, and give rise to another generation of pests in your garden. The next time when you spray pesticides, more of the pests will survive, because more of them carry that mutation. Each time you spray, you are selecting for insects that have beneficial mutations, and they reproduce and give rise to the next generation of pests. So over time, the **POPULATION** (not the individual organism) adapts to the pesticide and becomes resistant. The population is evolving!

Communities and Ecosystems Survive Through Ecological Succession

Succession is the gradual process of change in the composition and function of the various populations within a community or ecosystem. One common example of succession is what happens in an old-growth forest after a fire burns down all the trees. At first the only things that grow are grasses and weeds. Eventually small shrubs take over, and soon a few species of trees can be found. Finally, after several years, or several dozen years, the forest reaches the mature state it was in before the fire.

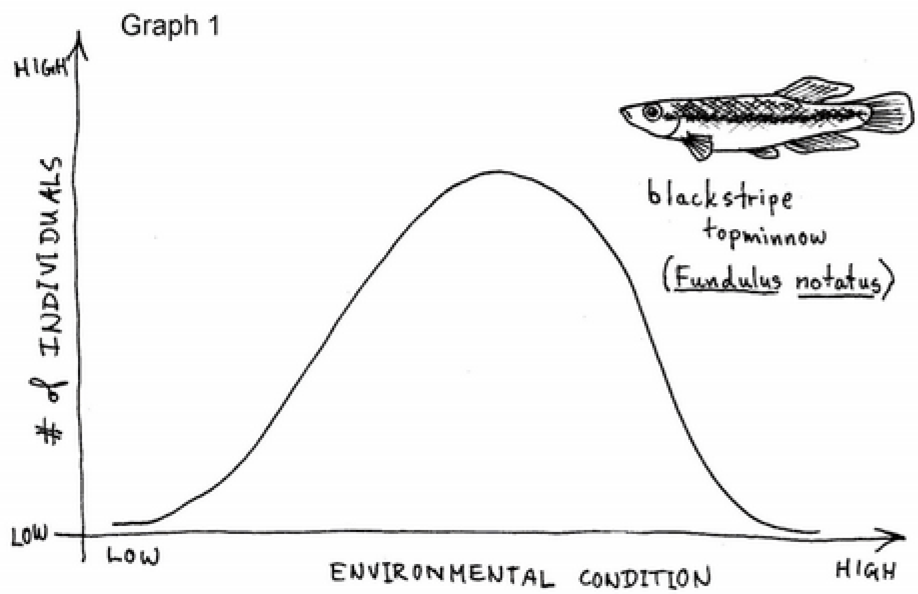
Life is found almost everywhere on Earth, but it is not distributed evenly around the planet. Different species are found in different areas; some species have overlapping ranges, others do not. Each species has a set of environmental conditions within which it can best survive and reproduce. Not surprisingly, those conditions are the ones for which it is best adapted. Many different physical, abiotic (non- living) factors influence where species live, including temperature, humidity, soil chemistry, pH, salinity and oxygen levels.

Just as species have geographic ranges, they also have tolerance ranges for the abiotic environmental conditions. In other words, they can tolerate (or survive within) a certain range of a particular factor, but cannot survive if there is too much or too little of the factor. Take temperature, for example. Polar bears survive very well in low temperatures, but would die from overheating in the tropics.

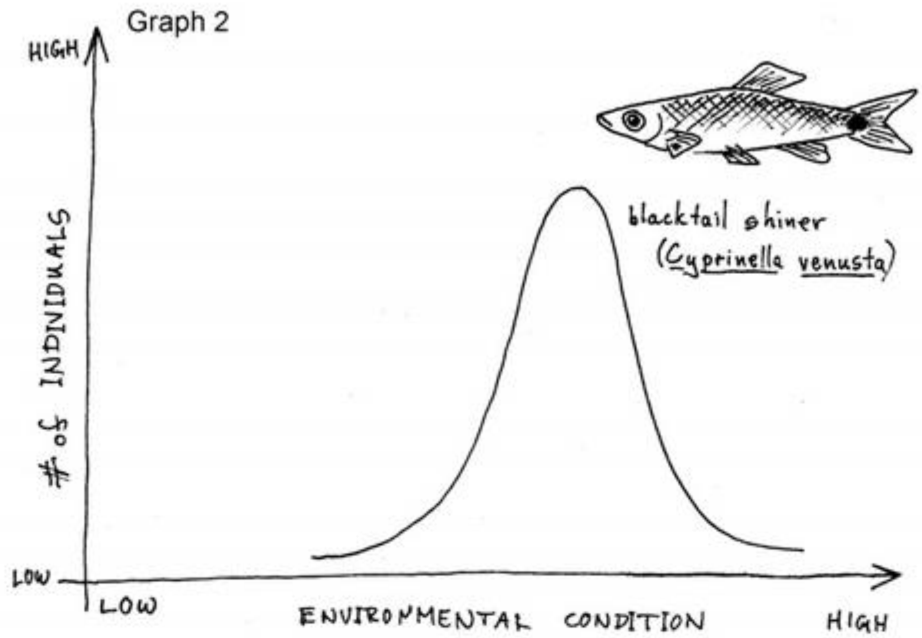
On the other hand, a giraffe does very well in the heat of the African savanna, but would quickly freeze to death in the Arctic. This example points out an important aspect of tolerance ranges – different types of organisms have different tolerance ranges for the same factor. And in fact, the tolerance range of a single individual may change over time; individuals of a certain species of salmon, for example, start life in a freshwater stream, migrate out to the open ocean, and then come back to their home stream to reproduce. The salmon tolerates huge changes in the salinity (salt content) of the various water it passes through during its journey, and also experiences many changes in water temperature.

Another important aspect is that all organisms have tolerance ranges – microbes, fungi, plants, and animals, including humans. While human technology has allowed us to live and work in more extreme environments, humans still freeze to death, die from heat stroke, drown, suffocate, and die from exposure to acid or lack of fresh water to drink. Our protective technology and our tolerance for too much or too little of these factors only goes so far – beyond the tolerance range, we cannot and do not survive.

Biologists are frequently interested in studying and understanding the tolerance ranges of different species for different environmental factors. If you draw a graph of how many individuals in a population live under which part of the range of any given factor, you almost always get a bell-shaped curve. Take a look at the two tolerance range curves shown below. The horizontal axis could be any of the abiotic factors (environmental conditions), but for now let's say it is for oxygen levels in freshwater lakes. If you are studying a particular species of fish, let's say the blackstripe topminnow (Fundulus notatus), you could go out and measure the oxygen level of every lake where you find the topminnow and also count how many topminnows are in each lake. When you make a graph of your data, it might look like Graph 1. That graph is telling you that the majority of the topminnows live in the middle part of the oxygen range; that's where the curve is highest. As you move from the middle part to lower oxygen levels (to the left) or to higher oxygen levels (to the right), the curve is not as high – there are fewer individuals that live in lakes that have the lower or higher amounts of oxygen. And if the oxygen level is extremely low or high, it is beyond the tolerance range of the species and no topminnows live in those lakes.



Now take a look at Graph 2, which represents the oxygen tolerance range curve for a different species of fish, in this case the blacktail shiner (Cyprinella venusta).



What is Graph 2 telling us about shiners compared to the topminnows? Shiners have a much narrower tolerance range for oxygen than topminnows do. The shiner can only survive and thrive in a narrow band of oxygen levels, so you would expect that its geographical range would be more restricted; it would not be distributed as widely as the topminnow since it wouldn’t do well in stagnant ponds with lower oxygen levels, for example. If you look closely, you’ll also notice that the peak of the curve for the shiner is a little bit to the right of the peak of the curve for the topminnow. This tells us that compared to topminnows, shiners do best in water that is slightly more oxygenated.

Both Graph 1 and Graph 2 are bell-shaped curves. That’s the normal or typical curve you get when graphing tolerance ranges, and interestingly enough, curves shaped like this illustrate what is referred to as a normal distribution. In some ways, you could say it is the "Goldilocks curve" – it shows where conditions are just right for a species: not too hot, not too cold; not too salty, or not salty enough; not too wet, not too dry. These preferences and needs for certain types of conditions greatly influence the distribution of species around the planet, and it can get fairly complex when you consider that multiple abiotic factors are simultaneously influencing any given individual and species.