Organisms in Ecosystems

- Organisms must reconcile their needs with what the environment provides
- Organisms need a fairly constant internal environment. Because of entropy, organisms must acquire and use energy to maintain homeostasis
- Maintenance of homeostasis is possible only under a certain range of conditions (tolerance limits). These tolerance limits vary with the individual and over time and space
- Organisms cannot do equally well in different environments (habitats). Distribution of organisms in habitats reflects environmental variation and evolutionary history
- Environmental challenges are countered by adaptations: inheritable traits that influence fitness
  - Adaptations are the product of natural selection
  - Organisms must be adapted to abiotic conditions within the habitat, e.g., temperature, moisture, light, radiation, salinity, pH, and gravity
  - Organisms generally live in habitats together with organisms with similar requirements. Must be adapted to these competitors
  - Organisms must also be adapted to diseases, predators, parasites, etc.

Limiting Factors

- When limits for one or a few factors that affect homeostasis are approached, those factors generally become most important in determining survival, that is, they become limiting factors
  - Proposed by Liebig (1840) as “The Law of the Minimum”: the growth and/or distribution of a species is dependent on the one environmental factor that is in shortest supply
  - Important in understanding physiological limits on animal distribution and abundance
- The exception is when one factor changes the tolerance for limitation of another (e.g., temperature and salinity), or when a second substance can substitute for another when availability of the first is limited (e.g., Sr for Ca in coral skeletons)

**Tolerance Range**

Can be narrow (“steno-”) or broad (“eury-”), and is different for each abiotic factor or condition:

- Tolerance ranges differ both within and between populations (populations with fixed and genetically-determined tolerances are called ecotypes)
- The tolerance range for one factor may affect tolerance ranges for others
- Tolerance ranges can change with different seasons, lifestyle stages, condition, age, etc.

**Zones of Tolerance Range**

- Zone of tolerance - central range at which the animal is most comfortable
  - Within this range, there is often a narrower optimal range where the population does very well, and sometimes a preferred range that is actively sought out and used by individual organisms

**Tolerance Range**

Shelford (1940) Law of Tolerance - For each abiotic factor or condition, there is a range within which an organism can survive and reproduce

**Zones of Tolerance Range**

- Zone of tolerance is bounded by an upper and lower zone of physiological stress (or resistance), within which the organism can survive for an indefinite period
Zones of Tolerance Range

The bounds of the upper and lower zone of intolerance are determined by the upper and lower incipient lethal limits (ILL), respectively:

- ILL is the level where a stated fraction of individuals in a population (usually 50%) when brought rapidly to this level from a different level, will die within an indefinitely prolonged exposure.
- ILL is not fixed, determined by previous acclimation history of the organism.
- Acclimation has limits, however, and eventually the upper and lower ultimate incipient lethal limits are reached.

Niche Size and Overlap

- Niche sizes of different species differ.
  - Species with wide (broad) niches are generalists.
  - Species with narrow niches are specialists, e.g., starlings in England eat only the ticks off of sheep and deer.
- Niche overlap occurs whenever two or more organisms use the same resource. May result in:
  - Intraspecific competition if organisms are the same species.
  - Interspecific competition if organisms are different species.

"Normal" Physiology

- When environment is such that the organism is within tolerance limits for all factors, "normal" physiology occurs and the organism is free of stress.
- Often measured along a continuum from the molecular (e.g., induced proteins) to the ecosystem level (e.g., shifts in respiration:production or nutrient cycling).
- Most often, a measurement of "stress" is implied for any significant shift in a quality regardless of the level examined.
- Direct indicators (e.g., change in hormone levels)
- Indirect indicators (e.g., increased intensity of parasite infection)

Niche Reduction and Competitive Release

- Competition may force some or all organisms with overlapping niches to:
  - Decrease the size of their realized niches (niche compression).
  - Alter their realized niches (niche shift).
- In contrast, if competition is released (e.g., if a species colonizes a new habitat with no competitors), then niche size may expand (competitive release).

What Is Stress?

Definitions vary, even at the level of the individual.

- Adams (1990) compiled the following definitions:
  - "...the sum of all physiological responses that occur when animals attempt to establish or maintain homeostasis, the stressor being an environmental alteration and stress the organism’s response*"
  - "...adaptive physiological changes resulting from a variety of environmental stressors"*
  - "...a diversion of metabolic energy from an animal’s normal activities*"
  - "...the sum of all physiological responses by which an organism tries to maintain or reestablish normal metabolism in the face of chemical or physical changes*"
  - "...alteration of one or more physiological variables to the point that long-term survival may be impaired*"
  - "...the effect of any environmental alteration that extends homeostatic or stabilizing processes beyond their normal limits*"

Topic 4 – 2
What Is Stress?

"Everybody knows what stress is and nobody knows what it is."
—Hans Selye (1973)

1. Selye (1956, 1973) developed the concept of stress as: "...the state manifested by a specific syndrome which consists of all the nonspecifically induced changes within a biological system.”
2. Selye also clearly stated that stress is characterized by a specific syndrome in response to an external agent.
3. Stress is achieved during any of a variety of activities, including many non-detrimental activities, e.g., exertion.
4. Stress is also a distinctive or specific suite of responses that are beneficial or compensatory.

Stress is also a distinctive or specific suite of responses that are beneficial or compensatory.

Temporal qualities are central to the concept of stress: stress is a response to a recent disorganizing factor.

In this course:
- The external effect will be termed the stressor
- The response is stress

Types of Stress

Selyean Stress

- Specific or characteristic response to a recent disorganizing or detrimental factor
- Purpose is to maintain or reestablish homeostasis (i.e., energy flow, material cycling and/or system structure) within a defined norm
- Not characterized by previous adaptation to the stressor
- Example: increasing pulse rate or blood pressure with exertion

Preadaptive Stress

Similar to Selyean stress, but characterized by a previous adaptation to the stressor, i.e., the system has specific information with which to mediate the effect of the stressor.

- Adaptation may be recent and transient (e.g., acclimation) or long-term and relatively permanent (genetic adaptation)
- These responses tend to be specific to the stressor
- Example: induction of the P-450 monooxygenase system by polycyclic aromatic hydrocarbons (genetic response to a particular class of taxicants)

Determining Effects of Stress

Follows the hierarchical organization of life:

- **Subcellular**: molecular effects and biomarkers (e.g., induction of stress proteins)
- **Cellular**: cytotoxicological, histopathological, and genetic effects (e.g., chromosomal fragmentation, increased aneuploidy)
- **Individual**: sublethal, acute, and chronic lethal effects (e.g., declines in ability to capture food or evade predators, deaths due to continued exposure)
- **Population**: epidemiology, population genetics, population dynamics (e.g., changes in demography)
- **Community** and **ecosystem** (e.g., changes in biodiversity, photosynthesis/respiration ratios)
- **Landscape, regional/ecoregional, and biosphere** (e.g., watershed pollution, changes in atmospheric chemistry)
Types of Stress

Damage or Distress

Adverse effect(s) of a stressor that are not a consequence of a system response

- At lower levels of organization, this generally denotes cell, tissue, or organ damage
- Examples: thinning of bird eggshells from DDT exposure. Decreased predator hunting efficiency due to intoxication

Stress Effects on Individuals

- **Hormesis**: A stimulatory effect in response to exposures to low ("subinhibitory") levels of toxicants or physical agents

  - In ecology, this is associated with the so-called "subsidy-stress" hypothesis
  - In some animals, exposure to low-level ionizing radiation or other stressors causes an increase in lifetime reproductive output with no decrease in maternal lifespan
  - In humans, it forms the basis for homeopathic medicine

- **Physiological acclimation** and **acclimatization**: Adaptive changes in an individual in response to a change in environmental conditions

  - More specifically, acclimatization refers to adaptive shifts taking place under natural conditions
  - Acclimation refers to shifts taking place under controlled laboratory conditions, or the resource spent in the experimental setup before beginning measurements

Quantifying Acclimation

Shepard (1955) quantified acclimation of speckled trout (*Salvelinus fontinalis*) to low-oxygen conditions:

- Acclimation involved changes in the oxygen-binding capacity of blood
- Incipient lethal level (ILL, mg O₂ L⁻¹) for the fish would live indefinitely relative to the level where 100% would die) was linearly related to the acclimation level (A, mg O₂ L⁻¹), such that ILL = 0.086A + 0.87
- Estimated the ultimate ILL (the lowest concentration to which the fish may be acclimated and still have 50% or less mortality) by solving this relationship for ILL = A: ILL = 0.87(1 - 0.086) = 0.952 mg O₂ L⁻¹

Quantifying Acclimation

Chapman (1985) described a general toxic response model for acclimation to metals, based primarily on LC50 data:

- As with O₂, there is a zone of roughly linearly increasing tolerance with increased acclimation concentration producing increased LC50
  - Explanation: induced response to metal that enhances tolerance
- Maximum acclimation concentration above which tolerance decreases
  - Explanation: damaging effects exceed capacity of induced response
- Lower limit on acclimation, below which tolerance decreases
  - Explanation: no induced response, but damaging effects still occur

Hypothetical Thermal Tolerance in Fishes

Quantifying Acclimation

Dixon and Sprague (1981) change in ILL for Cu with acclimation level and acclimation time in rainbow trout:

- Response surface is essentially a "3-D" version of Chapman (1985) results: the "ski-jump" shape is formed by the lower limit on induced response.

General Adaptation Syndrome (GAS)

- Also developed by Selye, consists of 3 phases:
  - Alarm reaction involves immediate reactions, e.g., increased pulse rate, blood pressure, and respiration ("fight or flight" response)
  - If stressor continues to exert effect on organism, resistance responses that "stimulate tissue-defense" (e.g., enlargements of the adrenal cortex, induction of metallothioneins)
  - After a characteristic period of exposure, the organism enters an exhaustion phase indicating that "finite adaptive energy" of individual has been reached. With continued exposure, the organism is unable to maintain itself and dies.