Thermoregulation Function

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Relevant Background Information

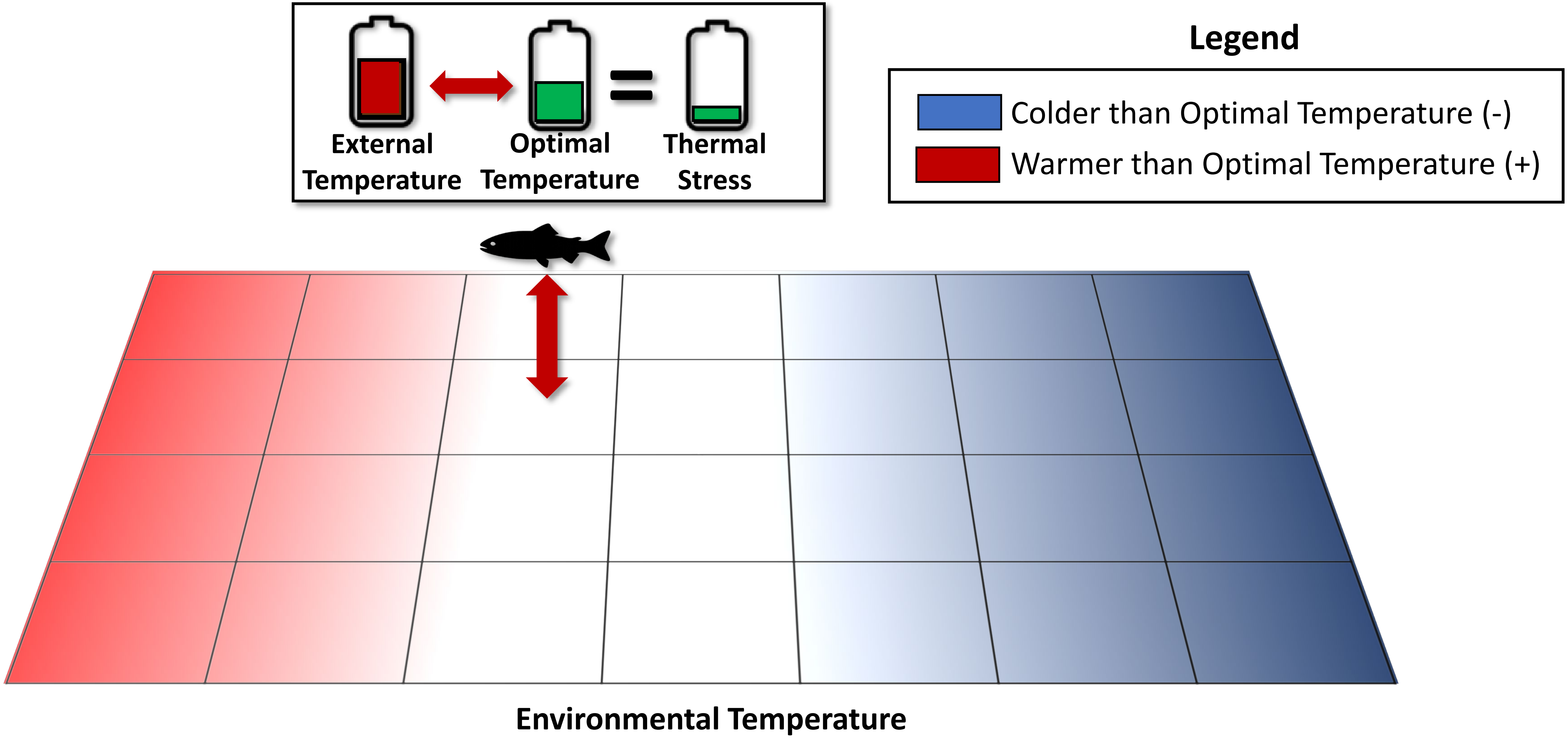
Term	Definition
Thermoregulation	How fish keep the right balance of temperature and water inside their bodies, even when the water around them changes.
Ectotherm	Fish whose body temperature depends on the temperature of the surrounding water.
Optimal Temperature	The water temperature where a fish can swim, grow, and survive most efficiently.
Thermal Tolerance	The range of temperatures a fish can survive in, from the minimum to the maximum limit.
Homeostasis	The ability of fish to maintain stable internal conditions, like energy use and performance, even when water temperature changes.

Model Objectives

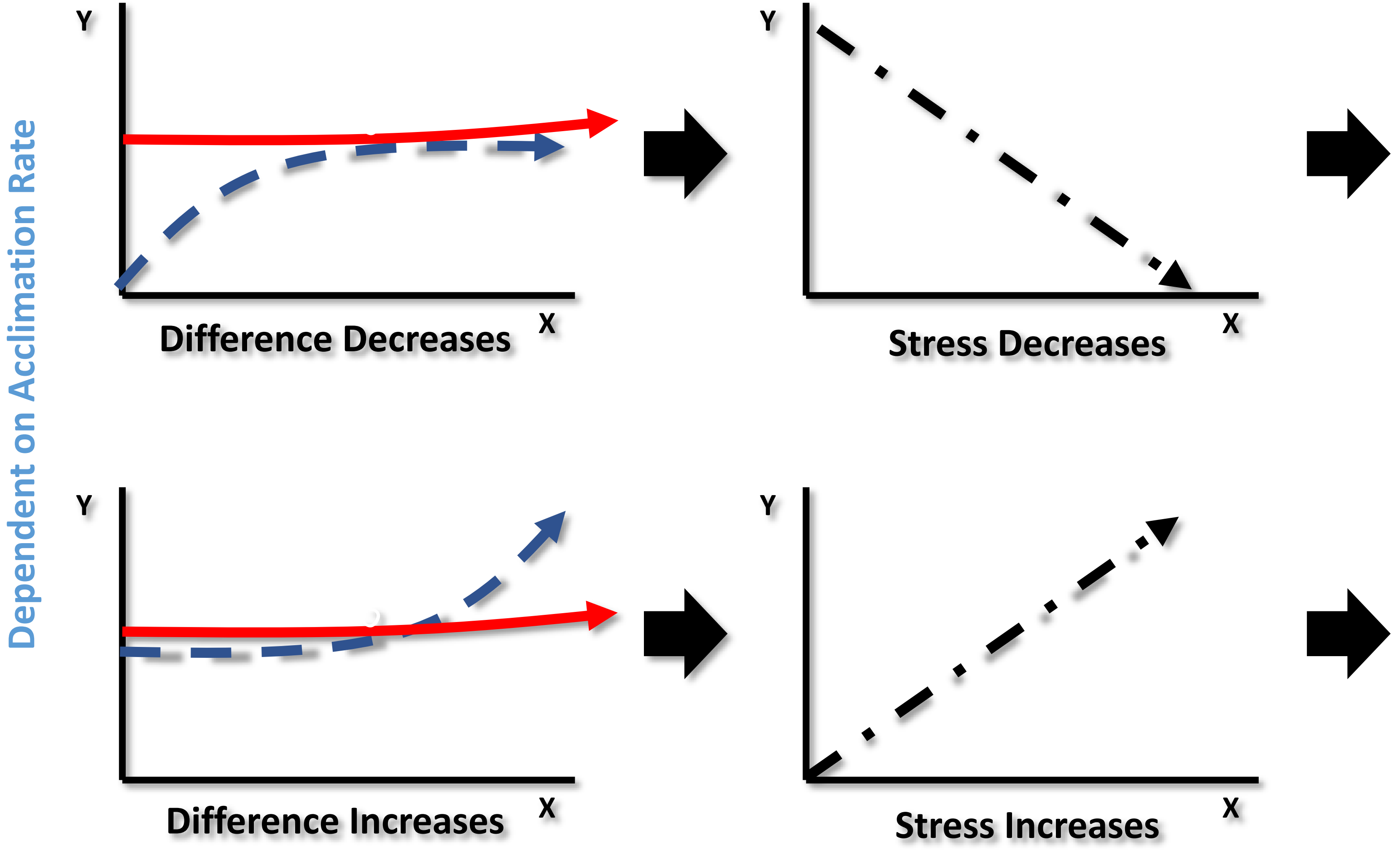
Purpose: Simulate how migratory fish experience and respond to temperature-related stress, including energy use, and swimming difficulty.

Objectives:

1. **Quantify Thermal Stress**
   Calculate the physiological stress experienced when water temperature deviates from a fish's optimal thermal range.
2. **Simulate Thermal Impacts**
   Represent changes in swimming performance, behavior, and mortality risk under cold or hot conditions.
3. **Estimate Energy Use**
   Track the energy fish spend to maintain homeostasis, adjust to new temperatures, and move under thermal stress.



Fish feel stress when the water is too hot or too cold for them. They use more energy to survive and move when they're outside their comfort zone.



Ecological Implication

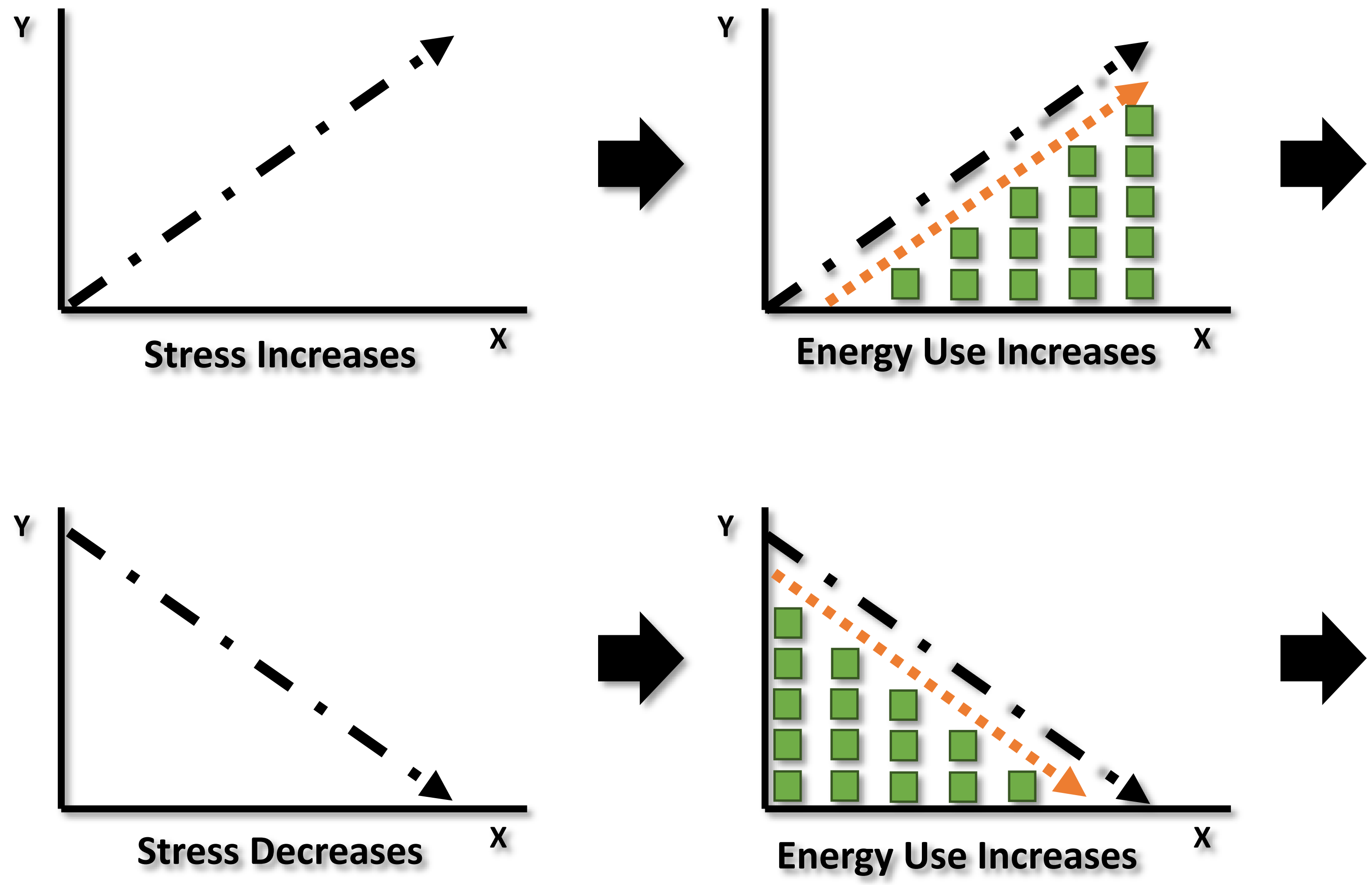
Fish is maintaining balance and thermal stress decreases.

Individual thermoregulation processes cannot keep up with maintaining balance of temperature in the fish and thermal stress increases.

Environmental Temperature

Optimal Temperature

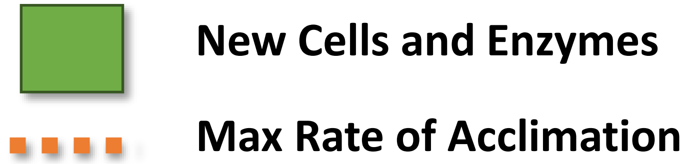
Thermal stress increases when environmental temperature doesn’t match the fish’s optimal temperature.



Ecological Implication

Stress initializes the creation of new cells and enzymes to maintain homeostasis, limited by a fish's acclimation rate.

Fish can remove excess chloride cells that are not needed to maintain balance.



Fish adjust their cellular and enzyme systems to function in new temperatures which costs energy.

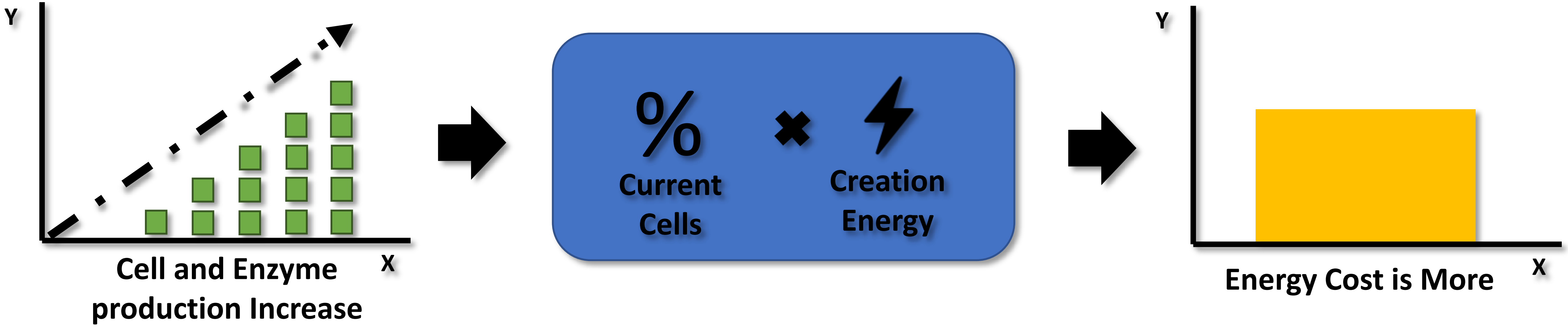
Calculate Patch Stress

Tracks the highest level of stress experienced in a patch.

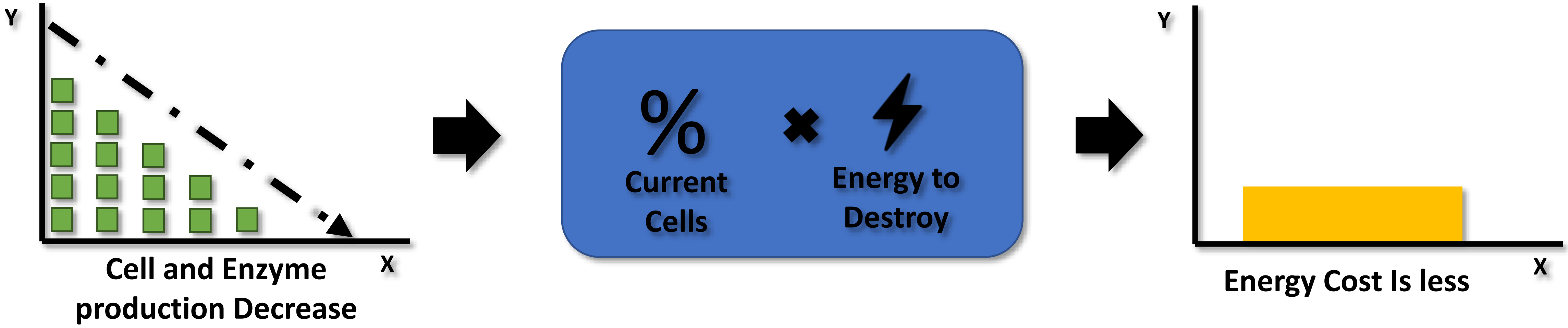
If Current **Stress** <= **Patch-Stress**
No Change

If Current **Stress** > **Patch-Stress**
Update **Patch-Stress** to Current **Stress**

Each location records how stressed fish were when they passed through, helping us see where temperature conditions are hardest on them.



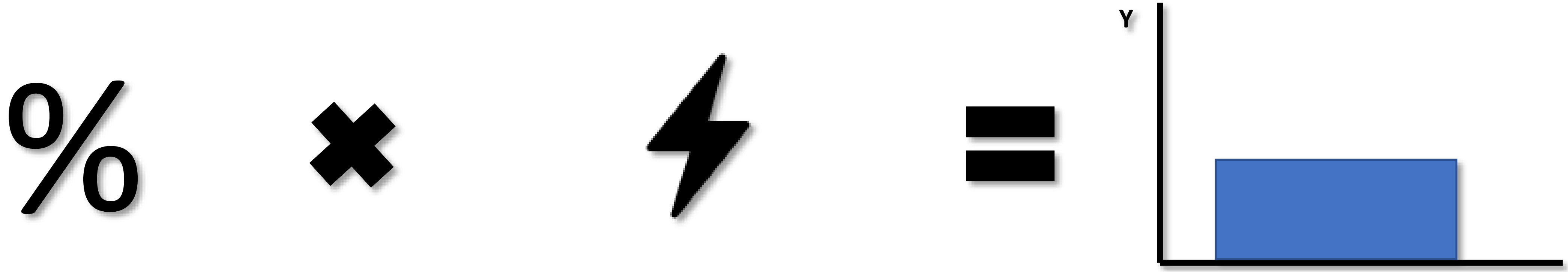
Stress initializes the production of new cells and enzymes which costs lots of energy



Fish can destroy cells and excess enzymes that are not needed, but this still uses some energy.

Making new cells and enzymes uses more energy than removing them, but both add to the total cost of thermoregulation.

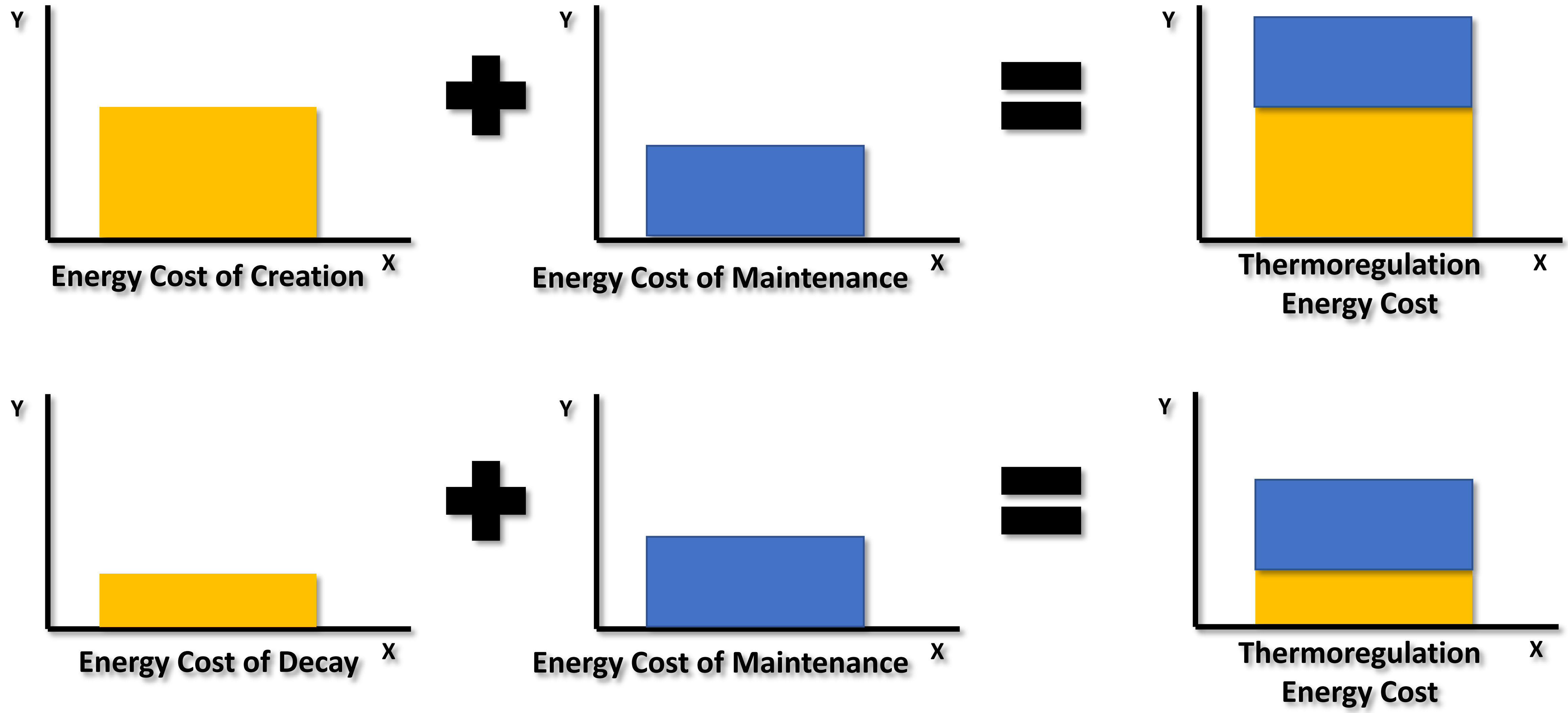
Cell Maintenance Energy



Current Cells **Energy Cost of Maintenance** **Net Energy Cost of Maintenance**

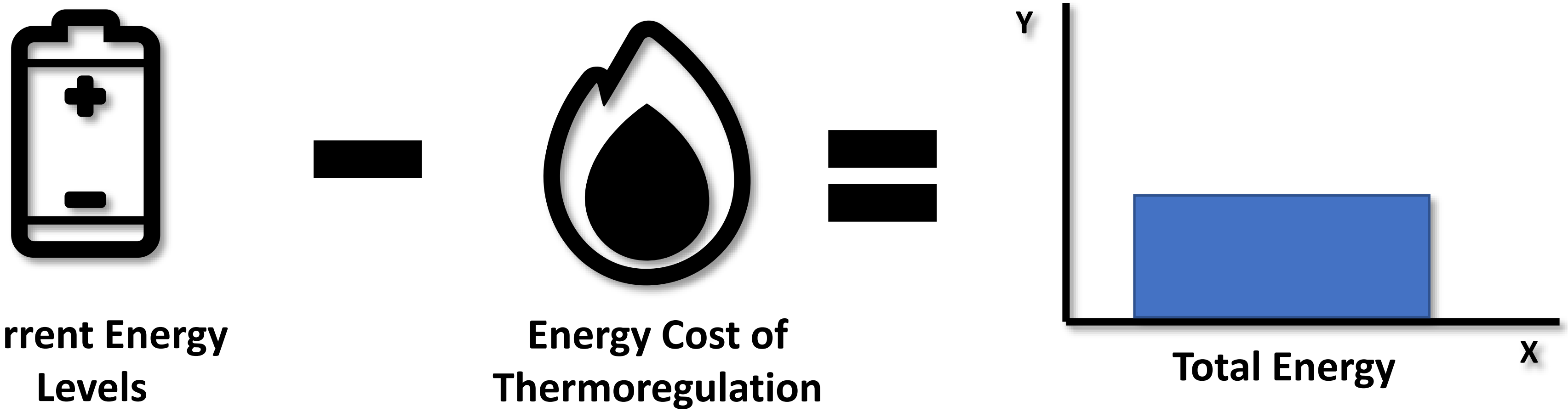
Maintenance Energy: amount of energy a fish must use to keep its existing chloride cells functioning properly, even when no new cells are being created or removed.

Even without new cell growth or removal, fish must spend energy to maintain their existing cells and enzyme levels.



The total energy cost includes adjusting to temperature, staying balanced, and swimming less efficiently when conditions are poor.

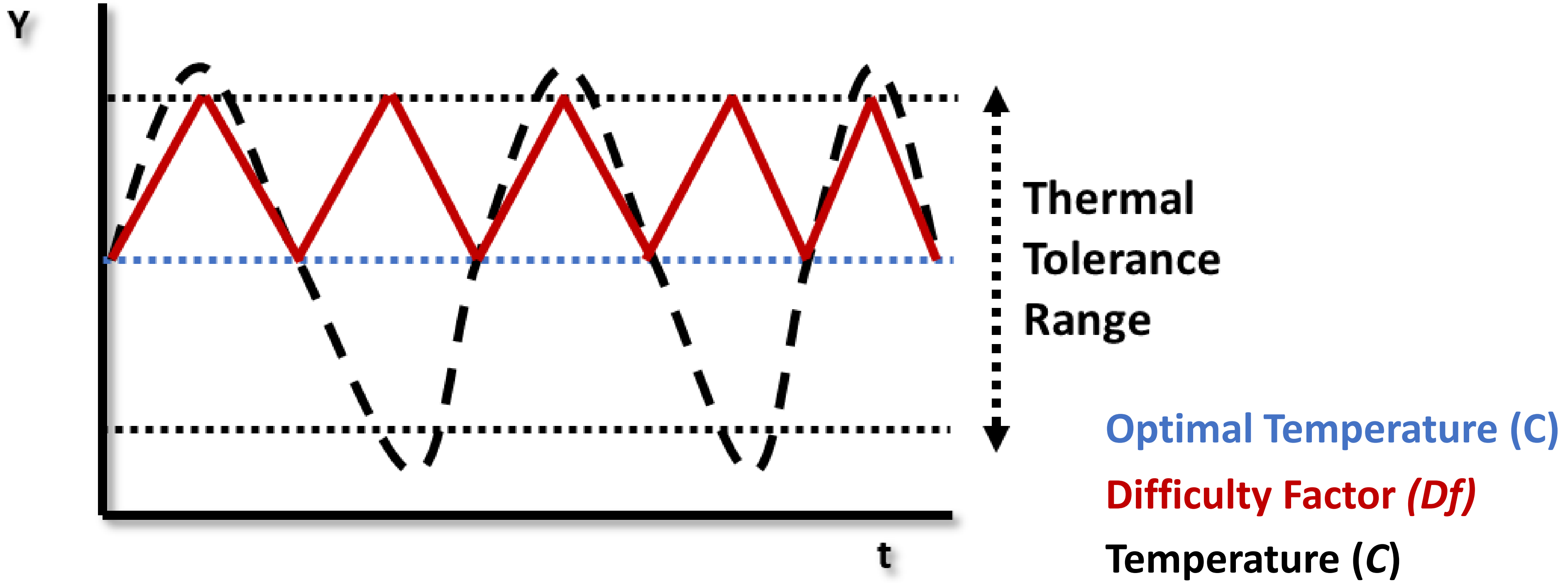
Total Energy Balance



Total Energy: amount of energy a fish has left to complete migration.

A fish's total energy budget depends on how much it starts with minus what's spent on thermoregulation

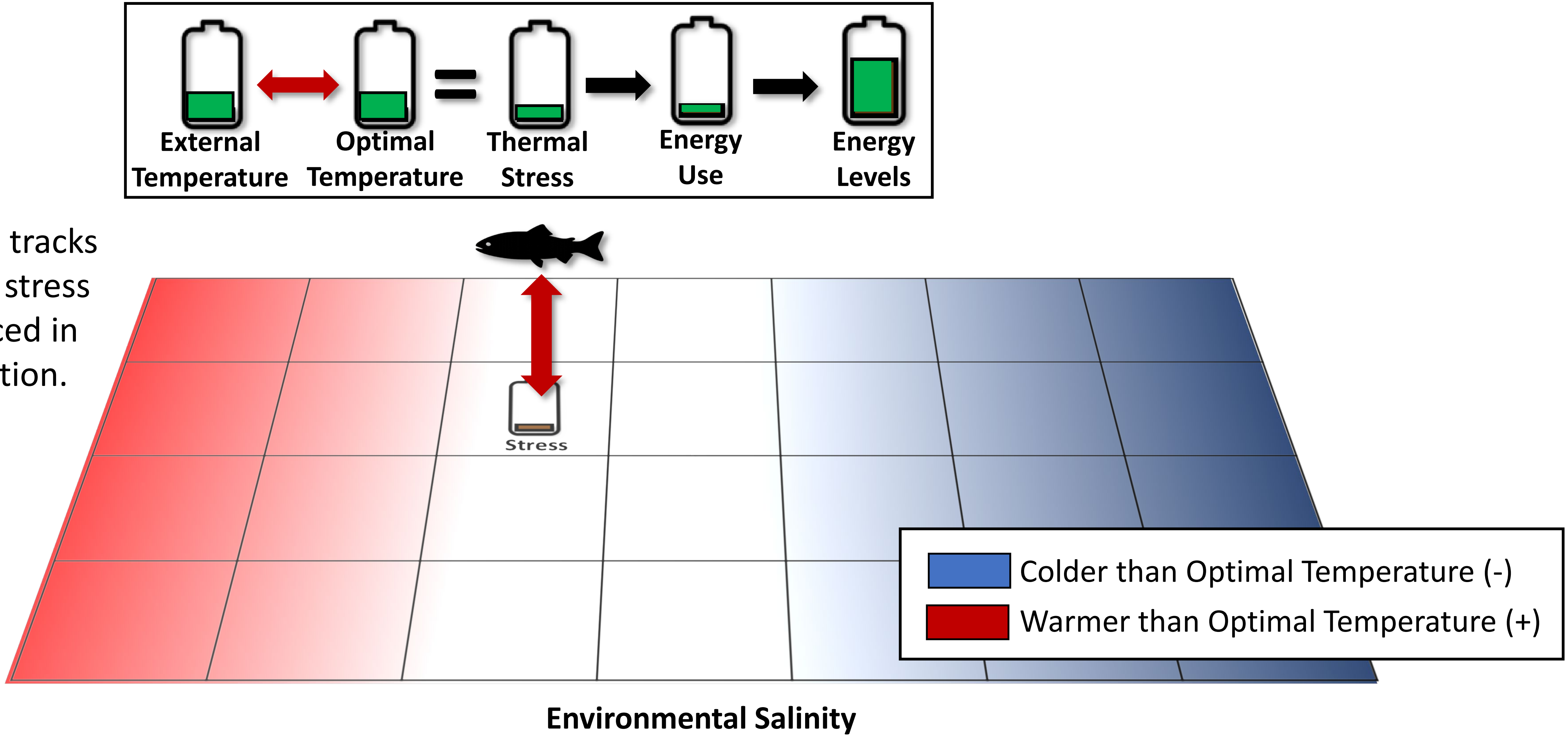
Temperature Impacts Swimming Difficulty



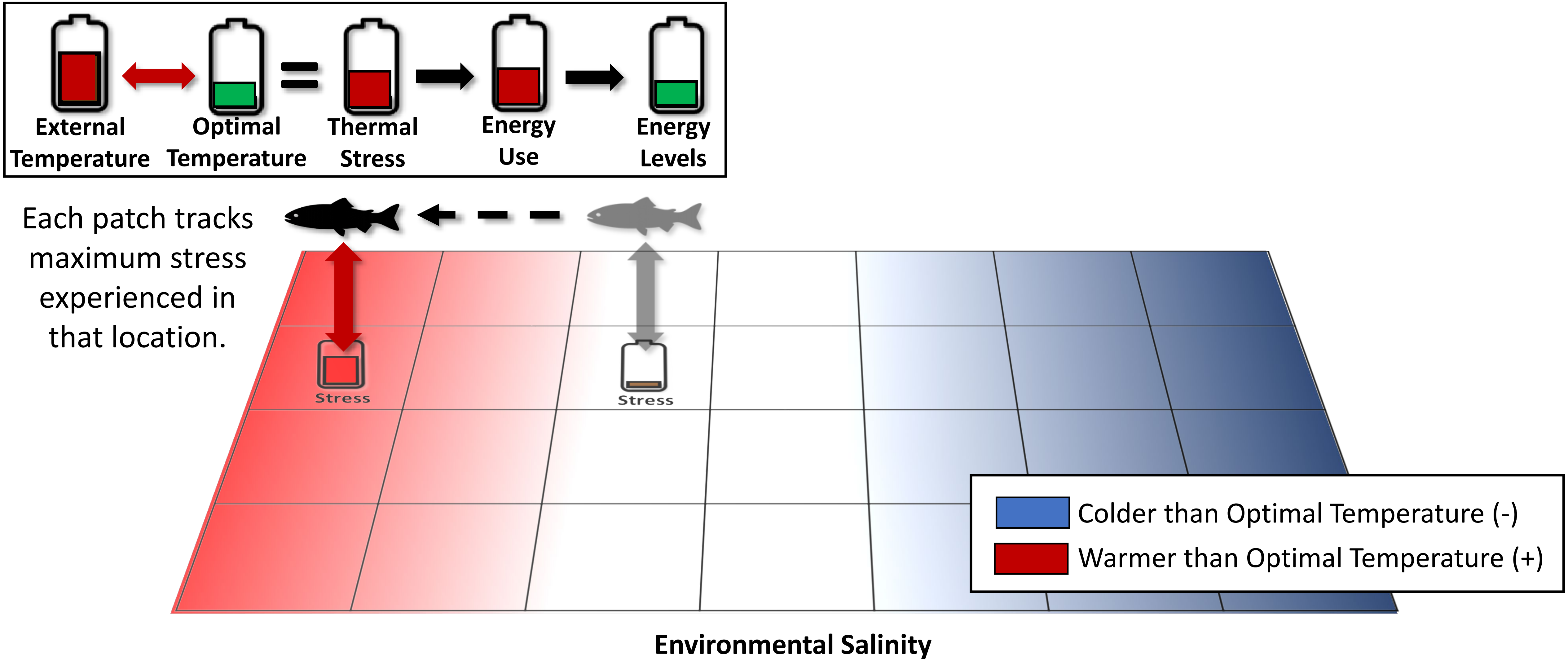
Max Difficulty: Lowest and Highest Boundary of Thermal Tolerance

Temperatures too high or too low impair swimming ability. Fish move slower and use more energy to keep going.

Each patch tracks maximum stress experienced in that location.

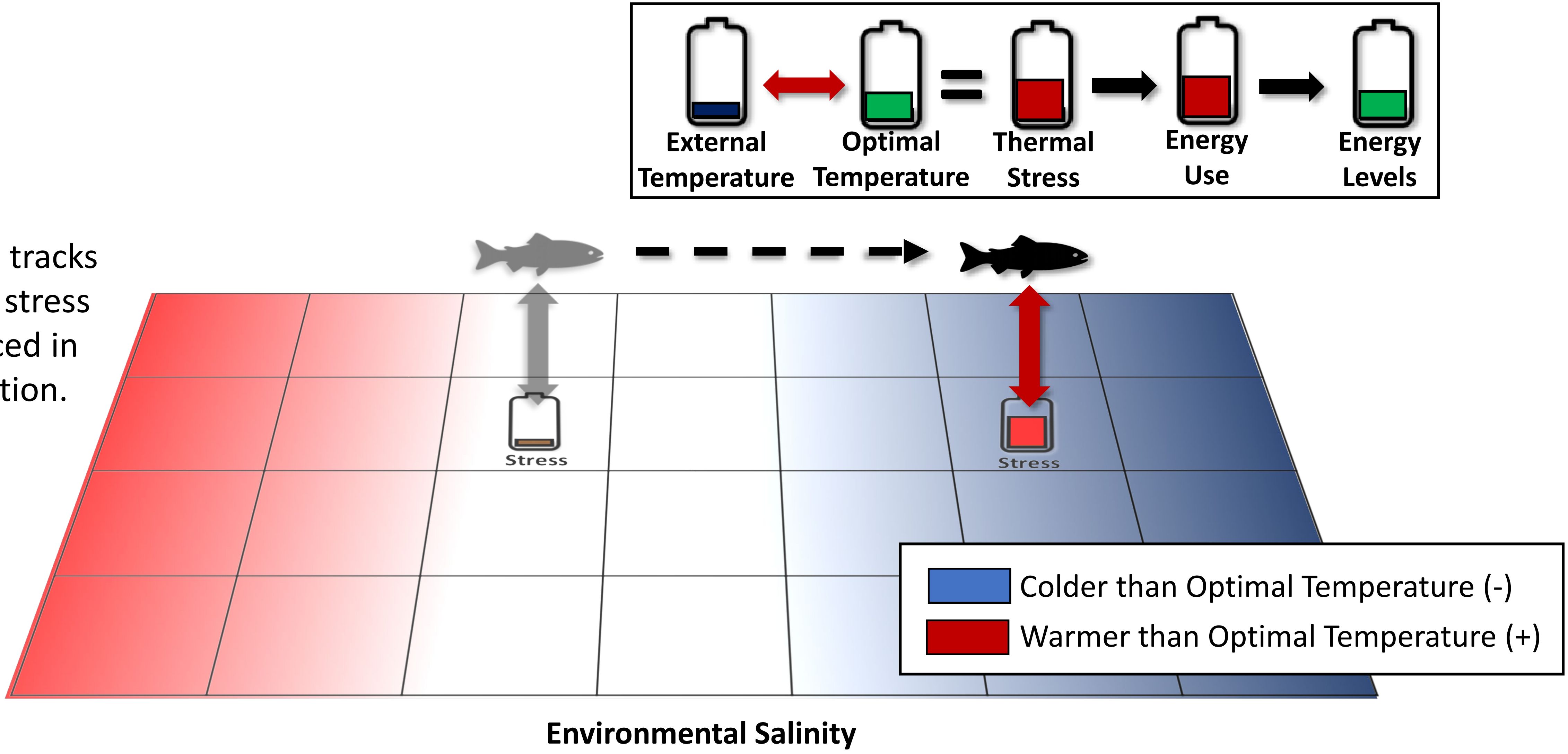


When optimal and environmental temperature are similar, fish experience low stress, expend less energy, and have less difficulty swimming .



When environmental temperature is higher than optimal temperature, fish experience higher stress, expend more energy, and have more difficulty swimming .

Each patch tracks maximum stress experienced in that location.



When environmental temperature is lower than optimal temperature, fish experience higher stress, expend more energy, and have more difficulty swimming .

Individual-Specific Traits

Trait Type	Generalization
Temperature Acclimation Rate	Higher for larger, older fish; species-dependent
Cell Growth/Decay Rate	Slower in larger, older fish
Creation Energy	Higher for large/old fish or energetically expensive species
Decay Energy	Lower than creation but still influenced by size and age.

Traits like age, size, and species affect how well a fish can handle temperature changes. Some fish adjust faster or are more vulnerable than others.

Outputs of Interest

Type	Variable	What It Tells Us
Temporal	Thermal-Stress	Shows how hard a fish is working to maintain normal processes as temperature changes. Higher stress means more physiological strain, and higher energy cost.
	Energy	Tracks how much energy a fish is using over time to thermoregulate.
Spatial	Patch-Stress	Identifies locations where fish experience the highest thermal stress, which may reduce their ability to stay healthy.
	Patch-Energy	Maps where fish are using the most energy to stay balanced, especially in areas with high or low temperatures.

Outputs highlight thermal stress hotspots and periods of high energy demand that may limit fish survival or guide restoration priorities.

Discussion Prompts

1. **Accuracy & Realism**

- How might energetic state prior to thermal exposure (e.g., post-spawning depletion or migration fatigue) influence mortality risk?
- Are current hydrodynamic models accurate enough to simulate localized thermal variation near structures like dams, culverts, or channels?

2. **Missing Variables, Traits, or Parameters**

- Are there other traits that might affect how fish handle heat or cold, like body size, energy reserves, or age?
- Are important environmental factors missing that could influence temperature exposure, like stratification or flow rate?

3. **Outputs of Interest**

- Are maps of cumulative thermal stress or mortality risk more useful for identifying vulnerable zones and informing monitoring?
- Could energy loss or avoidance behavior outputs help identify areas where restoration or engineered flow changes might reduce thermal bottlenecks?