Penobscot Estuary Community Modeling Workshop
ABM Draft Migration Function
August 6th, 2025

Migration

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Relevant Background Information

Term	Definition
Landward Migration	Movement of fish from marine or estuarine zones upstream into freshwater, typically during spawning migrations.
Seaward Migration	Movement of fish from freshwater or estuarine habitats toward the ocean, often seen in juvenile or post-spawning individuals.
Homing	The ability of fish to return to their natal habitat, guided by environmental cues like salinity, temperature, or chemical signals.

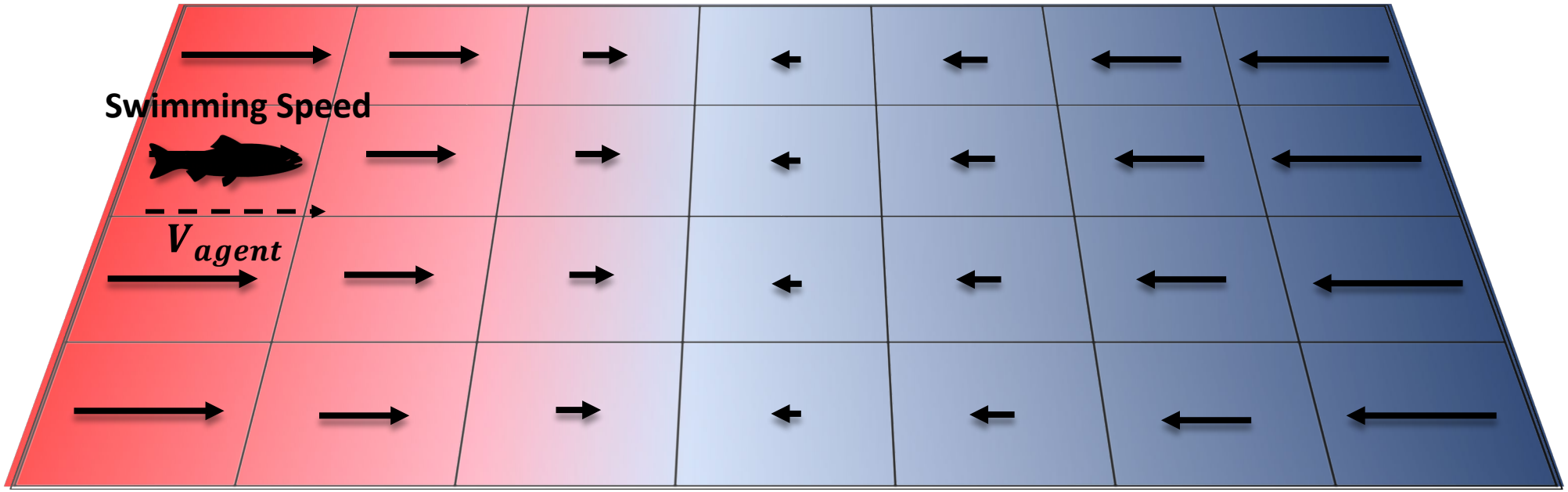
Model Objectives

Purpose: Simulate how fish migrate under flow resistance by calculating swimming effort, difficulty, and energy cost.

Objectives:

1. **Simulate migration movement under varying flow conditions**
   Calculate swimming speed based on fish energy and water velocity, capturing how fish respond to hydrodynamic resistance.
2. **Quantify energetic difficulty of movement**
   Use a velocity-based difficulty factor to scale the energetic cost of upstream swimming based on local flow and fish traits.
3. **Track movement and energy depletion**
   Determine fish position and energy loss at each time step, revealing where and when movement becomes inefficient or unsustainable.

Swimming Becomes More or Less Difficult as Fish Move Through Changing Flow Conditions



Current Velocity

Velocity Direction × Magnitude = Difficulty Factor (***Df***)

Highest difficulty:

→ Strongest velocity in the opposite direction of fish movement

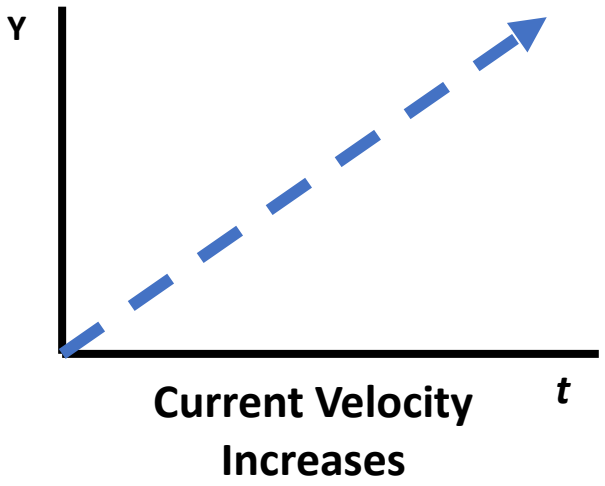
Lowest difficulty:

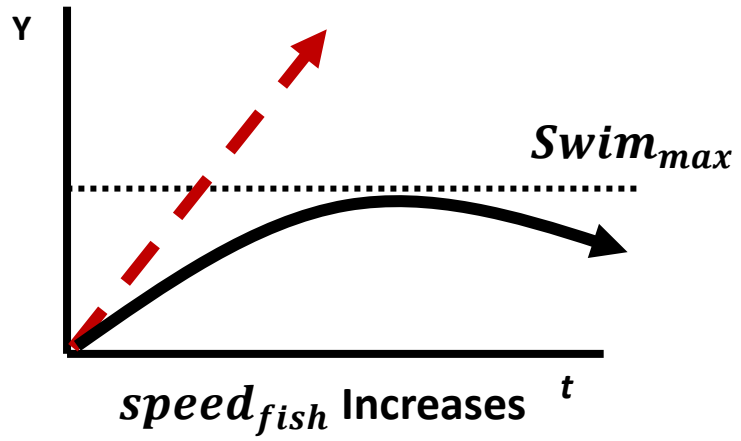
→ Weak or assisting flow in the same direction as fish movement

Legend

- Seaward Direction (-)
- Landward Direction (+)

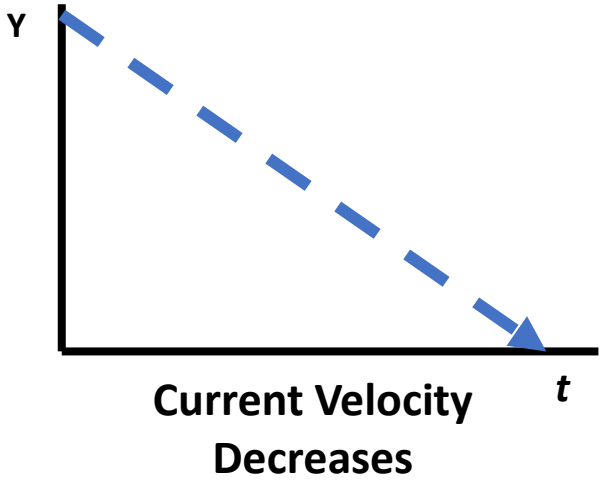
Swimming Against the Flow

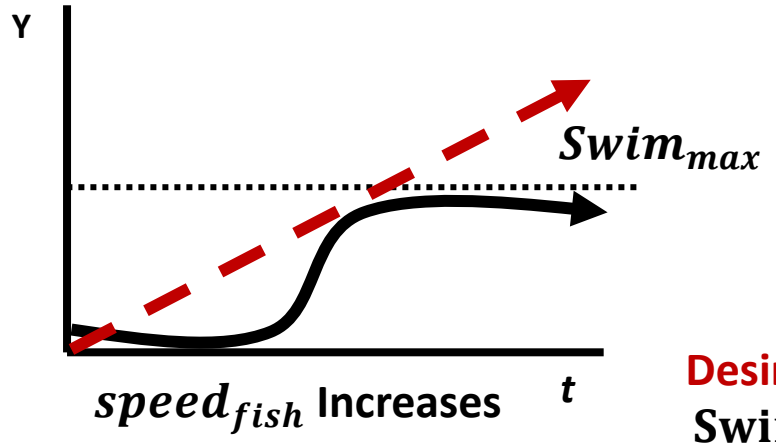




Ecological Implication

As flow strengthens, fish increase speed to counter resistance, constrained by their max swimming rate and how fast they can accelerate.

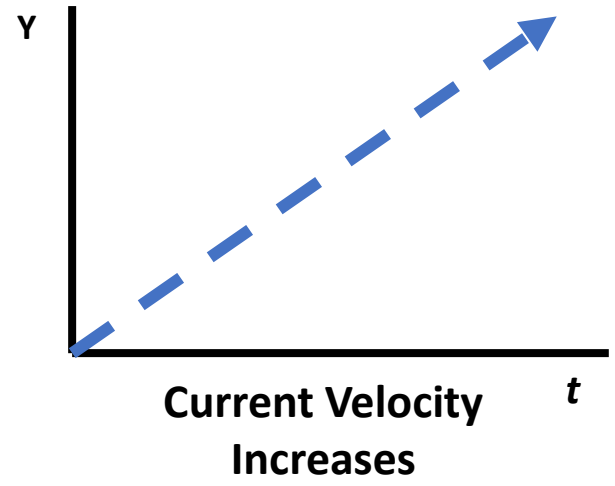


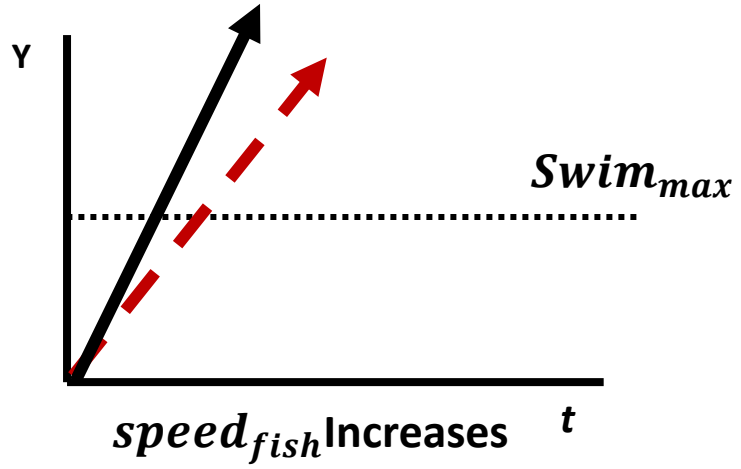


As flow weakens, fish reduce speed to conserve energy unless overcoming velocity is needed for continued migration.

Fish adjust their speed to overcome opposing currents, constrained by maximum velocity and rate of change.

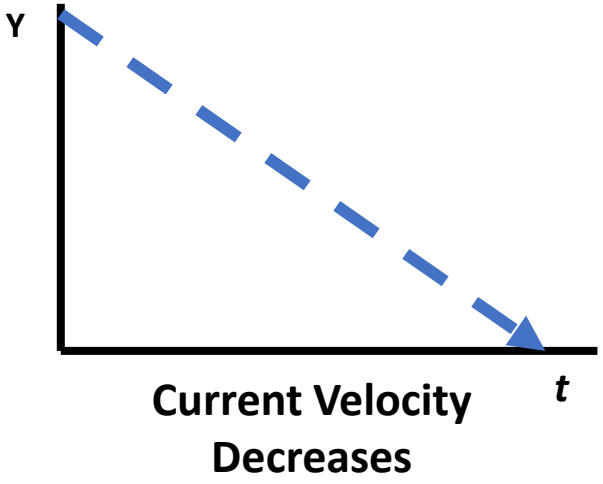
Swimming with the Flow

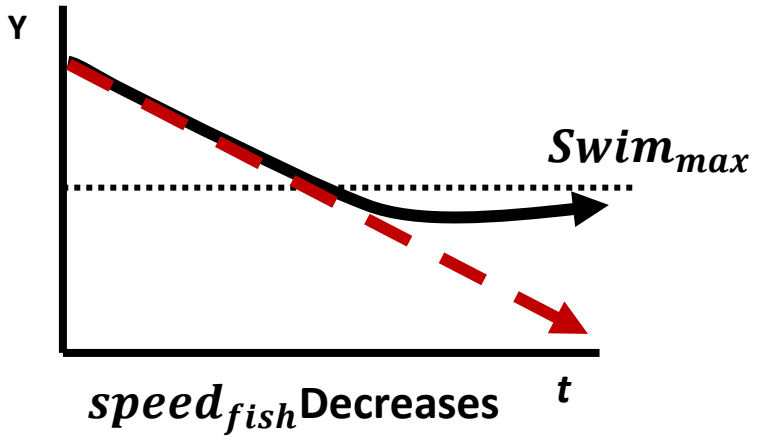




Ecological Implication

When flow aids migration, fish swim more efficiently but still face constraints from max speed and acceleration.



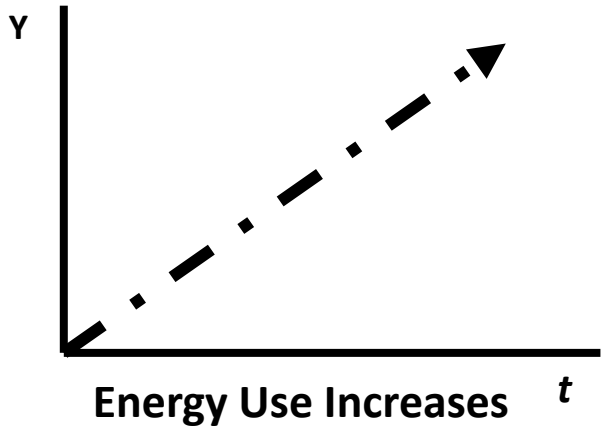


As favorable flow lessens, fish boost effort to maintain progress, using more energy if currents slow too much.

Desired Swimming Velocity
Swimming Velocity
Current Velocity

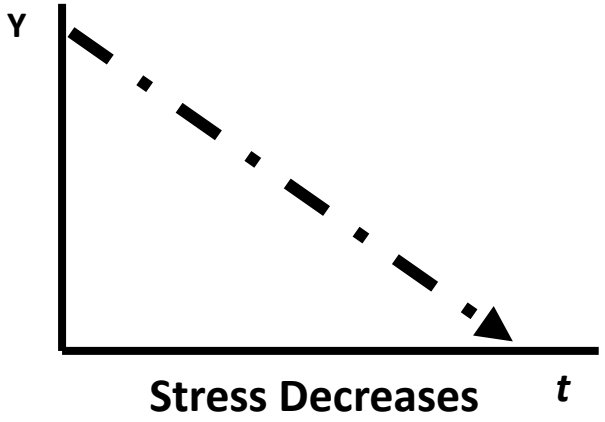
Fish use favorable currents to move faster with less effort, without being limited by their maximum swimming speed.

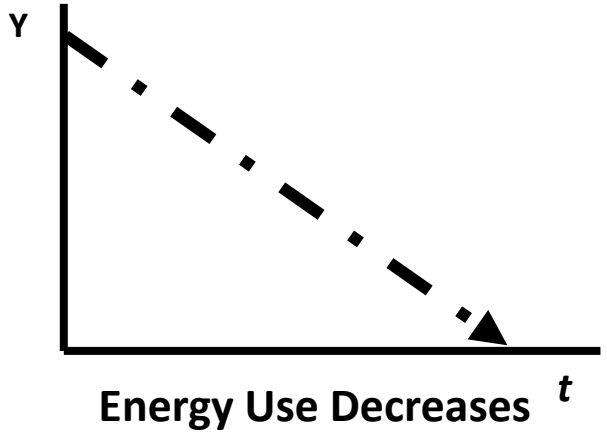
Calculating Energy Use



Ecological Implication

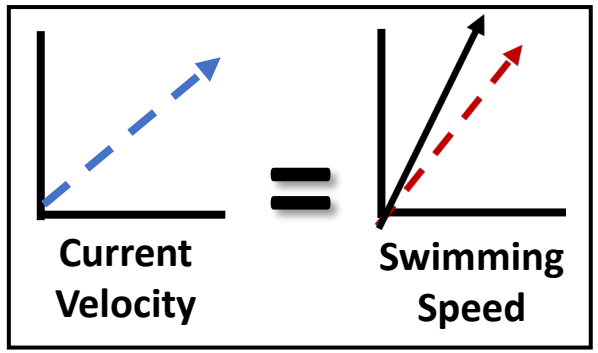
Greater difficulty forces fish to use more energy to maintain movement or balance.





As stress or resistance declines, fish reduce energy use, allowing recovery and longer endurance.

More difficult conditions require more energy to swim, making resistance a key driver of energy use.



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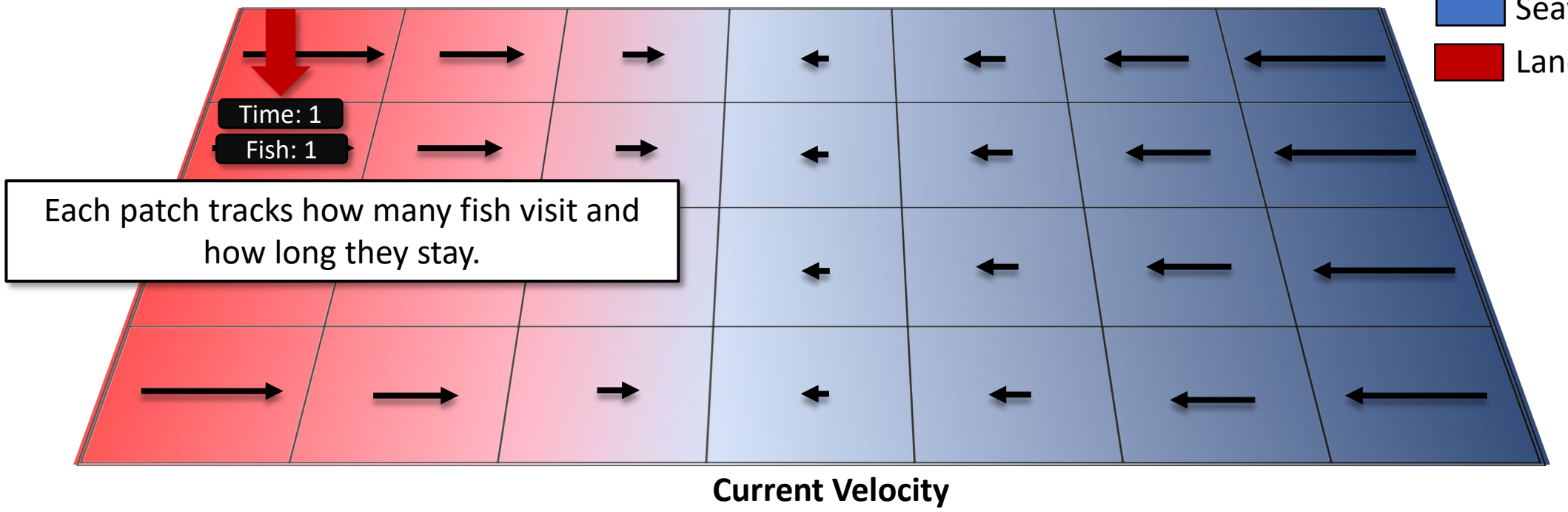
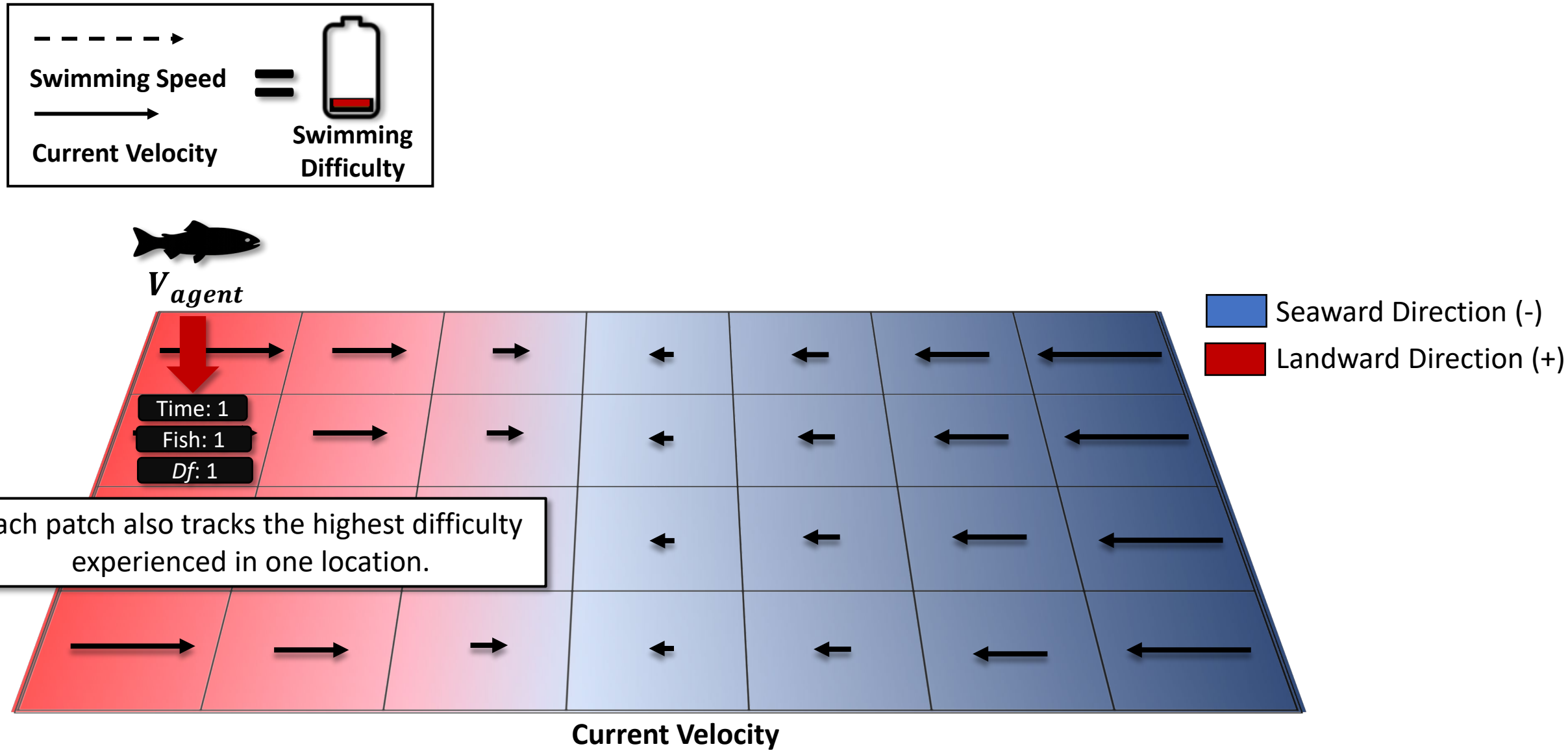
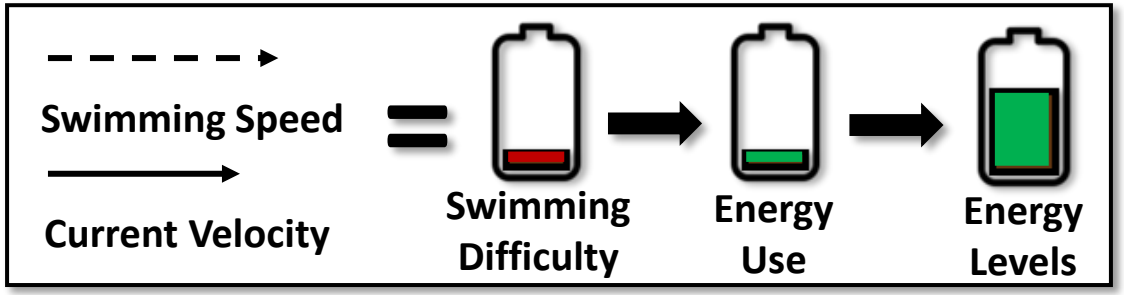
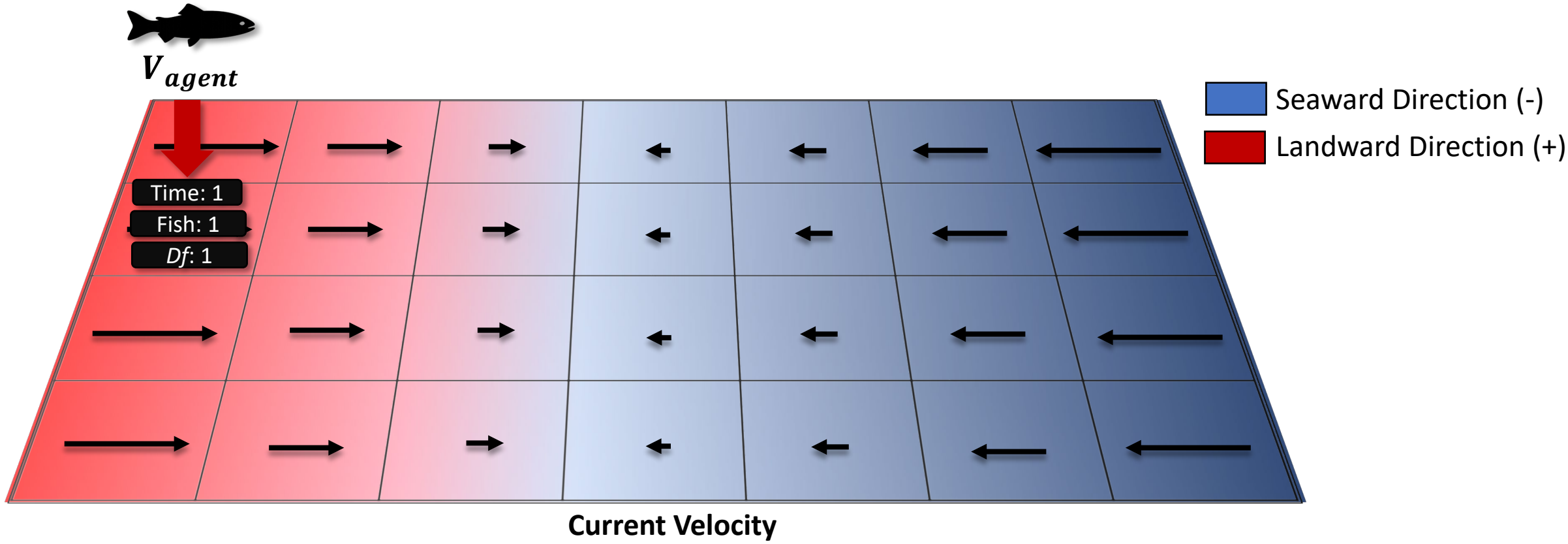


Fish use favorable currents to boost forward movement, increasing their swimming speed with the flow.

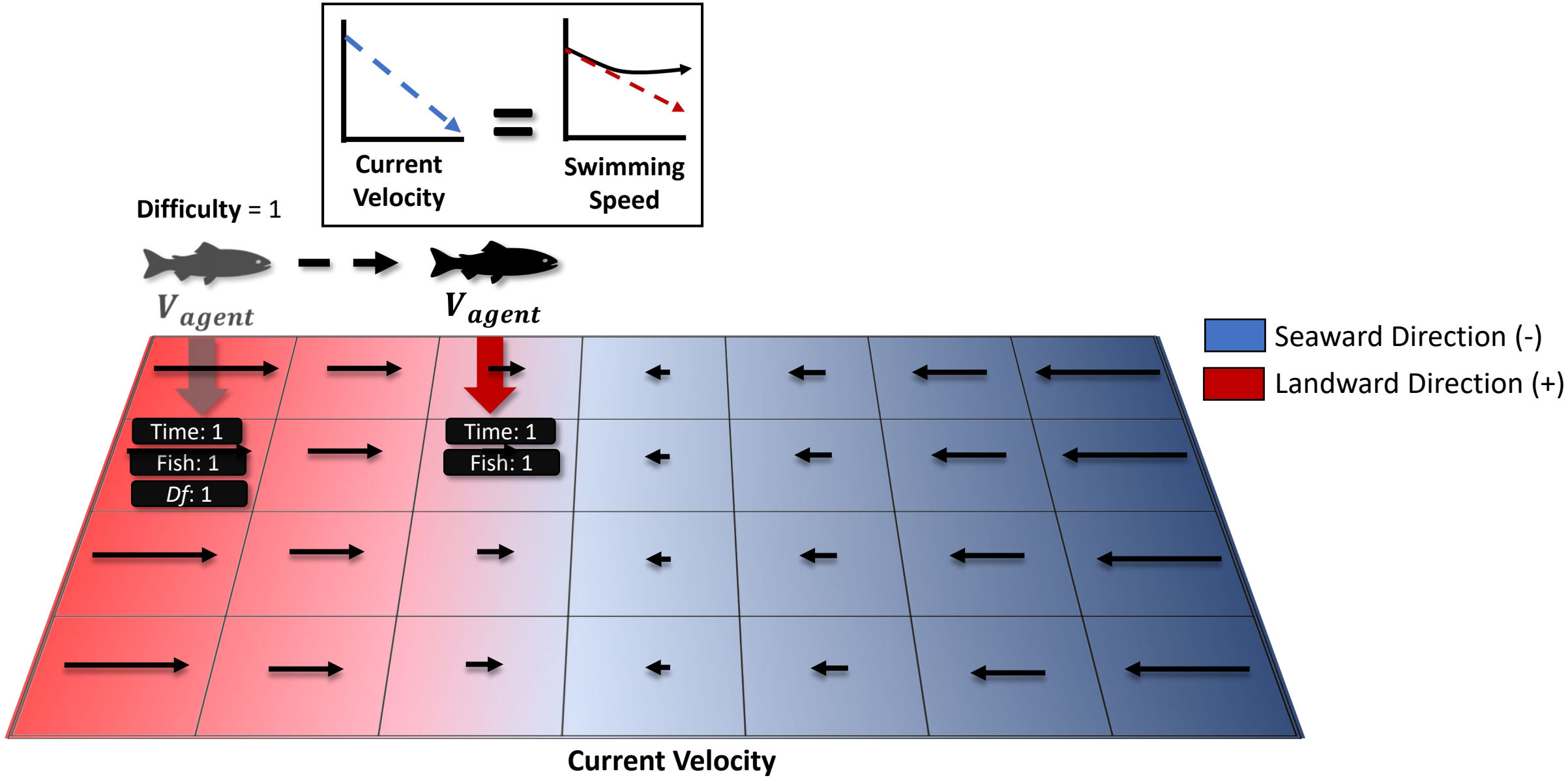


Reduced resistance during favorable flow conditions leads to lower swimming difficulty and improved migration efficiency.

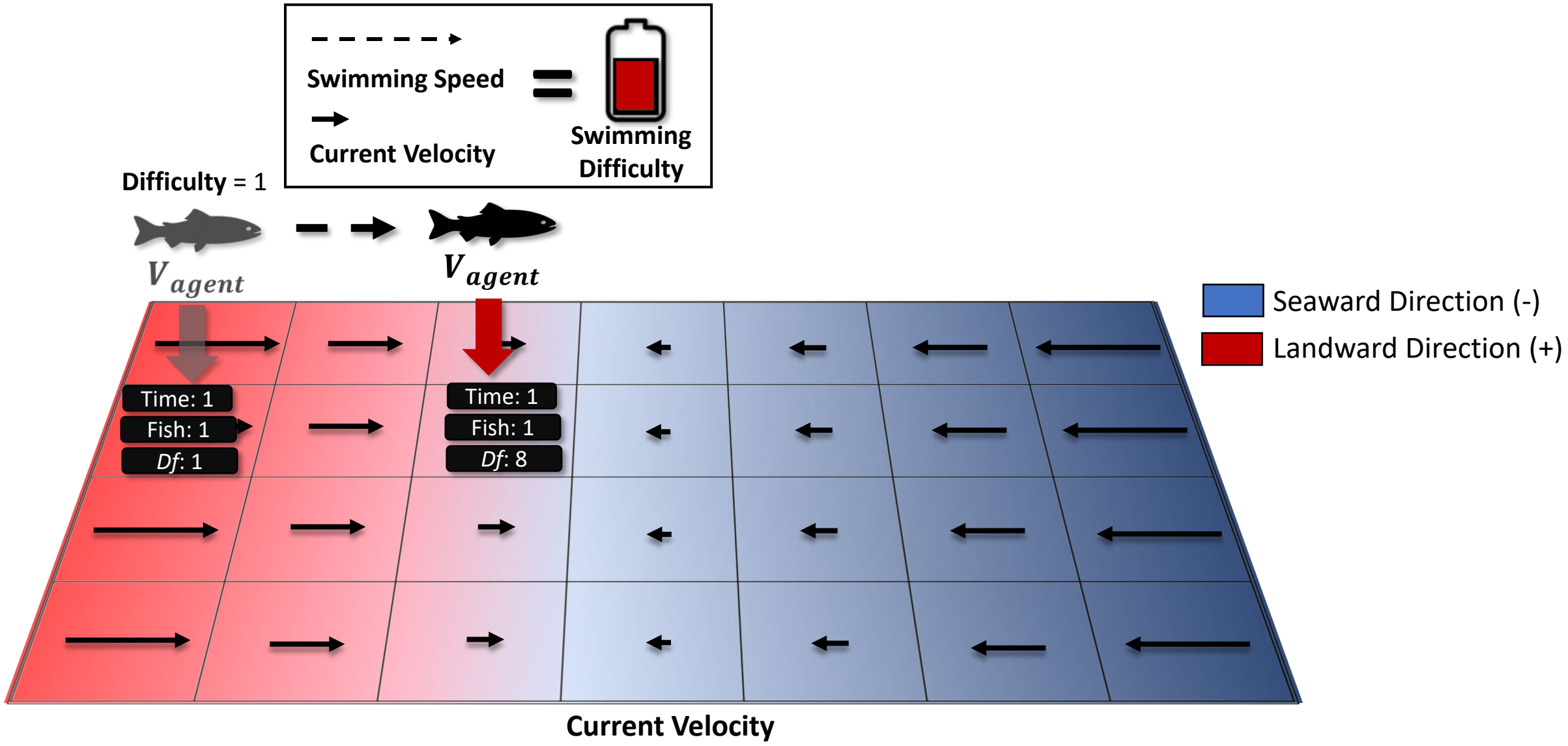




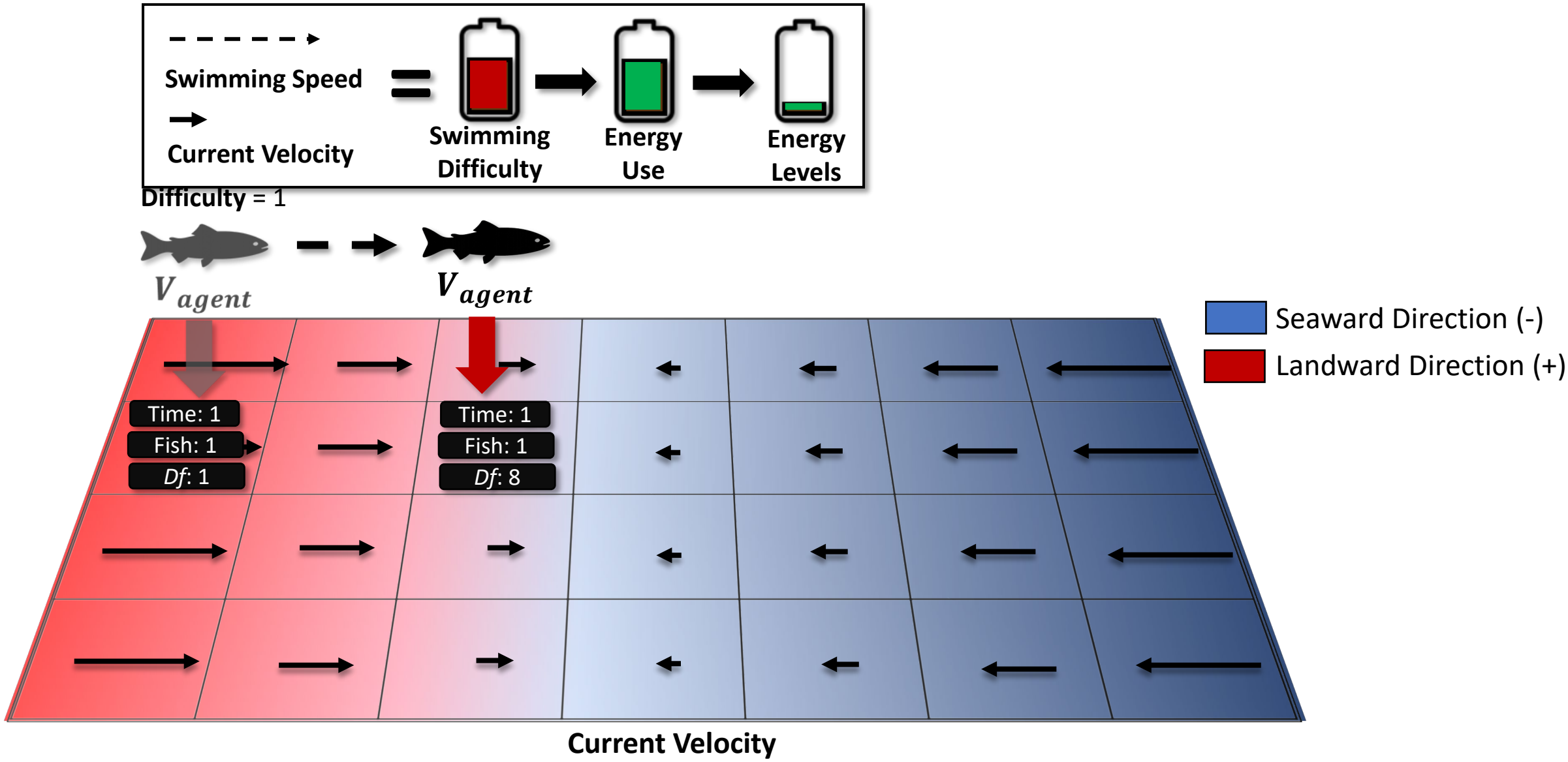
Lower swimming difficulty reduces energy expenditure, making movement energetically beneficial.



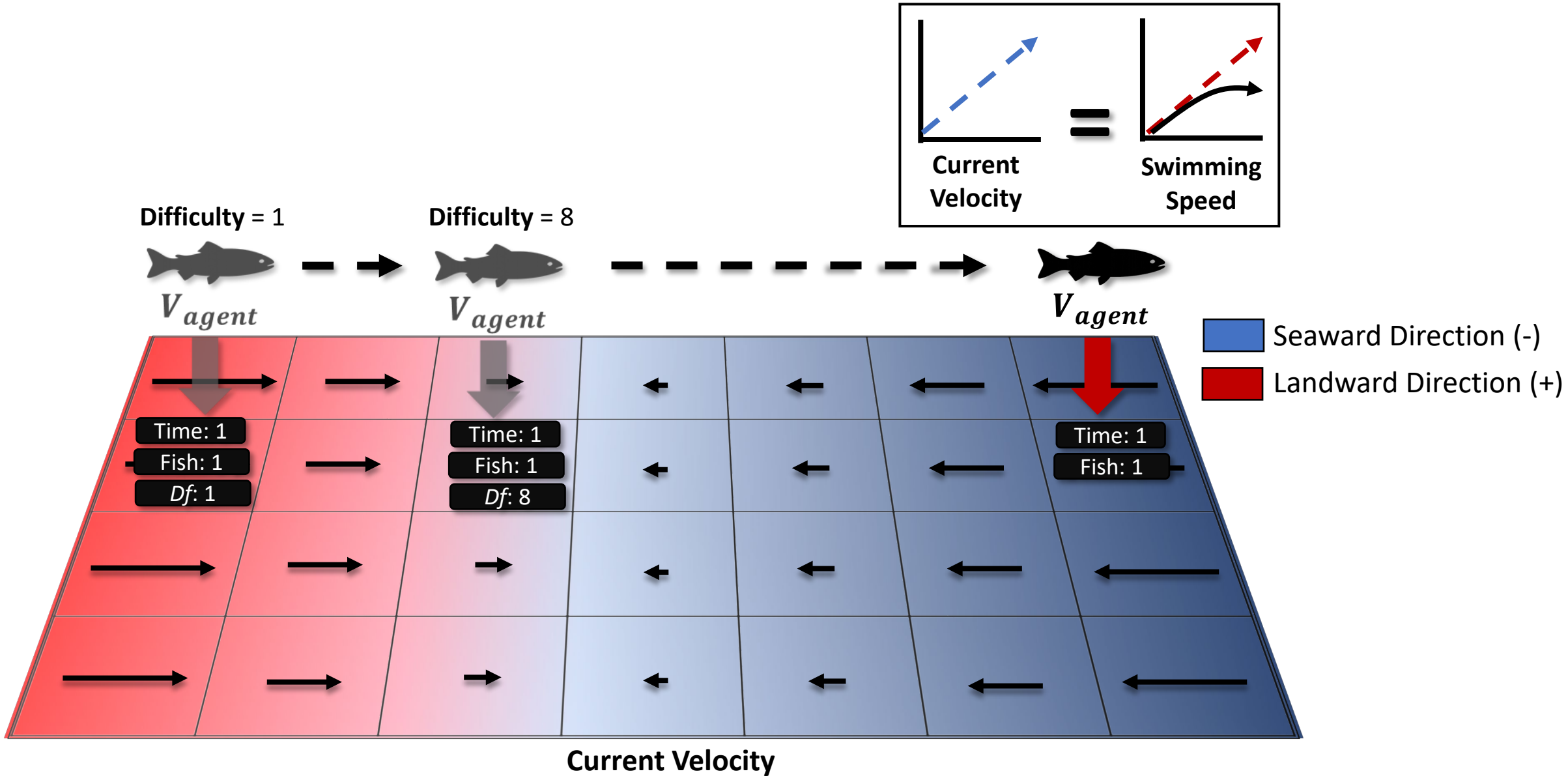
Fish decrease their swimming speed when supportive currents weaken, compensating to maintain migration progress.



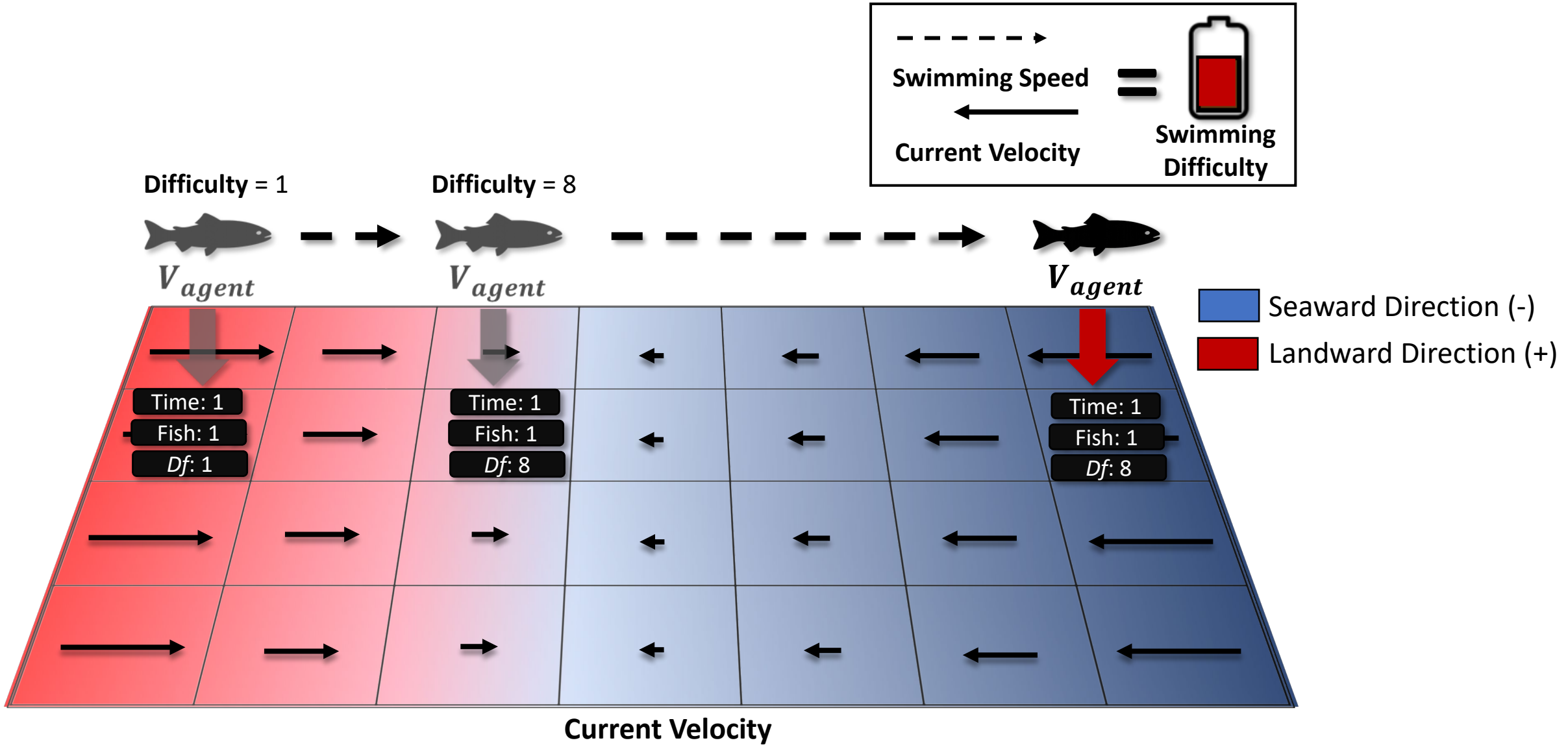
Reduced flow raises swimming difficulty because a fish must rely more on their own effort to continue forward.



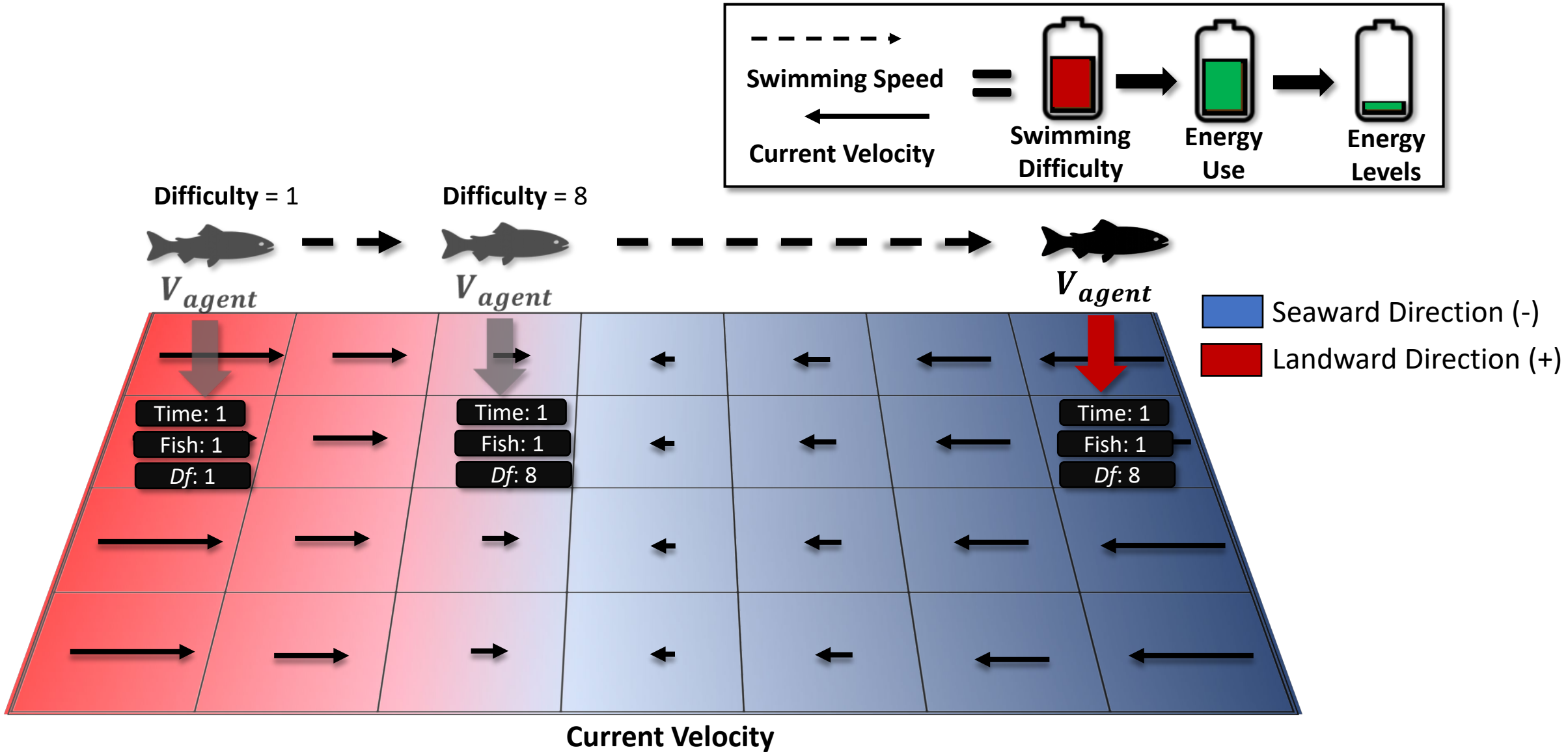
As difficulty rises, energy demand increases, reducing migration efficiency.



Opposing currents force fish to swim faster to overcome resistance.



This raises difficulty, forcing fish to work harder to maintain forward movement.



Energy reserves deplete faster when fish experience high difficulty.

Individual-Specific Traits

Trait Type	Generalization
Energy	Internal reserves used for movement and recovery.
Swimming Speed	How fast a fish can move and if they can overcome current velocity.
Maximum Speed	The upper limit of a fish's swimming ability, constrained by size, age, and species.
Swimming Energy	Energy cost of swimming, scaled by flow difficulty and swimming resistance.

Individual traits like size, age, and species influence a fish's swimming capacity, energy use, and ability to navigate changing flow conditions.

Outputs of Interest

Type	Variable	What It Tells Us
Temporal	Energy	Measures total energy use over time, reflecting migration effort and recovery needs.
	Swimming Difficulty	Tracks difficulty from swimming against or with the current, influencing energy expenditure.
Spatial	Patch-Difficulty	Maps areas with highest swimming difficulty and periods where fish struggle to migrate.
	Time	Shows where fish spend the most time, which may indicate resting zones or movement delays.
	Fish	Visualizes fish distribution by location, helping assess habitat use and crowding.

Model outputs identify where and when swimming becomes most difficult, highlighting zones of high energy demand during fish migration.

Discussion Prompts

1. **Accuracy & Realism**

- Do the swimming patterns and difficulty levels reflect your understanding of how fish move with or against the current?
- Does it make sense that fish would adjust speed based on current direction and strength?

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

- Are there other traits (like homing, spawning condition, or feeding behavior) that could influence swimming behavior?
- Are there environmental drivers (e.g., lunar phase, temperature, salinity) missing that could affect swimming difficulty or route selection?

3. **Outputs of Interest**

- Which outputs would help us understand where or when fish struggle most during migration?
- Are time-based outputs (e.g., time spent in high-difficulty zones) or spatial outputs (e.g., maps of swimming effort or resistance) more useful for understanding migration efficiency?