In Brief . . .

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This report documents the formulation of an individual-based model (IBM) of the cutthroat trout population of Little Jones Creek, Smith River drainage, Del Norte County, in northwestern California. The model is being built as a research joint venture of the USDA Forest Service's Pacific Southwest Research Station, Redwood Sciences Laboratory, and Lang, Railsback, & Associates, using the California Individual-based Fish Simulation System (CIFSS). The CIFSS is a modeling approach and software package for IBMs of stream fish. The main objective of the Little Jones Creek cutthroat trout model is to evaluate the IBM approach for management applications, such as predicting the individual and cumulative effects of timber harvest, water diversion, and habitat alteration on fish populations. The model will also be used to test hypotheses about the mechanisms of habitat selection by stream salmonids over daily and seasonal time scales and evaluate the importance of small tributaries to stream trout populations.

The model uses a number of key features and assumptions, including a 1-day time step for all model processes and a spatial resolution of several square meters. Habitat is modeled as rectangular cells with dimensions typically in the range of one to several meters across the stream and several meters in the longitudinal direction. Stream flow, water temperature, and food availability are the variables driving the model over time; food is the primary limiting resource for trout; and trout have complete knowledge of the mortality risks and food availability in a specific area of surrounding habitat. The model simulates three kinds of objects: habitat cells, fish, and redds (nests created by spawning trout).

We adapted a theoretical approach to IBM from the emerging science of complex adaptive systems. Two key principles of this approach are that IBMs are more powerful if realistic behavior patterns emerge from simple, fitness-maximizing rules for individual behavior; and the modeled behavior of individual fish is more realistic if the fish base their decisions on outcomes predicted over some time horizon instead of on the immediate outcome.

Habitat cells determine their depth and velocity from the daily stream flow rate; this calculation uses a lookup table imported from an external hydraulic model. The popular Physical Habitat Simulation (PHABSIM) and River Habitat Simulation (RHABSIM) hydraulic models can be used to create the lookup tables. Habitat cells also track the availability of food, velocity shelters for drift-feeding fish, hiding cover, and spawning gravel.

The fish in our model conduct four major actions each day:

- Spawning: Adult fish spawn if they meet a number of readiness criteria. Upon spawning, fish find appropriate habitat and create a new redd, with the number and size of eggs depending on the spawner's characteristics.
- Movement: Each fish examines the surrounding area each day and moves to the site with the best accessible habitat. Defining the "best" habitat is crucial and has been a major focus of our research. We assume fish move to habitat offering the highest probability of surviving and growing to sexual maturity over a specified time

horizon (e.g., 90 days). Survival and growth to maturity are functions of habitat-related mortality (e.g., extreme temperatures), predation mortality, and food intake, which affect starvation mortality, and growth.

- Feeding and growth: We simulate energy intake resulting from both stationary drift feeding and active searching for benthic food and overhead drop-in. Intake varies with depth, velocity, turbidity, fish size, food availability, and food depletion by competing fish. Energy costs of swimming also depend on the feeding strategy and the availability of velocity shelters. We assume fish use the more profitable of the two strategies, and calculate growth from energy intake and consumption using standard bioenergetics methods.
- Survival: Daily survival is a function of high temperature, high velocity, stranding by inadequate depth, spawning stress, starvation, and predation. Our predation formulation includes separate functions for terrestrial and aquatic predators, with survival probabilities that vary with depth, velocity, hiding cover, temperature, turbidity, and fish size.

Redds are modeled from when they are created until all eggs have died or emerged as new fish, with the development rate a function of temperature. Redds can suffer egg mortality due to dewatering at low flows, scouring at high flows, high or low temperatures, and superimposition of new redds.