ECOPHYS.FISH: A SIMULATION MODEL OF FISH GROWTH IN TIME-VARYING ENVIRONMENTAL REGIMES

William H. Neill
Texas A&M University
Department of Wildlife and Fisheries Sciences
College Station, Texas 77843-2258 USA
phone: (979) 845-5759 / fax (979) 845-3786/ email: w-neill@tamu.edu

John M. Miller
North Carolina State University
Zoology Department
212 David Clark Laboratories, Campus Box 7617
Raleigh, North Carolina 27695 USA

Robert R. Vega
Texas Parks and Wildlife Department
CCA/CPL Marine Development Center
4300 Waldron Road
Corpus Christi, Texas 78418 USA

Lance P. Fontaine
Texas A&M University
Department of Wildlife and Fisheries Sciences
College Station, Texas 77843-2258 USA

EXTENDED ABSTRACT ONLY - DO NOT CITE

Ecophys.Fish is a model for simulating rates of fish growth in environmental regimes that have simultaneous temporal variation in food, oxygen, temperature, pH, and conductivity/salinity. The purpose of this presentation is to introduce Ecophys.Fish to those who might want to use it as a framework or starting point for applications of their own.

Our model incorporates a quantitatively explicit statement of concepts originally formalized by F.E.J. Fry (Fry 1947, 1971) and subsequently elaborated by Neill and Bryan (1991), among others. Fry's "physiological classification of environment" and "metabolic scope" concept were coupled with conventional bioenergetics to provide the model's theoretical basis. Jointly, the factors of environment determine the animal's metabolic scope, which is the difference between its active (= maximum aerobic) and standard (= obligatory minimum) metabolic rates; metabolic scope is the animal's capacity to perform useful activities like locomotion, feeding, and the physiological processing of food that leads to growth.

Ecophys.Fish's central (and distinguishing) rule is this: Fish eat all appropriate food encountered or until available digestive or metabolic capacities become insufficient to support the processing of more food; the fish then partitions the consumed food energy and substrates in the usual ways (conventional bioenergetics), between various obligatory activities and growth; if obligatory activities cost more than available metabolic scope, the fish loses mass and energy (but does not die). Time-varying food, oxygen, temperature, pH, and conductivity/salinity are accommodated as limiting, controlling, and loading effects on metabolism and, thus, on metabolic scope. Because the present version of the model lacks explicit treatment of swimming and its metabolic costs, it has been expedient to adopt "Winberg's rule": routine metabolism is twice standard metabolism. This leads to a functional definition of metabolic scope for growth as the active metabolic rate less twice the standard rate.

As implemented in STELLA®, the model has two functional modules, metabolism and bioenergetics (Figure 1). The metabolism module has a STELLA subspace for each of Fry's five classes of environmental factors. (At present, the directive-factor subspace is empty; and, consideration of the lethal-factor subspace is beyond the scope of this presentation.) In the loading-factor subspace, the salinity subroutine computes and returns a standard-metabolism intercept, which is multiplied by a function returned by the temperature subroutine in the controlling-factor subspace, and by $Wfish^{-0.2}$, to give standard metabolic rate. Temperature's controlling effect on standard metabolism is modeled as the product of steady-state and transient-state components, reflecting both the Ahrennius effect and thermal acclimation. Both the temperature and pH subroutines in the controlling-factor subspace produce outputs that control weight-dependent active metabolism. These controlling effects are modeled as interactions with the limiting effect of DO, in the limiting-factor subspace. The residual intercept of active metabolism is MMSO, where MMS is marginal metabolic scope (Neill and Bryan 1991). MMSO we interpret to represent inherent metabolic efficiency of the fish-environment system, after the effects of temperature, pH, DO, conductivity/salinity, and fish size have been taken into account. MMS offers a practical measure of "water quality" from the fish's perspective and is relatively easy to determine, via automated routine respirometry (Neill and Bryan 1991).

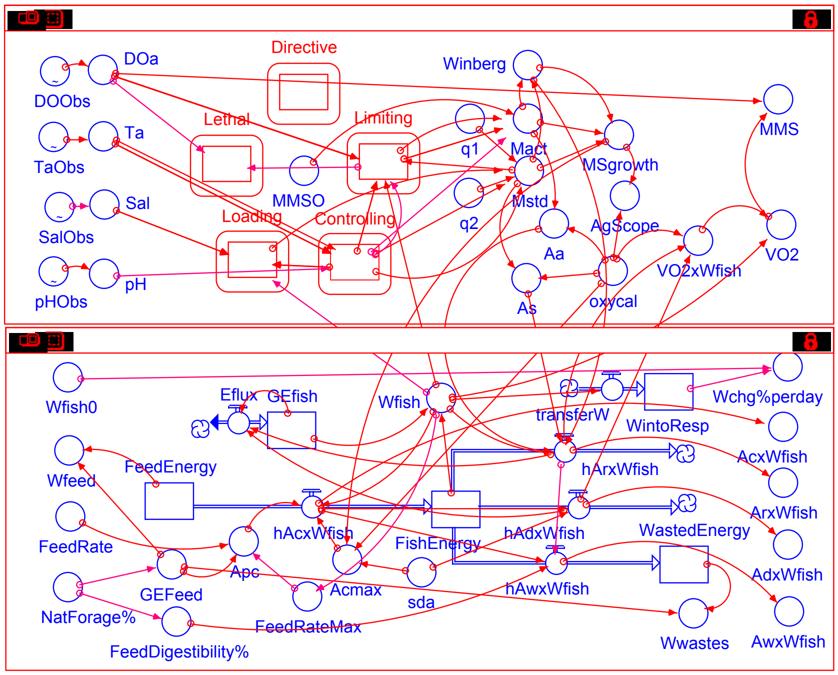

Figure 1. Ecophys.Fish: STELLA model of fish growth in response to ecophysiological factors.

The bioenergetics module reflects conventional "rules of thumb" (Warren and Davis 1967; Brett and Groves 1979), with the above-mentioned addition of a component for metabolic limitation of food intake. Consumed energy is converted to new fish biomass as a residual, after expenditures for standard and routine-activity components of metabolism, SDA (0.15*food energy, for most foods), and wastes (0.15 to 0.35*food energy). Our modeled fish conserves body form, by reducing and increasing caloric density of its tissues (within species-specific ranges) during times of food-energy limitation and surplus, respectively.

The model's inputs are time series of temperature, pH, DO, conductivity/salinity, food availability and energy content, and initial size of fish. Outputs are food consumption, oxygen consumption, waste production, energy-density of fish biomass, and growth.

Indirectly, the output is a measure of relative fitness of the fish-environment system to support fish growth.

Two variants of the STELLA simulation model represent red drum (*Sciaenops ocellatus*) and bluegill (*Lepomis macrochirus*). Ecophys.Fish had its beginnings in lab experiments with juvenile red drum, at Texas A&M; these experiments enabled definition of functions and their parameterization, leading to a working model that accurately simulated growth of red drum in various pond and estuary trials with caged fish (Figure 2). Subsequently, Ecophys.Fish was converted to simulate growth rates

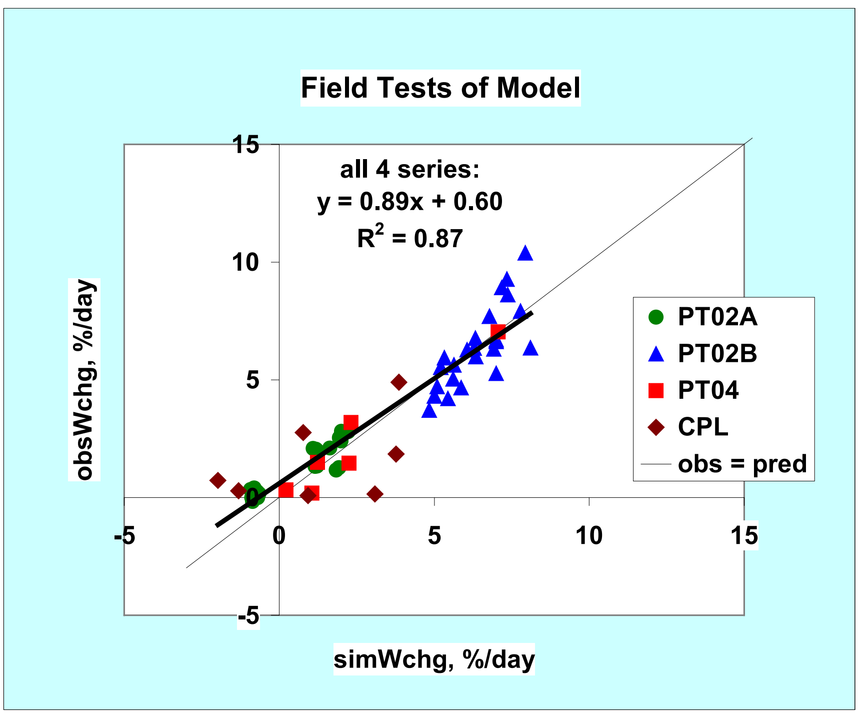

Figure 2. Observed versus simulated growth rates of caged red drum, in four field tests of model.

of caged bluegill involved in stream ecoassays. The latter work confirmed the utility of automated routine respirometry for estimating the model's MMSO parameter empirically.

We have gained confidence in the model to the degree that we now have come to consider deviations between observed and simulated results not so much as evidence of model flaws, as a source of insight into the biological and ecological processes involved in fish growth.

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