Fish Modelling using DEB theory

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Introduction

Oceans, rivers and lakes offer fish environments that are variable in space and time. Movements in these systems, either vertically or horizontally, impose gradients in growth and survival through the effects of temperature, food concentration, sensory capabilities, predatory density and detection risk. Moreover, all large and commercially important marine stocks undertake seasonal horizontal migrations. The extent of these migrations varies with age, size and environmental conditions. Understanding the forces that create spatial distributions of fish is a major challenge to ecology, but also has clear economic benefits to humans, by allowing more precise assessments of managed stocks (Giske *et al.,* 1998). While field studies may reveal patterns at a given time and place and laboratory investigations may isolate effects of single causes, models may combine several forces in continuous space and time.

Fish modelling- *state of the art*

Fish simulation models have been developed for assessment on fisheries and environmental quality management, simulating fish populations using individual-based models (IBMs). IBMs are created on the recognition that individual differ in their characteristics and abilities and that such differences may be important in ecology and population dynamics. These models simulate fish growth in terms of the biomass variation or using energetic based approach. One of the main features of IBMs with regard to spatial distributions has been the recent development of spatially explicit models, which incorporate spatial heterogeneity, individual variability and individual movement. One of the problems of IBMs is that they are little more than a way of accounting for individuals in a population. If IBMs are to become an important tool for explaining the behaviour of individual and populations, models that describe why individuals are motivated for actions are needed. This means that individual actions should be viewed in the light of what evolution is found favourable.

It has been ongoing the development of simulation models of fish behaviour, including fish movement, to predict the fish distribution and the influences of environmental conditions on fish survival. These studies often include a model of the fish biomass growth, dependent on its processes of feeding, respiration and excretion. In fact, environmental conditions affect these processes (directly or indirectly) and so these models consider biological constrains (food quantity and quality, predators of the studied species), system's physical-chemical conditions (*e.g.* bottom material, water temperature, current velocity, depth, dissolved oxygen, salinity, turbidity) and human-related stress (*e.g.* fishing, pollution).

DEB models use differential equations to describe the rates at which individual organisms assimilate and utilize energy from food for maintenance, growth and reproduction. Since these rates depend on the state of the organism (*e.g.* age, size, sex, nutritional status) and of environmental variables (*e.g.* food density, temperature), solutions of the DEB model equations represent the life history of individual organisms in a potentially variable environment.

DEB theory inspired models could be coupled to a fish-movement-model, with a lagrangian approach, dynamically simulating changes in functional response due to the knowledge of spatial and temporal food distribution. With a hydrodynamic model to provide existing flow directions (Miranda *et al,* 1999), one could use DEB model to create a powerful tool to manage fishing practices.

DEB Models for fish

As mentioned before, Dynamic Energy Budget (DEB) models describe the dynamics of how an individual organism acquires energy and utilizes it for physiological processes related to maintenance, growth and reproduction. DEB models are based on simple assumptions about the rates at which the organism acquires energy from its environment, and rules that describe how acquired energy is partitioned among maintenance, growth and reproduction. The fundamental hypotheses underlying a DEB model is that a set of physiological state variables (age, size, energy reserves, etc.) together with environmental variables (food density, temperature, etc) fully determine the life history of individuals.

There are two contrasting model formulations based on dynamic allocation rules that have been widely used (net production and net assimilation formulations) (Lika & Nisbet, 2000). The most complete body of theory for DEB models exists for a net assimilation model developed by Kooijman (2000). He formulated a single, parameter sparse, mechanistic model to describe the energetics of embryos, juveniles and adults. Species differ only in parameter values. Embryos differ from juveniles and adults in the way they acquire energy; juveniles and adults acquire energy from the ambient food, whereas embryo absorbs energy from the yolk, which is taken to be its environment. Juveniles differ from adults since they do not reproduce, whereas adults do.

Nevertheless, for fish, the juvenile stage must be separated in two to accommodate the larval stage. Nearly all bony fishes, especially marine ones, have a pelagic larval stage which is morphologically very different from the juvenile. In general, these larvae live in different places than the juvenile, have different behaviours, eat different foods and have different predators. During this larval phase, the fish develops from little more than an egg with a tail to a miniature adult with all organs fully operational. In addition, many species have highly specialised larval morphologies, with various structures such as strong spines on the head that are modified or lost upon metamorphosis.

Therefore, the larval stage can be seen as an intermediary state between eggs (embryo) and juvenile, but the change in shape from larvae to juveniles is too important to be negligible. Changes in shape affect the relationship between the maximum specific assimilation rate and the structural biomass. In addition, transition from larvae to juvenile stage enables real swimming, allowing a more effective search for food and escape from predators. This way more energy can be spent searching for food, but, on the other hand, food items encountered can have higher energetic value per structural biomass. This means that the gain from this transition can be merely in the reduced predatory pressure.

The extra effort of swimming should depend on the water velocity intensity and direction, as well as on the fish velocity, and can be inputted into maintenance costs.

One issue remains to be further investigated. It is known that some species of fish migrate to special places for reproduction, canalizing their total efforts in the journey. In the case of salmon, this occurrence is so extreme that they die after reproduction in upstream part of rivers. The fact that this phenomenon – motivation for displacement – is still not well understood hinders the evolutionary aspects of a coupled model.

Conclusion:

DEB theory gives a general ecological model, and some effort must be made to specify it to a particular species or ecosystem. In the case of fish models, some modifications must be made. These sorts of biological models, which can be regarded as zero dimensional, gain extra interest when coupled with a physical model that supplies the environmental variables.

DEB theory has the advantage of incorporating several environmental variables from the physical model, usually not accounted by usual growth models, and providing population fitness capacities to the fish movement model. These explicit relationships can help unveil poorly understood processes.

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