

## Movement index

SEAPODYM simulates the passive transport of tuna larvae and juveniles by oceanic currents in the epipelagic layer. On the other hand, young and adult tuna move voluntarily, with a swimming speed proportional to their size and the adult habitat index gradient. This movement is linked to a maximum sustainable speed  $V_{max}$  expressed in body lengths per second. For older age classes with voluntarily movement, as in conventional chemotaxis models (Keller and Segel, 1971; Czaran, 1998; Turchin, 1998), the velocity field  $V_a$  is proportional to the gradient of the quality of adult habitat.

$$V_a = X_a \left( \frac{\partial I_a}{\partial x}, \frac{\partial I_a}{\partial y} \right)^T$$

where the taxis constant  $X_a$  is proportional to  $V_{max,a}$  which is inversely related to the average size at age (Malte *et al.*, 2004):

$$V_{max,a} = V_m \left( 1 - \eta \frac{l}{l_k} \right)$$

where the parameter  $\eta = 0.1$  implies a small negative slope. We assume that individuals will tend to stay longer in the presence of favorable conditions (low diffusion) but will want to escape quickly from unfavorable habitats (high diffusion), thus diffusion values should be linked to habitat condition. According to the type of habitat, the maximum diffusion coefficient in the null habitat, extremely unfavorable (Turchin, 1998) is  $D_{max} = R^2/4t$ . We can also assume that an individual will cover the maximum distance at maximum speed  $V_{max}$  during the time  $t$ , the upper estimate of the diffusion coefficient is  $D_{max} = V_{max}^2 t / 4$ ; thus, in each habitat, the diffusion coefficient changes according to:

$$D_a = D_{max} \left( 1 - \frac{I_a}{c + I_a} \right) (1 - \rho |\nabla I_a|)$$

where  $c$  is the coefficient of variability of fish diffusion rate with habitat index. The expression  $(1 - \rho |\nabla I_a|)$  with  $\rho < 1$  balances diffusive and active movements assuring that both movements do not exceed the distance cover at maximum speed.

The movement index  $I_a$  includes the migration seasonality for those age classes exhibiting such behavior due to environmental variability. For young immature age classes, the habitat can be described by the feeding index, while for mature adults, the index must include the migration toward favorable spawning grounds due to daylight length changes. Based on the assumption that adult tuna tend to move to places with environmental conditions similar to those occurred during their birth (Cury, 1994), we reproduce the seasonal change by switching the movement index from the feeding habitat to the spawning habitat using a threshold value as a triggering effect:

$$I_a = \frac{H_{F,a}}{1 + e^{\kappa(\hat{G} - d - \hat{G})}} + \frac{H_S}{1 + e^{\kappa(\hat{G} - \hat{G} - d)}}$$

where  $H_{F,a}$  is the feeding habitat index (Link: Feeding\_habitat\_index\_html.doc) for the age class  $a$ ,  $H_S$  is the spawning index (Link: Spawning\_habitat\_index\_html.doc),  $\kappa$  is a large constant producing abrupt shift between feeding and spawning indices and  $\hat{G}$  is the triggering value for the daylight gradient. It is important to point out that the switching occurs earlier for species in higher latitudes, far from their spawning grounds in warmer waters (Figure 1). In low latitudes, the day-length

gradient is too low to have any effect; therefore, the adult habitat is always driven by the feeding habitat, leading to opportunistic reproduction.

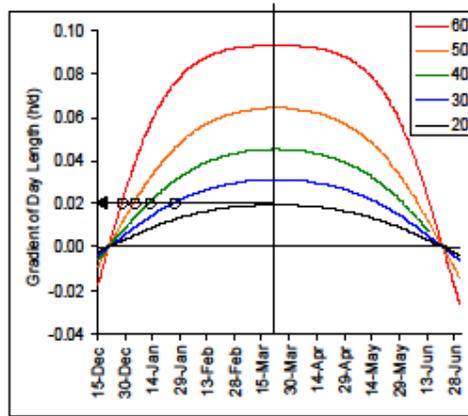


Figure 1. Example of seasonal cycles in gradient of day length at different latitudes in the North hemisphere. With a threshold set above 0.02 hours per day, the adult habitat constraining the fish movement will switch from feeding habitat to spawning habitat at the end of December for mature fish at latitude 60, and one month later at latitude 30. Movement of fish at latitude below 20 remain always driven by the feeding habitat.

## References

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