# CABM (C++ agent based model)

CABM expresses a fish stock as a collection of spatially referenced agents within a discrete spatial domain withcells. Agents in spatial cell are denoted by the set , where is the number of agents in cell . An individual agent denoted by is also a set where each element in is an agent attribute outlined in Table.

Table 1: Attributes recorded for all agents, where .

|  |  |
| --- | --- |
| Index | Description |
|  | Age (integer) |
|  | Length (continuous) |
|  | Length bin (integer) |
|  | Maturity (Boolean) |
|  | Sex (Boolean) |
|  | Weight (continuous) |
|  | Scalar = number of individuals |
|  | Natural mortality |
|  | Von Bertalanffy growth parameter |
|  | Natal cell (birth cell) |
|  | Current cell |
|  | Cartesian coordinate within the spatial domain |

Agent dynamics are functions responsible for modifying agents (growth), moving agents, creating agents (recruitment) and deleting agents (mortality). The inputs for these functions use both agent specific attributes (Table) and assumed parameter values. Agent dynamics are predominately stochastic, where agent actions are based on a randomly generated realisation from a random variable. For example, a dynamic that results in a binary outcome for an agent (e.g., an agent getting caught by a fishing interaction or an agent maturing) can be expressed by the Bernoulli random variable , where is the probability of an event occurring

Agent dynamics generally iterate over a collection of agents and for each agent, they apply an outcome based on a realisation from a random variable. The following example demonstrates the notation used when describing how an agent dynamic applies an event to all agents in cell

where denotes the ith agents () specific probability of the event occurring. This is the result of the function which uses agent attributes and parameters . denotes the Bernoulli distribution.

The agent dynamics described in the following sections define as a function of specific agent attributes (Table ). In all descriptions in is replaced with the specific agent attribute. For example, if was a function of an agent's length (), it would be defined as,

Agent Dynamics

## Ageing

Ageing is an implicit process in the model, each agent that is created or recruited gets assigned a birth year. The age of an agent is a calculation

Age = Current year – birth year

thus there is no explicit ageing dynamic occurs in CABM. Note that if age > max age the max age is returned. This is done for a coding convivence, often C++ objects are indexed by age and so age-specific containers will have a plus group.

This results in every agent automatically ageing by one at the end of the year, or you could think of ageing an agent at the very beginning of the year (tomayto, tomahto), just be aware that you don't have control over this process. Another consideration is that growth (link to section) is not directly tied with ageing, that is, an agent that ages one year does not also get a years’ worth of growth. This in unlike most partition-based models that will have an implicit assumption of growth with ageing. Although if one puts a growth process at the beginning or end of an annual cycle this can be achieved. This is just a side note to keep in mind when trying to align CABM to be consistent with other estimation models.

## Maturity

The process of converting an agent from immature to mature, only should be used if you have mature-biomass derived quantity (Section). This process changes the internal state of an agent i.e., no material change happens to the agent except . This could be useful down the track if we have dynamics that only occur to mature agents and so this internal flag can be checked against for use in a different algorithm. Maturity is applied using the ogive defined in the subcommand *maturity\_ogive\_label* in the @model block, and is applied for a single agent (assuming the agent is not already mature)

Maturity is applied to agents in cell at time-step following

where, is the probability of an immature agent at age becoming a mature agent, defined by the selectivity . Currently maturity can only be an age-based process, although this is not difficult to make a length based probability statement if someone in the future wanted this. A note about creating a logistic based maturity schedule. We recommend users use the selectivity *logistic\_producing* (Section) or a similar style of selectivity. The results will not be as expected if you use a normal logistic selectivity. This is because this is only applied to the non-mature agents and so the selectivity needs more thought than other situations.

An alternative way and perhaps more efficient method for capturing a snap shot of the mature biomass or abundance of all individuals in the population is by using the generic biomass or abundance derived quantities (Section ). Where we calculate mature agents at the time of the derived quantity, rather than having an explicit process that allows users to separate the maturation process from the summarising of abundance of biomass of the mature component.

## Recruitment

Recruitment is the process where new agents are created in the system. It is also the process that defines stock structure in the model. Stocks are not an explicit attribute of CABM so consideration on this process is important. How the stock is defined using the recruitment dynamic surrounds where we calculate Spawning Stock Biomass (SSB) and where the resulting recruits are first seeded. This means that for all recruitment types you will need to specify a or parameter and an associated derived quantity that defines the spatial resolution of the stock (SSB) for that event.

We have taken the parametrisation akin to that is a population-based formula (Mace & Doonan, 1988). There is scope to make this a “purer” agent-based model where we look at probability of finding a mate and etc, but for now this is all we have.

where is the compensation parameter known as the steepness parameter that represents the number of agents when the stock SSB is at 20% of , is the year class strength parameter also termed the stock recruitment residual that accounts for any deviation of the deterministic Beverton Holt relationship due to things like predation, environment etc. If there are multiple spatial cells that are associated with a recruitment event, then the allocation to a single cell is a simple multiplication with a proportion e.g.

where is the resulting agents in cell with proportion there is no stochastic behaviour in this process unlike other processes.

## Spawning stock biomass

The method for calculating SSB for and was the same and is shown below for

Where, Is the mature selectivity ogive.

## Growth

Growth is the agent dynamic responsible for changing an agent's length and weight over time. Length and weight are commonly used as inputs to other agent dynamics or used when calculating stock level quantities, i.e. spawning stock biomass. When an agent is created via the recruitment dynamic, it is assigned a growth parameter from a population level distribution. There are two growth models available in CABM, the Von Bertalanffy and generalised Schnute growth model. The Von Bertalanffy is described below

When the Von Bertalanffy growth model is assumed, each agent is assigned an asymptotic length parameter denoted by from the following normal (can also be lognormal)l distribution

where CV denotes the coefficient of variation, and is the population mean asymptotic length

When growth is specified in the annual cycle for time step , CABM will iterate over all agents and increment each agent's length following

Where is the global growth coefficient, is the ith agent’s length in time-step and denotes the proportion of annual increment to be added in time-step .

The growth dynamic changes an agent’s weight after changing its length using the following allometric length-weight relationship,

where and are length weight coefficients which are equal for all agents in the system.

## Movement

Agents move around the domain using a box-transfer dynamic. Each movement process has an assigned selectivity

If the movement dynamic is applied to the agent (), we use the multinomial random variable to assign the new cell the agent is move based on the user specified movement probabilities . is a dummy vector filled with zeros and a single 1 value which indicates the cell an agent will move to

## Fishing

Fishing processes remove agents from the model. There are a range of different mortality processes, the most common are Baranov and exploitation

The Baranov catch equation was used to apply fishing mortality (F) to agents over time. Annual values of F are required for each fishery, denoted by along with an assumed selectivity for each fishery denoted by . If all selectivity’s are age-based CABM calculates an annual F by age as

In addition to an annual F, the probability of an agent being caught by fishery at age is defined as

Fishing iterates over all agents and applies the following

If an agent dies from fishing it is then assigned to a specific fishery using a multinomial distribution denoted by the indicator variable , where denotes the number of fisheries.

Where, is the probability that an agent with age . If is assigned a 1, the agent is assigned to the fishery. This agent will contribute to reported catch and compositional observations for this fishery.

# Initialisation

CABM calculates the number of individuals that an agent represents during initialisation. It is derived following,

where, is the age, is the minimum age, is the maximum age, is the initial natural mortality rate is the average number of individuals expected in the absence of fishing and is the number of agents assumed from the users to model the initial stock. The choice of is a tradeoff between model run time and agent resolution of the stock. As increases CABM moves towards an IBM () but this comes at computational cost and larger model run times.

Once CABM calculates , it creates the number of agents for the first age (). This is calculated as

When agents are created, they are also assigned agent attributes based on their age and agent specific attributes. The above actions from CABM assume an equilibrium age-structure of agents in each cell, but ignore movement and other dynamics that may affect starting conditions. To account for these dynamics, CABM then iterates over the annual cycle without fishing dynamics for a user defined number of cycles denoted by . This populates the agents around the spatial domain according to the annual cycle assumptions.

# References

Mace, P. M., & Doonan, I. J. (1988). *A generalised bioeconomic simulation model for fish population dynamics*.