CMFRI

Winter School on

Towards Ecosystem Based Management of Marine Fisheries – Building Mass Balance Trophic and Simulation Models

INFORMATION ONLY

Compiled and Edited by

Dr. K.S. Mohamed, Director, Winter School & Senior Scientist,
Central Marine Fisheries Research Institute [CMFRI],
PO Box 1603, Cochin – 682018, Kerala
ksmohamed@vsnl.com

Technical Notes

20

OVERVIEW OF COMPUTER SIMULATIONS

T.V. SATHIANANDAN
RC of Central Marine Fisheries Research Institute, Chennai

Computer simulation is the discipline of designing a model of an actual or theoretical physical system, executing the model on a digital computer, and analyzing the execution output. Simulation embodies the principle of ``learning by doing'' - to learn about the system we must first build a model of some sort and then operate the model. The use of simulation is an activity that is as natural as a child who role-plays. Children understand the world around them by simulating (with toys and figurines) most of their interactions with other people, animals and objects. As adults, we lose some of this childlike behavior but recapture it later on through computer simulation. To understand reality and all of its complexity, we must build artificial objects and dynamically act out roles with them. Computer simulation is the electronic equivalent of this type of role-playing and it serves to drive synthetic environments and virtual worlds.

Simulation definitions:

- A representation of an item of equipment, device, system, or subsystem in realistic form. Simulation enables the learner to experience the operation of the target item without possibility of destroying it.
- "The process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system".
- The process of conducting experiments with a model (an abstraction or simplification) of an item, within all or part of its operating environment, for the purpose of accessing its behavior under selected conditions or for evaluating various strategies for its operation within the limits imposed by developmental or operational criteria.
- "a simulation is a software package (sometimes bundled with special hardware input devices) that re-creates or simulates, albeit in a simplified manner, a complex phenomena, environment, or experience, providing the user with the opportunity for some new level of understanding. A simulation is based on some underlying computational model of the phenomena, environment, or experience that it is simulating.
- The imitative representation of the functioning of one system or process by means of the functioning of another.
- A technique for solving complex problems that is not amenable to solution using formal analytical techniques. Essentially simulation consists of a representation of a system or organization by means of a model and then analyzing the behavior of the system under various possible operational conditions or assumptions through repeated manipulation of the model.
- The use of a model system, e.g., a mathematical model or an animal model, to approximate the action of a real system, often used to study the properties of a real system.

- ✍ The use of models and logic tools to test the outcomes of a proposed group of inputs and processes, prior to or in place of their implementation in a live system.
- ✍ A simulation is an experiment run as a model of reality. The simulations are run on a computer using mathematical models. They are also stochastic, that is they involve input generated to follow probability distributions.
- ✍ The examination of a problem often not subject to direct experimentation or analytical solution- most often by the use of a computer.
- ✍ The technique of representing the real world by a computer program; "a simulation should imitate the internal processes and not merely the results of the thing being simulated".
- ✍ The act of imitating the behavior of some situation or some process by means of something suitably analogous (especially for the purpose of study).

Within the overall task of simulation, there are three primary sub-fields: model design, model execution and model analysis. To simulate something physical, you will first need to create a mathematical model, which represents that physical object. The next task, once a model has been developed, is to execute the model on a computer - that is, you need to create a computer program which steps through time while updating the state and event variables in your mathematical model. There are many ways to ``step through time." You can, for instance, leap through time using event scheduling or you can employ small time increments using time slicing. You can also execute (i.e., simulate) the program on a massively parallel computer. This is called parallel and distributed simulation. For many large-scale models, this is the only feasible way of getting answers back in a reasonable amount of time.

Simulation of a system can be done at many different levels of fidelity so that whereas one reader will think of physics-based models and output, another may think of more abstract models, which yield higher-level, less detailed output as in a queuing network. Models are designed to provide answers at a given abstraction level - the more detailed the model, the more detailed the output. The kind of output you need will suggest the type of model you will employ.

Why do Simulation?

You may wonder whether simulation must be used to study dynamic systems. There are many methods of modeling systems which do not involve simulation but which involve the solution of a closed-form system (such as a system of linear equations). Simulation is often essential in the following cases:

1) the model is very complex with many variables and interacting components;
2) the underlying variables relationships are nonlinear;
3) the model contains random variates;
4) the model output is to be visual as in a 3D computer animation.

The power of simulation is that, even for easily solvable linear systems, a uniform model execution technique can be used to solve a large variety of systems without resorting to a ``bag of tricks" where one must choose special-purpose and sometimes-arcane solution methods to avoid simulation. Another important aspect of the simulation technique is that one builds a simulation model to replicate the actual system. When one uses the closed-form approach, the model is sometimes twisted to suit the closed-form nature of the solution method rather than to accurately represent the physical system.

Simulating Random Variables: In any area of research the variable we are interested in will be mostly of stochastic in nature. These variables, known as random variables, will follow some probability distributions such as Binomial, Poisson and Normal. The first two are of discrete type and the last is continuous type. When we study two related variables together, we may have to use bivariate normal distribution for generating these random variables together. In simulation studies we will have to simulate such random variables – other wise known as sampling from a known probability distribution. Different methods are available for simulating such random variables and one method each is given below for these probability distributions.

Uniform Random Number Generation: Random number generation is a vital part of any simulation experiment. We may have to generate random variables having specified probability distributions with known parameter estimates. The basis for generation of such random variables is mostly on uniform random number generation especially that between 0 and 1. Wichmann and Hill (1982) presented an algorithm for generating Pseudo-random numbers between 0 and 1 and this is described below.

1. Use three random seeds between 1 and 30,000 say S_1, S_2 and S_3 (to be used only once).
2. Recalculate these values as

$$S_1 \ ? \ \ 171 ? \mathrm{mod}(S_1, 177) \ ? \ 2 ? \mathrm{int}(\frac{S_1}{177})$$

$$S_2 \ ? \ \ 172 ? \mathrm{mod}(S_2, 176) \ ? \ 35 ? \mathrm{int}(\frac{S_2}{176})$$

$$S_1 \ ? \ \ 170 ? \mathrm{mod}(S_3, 178) \ ? \ 63 ? \mathrm{int}(\frac{S_3}{178})$$

3. When the recalculated values are negative, reset them as

$$S_1 \ ? \ \ S_1 \ ? \ 30269$$
$$S_2 \ ? \ \ S_2 \ ? \ 30307$$
$$S_3 \ ? \ \ S_3 \ ? \ 30323$$

4. Compute the random number as

$$R \ ? \ \frac{S_1}{30269} \ ? \ \frac{S_2}{30307} \ ? \ \frac{S_3}{30323}$$

5. The required uniform random number between 0 and 1 is then obtained as

$$X \ ? \ R \ ? \ ?R?$$

6. Repeat steps 2 to 5 for generating another indepentent uniform random number between 0 and 1.

Simulating Binomial random variable: There are many methods available in literature for the generation of binomial random variables. The geometric method given by Devroye and Naderisamani (1980) is as followed.

Suppose *n* and *p* are the known parameters using which we have to generate a binomial random variate.

1. Set $y \ ? \ \ 0, \quad x \ ? \ \ 0$ and $c \ ? \ \ \ln(1 \ ? \ p)$
2. If $c \ ? \ 0$ then the generated variate is $x \ ? \ 0$
3. Generate a uniform random number *u* between 0 and 1.

4. Set $y ? \ \ y ? \begin{matrix} ?\ln(u)? \\ ?\overline{\ \ c\ \ }? \end{matrix} ? 1$ where the notation $?s?$ denotes the integer portion of *s*.
5. If $y ? n,$ set $x ? \ \ x ? 1$ and go to step 3.
6. Return the generated random variate *x*.

Simulating Poisson random variable: To simulate a Poisson random variable with known parameter $?$, one of the methods is as followed.

1. Set the counter $n ? \ \ 0$
2. Set the product $Z ? \ \ 1$
3. Generate an independent uniform random number u_n between 0 and 1.
4. Set the counter $n ? \ \ n ? 1$
5. Update the product $Z ? \ \ Z ? u_n$
6. Compare the product $Z ? e^{?}$ and if it is true go to step 3.
7. Return the random variable as $X ? n ? 1$

Simulating Normal random variable: To generate a Normal Random Variable with specified mean $?$ and standard deviation $?$ the procedure is as followed.

1. Generate two independent uniform random numbers u_1 and u_2 between 0 and 1.
2. Compute the quantities *X* and *Y* as given below which will be distributed as independent standard normal variates

   $X ? ?2\ln(u_1)\, Cos(2? u_2)$

   $Y ? ?2\ln(u_1)\, Sin(2? u_2)$
3. Generate the required normal random variate as

   $Z ? ? ? X?$ or

   $Z ? ? ? Y?$

Simulating Bivariate Normal random variables: To generate random varaiates with bivariate normal distribution having specified mean vector and dispersion matrix the procedure is as followed.

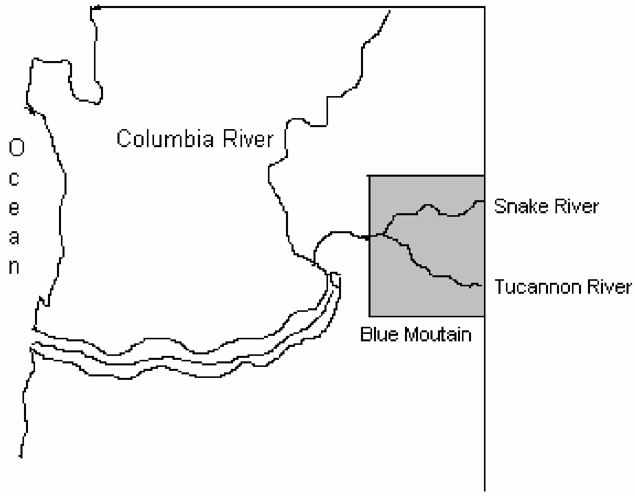
1. Suppose $? ? \begin{matrix} ??_1? \\ ? \quad ? \\ ??_2? \end{matrix}$ is the required mean vector for the bivariate random variable and

   $? ? \begin{matrix} ? & ?_1^2 & ??_1?_2 & ? \\ ? & & & ? \\ ? & ??_1?_2 & ?_2^2 & ? \end{matrix}$ the dispersion matrix where $?$ is the correlation coefficient between the variates x_1 and x_2 and $?_1, ?_2$ the respective standard deviations.
2. Generate two independent standard normal variates $?z_1, z_2?$.
3. Compute the required quantities x_1 and x_2 having bivariate normal distribution as

   $x_1 ? ?_1 ? ?_1 z_1$ and

   $x_2 ? ?_2 ? ?_2 [? z_1 ? (1 ? ?)\, z_2$

<u>Example (Systems analysis & Simulation)</u>: The system considered here is the Chinook salmon population in Tucannon river.



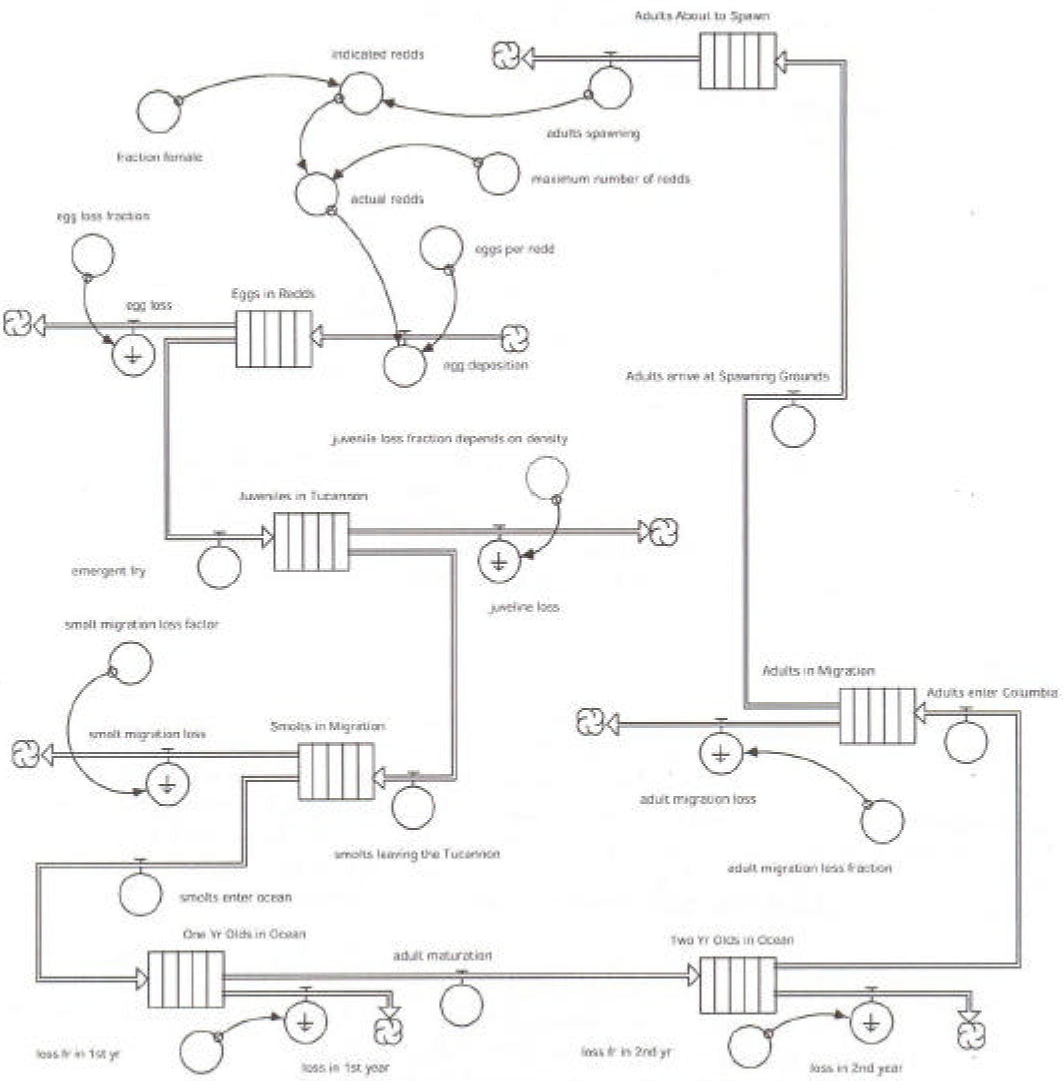
Background: Tucannon river rises in the Blue Mountains and flows towards the snake river. This 50 miles of stretch is suitable for Chinook salmon habitat and each mile supports around 65 redds (spawning nest formed in the gravel). Each redd contains thousands of eggs that hatch in the spring and the hatchlings live for a month or more on nutrients stored in yolk sacs. Juveniles of salmon spent one year in Tucannon river competing for food after which they undergo smoltification that triggers migration urge. Smolts migrate about 50 miles to reach the Snake river and then about 400 mile through the Columbia river to reach the ocean. They spent two years in the ocean and then return to the Columbia river mouth in the spring of the final year. They migrate up the Columbia and Snake rivers to reach the mouth of Tucannon. They reach the spawning grounds in the fall to build redds for the next generation.

Objective: Study the long term trends in the Salmon population over several decades by analyzing the system, developing a model and then simulating the system. Knowing the fundamental pattern, the primary objective is to develop a model to simulate the growth in salmon population under the pre-development conditions.

Model design: The model design consists of seven components to keep track of the population in various phases of it s life cycle. Salmon move through these phases in tightly controlled patterns.

The life cycle of Chinook salmon begins in the fall when spawners build the redds. The seven phases (sub-systems) in the life cycle of Salmon are:

No.	**Phase**	**Duration (Months)**	**Parameters**	**Estimate**
1	Adults about to spawn	1	Female fraction	0.50
2	Eggs in redds	6	Eggs per redd	3900
3	Juveniles in Tucannon	12	Egg loss fraction	0.50
4	Smolts in migration	1	Smolt migr. loss fr.	0.90
5	One year olds in ocean	12	Loss fr. for 1st year	0.35
6	Two year olds in ocean	12	Loss fr. for 2nd year	0.10
7	Adults in migration	4	Adult migr. loss fr.	0.25



A model of the salmon life cycle.

Simulation calculations: With the assumption of 2000 adults about to spawn in the beginning we make the following calculations.

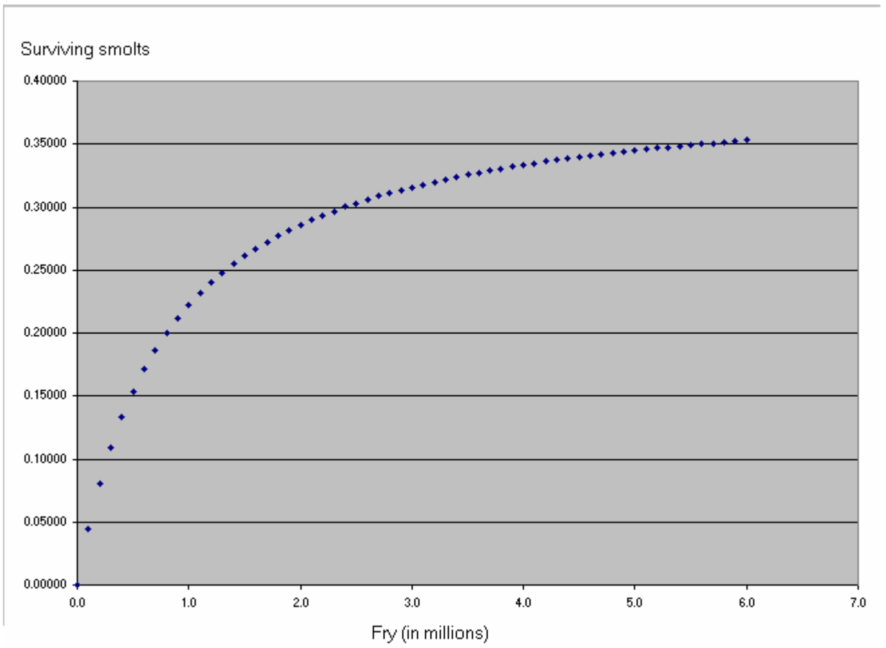
Phase		Population size	Remarks
i. Adults about to spawn	=	2,000	
ii. Adult females about spawn	=	1,000	2000 × 0.50
iii. Number of redds in Tucannon	=	1,000	1000 ×1
iv. Eggs in redds	=	3,900,000	1000 ×3900
v. Fry emerging from eggs	=	1,950,000	3,900,000 × 0.50
vi. Juveniles in Tucannon	=	1,950,000	

But there are limits to the number of juveniles that can survive their first year in Tucannon river. In summer they have to compete for limited feeding sites and in the falls they compete for limited amount of cover. These facts will constrain the juvenile population and juvenile survival heavily depends on juvenile population density. That is juvenile loss fraction depends on density. No matter how many fry emerge, there can never be more than a fixed number of smolts (say 400,000 smolts) one year later which is the carrying capacity of the Tucannon river.

The relationship between emergent fry and surviving smots is non-linear and this relationship is given by Beverton and Holts as

$$Surviving\ smolts = \frac{fry}{\frac{fry}{CC} ? \frac{1}{S}}$$

Fry: number of emergent fry (in millions)
CC: carrying capacity
S: slope of the curve at the origin.



Assuming 4,00,000 smolts as the carrying capacity and 0.50 as the slope of the curve survival of juveniles can be worked out.

	Phase		Population size	Remarks
vii.	Juveniles surviving the first year of life in Tucannon	=	280,000	$\frac{1{,}950{,}000}{\frac{1{,}950{,}000}{400{,}000} ? \frac{1}{0.5}}$
	These are the smolts that migrate to the ocean in the following spring			
viii.	Smolts migrating and reaching the ocean	=	28,000	280,000 × 0.10
ix.	One year olds in ocean	=	18,200	28,000 × 0.35
x.	Two year olds in ocean	=	16,380	18,200 × 0.90

They migrate to the mouth of Columbia river

xi.	Adults reaching the spawning ground	=	12,285	16,380 × 0.75

There can be limits at different phases. For example the maximum number of redds that can be built in the river, when we assume @ 65 redds/mile, is 3250 redds. Also, randomness can be introduced into the model in different phases.