A System Dynamics Model for a Sustainable Fish Population

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ABSTRACT

To visualize or address complex real world problems, eliciting and mapping of a mental model is reasonable approach but it is far from sufficient by itself. In this article we present a system dynamics model. The purpose of the model is to develop a sustainable model for fish population, growth, and harvesting. The model was run through several important tests to determine its sensitivity to changing in key parameters and initial values with different scenarios and boundary conditions. Model results show that fish birth, growth, stocks and catch can be controlled quickly in different real-world changing conditions to maintain a sustainable fish population.

Keywords: Fishery, Simulation, Sustainability, System Dynamics, System Dynamics Model

1. INTRODUCTION

Systems modeling is an extremely powerful technique that easily lends itself as a tool to understand the complexity found in the business world today. Models enable to see how a real-world activity will perform under different conditions and test various hypotheses at a fraction of the cost of performing the actual activity (Laguna & Markland, 2005). Eliciting and mapping of mental model is always necessary but it is far from sufficient to visualize or address complex real word problems (Sterman, 2000). The mental models are runnable in which there is a sense of deriving answers via mental simulation rather than logical reasoning (Forbus & Gentner, 1997). With mental model we cannot take into consideration many aspects of a real-world problem. The mental models are dynamically deficient, omitting feedbacks, time delays, accumulations, and nonlinearities (Sterman, 2000). Simulation is a practical way to test any model (Lindenmayer et al., 2000). Simulation is a running model in order to estimate or project its behavior, either by solving the equations in the case of systems dynamics, or by generating random numbers representing events and decisions in the case of discrete system simulation.

System dynamics is a powerful method to gain useful insight into situations of dynamic complexity (Pruyt, 2006b) and policy resistance. It is increasingly used to design more successful policies in companies and public policy settings (Sterman, 2000). In this article, we demonstrate a sustainable fish population growth model with

DOI: 10.4018/ijtd.2014040104
help from a system dynamics modeling tool (Vensim, Inc., 2012). With the growth of world population, continuous over-catch of fish, and the waste of natural resources sustainability of fish population is at risk. Governments, authorities, and regulating bodies have become concerned about declining fish population in ponds, rivers, and seas. In line with real-world problem of fish population decline we try to come up with a dynamic model to maintain sustainability.

Different aspects of dynamic models for fish population have been investigated by researchers (Hallam et al., 2000; Wakeland et al., 2003; Pruyt, 2006; Flottmann, 2014; Rose et al., 2001). As part of building a dynamic model for fish population growth we take several constraints into consideration. First, there is a carrying capacity, that is, \( K \). Should the population rise above \( K \), population should begin to decline to eventually stay within the maximum capacity limit. Second, the birth and death rates have been specified for the fish population growth model. When a population is near zero, the maximum birth rate would be expected. As population approaches the carrying capacity, the birth rate might fall by a factor of four or five but, never entirely to zero, even in situations where the population exceeds the carrying capacity \( K \). When a population is near zero, the minimum death should be at least 10% of the fish population in any time period. If the population ever exceeds the carrying capacity, the death rate might be expected to be even high, as great as 3-4 times the minimum. The birth rates and death rates are closely linked to population density \( N/K \) which is the ratio of the total population \( N \) to the carrying capacity \( K \). Given the constraints, the ‘goal seeking’ behavior of fish population growth will be explored. The key idea is to construct a model that employs the concept of population density as a factor that influences both birth and death rates. Goal seeking behavior is a system that is strongly influenced by the presence of one or more goal-seeking feedback loops.

2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

Simulation as a concept consists of a few basic steps including building a simulation model; running the simulation model; analyzing the performance measures; and evaluating alternative scenarios (Laguna & Markland, 2005). With the advent of software and computer engineering, nowadays, dynamic simulation modeling tools (Richardson, 2013; Martinez-Moyano & Richardson, 2013) are being used to measure sustainability of various ecological (Thakker et al., 2013), economic (Rahmandad & Sibdari, 2012; Pierson & Sterman, 2013; Wyburn & Roach, 2013), social (Abdel-Hamid, 1989; Onggo, 2012; Black, 2013; Eberlein & Thompson, 2013; Morrison et al., 2013), technological (Rahman & Akhter, 2010; Jones et al., 2002; Morrison, 2012; Ng et al., 2012; Jammoussi et al., 2013) and natural phenomena (Barker, 2008).

System dynamics approaches have been applied in various disciplines. Celine et al. (2011) examined the economic and business impacts of automating information management in clinical trials in new drug development using system dynamics model. Loebbecke (2011) examines the global system of mobile (GSM) communication using system dynamics to capture the complexity. Choi et al. (2008) examine the impact of potential staffing strategies under various conditions, and provide guidance for staffing decisions, using a systems dynamics approach. Wyburn and Roach (2013) employed system dynamics model and different dynamic hypotheses to analyze the price history of comic book market. Bhushan (2012, 2013) applies systems dynamic model to streamline the structural complexity of innovation diffusion. Thakker et al. (2013) use a system dynamics approach to quantitatively analyze the effects of mobile broadband ecosystem’s variables on demands and allocation of wireless spectrum for the cellular industry. Onggo (2013) demonstrates that system dynamics modeling can
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