Ecological Modelling 337 (2016) 107–122

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Ecology and equity in global fisheries: Modelling policy options using theoretical distributions

Crelis Ferdinand Rammelt[a,*], Maarten van Schie[b]

[a] International Development Studies, Department of Human Geography and Planning, Faculty of Geosciences, Utrecht University, Heidelberglaan 2, 3508 TC Utrecht, The Netherlands
[b] Bijltjespad 30B, 1018 KH Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 20 December 2015
Received in revised form 15 June 2016
Accepted 17 June 2016

Keywords:
Fishing economy
System dynamics
Ecological economics
Environmental justice
Political ecology

ABSTRACT

Global fisheries present a typical case of political ecology or environmental injustice, i.e. a problem of distribution of resources within ecological limits. We built a stock-flow model to visualize this challenge and its dynamics, with both an ecological and a social dimension. We incorporated theoretical distributions for non-linear variables that serve to calibrate the model as well as facilitate real-time exploration of scenarios. These scenarios represent potential policy interventions aimed at addressing ecology and equity concerns in fishing. Model results show oscillation representative of predator-prey dynamics, as well as various degrees of stabilisation, inequality in resource extraction and/or collapse. Our results support the view that the most effective policy choices directly affect the growth of physical capital for ecological stabilisation, and in the social dimension reduce inequity in political control over the accumulation of capital and allocation of resources.

1. Introduction

Acknowledging the methodological limitations, the Global Footprint Network (2015) estimates it takes the Earth one year and six months to regenerate what renewable matter we use in a year. Our way of life cannot be sustained in the long-term. At the same time, roughly 20% of the world population account for 86% of the world's total consumption expenditure, while another 20% at the other end consumes less than 1.3% (UN 2007). In a context of biophysical limits, the issue of economic distribution of resources is even more consequential.

In this paper we take the fish economy as a case study for a renewable resource economy. A necessary condition for sustainability is that any temporary imbalance between the in- and outflow from the renewable stock (of fish) is compensated at some point in the future (Daly and Farley, 2004). A long-term imbalance between harvest and regeneration has already resulted in depleted fish stocks around the world. This ecological approach to sustainability should be complemented by other approaches, such as "political ecology" or "environmental justice", which recognize that environmental problems are socially distributed (Dodds, 1997; Hornborg, 1998). Indeed, the fishing sector represents not just a source of profit, but also a source of food and employment for society. The inequality in control over and in the use of productive resources is very clear in many parts of the world; artisanal fisheries are overwhelmed by larger-scale industrial trawling. As a result of EU imposed restriction on North Sea cod fishing, for example, some European industrial fleets procured licenses to catch off the coast of Africa. Small-scale fishermen in Senegal and Mauritania have experienced a consequent reduction in their local catches (Kaczynski & Fluharty, 2002).

Operating within ecological limits implies that we cannot expect to resolve conflicts over use or environmental injustices by constantly increasing the size of the pie, but that we need to find ways of sharing it more equitably. Matters of distribution of income and of access to food, resources or technologies are often blurred. The easy way out has been to look merely at financial indicators of inequality, in other words, at who gets what as consumers in a market system. However, the dynamic of markets seems to aggravate inequities as resources are diverted away from those that lack the money to provide for their basic needs towards the preferences of groups with stronger purchasing power (Dodds, 1997). For example, fish exports from Senegal may generate foreign currency, but they also threaten the Senegalese population's food security (Ndiaye, 2003). When dealing with imbalance of payment or debt repayments, governments in the global South may be driven to forego long-term durability of their nations' resource stocks for

* Corresponding author.
E-mail addresses: c.f.rammelt@uu.nl, crelisr@gmail.com (C.F. Rammelt), schiemaartenvan@gmail.com (M. van Schie).

http://dx.doi.org/10.1016/j.ecolmodel.2016.06.011

short-term over-exploitation. While benefiting certain constituencies, these choices often imply a reduction in entitlements for other usually more vulnerable population segments. To address this problem within the current market system, it may be justified to increase salaries in the lower income brackets. The associated growth in production and consumption will however generate further ecological disruption. Interconnections between development and environment are inevitable.

System dynamics has already been applied for understanding the fishing economy and for assessing possible interventions (see for instance Whelan, 1994; Dew, 2001; BenDor et al., 2009; Dudley, 2008). We build on an existing model that combines ecological and economic dynamics from Meadows and Wright (2008) and that was further developed for a university classroom exercise on system dynamics (Rammelt, 2015). This basic model includes a stock of fish (a renewable natural resource) and a stock of fishing boats (capital). The ecological system boundaries limit and define the economic behaviour of the system in ways that would not become clear from linear-type economic models, and the economic model affects the ecological system in ways that would not become clear from models that focus only on ecology.

Our first contribution to these existing models is the development and application of theoretical distributions. Meadows and Wright (2008) draw graphical functions that serve to calibrate the model but do not have strong theoretical underpinnings. Based on theoretical distribution functions, we have developed a way to represent the often complex dynamics of boundary conditions into simplified mathematical formulae. Distributions form one of the building blocks of statistical analysis and we therefore consider their usage robust and justifiable in modelling the 'ideal behaviour' of complex relations. Moreover, these formulae can be calibrated based on empirical knowledge of a variable such as a fish population, for example. This provides increased flexibility over existing options for exploring calibrations in the form of policy scenarios, as will be elaborated below.

Our second contribution pertains to equity.[1] We have combined two (mirrored) capital substructures adapted from Meadows and Wright (2008); one capital stock belongs to industrial trawling, and one to artisanal fisheries. Both harvest fish from the same resource stock. Some clarity will emerge from exploring the long-standing discussion on inequality by looking at the physical rather than the financial economy (Kaufmann, 1987). With this in mind, Rammelt and Boes (2013) suggested applying a "dual capital structure", which looks at changes in (1) the distribution of the ownership of the (physical) capital stock, (2) access to the services it generates, and (3) control over maintenance and investment decisions that change the composition of the stock. In other words, inequalities can be found in ownership, services and control. No system dynamics application to the fish economy has dealt explicitly with the economic issue of distribution as far as we know.

Based on this model, we explore the consequences of various policy choices to address not only (over)fishing, but also inequity. For this, we were inspired by some of the interventions in the fishing economy suggested by Whelan (1994). With system boundaries, stocks, flows and other conceptual tools, systems dynamics serves to explore how science, industry, legislation and policy can leverage more ecologically sound and equitable dynamics.

In short, our paper contributes to existing system dynamics models of renewable resource use by incorporating and experimenting with theoretical distributions, and by bringing in a dual capital stock perspective to integrate a justice perspective with existing ecological economic models. The following materials and methods section describes the model itself and the theoretical distributions used. The results section explores the scenarios and policy interventions.

[1] We associate equity with fairness in social justice and an impartial form of distribution of services and benefits. Equity is therefore not the same as equality.

2. Materials and methods

Our basic system dynamics model builds on Meadows and Wright (2008) and is developed using STELLA Professional. Its basic elements consist of stocks,[2] flows[3] and model parameters. These elements are linked through connections, which can provide remarkably intricate system dynamics, including reinforcing and balancing feedback loops[4] (see basic language description in Costanza and Gottlieb, 1998; Costanza and Voinov, 2001). In our paper, modelled variables and parameters are referred to in their model-language form, e.g. as "*capital_stock*".

2.1. Model components and system boundaries

The model shown in Fig. 1 is developed around two stock variables: *capital*, which can be thought of as a fleet of fishing vessels; and a renewable population of fish, or *resource*. The model also includes four flow variables entering or leaving the stocks. Flows of *investment* and *depreciation* respectively fill and drain capital; *regeneration* and *harvest* do this for fish populations. The *regeneration* variable is a bi-flow, which indicates that it can also be negative as will be explained later. The clouds indicate that, for this exercise, we are not interested in the origin and destination of the flows; they lie beyond the system boundaries. It should be noted that in reality, unmodelled limits or dynamics might unfold in these sources and sinks.[5]

In terms of predator-prey dynamics,[6] *capital* is the effective predator population, rather than business size or industry cash flow (money doesn't catch fish). These physical capital goods wear out over time and eventually break down, leading to value reduction. This depreciation is modelled as outflow of capital, and must be compensated for with new investments. The longer the 'life expectancy' of a fishing boat (assumed to form the majority of fishery capital stock), the smaller the fraction of capital that must be replaced. We assume that a ship can be in operation for 20 years before it needs to be replaced (the *capital_lifetime* constant in the diagram). This means a *depreciation* outflow of 5% per year. We further assume that the fishing industry wishes to grow its capital by 5% (the *growth_goal*). With 5% *depreciation* and 5% *growth_goal*, the *investment_rate* must be 10% of the capital stock. Each year, profit margins (the net gains to the fishing industry) determine whether or not the industry can attain this *investment_rate*. A condition is therefore included in our model: If *profits* are lower than the *investment_rate*, the industry invests whatever it can (in this case, all of its profits). External investments are not considered for this model, that is to say the fishing-economy is considered as, and insofar as

[2] A stock variable indicates a store or a quantity of material or information that has built up over time. In systems terminology, physical (and information) stocks are also called state variables.

[3] A flow variable produces a change in the stock variable, usually an actual physical flow into or out of a stock. In systems terminology, physical (and information) flows are also called rate variables.

[4] Feedback loops are patterns of causality that slow down or speed up the flows. In systems' language, we speak of so-called balancing or reinforcing feedback, respectively.

[5] Sources and sinks represent systems of stocks and flows outside the boundary of the model. A source is where flows originate outside the system. A sink is where flows terminate outside the system.

[6] When many foxes prey on rabbits, the number of rabbits declines; then because rabbits are scarce, foxes starve and their numbers dwindle, allowing the rabbit population to build up again.