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Optimization of shellfish production carrying capacity at a farm scale

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ABSTRACT

In this paper, we investigate the relationship between the production and ecological carrying capacity of shellfish cultured species (mussels, oysters, clams, etc.) and the spatial distribution of shellfish density within a licensed area. In order to achieve this goal, we used an analytical model for simulating the impact of a shellfish farm on the concentration of suspended particles or dissolved substances, namely dissolved oxygen in steady-state conditions. The results show that the impact depends on the spatial distribution of the rearing density within the licensed area. In particular, we found a family of non-homogeneous distribution of rearing density which allow one to increase the biomass yield in respect to the homogeneous one, while complying with constraints on suspended particles or dissolved substances. These results may be relevant for enhancing both the production and ecological carrying capacity of shellfish farms.

1. Introduction

Shellfish aquaculture is a rapidly growing resource sector around the world (see [5]). Bivalve shellfish culture (mussels, oysters, clams, etc.) is a particularly attractive form of aquaculture as this type of farming does not require the addition of artificial food supplements. However, the fact that bivalve culture relies on natural sources of food is a significant constraint on the production potential of growing regions. Hence, bivalve farmers have a strong interest in assessing the biomass density can be supported by the surrounding environment.

On the other hand, most shellfish farming activities occur in estuaries, inshore coastal waters, and, more recently, in open off-shore coastal areas which often host a diverse range of human activities. As a consequence, opposition to the expansion of shellfish farming by other users of coastal waters has increased, especially in developed countries [9].

Objections to expansion have generally centered on loss of amenities and recreational areas, and degradation of the environment. As a result, shellfish aquaculture, widely promoted as a "green" industry, is now on the environmentalists' radar screen. According to [3] environmental hazards of shellfish farming activities include: (i) organic enrichment of the sediment around shellfish farms [10], (ii) reduction in food supplies for other filter feeding organisms and (iii) habitat disturbance and degradation. These issues led to identify four categories of carrying capacity [11]:

(a) Physical carrying capacity: the total area of marine farms that can be accommodated in the available physical space.
(b) Production carrying capacity: the stoking density of bivalves at which harvests are maximized.

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(c) Ecological carrying capacity: the stocking or farm density which causes unacceptable ecological impact.
(d) Social carrying capacity: the level of farm development that causes unacceptable social impacts.

Determining the above categories is increasingly difficult and, as suggested in [11] this task should be accomplished using a hierarchical approach, from (a–d). Mathematical models play a fundamental part in the process, at least as far as the first three categories are concerned (as regards the fourth category see [7]). A range of modelling tools is available for estimating the production carrying capacity, at a farm, e.g. [2], or basin scale, see [11] for a recent review. Ecosystem scale models may include the simulation of both transport and ecological processes and can be used for investigating the overall relationships between biomass production and stock density at a regional, i.e. water body, level [1,4]. Farm scale model can be usefully employed for site selection and for assessing the local impact of a shellfish farm: in this case many variables, either physical (i.e. water velocity, water temperature, salinity, etc.) or bio-chemical (i.e. food particle concentration) are regarded as forcing functions and their temporal evolution is estimated using both larger scale models or site-specific data. Though, in principle, ecosystem scale models are needed in order to estimate the ecological carrying capacity, in many instances such models may not be available, since their calibration and application to a specific site require a considerable effort.

Nevertheless, an assessment of production and ecological carrying capacity at screening level may be needed, in order to manage shellfish aquaculture in a sustainable manner. To this aim, the web-based model "FARM", available at <http://www.farmscale.org/>, was recently proposed in [6]. The model allows one to analyze the effect of different environmental conditions and spatial distribution of rearing density on the overall farm biomass yield for a number of cultured species.

In order to minimize the requirement of input data, the model is run assuming that the main current velocity is constant and that the concentrations of suspended particle and dissolved substances are constant throughout the rearing cycle. However, no attempt of determining the spatial distribution of rearing density which, on the one hand, would decrease the impact on the water column and, on the other, would keep the biomass yield as high as possible, is suggested.

In this paper, we propose to use an analytical approach for establishing an explicit link between indicators of the impact of the farm on the water column and the spatial distribution of the rearing density within the licensed area. Therefore the rearing density can be used as a "control variable" for enhancing the production or ecological carrying capacity of the farm.

The paper is organized as follows. In the methodological section we describe the set of equations and approximations used and show how the problem can be stated in analytical terms. In the following section, we show that the homogeneous rearing density within the licensed area is not the most efficient one when the farm is approaching its ecological carrying capacity. Instead, a family of non-homogeneous rearing density allow one to enhance the ecological carrying capacity.

2. Methods

The general layout of a typical shellfish farm is shown in Fig. 1. This basic structure can be applied to suspended culture, from rafts or long-lines, as well as to bottom culture. The evolution of concentration of generic dissolved or suspended substance, here denoted with ρ, is simulated using a two-dimensional reaction-transport model. The transport term includes horizontal advection and horizontal and lateral diffusion. In this preliminary application, vertical transport terms were not considered. This means that we assumed that the water column is completely mixed along the vertical. Furthermore, we assumed a constant horizontal velocity: this approximation is reasonable, according to [6].

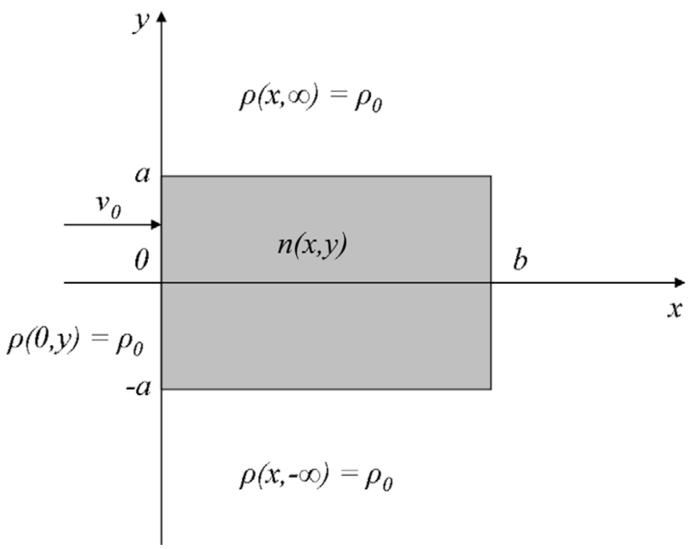

Fig. 1. Farm, layout boundary conditions.