USING SYSTEM DYNAMICS TO EVALUATE POLICIES FOR MANAGING NEW YORK'S HARD CLAM FISHERY: SOME UNEXPECTED INSIGHTS

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Abstract. A three sector system dynamics model (clams, natural predators, and baymen who harvest the clams) was developed to evaluate measures to counter the sharp decline in New York's hard clam (*Mercenaria mercenaria*) fishery. Six management alternatives were evaluated: effect of shellfish hatchery production on increasing the abundance of clams; growing seed clams on racks to protect them from predators; a maximum size limit on the harvesting of clams; limiting entry of baymen into the fishery; a bounty on predators; and setting aside a portion of the bay as a natural nursery. Model results, which were largely unanticipated, are described.

INTRODUCTION

Until recently, New York State produced over half the hard clams (*Mercenaria mercenaria*) sold in the United States. This valuable fishery is now in a period of significant decline, with production down by 75 percent since 1976. While there are a number of management strategies which could be introduced, lack of basic biological information makes it difficult to use traditional fisheries management models (Clark, 1985). As a result, a series of system dynamics models were built to evaluate various policies (Steinberg 1980, 1981, 1985). This paper contains three sections. Part one provides a brief overview of the CLAM4 model. Part two describes the model's results. Part three explores the implications of those results for (1) understanding the dynamics of the fishery, (2) guiding basic biological research, and (3) recognizing the effect that disciplinary training may have on the choice of policies that are taken into consideration.

THE CLAM4 MODEL

The CLAM4 model consists of three sectors: clams, natural predators, and the baymen, or harvest, sector (see Figure 1). A full description of the model, including equations, can be found in Steinberg (1985). The clams are divided into six levels, corresponding to their ages: larvae, seed, juveniles, littlenecks, cherrystones and chowders. Because the clams are filter feeders, the rate of cannibalism of free-swimming larvae

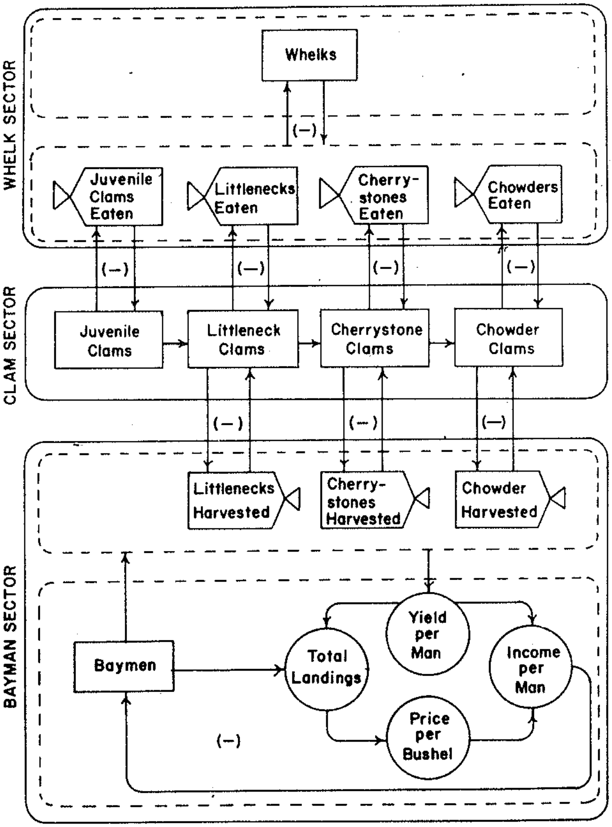


Fig. 1 Sector diagram.

increases with the density of adult clams at the bay bottom. As a result, The clam sector consists of a positive, or growth loop and a negative, or control loop (see Figure 2).

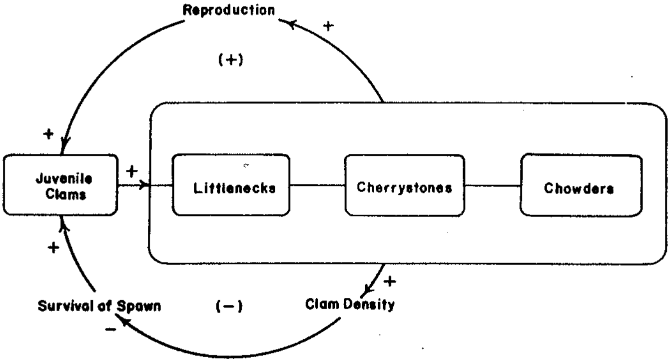


Fig. 2 Clam sector causal loop.

The natural predators on clams fall into two major categories. The first, those which prey on seed clams, are short-lived, fast-growing, high-metabolism species such as the mud crab or green crab. These predators are generalized within the clam sector, using a series of table functions relating survival of seed to predator density. The predator sector represents the second group, those which prefer to eat larger clams, are longer-lived, slow-growing, low-metabolism species such as the whelk. The relationship between predator and prey is shown in Figure 3.

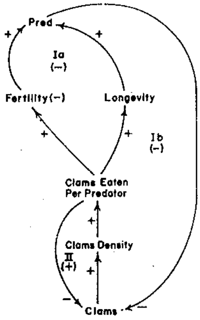


Fig. 3 Prey-Predator Causal Loop

The third sector, called the harvest or baymen sector (after those who harvest the clams), can be seen as another, but more complexly motivated, predator on clams. The behavior of baymen is complicated by the role of economics, which includes traditional supply and demand. Additionally, the baymen's preference for this lifestyle, even if he is driven to clamming only part-time, and his tendency to work only until he reaches his income goal are factored in. Figure 4 examines the interaction between clams and baymen.

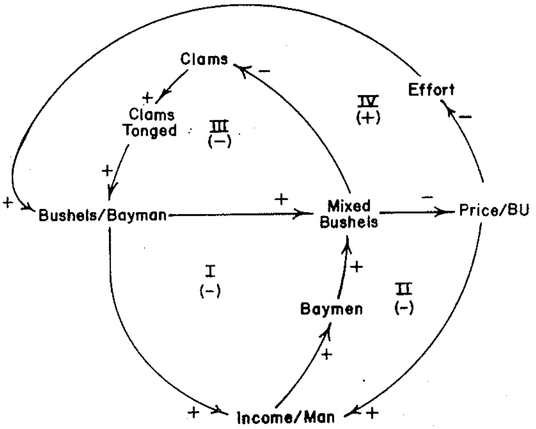


Fig. 4 Interaction between clam and baymen sectors.

RESULTS

Six management alternatives were evaluated: (1) seeding (adding young clams, called seed, from hatcheries); (2) seeding on racks (growing seed clams on elevated racks to protect them from predation); (3) maximum size limit (setting aside, through a maximum size limit, larger clams as breeding stock); (4) limited entry (limiting entry of baymen to the fishery through licensing); (5) bounty (instituting a bounty on predators); and (6) sanctuary (setting aside portion of the bay as nursery grounds).

Regardless of the specific approach, the six policies described above had but one purpose--to increase the number of clams in order to produce a significant fishery. The critical differences occur, then, in how each interacts with the structure of the Base Model.

Four of the policies (maximum size limit, hatchery seeding,

seeding on racks, and the sanctuary), attempt to directly add more clams to the Bay by inserting factors which intervene in different portions of the model (see Figure 5). Both maximum size limit and sanctuary policies are aimed at increasing the number of chowder clams, because chowders have relatively high fertility rates. The maximum size limit intervenes by setting the rate of harvesting of chowders to zero, thus breaking the link between the baymen and chowder clams. The sanctuary concept takes a different approach, duplicating the model in its entirety, and then cutting the link between the baymen and all harvestable clams in the sanctuary half of the model. Hatchery seeding, however, concentrates on the beginning rather than the end of the clam aging chain, adding clam seed from an external source to supplement the natural set. Seeding on racks adds clam seed to the Bay and additionally increases the number of harvestable clams by decreasing the loss of these seed by predation.

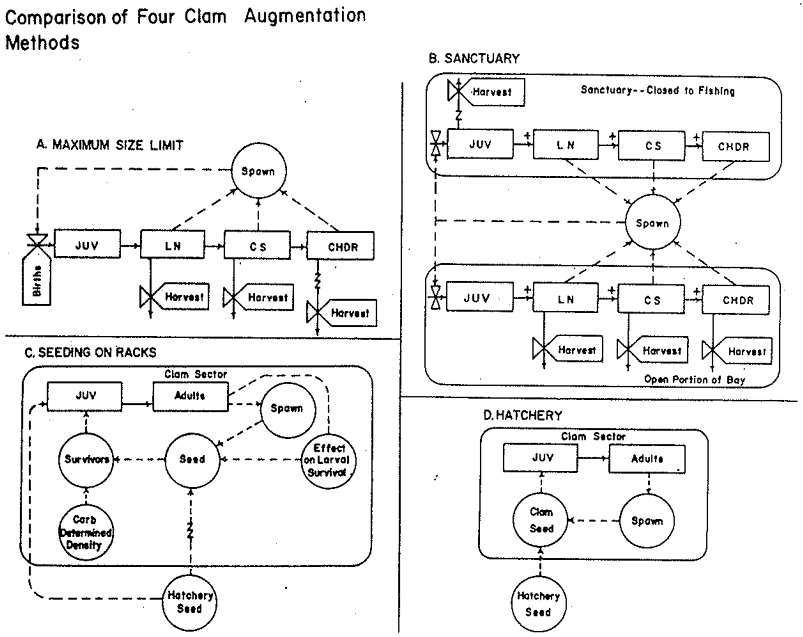


Fig. 5 Clam augmentation methods.

An entirely different approach can be used to increase the size of the clam population. Rather than adding clams, the CLAM4 model suggests that we might attempt to remove predators. One method of doing this is to establish a bounty on whelks. Figure 6 compares the difference in the direct and indirect approaches.

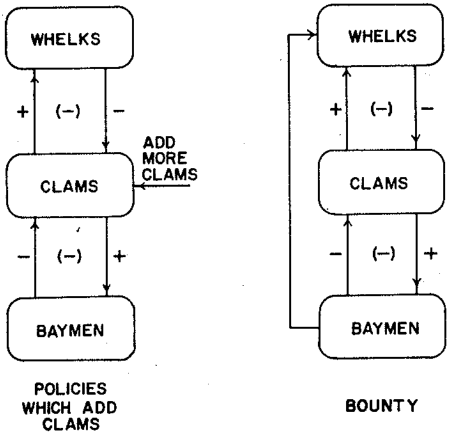
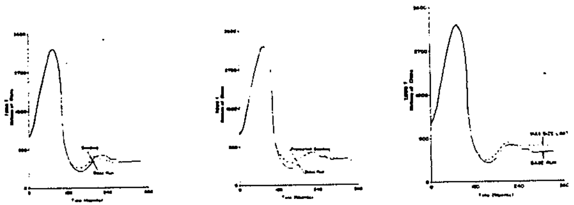


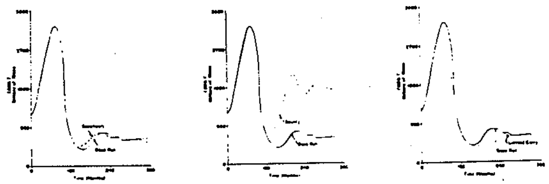
Fig. 6 Comparison of adding clams with bounty.

The final policy, limited entry, involves an attempt to increase, or at least stabilize, the clam population, by putting an upper limit on predation from another source, that of the baymen themselves. Thus, three general types of policies are examined: those that are directed at the clam sector, those that are directed at the predator sector, and those that are directed at the baymen, or harvesting, sector.

Figure 7 shows how each of the policy alternatives affects the size of the clam population. When compared to the Base Run, four of the policy alternatives--the hatchery, seeding on racks, sanctuary and limited entry--have little or no effect on clam abundance. One policy, the maximum size limit, leads to a small increase in the size of the clam population. Only one policy, the bounty, appears to significantly increase the number of clams in the bay.



A. Hatchery Seeding B. Seeding on Racks C. Max Size Limit



D. Sanctuary E. 50% Bounty F. Limited Entry

Fig. 7 Effect of policies on clam abundance.

Analysis of Policy Behavior

Those policies focusing on directly increasing the size of the clam population use several strategies, and interact with the model in different ways. The maximum size limit eliminates the harvesting of chowders, thus increasing the clam fishery's reproductive capacity. Establishing a sanctuary operates in a similar manner, isolating a portion of the entire clam population from harvesting in order to enhance natural reproduction. Alternatively, clam reproduction can be supplemented exogenously, by adding clam seed raised in hatcheries. Further efficiencies can also be introduced by growing hatchery-produced seed on racks, thus protecting the hatchery-reared seed from predation during their first year.

Why, then, if each of these policies acts on the model in different ways, are their results so similar? In each case the policy is initially successful in increasing the size of the clam population, but the greater abundance of clams leads to an increased growth of the whelks, pushing the clams back to a whelk-determined equilibrium.

Since the size of the clam population in this model is controlled by predator-determined density, it is only when the predators themselves are continuously removed that a significant increase in the size of the clam population may be attained. Thus only a bounty which has the effect of increasing the death rate of whelks, thus lowering the equilibrium value of the whelk population, is effective. A final policy, limited entry, regulates the number of baymen directly. It fails because the limit is introduced after the actual number of baymen has fallen below the limit. Baymen will, in any event, be forced out of the fishery as increasing numbers of whelks deplete the clam population below the level needed for an acceptable economic return.

Discussion

Analysis of the CLAM4 model and six policies aimed at increasing the bay's ability to support a clam fishery show that the system is controlled biologically by a predator-determined density of clams. Thus only changes in the number of predators or protection of the clams from the predators raised the density of clams to a level needed to provide the baymen with a minimal income. These results withstood a substantive set of sensitivity tests. Only changes in the large predator-determined density affected the long-term values for clams or baymen. None of the changes, however, affected the original results of the various policies.

In fact, removal of predators would enhance the fishery regardless of the specific values used in the model. Fisheries managers often use a simple model similar to that shown in Figure 8. It indicates that the stock, which in the CLAM4 model is the hard clam, is augmented through recruitment and diminished through predation and fishing (as well as natural mortality). Most fishery management strategies thus focus on enhancing recruitment; consideration is also given to minimizing fishing pressure through strategies such as limiting entry or regulating equipment. Rarely is attention focused on natural predation.

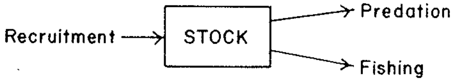


Fig. 8 General fishery management model.

Two conditions can apply in a fishery, as shown in Figure 6.2. Either the predator-determined clam density is lower or higher than that needed to sustain a fishery. We have already seen that the removal of predators under condition "A" can restore a fishery (Figure 9). It should be equally obvious that removing predators under condition "B" would also leave more clams available for harvesting by baymen. When the predator-determined equilibrium is raised from a density of 10 to 20 clams per square meter, introduction of a bounty (Figure 6.4) shows that even where the system <u>will</u> support a fishery, that fishery is enhanced by the introduction of predator control. Thus predator control is effective regardless of the specific values used in the model.

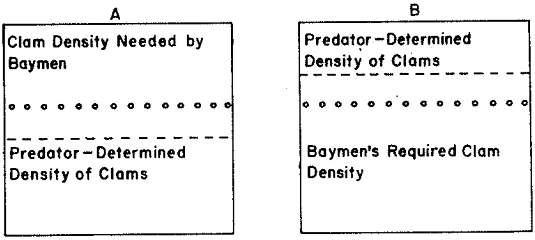


Fig. 9 Comparison of two alternate system constraints.

CONCLUSIONS

System Dynamics practitioners delight in discoveries of "surprise behavior" and other insights generated from building and testing their models (Forrester, 1980). Perhaps the most significant results from the CLAM4 model are in this category.

First, the policies tested represented an amalgam of current shellfish management practices, concepts borrowed from general fishery management, and ideas suggested by the causal loops and flow diagrams of the CLAM4 model. Contrary to current management practice, which focuses on hatcheries as well as temporal and equipment limitations placed on harvesting, the only practice that increased the size of the clam population, permitting a concommitant increase in the number of baymen the fishery could support, was the bounty on predators. This was particularly unexpected, since this is a policy not in general use by fishery managers, but one that was developed based on analysis of the model's structure.

Secondly, the model indicated that the growth of the clam resource (and the number of baymen) was, in large part, a function of the relatively young age of this resource. clams had not become biologically significant until external events (a hurricane) breached a barrier bar and changed the salinity of the bay some forty years earlier. Since this change also supported the growth of large predators such as whelks, which are long-lived, slow-growing and have relatively low metabolisms, the clams increased far faster than the whelks. As a result, the model suggested that there would be a growing clam resource for many years, with or without fishing, until the slowly reproducing large predators caught up and, in a classic case of "overshoot and collapse", reduced the clam population to a predator-determined equilibrium.

This analysis therefore suggests that biologists should concentrate their limited resources on the relationships between the density of clams and whelk fecundity and longevity, as well as the predator's feeding behavior.

Finally, individuals with different disciplinary training tend to select different types of models (Silvert, 1984). Each of these models is composed of a suite of variables and constraints operating within a given framework. The specific variables, constraints, and structure of each of these models suggests certain policy options and makes it impossible or difficult to test others. In general, therefore, the model selection distorts and constrains the kinds of policies that are considered.

For example, as someone trained in public administration, with a particular emphasis on policy analysis, I had available to me a number of modelling techniques. When I was asked about ways to look at the problems of the clam fishery, the system dynamics method appeared particularly promising. During the model's development I worked closely with a team of shellfish biologists, explaining my needs for understanding as well as specific information. As part of this exchange process, it was pointed out to me that biologists look at the resource management problem in a different way. Their fisheries models tend to concentrate on fish and fishermen but, until recently, did not consider ecosystems effects. As a result, it became clear why policies aimed at improving the fishery by removing predators were not generally explored. System dynamics was thus able to provide a new and valuable perspective on management of the clam fishery.

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