HOW MANY SHELLFISH CAN I GROW ON MY FARM?

*By Michael A. Rice**

For many shellfish farmers a key question is how many shellfish could be grown on their farms, but more importantly, how many shellfish could be grown to maximize farm profitability or overall long-term sustainability with minimal environmental impact? Another way of putting this is, just what is the carrying capacity of my farm?

A few years back, Dr. Christopher McKindsey and coworkers provided an excellent review of this topic that categorized carrying capacity models into four basic categories: 1) physical carrying capacity; 2) production carrying capacity; 3) ecological carrying capacity; and 4) social carrying capacity [see McKindsey et al., Aquaculture 261:451-462 (2006)].

The physical carrying capacity model for shellfish farms or the amount of space that can be physically occupied by farm gear is very rarely used because the amount of food required by the shellfish to grow and thrive is most frequently insufficient to sustain all the shellfish that could be physically held on the farm. Mr. Luther H. Blount's Prudence Island Oyster Farm in my home state of Rhode Island is an example of a shellfish farm designed to operate by stocking the farm with oysters at a density approaching the physical carrying capacity of a 60m x 20m (0.12 ha or about 0.3 acre) tidally fed 'oyster pond' that he had constructed on his property on Prudence Island in the middle of Narragansett Bay. Mr. Blount was the president of a highly successful boat building company, but his family had made their original fortune in the oyster farming business in the late 19th and early 20th Centuries, with Luther growing up on those farms. He vowed to see that oyster farms returned to Narragansett Bay after their complete demise in the 1950s.

In the late 1970s, Luther applied for a lease in Narragansett Bay to set up an oyster farm, but his application was denied. In a determined response, Luther acquired some property on Prudence Island near the tidal estuary of Jenny's Creek and went to Japan to study the Japanese methods of off-bottom oyster culture using the raft method. Upon returning home and securing his permits, he constructed his oyster pond with a set of subtidal seawater culverts leading into the pond from Narragansett Bay and he filled the pond with Japanese-style oyster rafts with suspended nets with seed oysters (see Figure 1). Unfortunately, and much to his chagrin, the oysters only grew to about an inch and few ever reached marketable size before dying. His oysters were essentially starving to death at the stocking density that he had calculated to be sufficient to pay back the expenses needed to build the ponds.

Production carrying capacity models are often the most useful for farmers to gauge their shellfish stocking density to the amount of available food flowing by in the water. The production carrying capacity provides an

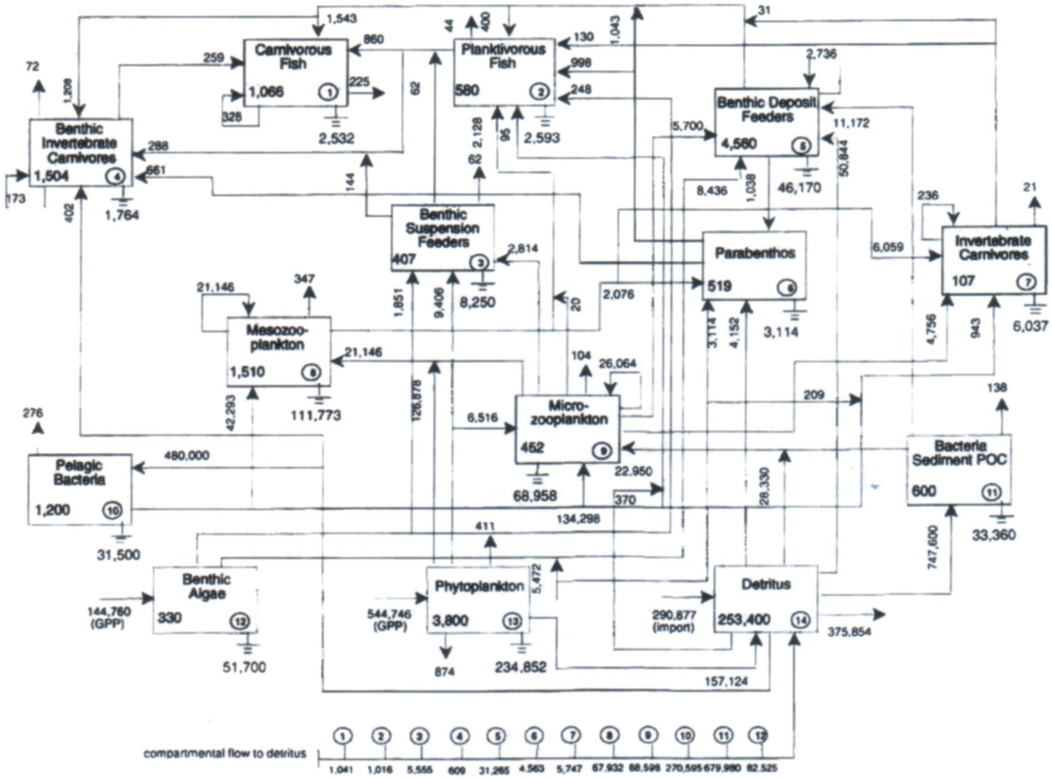
An oyster culture longline system on Rhode Island's Narragansett bay. Photo Courtesy of Saltwater Farms, North Kingstown Rhode Island.

estimate of the maximum shellfish stocking density allowable, usually at the individual farm scale, before unacceptable levels of shellfish stunting or growth inhibition occurs. A very simple production carrying capacity model for shellfish farms was developed in 1981 by Dr. Lewis Incze and his colleagues that related maximum attainable shellfish stocking densities to the available concentration of particulate food in the water (mostly phytoplankton as particulate organic matter) and the volume of water flowing through the farm [see: Incze etal., *Journal of the World Mariculture Society* 12:143-155 (1981)]. They modeled an array of mussels on dropper lines suspended from multiple floating longlines (called tiers in their model) arranged perpendicularly to the tidal flow of water in an estuary. In their model, individual mussels filtered water at a uniform rate, but the variables of the model included numbers of mussels stocked, the physical dimensions of the farm, numbers of tiers (or longline units), the initial concentration of particulate food in the water and the average tidal current rate through the farm. Their model also assumed that once the concentration of food reaching downstream tiers of shellfish reached half the initial food concentration, the shellfish would begin stunting.

This simple production carrying capacity model in reality is poor in precisely guiding farmers on how to stock their shellfish farms given the complications of real-life estuaries, but it is very valuable in getting people to think about the interplay between food availability and the demand for food by growing shellfish. It also illustrates conceptually how most all other more recent and practically useful production carrying capacity models for shellfish farms work. It is for these reasons that I like to use this simple model with my undergraduate students to help them develop an intuitive appreciation for the basic concept of food supply and demand in shellfish aquaculture so as to at least avoid costly miscalculations similar to the one made by Mr. Blount.

Ecological carrying capacity modeling seeks to predict any effects that shellfish aquaculture farms might have on the community of other organisms that make up the estuary or other water body in which shellfish farming is being conducted, including potential impacts the farms might have on wild-harvest shellfisheries conducted in that same water body. This sort of modeling requires a careful collection of a wide variety of environmental variables including phytoplankton abundances, zooplankton abundances, fish and benthic invertebrate abundance as well as inputs and variability of nutrient availability that drive the rates of production (see Figure 2). One good example of an ecological carrying capacity model is in a carbon budget analysis of mussel farms in Saldanha Bay in South Africa [see: Grant et al., Journal of Shellfish Research 17:41-49 (1998)]. In this study Dr. Jon Grant and his colleagues concluded that the then present rate of mussel farming in Saldanha Bay was below the ecological carrying capacity, leaving abundant sources of food for other marine organisms in the bay.

Figure 1. Japanese-style floating oyster rafts filling the pond at Blount's Prudence Island Oyster Farm. The oyster pond is fed by incoming tidal waters from the adjacent Narragansett Bay flowing trough subtidal culvert pipes underneath the earthen berm. Photo by Michael A. Rice, 1988.



Average annual energy flow (mg C m^{-2} yr^{-1}) and compartmental biomass (mg C m^{-2}) in Narragansett Bay

Figure 2. An example of a complex energy flow model to analyze the trophic structure of Narragansett Bay. Figure from Monaco & Ulanowicz, Marine Ecology Progress Series 161:239-254 (1997).

In a more recent study, Dr. Carrie Byron of University of New England and her colleagues studied the carrying capacity of oyster aquaculture in Narragansett Bay, concluding that the carrying capacity biomass of farmed oysters would be 297 metric tons/km^2 or 625 times the then current level of farmed oyster production [see: Byron et al., *Ecological Modelling* 222:1743-1755 (2011)]. Interestingly enough, their estimate of the carrying capacity biomass of farmed oysters in Narragansett Bay is in the same order of magnitude as our estimated farmed oyster standing crop of 371 metric tons/km^2 in 1911, the historic peak year for the production of farmed oysters on 21,000 leased acres (85 km^2) in the bay and other coastal waters of the state. As part of a study to investigate the impacts of oyster culture on various measures of water quality and phytoplankton abundance, we estimated from historic records of landings and oyster sales the standing crop biomass of oysters in Narragansett Bay to be 144,562 metric tons over a total 389.3 km^2 of the bay [see: Pietros and Rice, Aquaculture 220:407-422 (2003)]. These studies strongly suggest that the size of the shellfish aquaculture industry in Narragansett Bay *could* be greatly expanded without much worry of incurring any negative environmental impacts.

Whether or not the shellfish aquaculture ultimately can expand is frequently determined by public acceptance of the practice. The concept of social carrying capacity presented by McKindsey and his colleagues is described as the maximum amount of shellfish that could be produced in an estuary without incurring unacceptable social impacts. This concept of social carrying capacity is a particularly important concept for shellfish farmers because most if not all shellfish farming in North America is conducted in 'public trust waters' or waters held in common and managed by a public authority.

In the case of production of farmed oysters in the public trust waters of Narragansett Bay, the social carrying capacity for the culture of oysters would be greatly exceeded well before either the 2297 tonnes/km^2 ecological carrying capacity would be reached or even the 371 tonnes/km^2 of oyster biomass estimated to be in the 1911 oyster farms covering 21,000 leased acres (85 km^2) or about 22 % of the entire area of Rhode Island's state waters would be reached. According to landing statistics maintained by the Rhode Island Coastal Resources Management Council, Rhode Island's aquaculture industry was growing at a rate of about 30 percent per year on average between 1995 and 2007 This rapid rate of industry growth generated considerable concern primarily among the community of wild harvest shellfishers in the state concerned about potential future exclusion from the shellfishing grounds, as well as members of environmental non-governmental organizations and some of the coastal landowners who place a high value on their ability to freely navigate through the state's waters and enjoy the natural aesthetics of the seashore.

In early 2007, a process to review aquaculture regulations in the state began in earnest among stakeholders wrestling with the question of how big the shellfish aquaculture could become before it became too big. After a year of meetings and public discussions, including presentation of the data and conclusions regarding the ecological carrying capacity of shellfish aquaculture in the state's waters, a consensus recommendation was made to limit the amount of leased coastal waters in any particular water body to 5 % of the total water surface of that water body and to limit the sizes of individual farms in the coastal salt ponds where there is a particularly acute concern about assuring that these water bodies being heavily used by recreational users particularly during the summer months. A copy of the report outlining the process and output of this effort can be found at http://www.crmc.ri.gov/aquaculture/riaquaworkinggroup/CRMC_WG_AquaPlan.pdf.

Since 2008, this '5 % rule' limiting the area to be leased by the state for shellfish farming has been considered a *de-facto* social carrying capacity. The growth of shellfish aquaculture in Rhode Island has continued unabated over the last 10 years and the 5 % limit rule is still in place without yet being reached. However, since the coastal salt ponds of Rhode Island are productive and offer easy access for shellfish farmers, they have been very popular for shellfish aquaculture lease proposals, making them likely to be the first water bodies in the state to run up against social carrying capacity limits. However, social carrying capacity is not as easily defined in mathematical terms as the production and ecological carrying capacity models, and the actual limit may be much more 'fluid' in nature. In the end, the size of the social carrying capacity of shellfish farming in public trust waters may well depend entirely on good stewardship and being a good neighbor. am

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