Bioeconomics of giant clam mariculture

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Abstract

Since the 1980s significant research efforts have been directed into developing methods for the mariculture of giant clams in the tropical Indo-Pacific. In t[illegible]y the motivation for this research was to develop mariculture techniques to rest[illegible]efs where giant clams had become extinct, thereby providing coastal communities with giant clam stocks sufficient to satisfy their subsistence needs. However, the interest in and prospects for commercial giant clam mariculture were greater than for subsistence mariculture. Hence, the ultimate goal of this research, which continues to date, became to develop commercially viable giant clam mariculture industries for coastal communities. In this paper, a model outlining the development of such mariculture is presented. The model includes both demand and supply aspects of commercial giant clam mariculture, with particular emphasis on the latter, within a framework that incorporates relevant biological, sociological and economic information. The potential supply of giant clams of different sizes and ages is estimated through a bioeconomic model, which also permits the simulation of alternative market and environmental conditions. The study of factors affecting the rate of adoption by coastal communities, which will ultimately determine the actual supply, is a subject for future research. The model can be used to study the benefits of alternative research and extension programs.

keywords: bioeconomics, giant clams, mariculture

Introduction

Giant clams are marine bivalve molluscs native to the tropical and subtropical reefs of the Indo-Pacific region, throughout which they have been harvested for both subsistence and commercial purposes by coastal communities and other fishers. Traditionally, they were harvested for their flesh for human food consumption, and their shells for ornamental and utilitarian uses, but more recently, they have also been harvested for trade as aquarium specimens (Tisdell and Menz 1992).

Due principally to unsustainable exploitation of the capture fishery, many giant clam populations became extinct. This resulted in their being listed under the Convention on International Trade in Endangered Species (CITES) in 1983, prohibiting international trade between its signatories in giant clam products obtained from wild stocks (Tisdell et al 1994).

Giant clam mariculture technology has subsequently been developed, backed by intensive field and laboratory research, funded by organisations such as the Australian Centre for International Agricultural Research, International Center for Living Aquatic Resources Management, and Micronesian Mariculture Demonstration Centre (Tisdell and Menz 1992). Although the original intent of this research was to repopulate reefs where giant clams had become extinct, the mariculture technology appears to offer attractive commercial possibilities (Tisdell et al 1994). Commercial mariculture has not, however, been well adopted by potential village farmers.

By the time technology for the mariculture of giant clams was well developed, markets reliant on the giant clam capture fishery had substantially collapsed due to the increasing depletion of wild stocks and the growing impact of the CITES ban. Commercial trade in maricultured giant clams has, therefore, required new markets to be developed, which has been the case for seedstock and broodstock, and attenuated markets, that existed for food, shells and aquarium specimens, to be re-established (Tisdell 1994).

In this paper, the biology and mariculture of giant clams is outlined, a conceptual model illustrating the development of commercial giant clam mariculture is described, and a simple bioeconomic model of the potential commercial supply of maricultured giant clams is developed. Possible applications of, and extensions to the model are discussed.

Biology and mariculture of giant clams

Four main phases may be distinguished in the mariculture of giant clams, namely the hatchery phase, land-based nursery phase, ocean-nursery phase and grow-out phase (Crawford et al 1988). It is these last two ocean phases that are the focus of this paper, in which small juvenile clams, called seed clams, are obtained by coastal village farmers and grown out in the field. Initially, they are placed in protective containers, on the ocean floor, or suspended near the water surface from floats. Once they are large enough to be virtually free from predation, they are placed directly on the ocean floor in unprotected conditions. Grow out may take several years depending on the species being cultured and the markets being targeted.

The grow out of giant clams differs from that of other bivalves, such as oysters, scallops, and mussels, in that they can only be grown in two-dimensional systems rather than in multiple layers throughout the water column (Crawford et al 1988). This is because giant clams are almost exclusively reliant for their nutrition on the products of photosynthesis of symbiotic dinoflagellate algae, called zooxanthellae, that reside within their mantle tissue. Giant clams may also augment their nutrition through filter feeding, mainly of particulate organic matter, but also of plankton and dissolved organic and inorganic matter, from seawater flowing through their gills (Klumpp et al 1992).

The nutrition of giant clams may be described by Figure 1, in which it is illustrated that through photosynthesis from available light, and filter feeding of water containing particulate organic matter, giant clams obtain energy in the form of organic carbon for respiration (ie. maintenance or basal metabolism) and growth. These modes of nutrition are also influenced by other environmental factors, such as temperature, emersion, depth and turbidity (Lucas et al 1989).

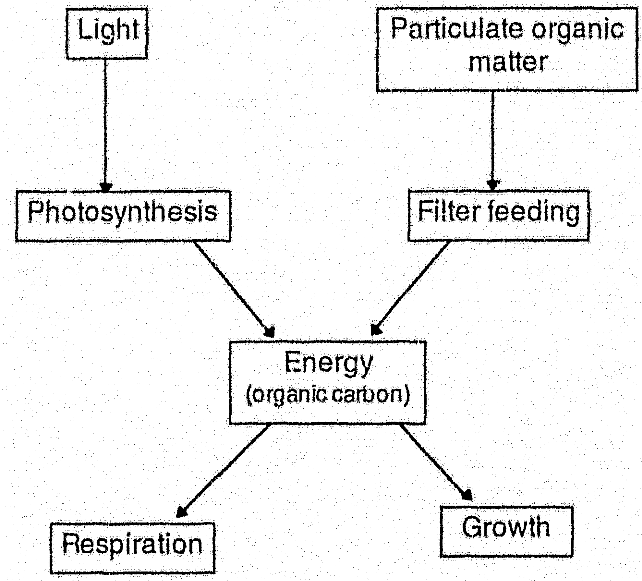

Figure 1

Conceptual Framework

Commercial giant clam mariculture for coastal communities in the Indo-Pacific region, may be illustrated using the conceptual model outlined in Figure 2. The model includes both demand and supply aspects of commercial giant clam mariculture, within a framework that incorporates relevant biological, environmental, technical, sociological, and economic information. Central to the model is the potential supply of maricultured giant clams. The actual market supply will, however, depend on the rate of adoption of the mariculture technology by potential village farmers, and the establishment of stable markets, as well as the rate at which supply is redirected into other uses, such as restocking reefs and satisfying subsistence needs.

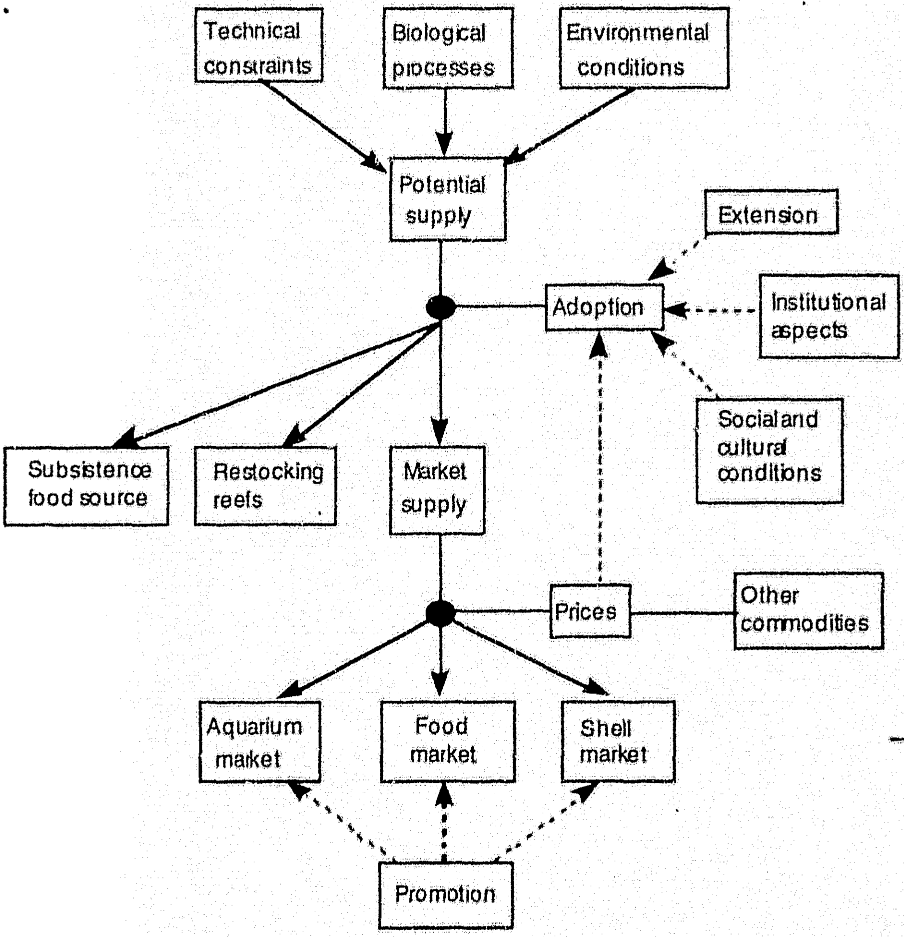

Figure 2

Bioeconomic Model

In this paper, the major focus is on the potential supply of giant clams that results from the existing mariculture technology and management strategies adopted by village farmers. Given that giant clams are self feeders, village farmers have no direct control over the food supply of maricultured clams. Hence, the farmer's decision problem is to determine the optimal timing for stocking and harvesting, as well as the optimal stocking rate. Since the farm can be harvested as well as stocked continuously, the model can contain, at any time, giant clams of a wide range of ages. In the model, only one market for giant clam products is considered.

From the individual farmer's perspective, the decision problem can be expressed in an optimal control framework, as follows.

(1) $$\text{Max} \quad \pi = \int_{t=0}^{T} [R_t - C_t] e^{-rt} dt$$

in which:

(2) $$R_t = \sum_{i}^{k} w_{i,t} h_{i,t} P_{i,t} \qquad \text{for } i=1,2,3,\dots k$$

(3) $$C_t = C_t(L_t, K_t, s_t)$$

subject to:

(4) $$\frac{\partial w_i}{\partial t} = \frac{\partial w_i}{\partial t}(w_{i,t}, B_t, I_t, POM_t)$$

(5) $$\frac{\partial n_i}{\partial t} = s_t \qquad \text{for } i=1$$

(6) $$\frac{\partial n_i}{\partial t} = \frac{\partial n_i}{\partial t}(n_{i-1,t-1}, h_{i-1,t-1}, M_{i-1,t-1}) \qquad \text{for } i=2,3,\dots k$$

(7) $$s_t \geq 0$$

(8) $$0 \leq h_{i,t} \leq n_{i,t}$$

(9) $$w_i(0) = w_{i,0} \quad \lambda_{w_i}(T) = 0 \quad w_i(T) \text{ free}$$

(10) $$n_i(0) = n_{i,0} \quad \lambda_{n_i}(T) = 0 \quad n_i(T) \text{ free}$$

where:

π	is the net present value of cumulative profit
R	is revenue
C	is cost
r	is the discount rate
t	is time
T	is the terminal time, or end of the planning period
w	is weight of an individual giant clam
i	is the age classes 1,2,3, ... k
h	is the number harvested
P	is price
L	is labour
K	is capital
s	is seed clams
B	is biomass, which is given by $B = \sum_{i=1}^{k} w_i n_i$
I	is irradiance, or light
POM	is particulate organic matter
M	is mortality

The equation of motion for weight (ie. equation (4)) can be represented by a biological model that accounts for photosynthesis, filter feeding, and respiration, as follows:

$$\frac{\partial w}{\partial t} = P_c + F_c - R_c \tag{11}$$

in which:

$$P_c = \%TR \,.\, P_{\max} \tanh\left(\frac{I}{I_k}\right) . \alpha w^{\beta} \tag{12}$$

$$F_c = \gamma w^{\delta} \,.\, POM \,.\, \%AE \tag{13}$$

$$R_c = \varepsilon w^{\zeta} \tag{14}$$

where:

P_c	is photosynthesis
F_c	is filter feeding
R_c	is respiration
$\%TR$	is percentage translocation from zooxanthellae to the clam
$P_{\max}$	is the photosynthesis of zooxanthellae at the level of saturating irradiance

I_k is the irradiance at which the initial slope of the photosynthesis-irradiance curve for zooxanthellae intersects $P_{\max}$

$\% AE$ is the clam's absorption efficiency for particulate organic matter

According to the biological model, the clam receives energy from photosynthesis and filter feeding, and expends energy through respiration. All excess energy is available for growth. The influence of irradiance and particulate organic matter on growth is explicit in the model, while the influence of other environmental factors, such as temperature, emersion, depth and turbidity, is captured through their effect on the model's parameters ($\% TR$, $P_{\max}$, I_k, $\% AE$, α, β, γ, δ, ε, and ζ).

Energy received from photosynthesis (equation (12)), is the product of three terms describing the translocation of photosynthetic energy from the zooxanthellae to the clam, the photosynthesis of the zooxanthellae per unit of Chlorophyll a, and the Chlorophyll a content per clam (Fisher, Fitt and Trench 1985). Energy received from filter feeding (equation (13)), is described by the product of the clearance rate, or the volume of water cleared by the clam, the particulate organic matter concentration of the water, and the efficiency with which the clam absorbs particulate organic matter from the water (Klumpp et al 1992). Energy expended through respiration (equation (14)) is simply described by a power function dependent on the size of the clam (Klumpp et al 1992).

Parameter Estimation

An extensive database has been compiled on biological research of giant clams, from which biological and environmental data has been collected. This data is being used to estimate parameter values for $\% TR$, $P_{\max}$, I_k, $\% AE$, α, β, γ, δ, ε, and ζ, and how they vary with clam species and environmental conditions.

Application

Solving the model will permit estimation of the potential supply of maricultured giant clams of different ages and weights, and the profitability of their production, under alternative market and environmental conditions. Hence, the model can be used to evaluate the benefits of alternative research and extension programs.

For example, biological research, which impacts on the parameters of the biological model, can be evaluated through its effect on growth; as can extension programs which lead to the mariculture of giant clams in different habitats, and for which different magnitudes of the biological parameters are appropriate. Extension that results in more cost-effective management practices can, similarly, be evaluated through its impact on costs, while marketing policies, such as pricing, advertising and sales promotion, can be evaluated through their effect on prices.

Model results, identifying those aspects of production to which profitability of the village farm is most sensitive, can then be used in the setting of research priorities and the allocation of research funding.

Another possible use of the model is in the evaluation of losses to the village farm due to externalities caused by third party activities, such as recreational use of reef areas, fishing and forestry, which cause water turbidity, thereby reducing light available for photosynthesis.

Model Extensions

In the model presented above, it is assumed that there is only one market for giant clam products. The inclusion of additional markets represents a significant extension. The model is currently deterministic, in which the inclusion of additional markets will simply result in giant clams being allocated to the most profitable market. To capture the allocation of giant clams among more than one market will, therefore, require the model to be made stochastic in some way, or for risk to be included. This could be achieved through the inclusion of stochastic environmental conditions which would impact on the growth of giant clams through the parameters of the biological model. Price appreciation due to growth could also be captured by using quadratic prices (where price is a function of weight) to describe the prices in each market, and by constraining the harvest weight for each market.

In the model, it is also assumed that giant clams grow uniformly so that with each age increment they grow on to the next age class, unless they are harvested or die. However, there is marked variability in the growth rate of individual clams (Pearson and Munro 1991). Hence, it may be more realistic to use a Markov model in which the stock is differentiated by weight class, and a probability is associated with clams growing on to further weight classes (Leung and Shang 1989).

The model described here could eventually be extended to study problems such as, the (i) assessment of the environmental costs of giant clam mariculture, due to, for example, unfavourable visual impacts and adverse effects on other species (Tisdell

1991); and (ii) assessment of the conservation benefits of giant clam mariculture, the value of which will be at least equal to the market value.

Another avenue of research is the study of factors affecting the rate of adoption of giant clam mariculture by potential village farmers, which may eventually lead to including social factors in the model.

Conclusions

The bioeconomic model presented in this paper, represents the first known attempt to formally integrate the considerable body of knowledge that has accumulated over 15 years of research at the International Center for Living Aquatic Resources Management, Micronesian Mariculture Demonstration Centre, and elsewhere. The opportunity exists for the model to contribute significantly in its application to many interesting issues in the ongoing development of commercial giant clam mariculture.

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