SEA-FARMING OF MARINE GASTROPODS WITH EMPHASIS ON THE FEASIBILITY OF THE MURICID *CHICOREUS RAMOSUS* (L., 1758)

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ABSTRACT.

Culture of *C. ramosus* using the approach of sea-farming is evaluated in terms of growth rate, sediment preference, settling, migration and other behavioural aspects, and combined with the existing literature on sea-farming of marine gastropods. Worldwide *Trochus niloticus*, *Strombus gigas* and *Haliotis* spp., are the preferred marine gastropods in culture. They have several biological similarities with *C. ramosus* which makes it a potential candidates for sea-farming. The success of enhancement programmes depends to some extent on a proper definition of objectives. If the aim is strictly commercial then it is necessary to obtain a higher market value than at present for the meat of *C. ramosus*, to promote and sell younger snails, to fence in released juveniles, to improve rearing techniques and lower the costs of producing juveniles. If the aim is solely restocking then it should be noted that the migrational habits of *C. ramosus* would facilitate dispersal of the stock, but release sites should be carefully considered to avoid introducing this carnivore in areas of other cultured molluscs. Restocking should be combined with a management programme using sanctuaries to protect the release sites against over-fishing. Restrictions on size of harvestable snails may not be necessary due to the ability of juveniles to hide.

INTRODUCTION.

Sea-farming of marine gastropods is a relatively young discipline, which is a response to over-fishing or depletion of commercially important species. The continued demand for these species and the existence of farming technology has led to the development of sea-farming. It is possible that this kind of aquaculture may evolve into an important industry in the near future (Fallu, 1991).

Sea-farming is basically a production system in which man's intervention is restricted to, or emphasizes, the introduction of additional organisms at a particular stage of their lifespan. This is generally achieved through the seeding of open aquatic ecosystems with spat, juveniles, or other early stages of selected species for the purpose of sustaining or enhancing the recruitment from wild populations, or creating new populations and new production in new areas. Sea-farming and resource management of the chosen species are generally combined to protect the populations, either by limiting the size or amount of catch, restricting seasons or establishing sanctuaries.

The term sea-farming is poorly defined in the literature. Several terms are used to distinguish between stock enhancement activities, mariculture (Heslinga, 1980; Berg, 1976), ocean-ranching (Saito, 1984; Yamaguchi, 1988), extensive aquaculture (Troadec, 1991), reseeding (Heslinga, 1979), restocking (Iversen, 1983) and to some extend transplantation (Gillett, 1986; Yamaguchi, 1989). The term chosen depends on whether the purpose is commercial, conservation, or release of stocks from a different geographic area.

Bannister (1991) distinguishes between ranching/farming where an identifiable stock is released with the intent to be harvested by a limited group and this approach generally aims at commercial feasibility; or enhancement with the purpose of benefiting society in general.

Enhancement is subdivided into restocking-compensation for depletion of a natural resource and addition-genuine addition of new stock (*e.g.* stocking

artificial reefs, transplantations to new areas without a natural population).
In general, the term sea-farming will be used in this paper, because enhancement projects, as they are performed today have a specific user group, and attempts are made to secure feasibility.

BRIEF HISTORICAL REVIEW OF SEA-FARMING MARINE GASTROPODS.

Today sea-farming of *Haliotis* sp. *Trochus niloticus* (Linnaeus, 1767) and *Strombus gigas* (Linnaeus, 1758) is performed in large scale. Worldwide they are the preferred marine gastropods in culture.
C. ramosus has so far not been sea-farmed and to evaluate it's suitability, I emphasize the need to use the experiences and knowledge derived from the successful culture of the above mentioned species, and virtually all available literature concerning sea-farming of marine gastropods deals with them.

Trochus niloticus is a very important resource to the inhabitants of the Pacific islands. The shell is used for production of mother of pearl buttons and the meat is edible.
During the Japanese era in the Pacific (1914-1945) an extensive transplantation programme was carried out very successfully. For example in 1931, 1.7 tons *Trochus* were transplanted to Truk and in 1952, 220 tons were harvested from there (McGovan, 1958). In 1957, 40 adult *T. niloticus* were transplanted from Fiji to Aitutaki. This modest transplantation founded a new population which now supports commercial use and which since 1981 has been used for transplantations within the Cook islands (Zoutendyk, 1989).
The reason for transplanting this gastropod is mainly caused by their relatively short pelagic phase of veligers - approximately 3 days (Heslinga, 1981a). This period is too short to reach many of the remote Pacific Islands which have excellent environments for *Trochus* - therefore adult snails were transplanted from natural habitats of *Trochus* to these islands.
In my opinion, introduction of new species to areas without a natural population should be avoided, despite the success of such transplantations; both because of incalculable influences on the new environment in terms of competition and the possibility of introducing new parasites or diseases. The latter could be prevented by a quarantine period of the stock.

The first real example of sea-farming was also attempted by the Japanese in the mid sixties with abalone (Leighton, 1989; Uno, 1977). Abalone is highly priced as food and the shell is used for ornamental purpose. The fishing pressure had become more intense than natural recruitment could replenish. Abalones were reared in aquaculture and juveniles were released in the sea to enhance the fisheries. After some years their programme proved to be very successful and the government started to support these programmes. Today abalones are released in millions along the coast of Japan (Barnabé, 1990).

The major breakthrough in improving the over-exploited *Trochus* stocks in the Pacific occurred in the mid seventies, where *Trochus niloticus* stocks were reseeded using cultured juveniles after extensive research had been carried out (Heslinga, 1979; Heslinga and Hillmann, 1981; Hoffschir, 1990). This method was also used when the *Trochus* fishery had been ruined due to over-exploitation (Yamaguchi, 1989).

In the Caribbean Sea, a similar story took place, because the populations of the queen conch, *Strombus gigas*, also suffered from over-exploitation. *Strombus gigas* is a large commercially important gastropod in the Caribbean (Randall, 1964). It is an important source of food and the snails may weigh more than 2.7 kg, yielding up to one kg of meat and the shell is highly priced as souvenir (Iversen, 1968).

This gastropod was successfully reared through metamorphosis for the first time in 1976 (Berg, 1976). Since then a considerable amount of research has been invested in this snail and large scale sea-farming is now found on several of the islands (Davis *et al.*, 1989).

The conch fishery in the Caribbean region exceeded US$ 30 millions annually in 1992 (Stoner, 1994). In the following, I will describe some of the biological similarities between *C. ramosus* and the above mentioned species to find useful criteria for an evaluation of potential species for sea-farming, with the overall purpose of evaluating *Chicoreus ramosus* as a candidate.

ASPECTS OF SELECTION OF POTENTIAL SPECIES FOR SEA-FARMING.

To use the experience gained from the culture of *T. niloticus, S. gigas* and *Haliotis* sp. it is necessary to evaluate if this knowledge can be applied on *C. ramosus*. This depends on the similarity between *C. ramosus* and the mentioned species.

Presumably the very large size of the species was one of the basic reasons why they have been used for a long time and their size has also been part of the reason why they have been depleted in several areas, as the adults are easy to gather. Being easy to catch is advantageous in sea-farming, because harvesting is most commonly performed by divers.

The production of juveniles of *T. niloticus, S. gigas* and *Haliotis* sp. is performed routinely in large scale because extensive research has been carried out with these species. Similarly, after the recent development at Prachuab Khiri Khan Aquaculture Center, Thailand, it is now possible to produce juvenile *C. ramosus* routinely in large numbers.

Comparison between *C. ramosus* and the three other species shows that most similarities exist between *S. gigas* and *C. ramosus* - both in terms of behaviour during the veliger phase and during the adult phase.

T. niloticus spawns after a predictable schedule following a lunar cycle. Therefore, this species is easy to manage in hatcheries (Heslinga & Hillmann, 1981; Heslinga, 1981a; Heslinga, 1981b).
Spawning of abalone is induced by ultra-violet light and routinely managed. Abalones have lecithotrophic development and require no additional feeding during the comparatively short planktonic period (Fallu, 1991).
Eggs of *S. gigas* are collected from nature, as we have done with *C. ramosus*.
S.gigas and *C. ramosus* both have planktotrophic larvae with a pelagic phase from 1 to 3 weeks.

Herbivorous species such as *T. niloticus, Haliotis* sp. and *S. gigas* are triggered to settlement by extracts of their preferred algae (Heslinga, 1981a; Fallu, 1991; Davis *et al.*, 1990). But veligers of *C. ramosus* showed no preference given the choice between a sediment with food and an identical sediment without food (Bech, 1993a). The veligers of *C. ramosus* prefer a coarse sediment to a fine sediment when settling. In an experiment using 2496 veligers competent for settling, 72.8% settled on pebble sediment, 22.3% on granular sediment and only 4.9% on sand (Bech, 1993a).

This behaviour of *C. ramosus* indicates that mechanoreceptors are the means by which the larvae find a suitable sediment. Juveniles were fed sedentary benthic organisms (barnacles or bivalve spat) in captivity (Steenfeldt and Bussarawit, 1992) and the possibility of finding these organisms in nature is greater on pebble or rock than on sand.

The veligers of *C. ramosus* are photopositive as most planktotrophic larvae, but just after settling they become photonegative and hide. With respect to sediment selectivity, in the event of settling, darkness may also be a triggering factor because the possibility of encountering shade increases with grain size from sand to pebble.

The four species are nocturnal and rarely found as juveniles because they hide in crevices or bury in the sediment, which is an important behavioral aspect to avoid predation, when juveniles are released in large numbers.

Growth and survival rates of these four species in culture are considered to be satisfactory, but mainly because there are no feeding and maintenance costs from release of juveniles until harvest. The growth rates of juvenile *S. gigas* and *C. ramosus* in culture are similar - about 0.3-0.4 mm a day (Stoner, 1989b; Bech, 1993c).

T. niloticus migrates to some extent, but stays in shallow water <10 m, which limits migration (McGovan, 1958). Abalones have been recaptured as adults within 50 m from the point where they were released as juveniles, and are believed to migrate very little (Hayashi and Yamakawa, 1988).

Juveniles and adults of *C. ramosus* are positively rheotactic (Bech, 1992a; 1993b). In flume tanks, it was demonstrated, that juvenile *C. ramosus* could detect bivalve prey and actively distinguish between a water current which had passed bivalves and one which had not (Bech, 1993b). *C. ramosus* seems to prefer habitats influenced by strong currents (Bech, 1992a; Somneuk, pers. comm.) and the use of chemoreceptors in the search for food requires a positive rheotactic behaviour.

After several diving trips in *C. ramosus* habitats a selectivity of *C. ramosus* towards highly productive areas, coarse sediments, and areas strongly influenced by current, was found. Khokiattiwong (1992) states, that *C. ramosus* is found in productive areas including all types of substrate, except for mud. A selectivity for sediments which could hide the snails was observed in aquaria experiments (Bech, 1993c).

It is not yet possible to explain why *C. ramosus* prefer certain habitats, but the most obvious reason, along with their need to hide, would be because the bivalve prey prefers these habitats. A strong current protects the bivalves against being covered by sediment, and more water moving by, means more food to a filter-feeder.

One major difference between *C. ramosus* and other species currently used for sea-farming (*Trochus niloticus*, *Strombus gigas* and *Haliotis* sp.) is the fact, that *C. ramosus* is carnivorous, feeding mainly on bivalves. In general, the distribution of bivalves is patchy and their presence fluctuates with time, therefore a carnivore is expected to migrate comparatively more than a herbivore feeding on algae, especially in the light and temperature stable tropical environments.

Trochus niloticus and *Haliotis* sp. do not migrate far and duration of their pelagic phase is comparatively short, hence their potential of dispersal is limited. But apart from the diet, *S. gigas* and *C. ramosus* have several similarities. Both species migrate comparatively far at a similar rate of locomotion. *S. gigas* has been reported to move about 4.7 m/day (Stoner, 1989b) and *C. ramosus* at about 5.3 m/day (Bech, 1992a). *S. gigas*'s rate of locomotion depends on the available amount of food, and there is reason to expect a similar behaviour for *C. ramosus*. They both have planktotrophic veligers and the duration of the planktonic phase is in the order of weeks, meaning that they may be characterized as having a comparatively high dispersal potential. Both species are nocturnal and are mostly buried during the juvenile phase (Iversen and Jory, 1989; Bech 1993c).

Because *S. gigas* is very mobile, the grow-out phase is often in a protected bay or in a fenced area, and as described earlier, most sea-farming of *S. gigas* is commercial.

Planktotrophic offspring with a long pelagic phase permits rapid dispersal, repopulation of depleted areas, and establishment of dense populations when the larvae encounter optimal conditions (Radwin and Chamberlin, 1973). Offspring of sea-farmed lecitotrophic species with a short planktonic period would enhance the population locally in a demarkated area around the point of release (Shuto, 1974). In commercial sea-farming, non-migratory species with a short planktonic period should be preferred to limit the dispersal of the harvest.

I believe that almost any marine gastropod could be produced in hatcheries and sea-farmed. Selection of potential species depends mainly on a cost/benefit analysis between investments in research and the value of the product.

The choice of these species has probably not been based solely on their biological suitability for sea-farming, but mainly on the fact that they are a traditional food source and commercially important to the local people. But most of the constraints of production have been solved because of intensive research.

THE RISK OF INTRODUCING *C. RAMOSUS* IN AREAS OF CULTURED MOLLUSCS.

C. ramosus may delay settlement by several weeks and is able to migrate comparatively far after metamorphosis. This is a danger in large scale sea-farming of this species, because it is carnivorous.

In a *Tridacna* producing hatchery on the Solomon Islands, using the approach of sea-farming, predation by adult *C. ramosus* has been noted (pers. comm. Govan and Munro (ICLARM)). Similarly *C. ramosus* have been reported as a threat to commercial culture of *Tridacna* spp. elsewhere in the Pacific (Price and Fagolimul, 1988; Ledua and Adams, 1988).

C. ramosus, *C. palmarosae* and *C. brunneus* are the only muricids observed to prey on juvenile tridacnid clams (Govan, 1992). Large *C. ramosus* (20 cm in total length) are the only gastropods which have been observed to attack, kill and eat *Tridacna* spp. up to at least 300 mm shell length. The soft tissues of the clams were reached by insertion of the proboscis into the byssal gape (Heslinga *et al.*, 1984a). Due to carnivorous fish, octopus, crabs and *Chicoreus* spp., the nursery systems (Micronesian Mariculture Demonstration Center and Coastal Aquaculture Center, Solomon Islands) of tridacnid clams have been protected with mesh covers, which effectively exclude these predators (Perron *et al.*, 1985).

Govan (1992) states that *C. ramosus* does not appear to pose a severe threat as predator on ocean-nursery culture of tridacnids because the snails are easy to spot and remove during the regular checks on the ocean-nurseries. Further protection is achieved by using mesh cover, avoid placing the cages directly on the seabed, nor should the cages be designed as to provide hiding space for the snails. Juvenile *C. ramosus* prefer granule or cobble to pebble which enables them to bury themselves or hide in gaps (Bech, 1993c) and protection against *C. ramosus* could be achieved by avoiding ocean-based nurseries in areas with these sediments.

In the culture of *Crassostrea* spp. and *Tridacna* spp., smaller gastropods, especially *Cymatium* spp., are considered far worse pests, because they are hard to spot, too small to exclude by mesh, and *Cymatium* spp. is capable of settling inside a *Tridacna* spp. (Govan, 1992; Perron *et al.*, 1985; Muthiah *et al.*,1987). *C. ramosus* eats commercially important bivalves in captivity, but *C. ramosus* has not been reported as a pest in the culture of bivalves other than *Tridacna* spp. Floating culture is a typical culture technique used for several bivalves in the tropics, which prevents attack by predators from the bottom.

COMMERCIAL PERSPECTIVES OF SEA-FARMING *C. RAMOSUS.*

In my view, the meat of *C. ramosus* produced in commercial culture would hardly become feasible, unless a much higher price can be fetched in the future. The food conversion ratio of *C. ramosus* has not been investigated, but part of *C. ramosus*'s diet in nature and culture is bivalves used for human consumption, and it requires several times the weight of the bivalve meat to produce an adult *C. ramosus*. To justify this consumption of edible bivalves, a very creative marketing strategy has to be introduced to increase the value of *C. ramosus* meat. The name "King abalone" has been suggested to promote the market price of *C. ramosus* meat by Hylleberg (1992), utilizing the very successful marketing of abalone, and if prices similar to abalone meat will be reached, then the production of *C. ramosus* meat could become feasible. The meat of younger *C. ramosus* is considered more tasteful than older snails (Somneuk, pers. comm.). With the marketing strategy of abalone in mind it might be beneficial to harvest *C. ramosus* before the growth rate enters the lag phase of adults.

Improved marketing of the meat, combined with increased export of shells and opercula would improve the economy. However, most other cultured molluscs which generally are herbivores constitute hard competitors especially in countries where every possible seafood product is utilized.

The shells of juvenile *C. ramosus* are rarely found in nature and because of this, they are expensive as collectors items, but this market would quickly be flooded if hatchery reared juveniles were available in thousands. Large shells of *C. ramosus* presently go in tourist shops on the west coast of Thailand for less than US$ 10/piece and this market is easily saturated, as it has happened on the east coast of Thailand, where the price of shells is low and the number of tourists is less. Therefore, I believe that strictly commercial culture of *C. ramosus* will be difficult, but restocking this species has a potential. The importance of shell trade to the coastal villagers or to the nation cannot be measured solely in terms of cash earnings or Gross National Product. It is an industry, ideally suited to coastal villagers in that the harvest of shells does not require investments in expensive equipment or vessels; the shells require no preservation and are easily packed and stored; and the meat of the shell is easily processed to provide a source of locally produced and preserved high quality protein, or, with the proper marketing, an export possibility.
In my view the feasibility of sea-farming, apart from economics, has to be regarded in the view of both conservation and to support these often poor people and their traditional life which depends on the gastropod stocks.

CONCLUSION.

The success of enhancement programmes depends to some extent on a proper definition of objectives. Do we seek value over costs, an addition to natural stocks or a self-sustaining addition to recruitment?

If the aim is strictly commercial: then it is necessary to obtain a higher marked value than the present price for the meat of *C. ramosus*. The marketing strategy of abalone may be applied to *C. ramosus* using the name "King abalone".
Because younger snails are more tasteful than older ones, and the growth rate decreases rapidly with age, attempts should be made to promote and sell younger snails.
Juveniles of *C. ramosus* have to be fenced in, as it has proven necessary in commercial sea-farming of *S. gigas* because of their migrational habits.
Inducers of spawning would be very useful in commercial sea-farming to stabilize the supply of egg capsules.

If the aim is solely restocking: then the migrational habits of *C. ramosus* would facilitate dispersal of the stock, but considerations should be taken in the choice of release sites, to avoid introducing this carnivore in areas of other cultured molluscs.
I do not regard the veligers of *C. ramosus* as a serious threat to commercial cultures of other molluscs, because they are not triggered to settle by the presence of bivalve spat or barnacles (Bech, 1993a) and they stay in the pelagic phase for a minimum of two weeks. Their chance of finding and settling in an area of mollusc culture seems to be a matter of chance.

C. ramosus is positively rheotactic and its approximate range of locomotion is known. Combining this with sediment preference, predictions of dispersal should be possible. I would expect large muddy or sandy areas, without bivalve prey, to constitute barriers in the dispersal of juveniles and adults, which could be used to avoid these introductions of predators, but further research is needed to establish this. The typical raft culture techniques commonly used in tropical bivalve farming further reduce the probability of introducing a predator from the bottom.

Trochus niloticus, *Strombus gigas*, *Haliotis* sp. and *C. ramosus* are economically very important sources of food to the local people and all have been overfished due to their value and size, but

apart from this *C. ramosus* does not have much in common with the other species, though there are some similarities with *S. gigas*.
Whether spawning periods and succes of *C. ramosus* can be predicted or not is still unknown. Its larvae are planktotrophic with a comparatively long pelagic phase, which is a disadvantage in commercial culture, but presumably an advantage in restocking.
Post larvae are carnivorous constituting an expense in culture.

C. ramosus migrate comparatively far which would enhance the probability of their survival and colonization of new areas.
The optimal aim of restocking is to establish a self-sustainable population. This is a difficult task in an open system, compared to a closed system (*e.g.* ponds, lakes) and the use of organisms with a high dispersal potential further complicates it. When restocking *C. ramosus*, it is necessary to monitor the population dynamics of the released stocks thoroughly, to establish if continued introductions during a relatively long period of time have any influence on fluctuations of natural stocks, and harvest statistics from the local fishermen.

For that purpose the multiple census capture-recapture method, developed by Seber and Jolly (1965) quoted by Seber (1973) has proved to give reliable estimates of population size of carnivorous gastropods in a given area (Bech and Steenfeldt, 1992), because this method is open to immigration and emigration. By marking part of the released stock of juveniles with individual tags, growth rates, estimates of population sizes, and the proportion of the natural population of *C. ramosus* present in the chosen area, can be estimated.
The next step is to estimate size specific mortality in nature, to find the optimal size for release in relation to mortality and rearing costs. Enclosure experiments with juveniles of different sizes could be used to establish size specific mortality *in situ*, but certain benthic predators are excluded in these experiments. Tethering experiments, in which each juvenile is attached with a line to a pole, could solve this problem. The knowledge obtained from *S. gigas* indicates that a size larger than 4 cm would improve survival considerably in relation to rearing costs.

Further research is also needed in carrying capacity of the release site, which similarly could be performed with the use of enclosures with different densities of gastropods, placed on sediments with different densities of prey.
Sea-farming is mainly based on low-technology-extensive-culture, but evaluation of potential species for the approach of sea-farming, has to be regarded in an ecological and ethnographic view, rather than with exclusive focus on economics.

Restocking should be combined with a management programme using sanctuaries to protect the release sites against over-fishing. Restrictions on size of harvestable snails may not be necessary due to their ability to hide as juveniles.
I believe that restocking *C. ramosus* has potential, but further research is needed to answer the question implicit, to establish size specific mortality in situ, population dynamics, and carrying capacity of the chosen release sites.

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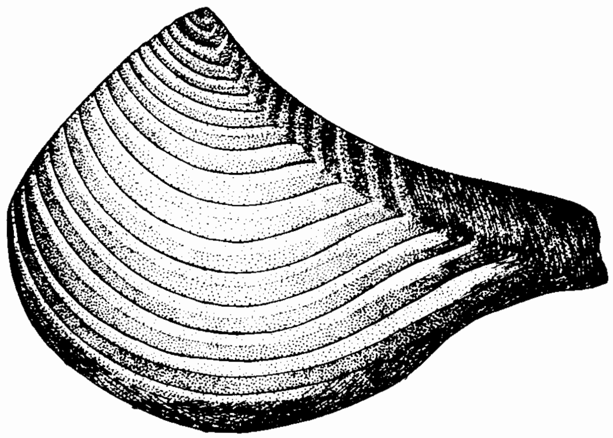

Crassatella radiata (Sowerby, 1825). PMBC 814. 2x.
Drawing by Patairat Singdam.