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PERFORMANCE OF SIMPLE LARGE-SCALE CEPHALOPOD CULTURE SYSTEM IN THAILAND

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ABSTRACT: A cephalopod culture system is simplified in order to reduce the cost of production. An open water supply system is considered to be less laborious. The size, shape and colour of concrete tanks in the hatchery are designed from experience to suit cephalopod habits as well as other purposes. The culture protocol consists of four phases, egg and spawner collection, egg incubation, nursing and grow-out. The management techniques of large-scale aquaculture have been employed. Fourteen species of neritic cephalopods are maintained, reared and cultured in the system: three loliginids, six sepioids and five octopods, serving research activity and seed (hatchling) release for restocking programs. Four species are cultured through the complete life cycle and yield consecutive generations. About 2.1 millionseeds were annually released for restocking during the years 1990–2002. The conceptual system design for the commercial scale is proposed as five components. The components are the cephalopod hatchery, the live feed hatchery, the artificial feed plant, the grow-out facilities and the artificial spawning reef.

INTRODUCTION

Cephalopods are dynamic predators and prey occupying a dominant position in the trophic relationships of complex marine ecosystems. Cephalopods are an important and potentially valuable fishery resource as food. More than 80% of the cephalopod body is suitable for human consumption and the remainder can be processed for livestock and poultry consumption. Cephalopod capture fisheries annually yield about 150,000 t of neritic species from Thai waters. The production is the highest among ASEAN countries. Two-thirds of this amount are processed and exported to Japan, Europe and USA, earning about US $200 million. Local consumption is about US $100 million so that the total value of cephalopod products in Thailand is US $300 million. These traditional fisheries generally met the market demand for protein for human consumption.

In the meantime, the status of the cephalopod resources in Thai waters, like other aquatic resources, is at high risk of declining (Supongpan, 1995). This situation generates interest in aquaculture. The absence of a true larval stage, the extremely rapid growth, the short life span and high nutritional value make cephalopods a highly promising species for aquaculture as food production (Nabhitabhata, 1995a). Live cephalopods are also in demand for use as experimental animals for cell biology and neuroscience as well as other biomedical research (Boletzky and Hanlon, 1983). Another market that seems to be more realistic for developing countries is the home and public aquarium market. Benthic cephalopods with exotic colour patterns, appropriate habits and good adaptability to aquarium conditions are suitable for this purpose. These markets create a demand for live cephalopods which could be conveniently supplied from aquaculture. Increasing demand for live cephalopods adds the value to the aquaculture products.

Fifty-seven species of cephalopods have been maintained, reared and cultured all around the world (excluding Thailand). Most of the studied species are neritic but the benthic forms, particularly, exhibit high tolerance to handling and good adaptability to the conditions in captivity. Open water systems have been used in studying 32 species, closed systems for 15 species and both types of system for 10 species (Boletzky and Hanlon, 1983; Boyle, 1991; Hanlon, 1987; Hanlon *et al*., 1991). Twelve species (21%) are cultured through the entire life cycle, seven in open systems, two in closed systems and three in both systems. The cultured species are neritic and comprise 11 benthic forms (five sepioids and six octopods) and one pelagic form, (a loliginid squid). However, there is no commercial culture of cephalopods anywhere at present.

Cephalopod culture in Thailand began in 1977 when Boonprakob *et al.* (1977a, b) reared the spineless cuttlefish, *Sepiella inermis*, in their laboratory for biological research. The Coastal Aquaculture Division of the Department of Fisheries also supported research on the feasibility of commercial cephalopod culture. The focal species were the bigfin squid, *Sepioteuthis lessoniana*, the pharaoh cuttlefish, *Sepia pharaonis*, (Nabhitabhata, 1978a, b) and the spineless cuttlefish, *Sepiella inermis* (Nabhitabhata *et al.,* 1984a). Research has gradually developed large scale systems as a consequence of studies on the grow-out of the bigfin squid in floating net cages (Nabhitabhata *et al.,* 1984b) and the grow-out of the spineless cuttlefish in an earthen pond (Nabhitabhata *et al.,* 1985). That research was halted when sufficient supplies of cephalopods became available from capture fisheries. In 1990, the Department of Fisheries launched the research program on cephalopod culture as an alternative species for coastal aquaculture. This program is presently ongoing. In 1993, a workshop on "Biology and Aquaculture of Cephalopods" was organized at Rayong Coastal Aquaculture Station (Nabhitabhata, 1995b) and yielded a compilation of the body of knowledge of cephalopods in Thailand for the first time.

Recently, 15 species of cephalopods have been maintained, reared and cultured in Thailand (Table 1). All of them are neritic species and comprise three pelagic, six benthic and six octopod cephalopods. Four of them are cultured through their complete life cycle and yield the further generations.

MATERIALS AND METHODS

Seawater Supply System

The facility is in Rayong province, east of the Gulf of Thailand. Fresh seawater is pumped from the sea close to shore from a pump house that is about 150 m from shore. The water is left for sedimentation in an earthen pond of 800m^2. After that the water is pumped through an anthracite filter. Filtered water is supplied to the concrete culture tanks in the cephalopod hatchery (Fig 1). The used water is drained out of the tanks into the treatment pond of 400 m^2. The wastewater is maintained for sedimentation and aeration and then released out to the sea.

Tank System

There are 30 circular concrete tanks 1.5 m in diameter, 0.6 m high and 1.15 m^3 capacity, for maintenance of the benthic spawners. These tanks are painted dark-blue. The concrete tanks for egg incubation are cylindrical, 1.8m in diameter, 0.6m high, 1.65 m^3 capacity and painted mid-blue. There are 32 tanks for the incubation of eggs. The nursing tanks are cylindrical, 2.0 m in diameter, 0.6 m high, 2.05 m^3 capacity and painted grey. The grey colour represents neutral brightness of the substrata for stress reduction, growth promotion and enhancing contrast for visual sensing of cephalopod food (Nabhitabhata and Nilaphat, 2000). The function of the above three sets of cylindrical tanks is interchangeable. There are 4 rectangular tanks of 40 m^3 capacity and painted dark-blue and 10 cylindrical tanks 3.0 m in diameter, 0.6 m high, 4.61 m^3 capacity and painted neutral grey, for maintenance and growing-out of pelagic species. The live feeds are reared in 10 rectangular tanks of 10 m^3 capacity, 1×10×1 m, and painted dark-blue. All tanks are covered over with a roof. The tanks are equipped with a drainage pipe at the center, except in the rectangular tanks where it is at the corner. The drainage is via pieces of movable pipe of the same diameter, serving as a stopper

Table 1. Cephalopod species that have been cultured, reared and maintained in Thailand.

species	references
Pelagic form:	
*Sepioteuthis lessoniana**	Nabhitabhata (1978a, 1996), Nabhitabhata and Kbinrum (1981)
Loligo duvaucelii	Nabhitabhata (unpub.), Wudthisin and Singhagraiwan (1988)
Loliolus sumatrensis	Nabhitabhata (unpub.)
Benthic form:	
*Sepia pharaonis**	Nabhitabhata (1978b), Nabhitabhata and Nilaphat (1999)
*Sepiella inermis**	Boonprakob *et al*. (1977a, b), Nabhitabhata (1997), Nabhitabhata *et al*. (1984)
Sepiadarium kochii	Nabhitabhata (1995a)
*Euprymna hyllebergi**	Nabhitabhata (2000), Nilaphat (2001) Nabhitabhata *et al.* (2003)
Idiosepius thailandicus	Nabhitabhata (1994a, b; 1998)
I. pygmaeus	Nabhitabhata (unpub.)
Octopus:	
Octopus dollfusi	Phanichpong (1985)
O. membranaceus	Nabhitabhata (1985)
O. neglectus	Nabhitabhata (2000)
O. rex	Nabhitabhata (2000)
Cistopus indicus	Nabhitabhata (1995a)
Hapalochlaena maculosa	Nabhitabhata (1995a)

* life cycle completed and further generations produced.

and water-level controller. In flowing-through mode, the water level is set by varying the length of the center drainage pipe. The pipelines for seawater and aeration are PVC pipes of drinking water standard elevated about 2 m above the tanks.

Quality of Supplied Seawater

The flow-through method is used in all phases of culture. The flow rate is adjusted to suit the culture phase. Together with siphoning during bottom cleaning this enables a change rate of about 1–3 times the tank volume per day. Water quality parameters are monitored daily, and sudden change is avoided. The criteria of water quality for cephalopod culture is similar in all phases and all cultured species (Nabhitabhata, 1993; Nabhitabhata *et al.,* 1991; 2001):

dissolved oxygen	more than 5 $mg.L^{-1}$
salinity	25–35 ppt
temperature	28–32 °C
pH	7.0–8.5
turbidity	as low as possible

Cephalopod Culture Protocol

The system consists 4 phases differing according to management and routine operation. The phases are generalized for all species with appropriate variation for different species.

1. *Spawner and Egg Collection Phase*:

Egg collection varies for cephalopods depending on quantities of eggs and convenient collection. Live eggs of the bigfin squid are collected as bycatch of the squid traps. Eggs at

Figure 1. Seawater supply system in Rayong facility for cephalopod seed production and research activity.

early embryonic developmental stages can better tolerate handling during transportation than eggs at later stages. Spawner collection is appropriate for cephalopods with lower egg quantities, if live spawners can tolerate handling during transportation. Spawners of pharaoh cuttlefish are collected live from squid traps operating nearshore in Rayong province in the eastern part of the Gulf of Thailand. The cuttlefish are maintained in the submerged chamber of the 3m-long fishing boat until return to the shore. Spawner collection is also possible for cephalopods that can not be collected by small-scale fishing gear. Live spineless cuttlefish and bobtail squids are collected from otter trawls with booms and live octopus from otter trawls. Live loliginid squids are collected with light-luring fishing gear. Handling and transportation to the hatchery must avoid damaging the mantle to prevent later infection. Stress has to be minimized to avoid ink ejection in the transportation tank and consequent polluting of the water. Temperature has to be decreased using ice cubes to reduce the metabolic rate. The transportation tank has to be covered with a black plastic sheet in order to avoid visual stimuli and, in the short term, reduce cold loss. In the hatchery, the spawners are maintained in concrete tanks of 1.5 m diameter and 1.15 m^3 capacity at a male to female ratio of 1: 2 (Fig 2). They mate and spawn in the tanks attaching their egg capsules in clusters to artificial substrates. The substrates are made from pieces of weighted nylon net for large species and PVC pipe and corals for small species. Octopus spawners are supplied with pieces of PVC pipes of about 10–15 cm length as artificial dens. The artificial substrates are economic and convenient for both egg collection and cleaning

2. *Egg Incubation Phase* :

Clusters of collected eggs are scissor-cut in order to segregate them into single egg capsules or single strands. The egg capsules are graded according to the embryonic stages by capsule size (Fig 2). The eggs are put into plastic baskets floating in the concrete tanks of 1.8 m diameter and 1.67 m^3 capacity. The eggs of large species at early stages (small size) are put into a basket of 5 mm mesh size and later stages into 10 mm mesh size. A basket of 2 mm mesh size is used for the eggs at all stages of small species. Aeration and

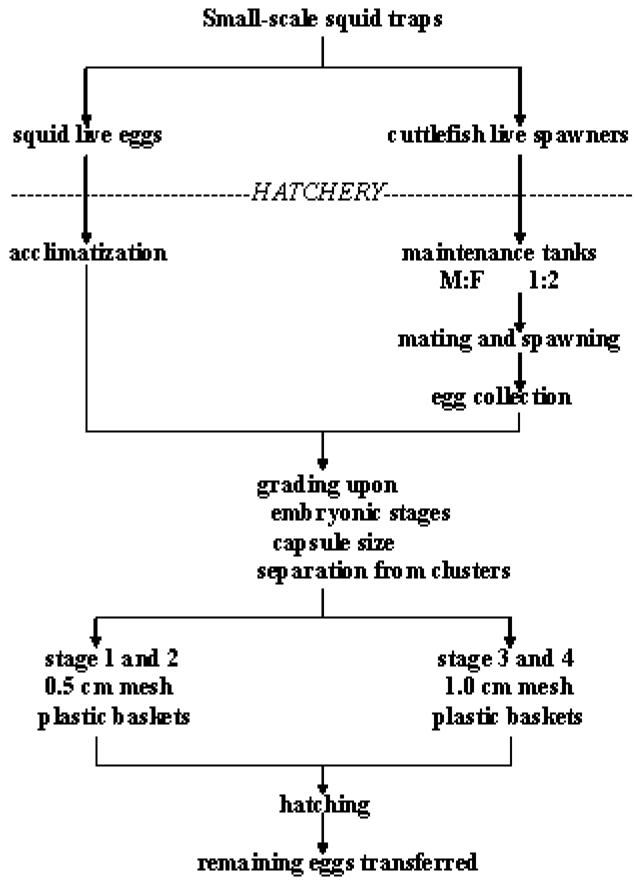

Figure 2. Cephalopod spawner and egg collection and egg incubation.

water flow at a rate of 1 L.min^{-1} are supplied continuously to avoid sudden change in temperature as well as other parameters. The tank bottom has to be cleaned regularly by siphoning. The unfertilized eggs, dead eggs and empty egg capsules are sorted out daily to avoid microbial infection. Light inside the hatchery is reduced by 80% with a fence of camouflaging net around the hatchery. Excess light would cause algal growth on the egg capsules, interfering with oxygen transfer. The eggs hatch in about 2–3 weeks according to the species, three weeks for pelagic squids and two weeks for benthic cephalopods. The hatchlings pass through the basket-mesh into the tank. When the optimum density in the tank is achieved the egg baskets are transferred to another tank of the same water quality. The incubation tank now becomes the nursery tank.

3. *Nursing Phase*:

Nursing is performed in the concrete tanks of 1.15 or 1.67 m^3 capacity from hatching to 30 days of age. Hatchlings are fed to excess on live mysids (*Mesopodopsis orientalis*) or the larvae or postlarvae of penaeid shrimp (*Penaeus merguiensis*). The size of the live feed is selected to correspond the size of the cephalopods (Nabhitabhata *et al*., 1996). The penaeid shrimps are routine products of a shrimp hatchery for commercial distribution to private aquaculturists and for a public program on aquatic resource conservation. The density of the biomass in the tank must be managed. The optimum density for the planktonic hatchlings is about 10 ind.L^{-1} and for the benthic hatchlings is 500 ind.m^{-2}. Size grading and water level adjustment are performed every ten days for suitable management of feed and avoidance of cannibalism. The density per tank is reduced by 20–30 % after each grading.

4. *Grow-out Phase*:

This phase begins after 30 days of age. After 20 days during the late nursing phase, the cephalopods are trained to feed on non-living fish meat (*Caranx leptolepis*) in order to reduce the cost of production and because of insufficient supply of live feeds. Grow-out phase to their final size takes about 3–4 months for the cephalopods, depending on species. The period is shorter for ornamental purposes since smaller sizes are required. Nursing tanks can become grow-out tanks for the small species. Grow-out of the large species as experimental animals for further research is undertaken in cylindrical concrete tanks of 3.0 m diameter throughout their life span.

The materials and methods for mass grow-out in the field vary according to the life history and behaviour of the species. The site and the type of enclosure have to be selected. A floating net cage is appropriate for the pelagic forms. The cage is hung from a floating buoy or a bamboo raft. Underwater hard frames are avoided to prevent collisions of the squids that would cause skin damage and consequent infection. The net is mono-filament type with 10 mm mesh size. A cage of this type can be used throughout the grow-out phase without need for change to a larger mesh size. The optimum density is about 10 ind.m^{-3}. Pens with fencing are appropriate for benthic cephalopods with burying behaviour. The pen is made of bamboo poles and net lining with a sinker inside. An earthen pond can also be used for grow-out of some benthic cephalopods such as spineless cuttlefish and octopus. Turbidity of the water in the pond has to be lower than the water used for grow-out of finfish and shrimps. Also salinity has to be higher than 25 ppt. The optimum density is about 10–15 ind.m^{-2}. In all cases, harvest must be performed before spawning in order to gain the maximum yield.

Routine Management

Tank bottoms for all activities have to be cleaned every day since the high tropical temperature generates rapid decomposition and microbial growth. The feces and remains of feed are taken out by siphoning. The ejected and soluble ink and mucus as well as other organic waste, are taken out by the flow-through water supply. The flow rate is adjusted to suit the culture phases. The flow rate of 1–3 L.min^{-1} enables the daily turnover of water of 1–3 times the tank volume.

Aeration is set to suit different phases. Consistent aeration throughout the water volume is necessary for the incubation to yield a high hatching rate. Aeration in the spawner and grow-out tanks is set to be strong enough for the high metabolism of the cephalopods. This also assists in removing waste products by producing upwelling flow to the drainage pipes. Aeration also serves as the current generator in the tanks. Adjusting current velocity reduces stress and energy consumption in counter-current swimming. This enhances survival and growth and hence production. Pelagic cephalopods, particularly planktonic hatchlings, need directed flow to suspend them in the water column. A simple air-lift system is used to provide horizontal flow in the cylindrical tank. A PVC pipe of 50 mm diameter is cut in half longitudinally. The air line and stone are attached to the interior of a half-pipe at one end through a drill hole. The prepared half-pipe is placed upright at 45° with the air stone at the bottom of the tank. The air stones and half-pipes face the same direction to generate a continuous flow. The current velocity can be adjusted by adjusting aeration rate. The numbers of the flow-generating pipes depend on the size and shape of the tanks. A generated current is not necessary for benthic cephalopods.

The water level in the nursery tanks is adjusted to aggregate the live feed organisms. Appropriate biomasses of feed and cephalopods in a tank reduce excess activity in food hunting. The initial water depth is 50 cm for planktonic hatchlings and 30 cm for benthic hatchlings. The level is increased by 5 cm every day or every second day. The initial density is 5–10 ind.L^{-1} for planktonic hatchlings and 500 ind.m^{-2} for benthic hatchlings. The density is reduced for 20–30% after size grading every 10 days due to rapid growth. The level and density settings have to change in relation to growth.

Feeding and Growth

Gross food conversion efficiency (%) was determined every 10 days and calculated according to Choe (1966a, b):

$$GFCE = (W_2\text{-}W_1) / F \times 100$$

where GFCE is gross food conversion efficiency (%),

F is total food consumed in wet weight basis (g),

W average weight (g)

W_1 initial weight (g),

W_2 final weight (g),

t - number of days (10-days period).

Growth was determined every 10 days in terms of gain in dorsal mantle length (ML, mm) and wet body weight (W, g). Instantaneous relative growth rate (%) of mantle length and weight was calculated according to Choe (1966a, b) and Mangold (1983):

$$DGRL = (ML_2\text{-}ML_1)/t[(ML_2+ML_1)/2] \times 100$$

and $$DGRW = (W_2\text{-}W_1)/ t[(W_2+W_1)/2] \times 100$$

where DGRL is daily relative growth rate in terms of mantle length (%),

DGRW daily relative growth rate in terms of wet body weight (%),

ML_1 initial mantle length (mm),

ML_2 final mantle length (mm).

RESULTS

Studied Species Account

In this system, 14 species of neritic cephalopods have been studied and four species, *Sepia pharaonis*, *Sepiella inermis*, *Euprymna hyllebergi* and *Sepioteuthis lessoniana*, were cultured throughout their life cycle for several consecutive generations. The result reveals their life history, growth, behaviour and production in relation to aquacultural interests. The eggs are single in benthic forms and aggregate in pelagic forms. The incubation period is 2–3 weeks. The larval stage is absent. The daily growth rate is 1–3 % in mantle length and 3–7% in weight. The first maturity is after 2–3 months of age, and senescent death follows intermittent, semelparous spawning. The life span is about 3–5 months with a reproductive period about 30% of the life span.

1. Pharaoh cuttlefish, *Sepia pharaonis*

The spawners of the pharaoh cuttlefish are collected from squid traps in the same manner as the bigfin squid. The egg capsule is single and is white in colour. It is larger than the capsule of the spineless cuttlefish. The incubation period is 9–25 days with average of 14.3 days. Hatchlings are benthic. Their mean size is 7.7 mm in mantle length and 0.18 g in weight. The hatching and survival rate is more than 90%. Feed efficiency is very high, about 70%, as benthic behaviour is an advantage. Average daily growth is 1.37% in length and 3.40% in weight. The cuttlefish is benthic and sexually mature after 90 days of age and spawns after 110 days. A body weight of 100 g can be attained after 140 days and the final size is 275 g after 210 days. The male is larger than the female. The life span ranges from 112–271 days with an average of 149.4 days. This species can be cultured for human food as well as for the home aquarium.

2. Spineless cuttlefish, *Sepiella inermis*

Eggs and spawners can be collected from nearshore and estuarine areas by push nets and otter trawls with booms. The egg capsule of the spineless cuttlefish is single and black in colour. The incubation period is 8–19 days with an average of 12.6 days. Hatchlings are planktonic for 3–5 days with initial mantle lengths of 4.3 mm and body weights of 0.04 g. The cuttlefish is benthic and mature sexually after 60 days, mating after 70 days and spawning after 87 days. Average daily growth rate is 2.43% in mantle length and 5.54% in weight. The final size is about 50g after 130 days. The advantage of this species is the hatching and survival rate of over 90%. Feed efficiency is about 30% due to its delayed benthic behaviour. The life span is 84–149 days with an average of 116.2 days. They are an active benthic form with good adaptability to feeding and the aquaculture environment either as human food or as ornamental and experimental animals.

3. Bottle tail squid, *Sepiadarium kochii*

Egg capsules are collected from otter trawls operating at night. The egg capsule is aggregate with 4–6 embryos. The incubation period is about 2 weeks. The hatchlings are benthic with 1–2 mm mantle length. The young have been reared for about one week in the Rayong facility.

4. Bobtail squid, *Euprymna hyllebergi*

Spawners are collected from otter trawls with booms operating at night. The egg capsule is single with calcareous outer layers. Eggs take 13–17 days for incubation with an average of 14.5 days. The hatchlings are planktonic for 6–8 hrs and then become benthic, lying on the bottom. Their mean mantle length is 2.3 mm and weight 0.0045 g. Average daily growth rate is 2.20% in length and 6.54% in weight. The squids reach maturity after 60 days of age, mating and spawning after 90 days of age. The average final size is 21.7 mm in length and 5.69 g in weight after 100 days of age. The female is larger than the male. The life span is 82–122 days with an average 105.0 days. The squids are suitable for rearing in the home aquarium and can be cultured through several consecutive generations.

5. Pygmy squids, *Idiosepius thailandicus, I. pygmaeus*

Spawners are collected from the intertidal zone, mangroves and estuaries by using dip nets. The female is significantly larger than the male. The average size of females is 10.4 mm in mantle length and 0.20 g in weight and males 5.9 mm and 0.02 g. The egg capsule is single type without a stalk. Incubation lasts 10–13 days. The hatchlings are planktonic with 1 mm mantle length. The adults are benthic with a distinctive seaweed association and reproductive behaviour. They are the world's smallest cephalopods. These characteristics make them appropriate for the home aquarium.

6. Indian squid, *Loligo duvaucelii*

Spawners are collected from squid light-lure fishing and then transported to the hatchery. The adults are pelagic with gregarious behaviour. The egg capsule is aggregate with 176–290 embryos. Eggs take 7–10 days for incubation. The hatchlings are planktonic with 1.1 mm mantle length. The young have been reared for 7–10 days.

7. Katoy squid, *Loliolus sumatrensis*

Live eggs are collected as byproducts from the trammel net. The egg capsule is aggregate with about 100 eggs. The capsule shape is leaf-like. The incubation period is 2 weeks. The hatchlings are planktonic with 1.5 mm mantle length. They survived for about one week in the Rayong facility.

8. Bigfin squid, *Sepioteuthis lessoniana*

Eggs and spawners are collected from squid traps operating in the nearshore zone. Egg collection is more economic. The year-round spawning season in natural waters ensures a good supply of eggs. The egg capsule contains 2–11 embryos.Eggs require about 3 weeks for incubation. Hatchlings are planktonic with average 5.4 mm mantle length. They become juveniles after about one week. Adults are pelagic with gregarious behaviour. Maturity is reached after 60 days, mating after 90 days and spawning after 112.2 days. Average daily growth rate is 2.79% in length and 6.36% in weight. The final size is 214 mm in length and 497g in weight after 130 days. Males are larger than females. Feed conversion efficiency is 36% and survival at harvest is 20–30%. The life span is 104–167 days with an average 123.5 days. From the commercial point of view, the bigfin squid is the most interesting species for aquaculture for human consumption because of its very high growth rate. Marketable size is attained after about 4 months from hatching, making three crops annually possible.

9. Octopus, *Octopus membranaceus, O. neglectus, O. rex*, *Cistopus indicus*, *Hapalochlaena maculosa*

Octopus spawners are collected from otter trawls. All species brood their eggs and carry their eggs on their arm webs behind their heads, except *Cistopus indicus*. The egg capsules are single without a tip and white in colour. The incubation period is about 14 days. The hatchlings are planktonic with 1 mm mantle length. King octopus,

Octopus rex, has been reared for 60 days and other species have been reared for about 10 days. The adults are benthic and live in dens, making them suitable for the home aquarium.

Cephalopod Growth in the Aquaculture Environment

The bigfin squid, *S. lessoniana*, has the fastest growth compared with pharaoh cuttlefish, *S. pharaonis*, and spineless cuttlefish, *S. inermis*, the three best studied species through their life cycles. Average daily growth rate of bigfin squids is 2.79% in length and 6.36% in weight compared to 1.37% in length and 3.40% in weight of pharaoh cuttlefish and 2.43% in mantle length and 5.54% in weight of spineless cuttlefish, respectively. From an aquaculture point of view, the final size of 214 mm in length and 497 g in weight after 130 days is a good yield and three crops/year are possible. The spineless cuttlefish ranked second in growth rate. This species adapts well to the aquaculture environment, either in concrete tanks or earthen ponds, as evidenced by survival rates over 90%. The final size of about 50 g after 130 days seems to be lower yield for human consumption but it is suitable for frozen product packaging. The pharaoh cuttlefish has the lowest growth among the three species but the high feed conversion efficiency of approximately 70% is an interesting point, compared to approximately 30–40% in bigfin squids and spineless cuttlefish. The weight of about 100g in about four months makes the yield of this species in consideration in the same manner as the spineless cuttlefish. The live pharaoh and spineless cuttlefish are well suited for experimental animals as well as home aquarium. The other well studied species, the bobtail squid, *E hyllebergi*, is a small species and should be considered in the same manner as the live cuttlefish.

Seed Releasing for Restocking

Since 1990, cephalopod hatchlings (known as seeds) of about 10 mm total length produced from the hatchery have been released into the natural water of Changwat Rayong, east of Thailand. The released species are bigfin squid *S. lessoniana*, pharaoh cuttlefish *S. pharaonis*, spineless cuttlefish *S. inermis*, bobtail squid *E. hyllebergi* and octopus *O. neglectus* and *O. rex*. The total numbers released for bigfin squid is 23.06 million, for pharaoh cuttlefish, 2.77 million and for others, 1.08 million, totalling 25.95 million during the 13 years from 1990–2002 (Table 2). The average release is 2.14 million seeds per year. About 90% of the seeds are the bigfin squid and 10% are the pharaoh cuttlefish and other species.

DISCUSSION

System Concept

The system developed from laboratory scale culture studies begun in 1978 and used intermittently until 1990 when the cephalopod hatchery was founded at Rayong Coastal Aquaculture Station. The key feature is the proper design of the tanks for cephalopod culture, which can also serve other purposes. For example, the cylindrical tanks are uniquely suited for nurseries for planktonic hatchlings, but tanks of any shape are adequate for the benthic hatchlings. Two periods of expansion of the hatchery increased the numbers of tanks in 1991 and in 2000. This created one set of tanks for live feed maintenance and another set for egg incubation. Despite the large numbers of tanks, the open water system is most effective. This system is simpler with lower operating costs in developing countries compared to recirculated or closed systems. The simple system avoids requirements for equipment for filtration (ammonia remover, protein skimmer), sterilization (UV, ozone generator), electronic apparatus for water quality monitoring and artificial seawater chemicals. Such facilities would be very expensive in a developing country. The simple tank design allows them to be used for multiple purposes. The good quality of the natural water means that only simple treatment is required. The water system, the tank system and the aquaculture protocol is flexible and suitable for both large and small scale.

The system incorporates the techniques of large or commercial scale aquaculture, such as non-living feeds, separation of nursing and grow-out facilities and size grading to allow good management to reduce the cost of production while increasing total production. Although the supply of live feed from routine activities is reasonably

Table 2. Numbers of cephalopod seeds (×10^4) produced in the system and released for restocking.

Fiscal year	Bigfin squid (*S. lessoniana*)	Pharaoh cuttlefish (*S. pharaonis*)	Others*	Total
1990	144.68	1.26	-	145.94
1991	166.86	2.66	-	169.52
1992	304.89	15.16	-	320.05
1993	198.38	20.21	-	218.59
1994	378.64	27.00	-	405.64
1995	86.42	53.09	-	139.51
1996	187.45	14.28	-	201.73
1997	225.21	33.26	-	258.47
1998	104.65	12.76	-	117.41
1999	147.40	44.16	-	191.56
2000	166.08	12.16	2.86	181.10
2001	173.83	32.36	6.71	213.58
2002	22.01	8.36	1.28	31.65
Total	2,306.50	277.22	10.85	2,594.75

*spineless cuttlefish (*S. inermis*), bobtail squid (*E. hyllebergi*), octopus (*O. neglectus, O. rex*).

reliable, advances in live feed production is the first priority for cephalopods.

Commercial Scale Aquaculture Conceptual Design

Present information indicates that the high growth rate of cephalopods gives them outstanding potential for commercial aquaculture, particularly in comparison to traditional species of marine finfish and shrimps (Nabhitabhata, 1995a). Cephalopod culture is already possible on a small scale. Seed production can be performed in back-yard hatcheries or in net cages at the site of grow-out cages. The home aquarium trade market can be reached through the small scale culture; however, Nabhitabhata (1995a) has outlined the profile for large scale cephalopod culture systems. The system consists of five components. The first component is the cephalopod seed production hatchery where the first two phases of culture protocol, egg or spawner collection and the nursery phase are performed. The second component is a live feed hatchery that could produce a feed supply, reliable in quantity, consistency and low cost. The routine products of the live feed hatchery would supply the cephalopod hatchery and excess products could be channeled to other aquaculturists, such as shrimp grow-out farmers. The cephalopod hatchery can supply seeds to the grow-out batteries (the fourth component below) and, for the public sector, to release back to natural waters for stock enhancement.

It should be noted that the live feed species is not necessarily the penaeid shrimps used in this study. Many species of finfish and shrimps, that can be mass produced at low cost, are appropriate, *i.e. Metapenaeus* spp., *Palaemon* spp. as discussed by Nabhitabhata *et al*. (1992, 1996). Young cephalopods intrinsically require feed with specific characters of shape, size, brightness, texture and locomotion during their first month. Attempt to feed young cephalopods with live feeds other than crustaceans and fishes have not succeeded (Nabhitabhata, 1978a, b; Toll and Strain, 1988; Segawa, 1993). Unfortunately, the most common feed for large scale aquaculture, *Artemia*, cannot be used as the main course for cephalopods. Young cephalopods fed on *Artemia* exhibit low growth and survival (Nabhitabhata, 1978a, b; Muthuwan *et al*., 1993).

The third component of the system is an artificial or formulated pellet feed plant. This plant would supply feed for the cephalopod hatchery as well as grow-out batteries. The possibility for grow-out pellet feed is much better than for nursery feed in the near future. After one month of age all species of the cephalopods can be trained to accept the non-living feed. The reason is that the degree of intrinsic selectivity is higher in the young stage than in the adult stage (Boucher-Rodoni *et al*. 1987). However, artificial feed in the nursery phase is not impossible. Detailed study of behaviour is the key. The development of live and artificial feed is the dilemma for large scale culture.

The fourth component is the grow-out battery the characters of which must correspond to the living forms of the cephalopods. Floating net cages are appropriate for neritic nektonic or pelagic cephalopods and pens, fencing or earthen ponds for benthic cephalopods. In Thailand, Nabhitabhata *et al*. (1984b) and Thapanand and Phetchsuthi (2000) demonstrated grow-out of the pelagic bigfin squids in floating net cages and Nabhitabhata *et al*. (1985) the benthic spineless cuttlefish in the earthen pond. Ranching or the fencing of large areas is appropriate for large school pelagic forms of oceanic squids. Manufacturing and organization can be separated for most components of the system but combination of the first and the second components seems most efficient in reducing operating costs.

The fifth component is the artificial spawning reef where substrates are installed in selected waters to create a man-made sanctuary for young and spawning cephalopods. Eggs and spawners can be collected by small scale fishermen and then supplied to the cephalopod hatchery. Released seeds from the hatchery can find their feeding ground and shelters and then migrate out later as natural stock recruits. The artificial spawning reef can also serve as a wave break for grow-out sites and facilities. Installation cost may be returned from the revenue from game fishing licenses in the reef area. This component is likely most appropriate for the public rather than the private sector because of its conservation value.

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