Southward transplanted cage-culture of sea cucumbers *Apostichopus japonicus* in China's Shengsi Islands

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Abstract

Three sizes of the sea cucumber *Apostichopus japonicus* were cultured in abalone cages, and survival and growth were monitored semi-monthly or monthly, from December 2007 to May 2008, using fermented seaweed as feed. The sea cucumbers in four sites had high survivorship (≥83%). Growth of large individuals (~70 g mean live weight) was slow when densities reached approximately 5 ind. layer^{-1}. Growth rates were negatively correlated with culture densities; for large juveniles at high densities, growth rates were the same as those for medium sized juveniles (about 30 g mean live weight) and small juveniles (50 g mean live weight) that were not stunted at high densities. Juveniles of all three sizes grew progressively except after April when sea temperatures increased. *A. japonicus* with a body weight of 40 g and in densities of 3–5 ind. layer^{-1} can be farmed successfully in abalone cages. Translating cages to more southerly (i.e. warmer) sites can extend the growing period of sea cucumbers, allowing them to reach commercial size over the course of the year. Naturally occurring populations of *A. japonicus* in the northern end of the East China Sea have a low growth rate during winter. Field-based growth trials for the purpose of culturing *A. japonicus* in the Shengsi Islands (southern China) were carried out.

Introduction

Sea cucumbers, especially *Apostichopus japonicus*, are among the most economically important and commercially exploited organisms in China due to their high quality meat and the successful techniques used in commercial hatcheries (Liao 1997). Sea cucumbers have been successfully bred to provide large numbers of juveniles (Sui 1988; Ito 1995), which holds great promise for restocking, stock enhancement, and sea ranching programmes.

A. japonicus is found in Russia, northern China, Japan, and North and South Korea (Sloan 1984). Sea ranching of sea cucumbers was initiated in Japan in the late 1930s and by the Yellow Sea Fisheries Research Institute in China in 1980 (Sui 1988), and was also developed more recently in the Pacific Islands (Battaglene and Bell 2004). In recent years, many sea cucumber farming techniques have been developed, such as farming in shrimp ponds, in offshore ponds, and in cofferdams filled by gravity-fed seawater (Chen 2003). Currently, in north China, *A. japonicus* is mainly farmed in nearshore waters in depths less than 15 m, which are often polluted — a problem that reduces the number of suitable areas for farming. The extension of farming areas to deep water and to southern China would provide more favourable environmental conditions and reduce the stress induced by farming in coastal areas.

The culture of hatchery-bred juveniles in southern China could reduce the time required to reach harvest size. Xiao and Gu (1981) transplanted adult and juvenile sea cucumbers in Xiamen, southern China for culture and spawning experiments. Sun et al. (2006) also transplanted juvenile sea cucumbers in Nanji Island (27°27'N, 121°05'E) in southern China; the results showed that the sea cucumber grew well. Juvenile sea cucumbers were bred artificially and acted normally, with good conditions and high survival rates even after aestivation from early June to the middle of November, which lasted for 160 days in the summer.

In northern China, seawater temperatures in winter drop below 5°C, which constrains the growth and survival of sea cucumbers. Cage-culturing sea cucumbers in southern China's warmer waters would provide many additional potential farming areas, reduce growth time before harvest, and make it possible to farm sea cucumbers in the winter months.

The Shengsi Islands (30°72'N, 122°45'E) in southern China comprise some 200 islands with a long history of marine aquaculture. However, rubble and rocky substrates needed for sea cucumber farming are scarce in the Shengsi Islands, where most substrates consist of sand and mud bottoms at depths that range between 5 m and 20 m. Sea cucumber

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habitat could be artificially simulated by adding hard substrata, although the cost would be high. Furthermore, light penetration decreases with depth, thereby constraining the growth of seaweed, which is used as cover and food for sea cucumbers. In addition, the nylon-mesh enclosures of scallop suspended-culture results usually in ulcers and death of sea cucumbers. By contrast, abalone cages suspended from rafts used by farming facilities are easily accessed.

There has been an increasing interest in the possibility of culturing deposit-feeding sea cucumbers that would consume sediments from the cages or pens used in scallop farming, thereby reducing the negative effects of scallop culture on the benthic environment and potentially producing a valuable secondary product. A previous study showed that *A. japonicus* grew well and reduced organic wastes when polycultured with scallops in lantern nets in northern China (Zhou et al. 2006). Paltzat et al. (2008) used oyster grow-out trays, which were designed to collect biodeposits and prevent sea cucumber escape, for the production of *Parastichopus californicus* Stimpson.

Figure 1. Locations of *Apostichopus japonicus* culture. G1, G 2: Gouqi Island (sites 1 and 2); HI: Huaniao Island; SI: Shenshan Island.

Deposit-feeding holothurians ingest sediment bearing organic matter, including bacteria, protozoa, diatoms, and detritus of plants and animals (Yingst 1976; Moriarty 1982; Zhang et al. 1995). In recent years, fermented seaweed, especially *Laminaria japonica* Aresch and *Ulva pinnatifida* have been used as food sources of cultured sea cucumbers in China (Sui 1988). Fermented seaweed mixed with debris such as mud, dead algae, and sea cucumber faeces that settle on the inside of the cages can provide the main organic nutrient resource for sea cucumbers. Those sea cucumbers that were fed with fermented seaweed or mixed diets grew well, indicating that fermented seaweed could be an ideal food for sea cucumbers (Yuan et al. 2006).

Only if juvenile sea cucumbers survive to commercial size will culturing them add value to local economies. This study determined growth and survival of the sea cucumber *A. japonicus* during southward transplantation in the Shengsi Islands in southern China. Sea cucumbers were in abalone cages with fermented seaweed as feed to test the feasibility of sea cucumber culture in southern China.

Materials and methods

Animal materials

Sea cucumbers were obtained from hatchery larvae produced in March 2007 in Yantai, Shandong Province in northern China. The mean size of sea cucumbers at the start of the experiment was 40.72 ± 17.18 g (n = 330). Body weight was measured while juvenile sea cucumbers were fully extended. Sea cucumbers were then packed into insulated boxes and transported by air to the farm within six hours. All animals were acclimatised in a 10-m^3 land-based, concrete tank with composite sand and natural light for at least one week before the experiments.

Study sites

The study was conducted from December 2007 to May 2008, in the area east of Shengsi Island in Zhejiang Province, in the East China Sea. The study areas were shielded by the mussel farming area in depths of 5–20 m. Seawater was clean with no obvious pollution. Tides and currents in this area are gentle and steady. Four sites were chosen for culturing juvenile sea cucumbers: two at Gouqi Island (G1: 122°38′E, 30°42′N and G2: 122°50′E, 30°39′N), one at Huaniao Island (HI: 122°44′E, 30°52′N), and one at Shenshan Island (SI: 122°24′E, 30°43′ N) (Fig. 1).

Environmental conditions

Seawater temperatures ranged from 7.5°C in February 2008 to 17.2°C in December 2007 (Fig. 2), which is within the optimal temperature range (10–17°C) for *A. japonicus* growth. Water transparency was around 2 m. The seawater was well mixed and remained saturated with dissolved oxygen. pH values were 7.8–8.2 and salinities were 30–32 ppt.

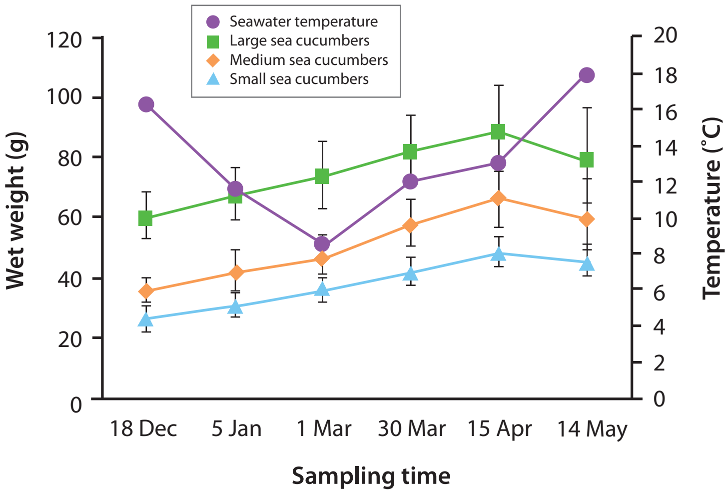

Figure 2. Seawater temperature and mean growth of large, medium and small *Apostichopus japonicus* at site G1. Bars represent standard errors (n = 20).

Culture facility

Six-layered abalone culture cages (0.4 m length × 0.3 m width × 0.8 m height, 1,250 cm^2 $layer^{-1}$) (Fig. 3) were used for the experiments. For each layer of the rigid plastic cages, six perpendicular substrates of 10 cm width were placed inside to provide sea cucumbers with extra habitable area and to trap sediment. Each underside was intact without impacting surrounding layers. A door was included on each cage for feeding and access. The cages were anchored to the longlines of a raft fixed on the sandy sea bottom, and suspended in depths of 3–6 m.

Experimental design

Three sizes of sea cucumbers were placed in a density of 6 ind. $layer^{-1}$ in fixed abalone cages at each site. Densities of large individuals were 3, 5, and 7 ind. $layer^{-1}$; densities of medium sized individuals were 4, 6, and 8 ind. $layer^{-1}$; and densities of small individuals were 6, 8, and 10 ind. $layer^{-1}$. Initial wet weights (mean ± standard error) were 60.18 ± 14.74 g for large sea cucumbers (n = 90), 35.73 ± 4.90 g (n = 109) for medium sized sea cucumbers, and 26.25 ± 5.43 g (n = 131) for small sea cucumbers in G1. Treatments were monitored fortnightly or monthly for six months.

Fermented seaweed, *Laminaria japonica* Aresch, and *Undaria pinnatifida*, were ground and placed in abalone cages twice a week; the weight of the seaweed equalled the wet weight of the sea cucumbers. About 13,500 kg of juvenile sea cucumbers — of individual weights of at least 40 g — were placed in the four sites; site SI had the greatest number of juveniles (7,500 kg).

Maintenance of culture area and measurement of survival and growth

During the experiments, survival and growth were quantified by counting and weighing juvenile *A. japonicus* in each cage and at all study sites. All sea cucumbers were measured every 15 or 30 days and then placed back in their respective layer within each cage until the next sampling period. Survival was recorded as the presence or absence of individual sea cucumbers in the assigned cage. Body weight was measured while each juvenile sea cucumber was fully extended.

Temperature, salinity, pH, and fouling were monitored every one to three days. Longlines, floats, and cages were inspected every day. Abalone cages were cleaned to remove the fouling organisms every week.

The specific growth rate (SGR) and growth rate (GR) were calculated as follows:

$$SGR\ (\%\ d^{-1}) = 100\ (\ln W_2 - \ln W_1)\ T^{-1};$$

$$GR\ (mg\ d^{-1}) = 1000\ (W_2 - W_1)\ T^{-1};$$

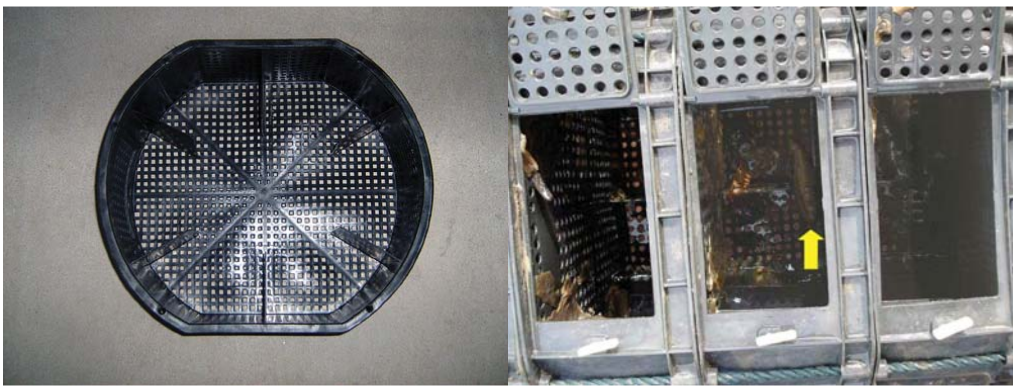

Figure 3. Single cage used for culturing *Aposticopus japonicus* in the present study (0.4 m length × 0.3 m width × 0.8 height, 1,250 cm^2 $layer^{-1}$) and assembled six-layer cage. Note cultured *A. japonicus* (arrow) laid in abalone cage.

Where W_1 is the previous wet weight (g) and W_2 is the current sampling wet weight (g) of the sea cucumber. Temperature was recorded throughout the experiments.

Data analysis

Statistics were performed using SPSS 11.0 software. A two-factor analysis of variance (ANOVA) with cultured density within the size was used to determine any significant differences in survival and growth of juvenile *A. japonicus* cultured in different habitats. Data are presented as means ± standard error of the mean (SE). We analysed the growth of sea cucumbers at three different densities in G1, and compared the difference between SGR and GR for each size at each different density at all four sites. Data were tested for homogeneity of variances with Cochran's tests; all data were suitable for analysis without transformation. One-way ANOVA, followed by Duncan's multiple rang tests, were used to test the differences among treatments. Differences among sampling dates were considered significant (P <0.05).

Results

Sea cucumber survival

Overall, survival at all study sites was high throughout the experiments, reaching as high as 100% for large juveniles, 93% for medium sized juveniles, and 83% for small juveniles. Size and survival of juvenile sea cucumbers were positively correlated.

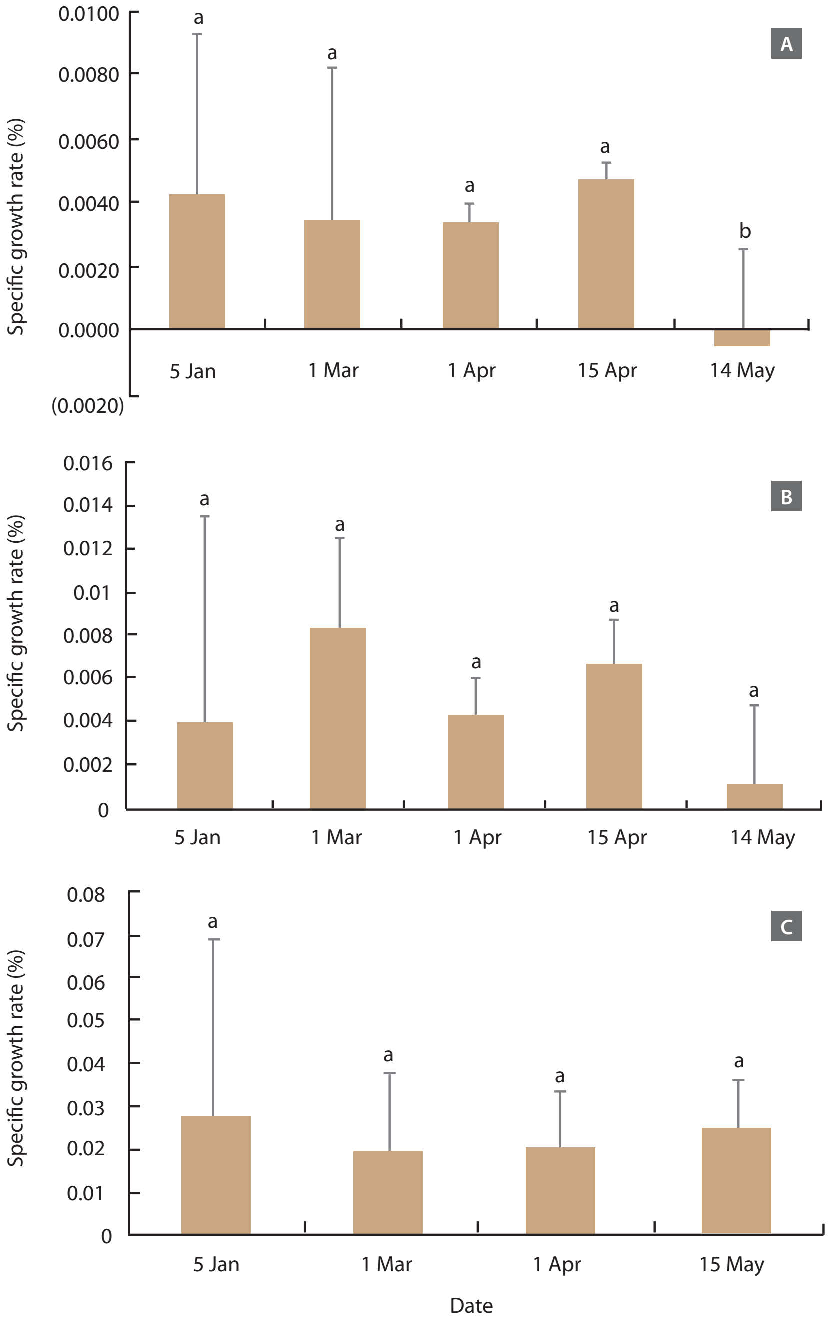

Figure 4.

Specific growth rates of large (A), medium (B) and small (C) *Aposticopus japonicus* during a six-month growth experiment east of Shengsi Island, southern China. Means with different letters indicate significant differences (P <0.05), and bars represent standard errors of the means (n = 4 sites).

Effect of size on specific growth rates of A. japonicus

At G1, initial wet weight (mean ± SE) of small *A. japonicus* 26.25 ± 5.43 g ind^{-1} increased to 45.48 ± 7.95 g ind^{-1} after six months (Fig. 2). Medium sized *A. japonicus* of 35.73 ± 4.90 g ind^{-1} initial weight grew to 60.57 ± 15.29 g ind^{-1}, and large *A. japonicus* of 60.18 ± 14.74 g ind^{-1} initial weight grew to 79.87 ± 20.81 g ind^{-1}.

SGR of juvenile sea cucumbers of all sizes and times showed progressive growth, except that the lowest SGR occurred in May for large juvenile sea cucumbers (Fig. 4A), perhaps because temperature increased. Differences in SGR were not significant for small and medium sized sea cucumbers (Figs. 4B and 4C) as determined by a one-way ANOVA (P <0.05).

Effect of culturing density on growth rates of A. japonicus

The GR at different densities and times was variable and density-dependent (Fig. 5) as determined by a Duncan multiple comparison test. There was negative correlation between GR and culturing densities (p <0.05), for example, absolute daily growth rates for large juvenile sea cucumbers farmed at different densities averaged 0.18 ± 0.10 g d^{-1} at a density of 3 ind. $layer^{-1}$ over the whole experiment, which was not significantly different from GRs of 0.13 ± 0.04 g d^{-1} at a density of 5 ind. $layer^{-1}$, or 0.09 ± 0.06 g d^{-1} at a density of 7 ind. $layer^{-1}$. Daily GRs decreased with increasing densities of sea cucumbers.

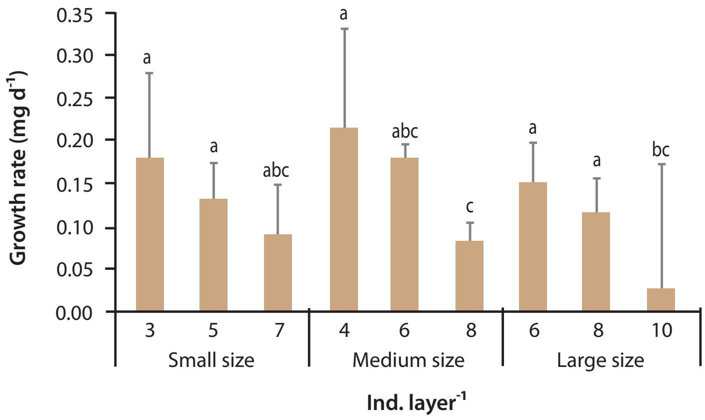

Figure 5. Effect of culture density on the growth rate of *Aposticopus japonicus* during a six-month growth experiment east of Shengsi Island in Zhejiang Province, southern China. Different letters indicate significant mean differences (P <0.05), and bars represent standard errors of the means (n = 4 sites).

Discussion

This study employed a caging method that would be practical for the commercial culturing of the sea cucumber *A. japonicus* in southern China. Other experiments with *A. japonicus* culture in southern China were mainly restricted to hatcheries and ponds (Xiao and Gu 1981), and experiments were of small scale (Sun et al. 2006). This study examined about 13,500 kg of juvenile sea cucumbers of three different sizes packed in 900 cages, making this the biggest field-based transplanting experiment in southern China. The high survival at all densities in this study showed that transporting small sea cucumbers in mass numbers was logistically feasible.

In terms of maintenance, removal of fouling organisms on the outside of the abalone cages periodically can maximise water flow and inputs of organic sediments to ensure high survival and growth rates of sea cucumbers in culture. Habitats and culture facilities should be protected against strong storms.

The main limiting factor appeared to be temperature, which became too high after April. During the experiment, the optimal temperature range for sea cucumber growth proved to be 10–17°C. GR decreased with temperatures above 17°C after April.

Juvenile size at release significantly affected long-term survival, but survival was density-independent within the experimental range (Purcell and Simutoga 2008). There was high survival of *A. japonicus* of all sizes and densities in our experiment. Other recent studies have shown similar results: survivorship of *A. japonicus* was high when co-cultured with bivalves in lantern nets (Zhou et al. 2006); high survivorship of *Australostichopus mollis* occurred beneath a mussel farm across all caging densities (Slater and Carlton 2007); and survival of *Parastichopus californicus* was 100% in oyster grow-out trays (Paltzat et al. 2008).

A. japonicus preferentially inhabits bottom areas with flourishing macroalgae and rich detritus, which provides the sea cucumbers' main feed (Li and Wang 1994; Zhang et al. 1995). In hatcheries, newly settled larvae are commonly fed with diatoms, and later, juveniles in nursery tanks are fed with powdered seaweed. In China, Japan, India and Indonesia, powdered seaweed has been used for hatchery-produced juveniles of *A. japonicus* and *Holothuria scabra* (Sui 1988; Battaglene et al. 1999), and individuals reached an average of 40 g on naturally occurring algae. Thus, it is appropriate to use seaweed as a food source for sea cucumbers. Growth in *H. scabra* slowed when individuals averaged 40 g without any addition of seaweed in land-based nursery tanks (Battaglene et al. 1999). Therefore, it is necessary to add artificial food for this commercial sea cucumber to continue growing. Our results showed that *A. japonicus* could grow well on fermented seaweed and other organic debris, and in our experiment, the addition of fermented seaweed improved survival and growth of juvenile sea cucumbers.

GR and sea cucumber density were correlated. Juveniles stunted from being held at densities of 5–7 ind. $layer^{-1}$ subsequently grew at the same rate as juveniles that were not stunted at densities of 3 ind. $layer^{-1}$. We suggest that the optimal size and densities for culturing sea cucumbers is 3–5 ind. $layer^{-1}$. *A. japonicus* can be farmed successfully at a size of 40 g, and after six months of culturing can grow to a commercial size of 100 g.

Kang et al. (2003) demonstrated that cage-cultured *A. japonicus* sea cucumbers grow well with the charm abalone *Haliotis discus hannai* in suspended cages; sea cucumber survival was high, and abalones in co-culture groups grew significantly better than in monoculture. Zhou et al. (2006) reported that *A. japonicus* grew well by feeding on biodeposits from filter-feeding bivalves and that co-culture with bivalves in suspended lantern nets could be feasible. Cage culturing of sea cucumbers with scallops, and the extension of the new culture facility, should be the next target for mass production of sea cucumbers by culturing. Further research is needed on the effects of cage culturing of sea cucumbers and other species.

There are at least three advantages to sea cucumber cage-culture in southern China:

- cages are easily accessible and cost-efficient;
- culture facilities provide relative protection against storms and predators; and
- the cost of cage-culture is much lower than that of placing stone blocks on mud or sand substrate, as would be required for *A. japonicus* pond culture in southern China.

Co-culturing sea cucumbers with abalone enables farmers to add great value to their production. But, much remains to be learned about the growth and survival of sea cucumbers before they can be mass produced, and appropriate management regimes need to be in place before this happens.

References

Battaglene S.C. and Bell J.D. 2004. The restocking of sea cucumbers in the Pacific Islands. p. 109–132. In: Bartley D.M. and Leber K.M. (eds). Case studies in marine ranching. FAO Fishery technical paper, FAO, Rome.

Battaglene S.C., Seymour J.E. and Ramofafia C. 1999. Survival and growth of cultured juvenile sea cucumbers, *Holothuria scabra*. Aquaculture 178:293–322.

Chen J.X. 2003. Overview of sea cucumber farming and sea ranching practices in China. SPC Beche-de-mer Information Bulletin 18:18–23.

Ito S. 1995. Studies on the technological development of the mass production of sea cucumber juvenile, *Stichopus japonicus*. Bulletin of Saga Prefectural Sea Farming Center 4:1–87.

Kang K.H., Kwon J.Y. and Kim Y.M. 2003. A beneficial coculture: charm abalone *Haliotis discus hannai* and sea cucumber *Stichopus japonicus*. Aquaculture 216:87–93.

Li Y.S. and Wang Y.L. 1994. Studies on the living environment and the selection of sea area for *Stichpus japonicus*. Transactions of Oceanology and Limnology3:42–47.

Liao Y.L. 1997. Fauna Sinica, Phylum Echinodermata, Class Holothuroidea. Science Press, Beijing, China. 334 p.

Moriarty D.J.W. 1982. Feeding of *Holothuria atra* and *Stichopus chloronotus* on bacteria, organic-carbon and organic nitrogen in sediments of the Great Barrier Reef. Australian Journal of Marine and Freshwater Research 33:255–263.

Paltzat D.L., Pearce C.M., Barnes P.A. and McKinley R.S. 2008. Growth and production of California sea cucumbers (*Parastichopus californicus* Stimpson) co-cultured with suspended Pacific oysters (*Crassostrea gigas* Thunberg). Aquaculture 275:124–137.

Purcell S.W. and Simutoga M. 2008. Spatio-temporal and size-dependent variation in the success of releasing cultured sea cucumbers in the wild. Reviews in Fisheries Science 16:204–214.

Slater M.J. and Carton A.G. 2007. Survivorship and growth of the sea cucumber *Australostichopus (Stichopus) mollis* (Hutton 1872) in polyculture trials with green-lipped mussel farms. Aquaculture 272:389–398.

Sloan N.A. 1984. Echinoderm fisheries of the world: A review. Echinodermata (Proceedings of the Fifth International Echinoderm Conference). A.A. Balkema Publishers, Rotterdam, Netherlands. 109–124 p.

Sui X. 1988. Culture and stock enhancement of *Apostichopus japonicus*. Agriculture Press, Beijing, China. P. 54–55 (in Chinese)

Sun J.Z., Zhuang D.G. and Chen L.T. 2006. Cultivation of *Apostichopus japonicus* in the sub-tropical Nanji Island. Journal of Zhejiang Ocean University(Natural Science) 25:148–153. (in Chinese with English abstract)

Xiao S.X. and Gu G.C. 1981. Experiments on southward transplantation and artificial breeding of the sea cucumber *Apostichopus japonicus*. Journal of Fisheries of China 2:147–153. (in Chinese with English abstract)

Yingst J.Y. 1976. The utilization of organic matter in shallow marine sediments by an epibenthic deposit-feeding holothurian. Journal of Experimental Marine Biology and Ecology 23:55–69.

Yuan X.T., Yang H.S., Zhou Y., Mao Y.Z., Zhang T. and Liu Y. 2006. The influence of diets containing dried bivalve feces and/or powdered algae on growth and energy distribution in sea cucumber *Apostichopus japonicus* (Selenka) (Echinodermata: Holothuroidea). Aquaculture 256:457–467.

Zhang B.L., Sun D.Y. and Wu Y.Q. 1995. Preliminary study on the feeding habit of *Apostichopus japonicus* in the rocky coast waters along Lingshan Island. Marine Science 3:11–13. (in Chinese with English abstract).

Zhou Y., Yang H.S., Liu S.L., Yuan X.T., Mao Y.Z. and Liu Y. 2006. Feeding and growth on bivalve biodeposits by the deposit feeder *Apostichopus japonicus* Selenka (Echinodermata: Holothuroidea) co-cultured in lantern nets. Aquaculture 256:510–520.